STAMFORDWPCA

WASTE–TO–ENERGY PROJECT

STUDY REPORT (January 2011)

Stamford WPCA
111 Harbor View Ave.
Stamford, CT 06902

STAMFORD WASTE-TO-ENERGY DRAFT STUDY REPORT

APPENDICES

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.

SECTION 1

Introduction

1.1 Introduction and Project Background

Sustainable management of municipal wastewater residuals, or biosolids, remains a challenge for wastewater utilities across North America. Traditional beneficial use practices such as agricultural land application are becoming more difficult as a result of rising costs, regulatory uncertainty, and public opposition. The Stamford Water Pollution Control Authority (SWPCA) is facing particular challenges, given the State of Connecticut does not allow land application of biosolids. However, SWPCA desires a local solution for beneficial use, in lieu of landfill disposal or extensive transport for land application.

At the same time, significant growth has placed increasing electrical demands on the downtown area of Stamford. The electric utility supplier, Connecticut Light and Power, has recognized that it will have difficulty supplying sufficient electricity to the downtown Stamford area as demand increases, which in turn could impede development. This has resulted in an electricity congestion zone where energy demand exceeds ability to supply. Currently, the SWPCA and other downtown customers pay $0.18/kilowatt hour (kWh) for electricity, which is higher than the average cost of electricity elsewhere in the U.S. In addition, with the public's growing awareness of climate change issues, it is increasingly important to use renewable fuels such as solar power or wind power, and in this case residuals/biosolids to gain public support of new power facilities.

The City of Stamford has identified a need for up to 15 megawatts (MW) of additional electric power to supply new development in downtown Stamford. Because Connecticut Light and Power will have difficulty meeting this growing demand, localized generation of electricity in the downtown area is particularly valuable. A candidate for meeting a portion of this demand would be projects adding electrical generation at the Stamford Water Pollution Control Facility (SWPCF).

An innovative solution for biosolids management and electrical power supply is the adaptation of recent advances in renewable fuel technology to biosolids. The SWPCA, with CH2M HILL and Carlin Contracting, is exploring this technology with the assistance of a grant from the U.S. Department of Energy. The objective of the project is to demonstrate that dried and pelletized biosolids can be used as a renewable energy source to generate electric power. This project will identify and build the technology required to convert pellets of dried wastewater residuals into a renewable fuel called synthetic gas (syngas), which in turn will be cleaned and conditioned to be used as gaseous fuel to generate electric power in a prime mover, such as an internal combustion engine with a generator with a generator or a gas turbine/generator.

This project is divided into two phases. In Phase 1, CH2M HILL and Carlin Contracting constructed a 25-dry-ton-per-day (DTPD) thermal drying facility to dry biosolids at the SWPCF. This phase was completed in the fall of 2007, and the solids drying facility operation was turned over to the SWPCA in January 2008. Operated by Synagro, the facility uses thermal energy to dry the wastewater residuals. During the drying process, the residuals form a pellet, which is considered Class A biosolids as defined by 40 Code of Federal Regulations (CFR) Part 503. Currently, the facility produces 16 dry tons of pellets per day. These pellets are transported offsite and beneficially used as a soil conditioner in upstate New York. Phase 1 has eliminated the unsustainable landfilling of the dewatered residuals/biosolids and significantly reduced the impact of that operation on the immediate area of the SWPCA's facility.

Phase 2 of this project began in April 2007. In this phase, CH2M HILL is evaluating the feasibility of building and operating a Waste to Energy (WTE) facility that will convert up to 25 DTPD of biosolid pellets to electricity. The syngas produced from such a facility would be used to produce approximately 1-3 MW of electric power. Approximately 1 MW to 1.5 MW of electric power produced by the WTE facility would be utilized to operate the SWPCF. The remaining power would be supplied to the local electric distribution system. The elements of this feasibility study include technology evaluation and bench-scale and pilot-scale testing. The study will be followed by design and construction of the WTE facility.

Study Phase Project Goals

The goals of the study phase of the SWPCA WTE project are as follows:

- Evaluate and assess technology for thermal conversion of biosolids and electrical generation.
- Perform sampling, bench-scale testing, vendor testing, and laboratory analysis to identify the most acceptable gasification alternatives.
- Prepare a detailed alternative analysis of selected technologies.
- Develop a preliminary design for interfaces, structures, and equipment necessary to the generation process.
- Prepare order-of-magnitude cost estimates and implementation schedules for construction of the full-scale demonstration facility.

1.2 Organization of Report

This report summarizes all of the information gathered during the WTE study phase of the project. It is organized into 9 sections and 13 appendices. Exhibit 1-1 lists the sections of the report with a brief description of the contents of each.

EXHIBIT 1-1
Sections of the Study Report

Section Number	Title	Description
1	INTRODUCTION	Presents project background and goals.
2	TECHNOLOGY REVIEW AND ASSESSMENT	Review of vendor gasification technologies applicable to the proposed project.
3	ALTERNATIVE DEVELOPMENT AND TESTING	Describes the biosolids characterization, the onsite bench-scale testing completed by SWPCA, and the offsite bench-scale testing completed by UNDEERC.
4	TECHNOLOGY SELECTION WTE FACILITY	Summarizes the vendor RFP, vendor pilot testing, and applicability to the proposed facility.
5	POWER GENERATION	Describes applicability of power generation technologies to use with syngas.
6	AIR EMISSIONS	Describes air emissions from the WTE facility, control of the emissions, and permits required.
7	SOLID AND LIQUID WASTE	Summarizes the solid and liquid waste characteristics and the disposal options.
8	CAPITAL COST ESTIMATE	Summarizes the cost estimate and analyzes project alternatives.
9	CONCLUSIONS AND RECOMMENDATIONS	

SECTION 2

Technology Review and Assessment

2.1 Introduction

This section summarizes the technology reviews and assessments of options to produce syngas from the pelletized biosolids produced by SWPCF. This was accomplished first by performing a literature review to access how biomass including biosolids have been converted to useable energy. This data was then used to facilitate the team assessing the technologies, vendors, and resources available to aid in the development of the WTE Program, and apparent trends within this industry.

2.1.1 Task BO.1 - Literature Review

The goal of the literature review was to identify entities that have converted biomass and/or biosolids to energy in the past and have operating facilities. The literature review also identified entities that may offer technology support, personnel resources and/or financial support.

In April 2007, a plan for the literature review and assessment was developed by Brian Gackstatter, Tina Colgan, Jay Surti, Peter Burrowes, Denis Dandeneau, and Jay Mackie. Peter Burrowes and Jay Mackie are identified as lead project technologists, given their expertise in the biosolids industry. The plan consisted of:

- Compile a library of industry papers, data, research, websites, and presentations collected by the CH2M HILL biosolids experts.
- Perform an internet search of biomass and biosolids gasification, and power generation vendors identified by CH2M HILL. Review vendor websites for information on their products.
- Develop a set of criteria to aid in the evaluation of each vendor.
- Perform an Internet search of existing facilities, research, and other biosolids and/or biomass gasification projects, and syngas utilization.
- Have NERAC Inc. (www.nerac.com) perform a search of gasification vendors, research, and other biosolids and biomass conversion projects. NERAC is a technical research service consisting of engineers, scientists, and professors located in Tolland, Connecticut. NERAC specializes in finding the most up-to-date technical resources available in the market based on the needs of the client.
- Compile all information and identify which resources are useful and which do not apply to this project.
- Investigate the useful resources further in Task BO.2, the literature assessment.

The CH2M HILL team compiled all of the literature and data available through the CH2M HILL library, Internet search, and NERAC search. The NERAC search can be found in Appendix 2-A.

Each paper, presentation, and website was reviewed and classified in one of the following categories:

- Class 1 - Articles directly relevant to biosolids/biomass atmospheric (or pressurized) fluidized bed (or fixed bed) updraft (or downdraft) gasification, and other supporting processes such as syngas cleanup, syngas feed to IC engines, etc. Articles relevant to bench-scale and pilot-scale testing were also classified as Class 1.
- Class 2 - Articles that mention biosolids/biomass gasification; for example, a city's biosolids management plan would describe different biosolids management alternatives; one alternative would be gasification of biosolids.
- Class 3 - Articles that do not focus on gasification but other technologies that might be of interest, such as plasma arc technology, co-production of ethanol and electricity, hydrogasification of biosolids, etc.

The results were compiled in Exhibit 2-1, Literature Review Summary. Included in this table are the title of the article, the source, the classification, a description of the article, and comments on the review of the article.

This table was then sent to the CH2M HILL lead technologists and quality review team. The technologists were asked the following:

- Have we exhausted our search? Where should we look further? What are we missing? What do we need more of?
- Indicate which articles should be reviewed further in the technology assessment.

The CH2M HILL lead technologists believed that our literature search was comprehensive and suggested concentrating on speaking with the identified vendors in the literature assessment to identify which vendors were viable, currently had facilities in operation, and were interested in this project.

EXHIBIT 2-1
Literature Review Summary

ITEM NO.	ARTICLE NAME	SOURCE	CLASSIFICATION	DESCRIPTION	COMMENTS
1	Conversion Technologies for municipal residuals (pdf file)	California Integrated Waste Management Board	Class 2	Provides general description of waste to energy technologies, past, present and future practices, feedstocks (biomass, municipal waste and biosolids), economic feasibility and life cycle costs.	Scan through the article, read section on gasification/pyrolysis.
2	Gasification – The basics	Gasification Technology Council	Class 3	Explains what is gasification, focuses of coal and other solid residuals as feedstock. This article could be useful in understanding the principles of gasification.	Scan through the article, read section on gasification/pyrolysis.
3	Sewage Sludge Gasification – Kopf Plant Building	Balingen Sewage Works, Germany	Class 1	Talks about a commercial sized facility installed at the Balingen Sewage Works, brief description of the process, economic feasibility, environmental compatibility and operations	Review the article in detail. Contact Kopf (contact details available in the article). Use the Vendor Criteria sheet to generate information.
4	Volarisation of Sewage Sludge – Kopf Gasification Process	Balingen Sewage Works, Germany	Class 1	Provides detailed description of the gasification process at Balingen Sewage 5Works, provides operational data, feedstock and byproduct characterization data.	Review the article in detail. Contact Kopf (contact details available in the article). Use the Vendor Criteria sheet to generate information.

EXHIBIT 2-1
Literature Review Summary

ITEM NO.	ARTICLE NAME	SOURCE	CLASSIFICATION	DESCRIPTION	COMMENTS
5	Detailed Report - Evaluation of Alternative Solid Waste Processing Technologies	City of Los Angeles, Department of Public Works, Bureau of Sanitation	Class 2	Provides a description of thermal conversion, biological/chemical, and physical technologies for treating municipal solid waste (includes biomass and biosolids). Discusses environmental implications, public perception and economic feasibility for application of these technologies.	Briefly review the Report. Read sections related to feedstock characteristics and thermal technologies. Extract relevant data.
6	Summary Report – Evaluation of Solid Waste Processing Technologies	City of Los Angeles, Department of Public Works, Bureau of Sanitation	Class 2	A summary of the detailed Report (see item above)	None
7	Skygas Gasification (a ppt file)	MPN Technologies, Inc.	Class 1	Patented Skygas gasification – decomposition of organic molecules by hydroxyl ions produced by breakdown of water molecules	Potential vendor – contact the vendor to complete a vendor criteria sheet.
8	Integrated Gasification Combined Cycle	Steven Jenkins, CH2M HILL	Class 2	Describes basic gasification concepts – what it is, how it works, and lists few commercial sized installations in the US – focuses on coal as feedstock	Briefly read through the presentation.

EXHIBIT 2-1
Literature Review Summary

ITEM NO.	ARTICLE NAME	SOURCE	CLASSIFICATION	DESCRIPTION	COMMENTS
9	Biomass Gasification – Tar and Particles in Product Gas – Sampling and Analysis Dated: October 2004	Technical Committee CEN/TC BT/TF 143 "Measurements of Contaminant Gas (tars) in Biomass Producer Gas", the secretariat of which is held by NEN	Class 1	Describes sampling and measuring techniques for contaminants present in syngas – could be useful during bench scale and pilot plant study phase	Interim study report - should be reviewed in detail during the bench scale and pilot scale testing.
10	Rationale for using impinger bottles for sampling and analysis of gas contaminants Dated: January 2005	Technical Committee CEN/TC BT/TF 143- "Measurements of Contaminant Gas (tars) in Biomass Producer Gas", the secretariat of which is held by NEN	Class 1	Describes details of a specific technique called "impinger train" to conduct sampling of tars produced in syngas upon gasification of biomass	Interim study report - to be reviewed in detail during the bench scale and pilot scale testing.
11	Report – Sampling and Analysis of tar and particles in biomass producer gas Dated: July 2005	Technical Committee CEN/TC BT/TF 143 "Measurements of Contaminant Gas (tars) in Biomass Producer Gas", the secretariat of which is held by NEN	Class 1	A final report that describes various techniques established for sampling and analysis of tars and particles in biomass producer gas	Final Report - Should be reviewed in detail during the bench scale and pilot scale testing.
12	Fluidized Bed Gasification and Slagging Combustion System Dated: May 2001	EBARA Corporation	Class 1	Five different variations of fluidized bed gasification technologies are discussed	This article should be reviewed in detail. Contact vendor to conduct a vendor criteria evaluation.
13	EBARA TwinRec Process and UBE Process Dated: September 2002	EBARA Corporation	Class 1	Provides details of commercial sized application for the TwinRec Process and UBE Process (variations of fluidized gasification process)	This article should be reviewed in detail. Contact vendor to conduct a vendor criteria evaluation.

EXHIBIT 2-1
Literature Review Summary

ITEM NO.	ARTICLE NAME	SOURCE	CLASSIFICATION	DESCRIPTION	COMMENTS
14	Retrofit of coal fired power boilers using fluidized bed biomass gasification Dated: May 2001	Energy Products of Idaho (EPI)	Class 1	Description of fluidized bed gasification technology, commercial biomass gasification application and economics	Briefly skim through the article. Contact vendor to conduct a vendor criteria evaluation.
15	Fluidized Bed gasification - EPI	Energy Products of Idaho (EPI)	Class 1	Description of fluidized bed gasification from EPI's website	Briefly skim through the article. Contact vendor to conduct a vendor criteria evaluation.
16	Fluidized bed gasification as a means of converting waste to energy Dated October 2003	Natural Resources Canada, CANMET Energy Technology Center	Class 1	Description of fluidized gasification technology, performance and economics – compares three commercial biomass gasification applications	Review article in detail.
17	Development of a fluidized bed gasification system to supply cooking gas in rural China	Iowa State University	Class 1	Description of a fluidized bed gasification technology demonstration plant tested to supply cooking gas in rural China	Review the article. If necessary, contact the author at Iowa State University
18	Utilization of agricultural residue in a 2 MW fluidized bed gasifier	Carbon Energy Technology, Inc.	Class 1	Details of a fluidized bed gasification of agricultural waste gasification plant in Toledo, Iowa	Review the article. Contact vendor to conduct a vendor criteria evaluation.
19	Biomass technology group_biomass gasification_description (pdf file)	Biomass Technology Group	Class 1	Technical description of the gasification process	Review article to understand the gasification process.

EXHIBIT 2-1
Literature Review Summary

ITEM NO.	ARTICLE NAME	SOURCE	CLASSIFICATION	DESCRIPTION	COMMENTS
20	Biomass gasification plant in Skive by Carbona (pdf file)	Carbona, Inc.	Class 1	Provides description of a biomass gasification plant in Skive, Denmark by Carbona, Inc.	Review the article. Contact vendor to conduct a vendor criteria evaluation.
21	Biomass Gasification Demonstration Projects by Carbona (pdf file)	Carbona, Inc.	Class 1	Provides description of gasification technology developed by Carbona, and briefly describes their demonstration projects around the world	Review the article. Contact vendor to conduct a vendor criteria evaluation.
22	Degremont_ParisWWTP_gasification (pdf file)	Degremont	Class 1	Provides description of biosolids gasification by Degremont at the Valenton WWTP for the Authority of Sewage and Waste Water Treatment for the area of Paris	Review the article. Contact vendor to conduct a vendor criteria evaluation.
23	Memo_Visit to Valenton by CH2M HILL (MS Word file)	CH2M HILL	Class 1	Summary of site visit by CH2M HILL at the Valenton WWTP in Paris	Review memo. Contact author for further information if required.
24	Impediments to commercialization of biomass gasification (pdf file)	Biomass Technology Group	Class 1	The paper highlights the problems with demonstration projects, the specific market needs, the specific problems with implementation and the related problems in the commercialization stage.	Review article in detail
25	Introduction to the gasification process (pdf file)	GasNet	Class 1	Provides detailed description of the gasification process	Review article in detail

EXHIBIT 2-1
Literature Review Summary

ITEM NO.	ARTICLE NAME	SOURCE	CLASSIFICATION	DESCRIPTION	COMMENTS
26	Small Scale Gasification_biomass technology group (pdf file)	Biomass Technology Group	Class 1	Provides detailed description of the gasification process	Review article in detail
27	Status of Biomass Gasification in countries around the world (pdf file)	GasNet	Class 1	Highlights the progress of gasification, country by country	Identify biomass/biosolids gasification demonstration projects around the world, acquire details as required
28	Use of Gasification syngas in IC Engines (pdf file)	Biomass Technology Group	Class 1	Theoretical and practical aspects on the use of LCV-gas from biomass gasifiers in internal combustion engines	Review article in detail. Will be useful during the pilot plant and design phase.
29	Biomass Gasification paper by James Cobb (MS Word file)	James T. Cobb, University of Pittsburgh	Class 1	The paper identifies gasification demonstration projects around the world and in the US, and identifies a few manufacturers/vendors	Review article. Identify vendors to contact. Contact potential vendors to conduct a vendor criteria evaluation.
30	Production of synthetic gas by Biomass Gasification – a tutorial (ppt file)	James T. Cobb, University of Pittsburgh	Class 1	The presentation identifies gasification demonstration projects around the world and in the US, and identifies a few manufacturers/vendors	Review presentation. Identify vendors to contact. Contact potential vendors to conduct a vendor criteria evaluation.
31	Plasma arc technology – misc files (a folder)	Miscellaneous sources	Class 3	Summary of a plasma assisted sludge oxidation process	Briefly review files in folder

EXHIBIT 2-1
Literature Review Summary

ITEM NO.	ARTICLE NAME	SOURCE	CLASSIFICATION	DESCRIPTION	COMMENTS
32	Siemens IGCC Technology update (pdf file)	Siemens Technologies	Class 1	Provides update on Siemens IGCC experience, product enhancements and technology in pipeline	Review the article. Contact vendor to conduct a vendor criteria evaluation.
33	Advancement in Gasification Technology – GE Energy (pdf file)	GE Energy	Class 1	Provides summary of GE's experience in gasification technology	Review the article. Contact vendor to conduct a vendor criteria evaluation.
34	Multipurpose Gasification – Lurgi	Lurgi	Class 1	Provides summary of Lurgi's experience in gasification technology	Review the article. Contact vendor to conduct a vendor criteria evaluation.
35	Observations on the current status of biomass gasification – Gas Technology Institute	Gas Technology Institute	Class 1	Provides detailed description of the gasification process, and demonstration projects of different types of gasification technologies	Review article in detail
36	Thermal drying of sludge using biomass as primary fuel (pdf file)	Andritz	Class 2	The paper introduces the principle of thermal drying using primary energy source as biomass. The essential characteristics of convective and contact drying are outlined; applications, safety criteria and emissions are detailed.	Review article briefly

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Literature Review Summary

ITEM NO.	ARTICLE NAME	SOURCE	CLASSIFICATION	DESCRIPTION	COMMENTS
37	Sewage Sludge Gasification – Primenergy (MS Word file)	Primenergy	Class 1	Provides a brief description of a demonstration project at Philadelphia for gasification of sewage sludge	Review the article. Contact vendor to conduct a vendor criteria evaluation.
38	Gasification of agricultural waste	Stanley E. Manahan, University of Missouri	Class 1	ChemChar gasification process for gasification of agricultural waste	Review article. Contact author to acquire more information if required
39	Drying and gasification of sewage sludge – ChemChar Process (pdf file)	Stanley E. Manahan, University of Missouri	Class 1	Bench scale ChemChar gasification process experiment for gasification of sewage sludge	Review article. Could be useful during bench scale testing. Contact author to acquire more information if required.
40	Description of different type of gasifiers (MS Word file)	Google	Class 1	Provides brief description of updraft, downdraft, crossdraft and twinfire gasifiers	Review article.
41	Comparison of IGCC and Fluidized Bed gasification for petroleum coke (MS Word file)	Google	Class 1	Compares environmental and economic benefits of IGCC and Fluidized bed gasification using petroleum coke	Review article.
42	Gasification Process (MS Word file)	Google	Class 1	Describes drying, pyrolysis, oxidation and reduction phenomenon during gasification	Review article.
43	Gasifier Fuel Testing (MS Word file)	Innovative Technologies Ireland and Fluidyne	Class 1	The article describes the manufacturer's experience with gasification technology	Review the article. Contact vendor to conduct a vendor criteria evaluation.

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Literature Review Summary

ITEM NO.	ARTICLE NAME	SOURCE	CLASSIFICATION	DESCRIPTION	COMMENTS
44	Gasification – a gateway to a cleaner future (pdf file)	David J. White (Oct 1998)	Class 1	Environmental legislative drivers pushing gasification of sewage sludge, identifies vendors and demonstration projects	Review article
45	Heating value of gases from biomass gasification	International Energy Association Bioenergy Subcommittee	Class 1	Summary of a survey conducted with several organizations involved in gasification activities asking about the methods and data sources that are used for the heating values of the components forming the gases produced in gasification and similar processes.	Review article. Could be useful during pilot plant and design phase.
46	A strategy for minimization of liquid and gaseous emissions from the LR gasification (pdf file)	International Energy Association	Class 1	A project between Northumbrian Water Limited and Lurgi to develop a gasification plant	Review article to gather project information. Contact vendor to conduct a vendor criteria evaluation.
47	Industrial Sludge Gasification – US Centrifuge (pdf file)	US Centrifuge	Class 1	Provides summary of US Centrifuge's experience in gasification technology	Review the article. Contact vendor to conduct a vendor criteria evaluation.
48	Sewage Sludge Gasification for CHP Applications (pdf file)	Dr. Karen Laughlin	Class 1	Summary of study project on sewage sludge gasification; a collaborative effort between university and commercial gasifier vendors	Review article. Contact author to obtain additional information from the study

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Literature Review Summary

ITEM NO.	ARTICLE NAME	SOURCE	CLASSIFICATION	DESCRIPTION	COMMENTS
49	Thermal Treatment of Sewage Sludge for CHP Application (pdf file)	Sharon McCahey	Class 1	Summary of study project on sewage sludge gasification; a collaborative effort between university and commercial gasifier vendors	Review article. Contact author to obtain additional information from the study
50	Alternatives to expanding the landfill (ppt file)	Thorington	Class 3	A presentation to high school students on different waste management alternatives to landfill; including thermal treatment and conversion processes	Review article briefly.
51	Modular Fluidized Bed Gasification (pdf file)	Prenma Consulting	Class 1	A paper on fluidized bed gasification; pilot plant setups developed by the vendor to conduct pilot runs	Review article. Contact vendor to conduct a vendor criteria evaluation.
52	Gasification Demonstration Project – Anglian Water (pdf file)	Prenma Consulting	Class 1	Provides details for a demonstration project for Anglian Water	Review article. Contact vendor to conduct a vendor criteria evaluation.
53	Alternatives for sewage sludge disposal (pdf file)	N/A	Class 2	The paper describes different alternatives for sludge disposal including thermal treatment and gasification	Review article briefly. Review section of thermal treatment and gasification in detail
54	Combustion and gasification of biomass and waste fuels (pdf file)	University of Cambridge	Class 1	The paper describes bench scale gasification testing of sewage sludge and other wastes	Review article. Contact author to obtain more information for bench scale testing

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Literature Review Summary

ITEM NO.	ARTICLE NAME	SOURCE	CLASSIFICATION	DESCRIPTION	COMMENTS
55	Sedis Biomass Gasification (pdf file)	Institut für ZukunftsEnergieSysteme	Class 1	Describes a proprietary ETVS process to process sewage sludge and solid biomass such as wood waste and to utilize the product-gas for Power-Generation and ash as rest direct on site.	Review article. Contact author to obtain additional information.
56	Atmospheric fluidized bed gasification – Foster Wheeler (pdf file)	Foster Wheeler	Class 1	Provides update on Foster Wheeler's experience with atmospheric fluidized bed gasification	Review the article. Contact vendor to conduct a vendor criteria evaluation.
57	What is Gasification (MS Word file)	N/A	Class 1	Provides description of the gasification process	Review article
58	Advanced Concept Technologies (pdf file)	Advanced Concept Technologies, LLC.	Class 1	Pyrolytic steam reforming gasification and catalytic production of Ethanol	Review article. Contact vendor to conduct a vendor criteria evaluation.
59	Biogasification_paper_WEF_April_2002 (pdf file)	Water Environment Federation	Class 1	The paper describes biogasification of sewage sludge process, viability and economics	Review article
60	Gas turbines – gas cleaning requirements for biomass-fired systems (pdf file)	Power Generation Technology Center	Class 1	This paper discusses gas cleaning requirements for gas generated by biomass fired systems, before being sent to gas turbines	Review article. Could be useful during the pilot plant and design phase of project. Contact author if necessary.

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Literature Review Summary

ITEM NO.	ARTICLE NAME	SOURCE	CLASSIFICATION	DESCRIPTION	COMMENTS
61	Gasification Feed System Report_DOE (pdf file)	Energy and Environment Research Center, University of North Dakota FOR Department of Energy	Class 1	The goal of the project is to identify and evaluate low-value fuels that could serve as alternative feedstocks and to develop a feed system to facilitate their use in integrated gasification combined cycle and gasification coproduction facilities.	Review article. Could be useful during the pilot plant and design phase of project. Contact author if necessary.
62	Gasification of Dried sludge_abstract (pdf file)	University of Zaragosa, Spain	Class 1	Air Gasification of Dried Sewage Sludge in a Fluidized Bed: Effect of the Operating Conditions and In-Bed Use of Alumina	Request article, and review it.
63	Gasification_Enerkem Technologies (pdf file)	Enerkem Technologies, Inc.	Class 1	A presentation of why gasification, what is gasification, provides detailed mass balances and their portfolio of gasification projects	Review article. Review article. Contact vendor to conduct a vendor criteria evaluation.

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Literature Review Summary

ITEM NO.	ARTICLE NAME	SOURCE	CLASSIFICATION	DESCRIPTION	COMMENTS
64	Green Production of Hydrogen from Excess Biosolids originating from Municipal Wastewater Treatment (pdf file)	N/A	Class 1	Technical and economic aspects of equivalent hydrogen production from biosolids produced in wastewater treatment are evaluated in this paper. ASPEN+ simulation of the gasification of biosolids and coal provides the basis for the analysis of the technical performance of a gasification process.	Request article, and review it upon receipt.
65	Hydrogasification of biosolids_University of California (pdf file)	University of California, Riverside	Class 3	A pilot-scale reactor was constructed and tested. The fundamental principle of the reactor is hydro-gasification; i.e., the reaction of organic carbon with a hydrogen - rich gas to produce useful fuel and heat.	No further action required.
66	Hyperion Energy Recovery System (pdf file)	F. Michael Lewis	Class 1	Energy Recovery System at the Hyperion Wastewater Treatment Plant in Los Angeles, CA. The paper describes use of staged combustion fluidized bed gasifiers.	Review article. Contact author for obtaining additional information if necessary.

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Literature Review Summary

ITEM NO.	ARTICLE NAME	SOURCE	CLASSIFICATION	DESCRIPTION	COMMENTS
67	Liberty Energy Center, Hamilton, CA (pdf file)	Liberty Energy	Class 1	Description of a project undertaken by Liberty Energy in Hamilton, CA for a 10 MW power generation facility using biomass and biosolids	Review article. Contact author for obtaining additional information if necessary.
68	Gasification_Juniper Consultancy Services, Inc. (pdf file)	Juniper Consultancy Services, Inc.	Class 1	The presentation describes the trend and drivers in the European Union for gasification of biosolids, provides statistics on existing projects and indentifies vendors	Review article. Contact vendor to conduct a vendor criteria evaluation.
69	SilvaGas Process from future energy resources	Future Energy Resource Corporation	Class 1	Details for a indirect heat biomass gasification demonstration project in Burlington, Vermont	Review article. Review article. Contact vendor to conduct a vendor criteria evaluation.
70	Synthetic Transportation Fuels from Carbonaceous Material Using Steam Hydro-gasification (pdf file)	College of Engineering, Center of Environment Research and Technology, University of California, Riverside	Class 3	Steam Pyrolysis and hydrogasification of biomass	Review abstract.
71	Thermal Gasification: A feasible solution for sewage sludge volarization (pdf file)	Laboratoire en Procédés Propres et Environnement, France (published in Chemical Engineering and Technology)	Class 1	How gasification technologies could be transposed to the treatment and valorization of sludge.	Request article. Review article upon receipt.

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Literature Review Summary

ITEM NO.	ARTICLE NAME	SOURCE	CLASSIFICATION	DESCRIPTION	COMMENTS
72	Gasification of sewage sludge for CHP applications_University of Ulster, UK	University of Ulster, UK	Class 1	A summary of study conducted by the University of Ulster and Invest Northern Ireland on gasification of sewage sludge	Review article. Contact author at university to get additional details for the study.
73	Advanced Gasification Combustion_GE EER (pdf file)	GE Energy and Environment Research Corporation	Class 2	A paper by GE EER on development of an innovative fuel-flexible advanced gasification-combustion (AGC) technology for production of hydrogen for fuel cells or combustion turbines, and a separate stream of sequestration-ready CO_2.	Review article.
74	Alternative_Manure_Utilization_PA Nutrient Mgmt (pdf file)	Pennsylvania Nutrient Management Annual Conference	Class 2	Alternatives of manure utilization other than landfill; discusses thermal treatment and gasification	Review article.
75	Bioenergy Update, Dec 1999	General Bioenergy, Inc.	Class 2	Describes in detail the SlurryCarb Process developed by Enertech	Review article.
76	Bioenergy_Brochure_WEF	Water Environment Federation	Class 2	Provides brief description of the biogasification process and other alternative technologies for production of bioenergy from biosolids	Review article.

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ITEM NO.	ARTICLE NAME	SOURCE	CLASSIFICATION	DESCRIPTION	COMMENTS
77	Biosolids and Residuals Master Plan_City of Toronto (pdf file)	City of Toronto, Canada	Class 2	Provides description of different technologies to manage biosolids including biogasification; identifies vendors and demonstration projects	Review the section on biosolids gasification and thermal treatment.
78	Biosolids_overview, processing, treatment and mgmt_ Canada (pdf file)	J.A. Oleszkiewicz and D.S. Mavinic	Class 2	Provides description of different technologies to manage biosolids including biogasification; identifies vendors and demonstration projects	Review the section on biosolids gasification and thermal treatment.
79	Community Power Corporation_BioMax	Community Power Corporation	Class 2	Summary of a pilot plant setup for gasification of agricultural waste	Review article
80	Company listing_waste to energy (pdf file)	Directory of waste to energy	Class 2	Index of organizations and processes that use garbage, sewage, unusable crop, and other waste products to generate energy efficiently and cleanly.	Review article
81	Cost savings through gasification (pdf file)	Duke Engineering and Services	Class 2	Article talks about close-couple gasification and combustion of biomass	Review article

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Literature Review Summary

ITEM NO.	ARTICLE NAME	SOURCE	CLASSIFICATION	DESCRIPTION	COMMENTS
82	Enersludge_sludge to oil (pdf file)	Environmental Solutions International Ltd	Class 2	Enersludge process to that involves thermo-chemical conversion of dried biosolids pellets to cleaner fuels. A 25 dry tonne per day (tpd) facility operating at the Subiaco WWTP in Perth, Western Australia. The paper describes the process in detail, reports operating results from the plant and assesses the economics of applying the technology in Europe.	Review article.
83	EPA_emerging technologies for biosolids mgmt (pdf file)	Environmental Protection Agency	Class 2	Provides description of different technologies to manage biosolids including biogasification; identifies vendors and demonstration projects	Review the section on biosolids gasification and thermal treatment.
84	Exergetic evaluation of biomass gasification (pdf file)	Department of Chemical Engineering and Chemistry, Eindhoven University of Technology, The Netherlands	Class 2	The purpose of this paper is to compare different types of biofuels for their gasification efficiency and benchmark this against gasification of coal	Review article. Contact author if found necessary to obtain additional information.
85	Hydrothermal Gasification (pdf file)	BioenergyWiki	Class 2	Gasification of biomass and other organic wastes in liquid phase	Review article

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Literature Review Summary

ITEM NO.	ARTICLE NAME	SOURCE	CLASSIFICATION	DESCRIPTION	COMMENTS
86	Iowa State University_indirect biomass gasifier (pdf file)	Bioenergy Update	Class 2	Small-scale biomass gasifier under development at Iowa State University	Review article
87	MWH_the future of international high tech biosolids treatment technologies in Australia (pdf file)	MWH	Class 2	Provides description of different technologies to manage biosolids including biogasification; identifies vendors and demonstration projects	Review the section on biosolids gasification and thermal treatment.
88	Report_Alternatives to landfill_EPA_Govt of Southern Australia (pdf file)	Environmental Protection Agency, Government of Southern Australia	Class 2	Provides description of different technologies to manage biosolids including biogasification; identifies vendors and demonstration projects	Review the section on biosolids gasification and thermal treatment.
89	Review Alternative Technologies for Biosolids Management_Greater Vancouver District (pdf file)	Greater Vancouver District	Class 2	Provides description of different technologies to manage biosolids including biogasification; identifies vendors and demonstration projects	Review the section on biosolids gasification and thermal treatment.
90	Sludge Disposal Techniques_European Environmental Agency (pdf file)	European Environmental Agency	Class 2	Provides description of different technologies to manage biosolids including biogasification; identifies vendors and demonstration projects	Review the section on biosolids gasification and thermal treatment.

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ITEM NO.	ARTICLE NAME	SOURCE	CLASSIFICATION	DESCRIPTION	COMMENTS
91	Super critical water partial oxidation_DOE and General Atomics (pdf file)	Department of Energy	Class 2	Under Cooperative Agreement No. DE-FC36-00GO10529 for the Department of Energy, General Atomics (GA) is developing Supercritical Water Partial Oxidation (SWPO) as a means of producing hydrogen from low-grade biomass and other waste feeds. The Phase I Pilot-scale Testing/Feasibility Studies have been successfully completed and the results of that effort are described in this report.	Review article
92	Viable biosolids market_CH2M and Tetratech_Report (pdf file)	CH2M HILL & TetraTech for Orange County Sanitation District	Class 2	Provides description of different technologies to manage biosolids including biogasification; identifies vendors and demonstration projects	Review the section on biosolids gasification and thermal treatment.
93	BRIenergy_ethanol from biomass (pdf file)	BRIenergy	Class 3	Describes a process developed to produce ethanol from biomass; includes gasification and fermentation	Review article
94	Coproduction of ethanol and electricity_BRIenergy	BRIenergy	Class 3	Describes a process developed to produce ethanol from biomass; includes gasification and fermentation	Review article

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Literature Review Summary

ITEM NO.	ARTICLE NAME	SOURCE	CLASSIFICATION	DESCRIPTION	COMMENTS
95	Current and Potential energy products from biomass_ppt (pdf file)	National Renewable Energy Laboratory	Class 3	A presentation on bioenergy; statistical data presented	Review article
96	Global Alternative Green Energy Inc (pdf file)	Global Alternative Green Energy, Inc.	Class 3	Describes a process developed to produce ethanol from biomass; includes gasification, production of syngas and use of catalyst to produce cleaner fuels	Review article
97	Rheology study paper_coal and biosolids slurry for gasification (pdf file)	Adelphi University/Dooher Institute of Physics and Energy	Class 3	Physio-Chemical Modeling of Coal and Coal/Biomass Slurries for Gasification and Direct Combustion Applications	Briefly review article
98	High temperature winkler gasification of MSW_Uhde Corp (pdf file)	Uhde Corporation	Class 1	Paper on a project to demonstrate feasibility of the high temperature winkler process (fluidized bed gasification) for gasification of MSW, auto shredder waste and sewage sludge.	Review article

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Literature Review Summary

ITEM NO.	ARTICLE NAME	SOURCE	CLASSIFICATION	DESCRIPTION	COMMENTS
99	Anglian Water and TXU Energy	World Wide Web	Class1	A news release of a joint venture between Anglian Water and TXU energy to built a gasification plant to gasify biosolids, produce syngas and use it to produce electricity for local businesses. The plant will be located at Anglian Water's WWTP in Corby, UK.	Briefly review article
100	Waste to Energy and Kwikpower (pdf file)	World Wide Web	Class 1	A news release of a partnership between Waste to Energy, UK and Kwikpower International. The partnership plans to build several biosolids, biomass and MSW gasification projects worldwide.	Briefly review article
100	Waste to Energy_ppt (pdf file)	Waste to Energy	Class 1	Presentation prepared by Waste to Energy regarding their gasification technology and experience.	Review article
101	www.gocpc.com.htm (html file)	Community Power Corporation	Class 1	Gasification vendor - provides modular gasification systems to produce electricity from biomass.	Review vendor website

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Literature Review Summary

ITEM NO.	ARTICLE NAME	SOURCE	CLASSIFICATION	DESCRIPTION	COMMENTS
102	Community Power Corporation & Ascent Power Systems (pdf file)	Community Power Corporation	Class 1	An article on successful demonstration to produce electricity from fuel cells using syngas produced by the Community Power Corporation's modular gasification systems.	Review article
103	Community Power Corporation_ppt (pdf file)	Community Power Corporation	Class 1	Presentation prepared by Community Power Corporation regarding their gasification technology, industry experience and business growth.	Review article
104	VIT_bench scale testing (pdf file)	VIT	Class 1	A cut sheet prepared by VIT describing their bench scale fluidization apparatus to conduct combustion tests.	Review article
105	Bench scale fluidized bed combustion testing_Alstom Power (pdf file)	Alstom Power, Inc.	Class 1	The report describes bench scale fluidized bed combustion apparatus prepared by Alstom Power for a study funded by the Department of Energy.	Review article

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Literature Review Summary

ITEM NO.	ARTICLE NAME	SOURCE	CLASSIFICATION	DESCRIPTION	COMMENTS
106	Centrifugal filter_tar & particulates removal (pdf file)	Community Power Corporation	Class 1	A research study conducted by Community Power Corporation in conjunction with MagStar to develop a centrifugal filter to remove tar and particulates present in the syngas upon gasification of biomass. The study was funded by Xcel Energy's Renewable Development Fund Grant.	Review article
107	Gasification demonstration project_Northumbrian Water (pdf file)	Entec (Consultants)	Class 1	A demonstration project for gasification of biosolids to produce syngas and electricity. Biosolids to be provided by Northumbrian Water, UK. Gasifier to the provided by Lurgi UK.	Review article
108	Biomass Conversion Technologies (pdf file)	National Renewable Energy Laboratory (NREL)	Class 1	Discusses feasibility of biomass combustion and gasification technology for combined heat and power applications, and production of liquid fuels	Review article

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Literature Review Summary

ITEM NO.	ARTICLE NAME	SOURCE	CLASSIFICATION	DESCRIPTION	COMMENTS
109	Biomass gasification_Gridley Project (pdf file)	National Renewable Energy Laboratory (NREL)	Class 1	Demonstration project for gasification of rice straws, produce syngas, and use syngas to produce ethanol in Gridley, California. The article to be reviewed to understand syngas production from gasification of biomass, and gas clean up.	Review article
110	Biopower technical assessment (pdf file)	National Renewable Energy Laboratory (NREL)	Class 1	The study focuses on all technologies in the market place to produce power from biomass, and feedstock options available. The study includes a detailed description on gasification.	Review article
111	Benchmarking biomass gasification technologies (pdf file)	US Department of Energy, National Energy Technology Laboratory	Class 1	The overall objective of this project was to survey and benchmark existing commercial or near-commercial biomass gasification technologies relative to end-use syngas applications.	Review article
112	Hot gas conditioning (pdf file)	National Renewable Energy Laboratory	Class 1	Provides research and development activities that have been conducted on gas cleanup and conditioning.	Review article

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Literature Review Summary

ITEM NO.	ARTICLE NAME	SOURCE	CLASSIFICATION	DESCRIPTION	COMMENTS
113	Lessons learned from existing biomass power plants (pdf file)	National Renewable Energy Laboratory	Class 1	This report includes summary information on 20 biomass power plant	Review article
114	Energy Study_EBMUD (pdf file)	East Bay Municipal Utilities District (EBMUD), Oakland, California	Class 1	A paper on study conducted by EBMUD on waste-to-energy applications at the WWTP. Technologies investigated include cogeneration using digester gas, biosolids gasification and biodiesel from fats, oil and grease (FOG)	Review article
115	Power generation from biomass_Foster Wheeler (pdf file)	Foster Wheeler Development Corporation	Class 1	Paper by Foster Wheeler on fluidized bed gasification of biomass	Review article
116	Biomass Energy Data Book (pdf file)	Energy Efficiency and Renewable Energy, US Department of Energy	Class 1	This book is a statistical compendium for production of biofuels, biodiesel and biopower from biomass	Briefly review through the book
117	Gas cleanup and cost estimates_wood (pdf file)	National Renewable Energy Laboratory	Class 1	A report on syngas cleanup and conditioning technologies	Review article

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Literature Review Summary

ITEM NO.	ARTICLE NAME	SOURCE	CLASSIFICATION	DESCRIPTION	COMMENTS
118	SCWG_California Energy Commission	Energy Innovation Small Grants Program, California Energy Commission	Class 2	This project researched the feasibility of a supercritical water gasification (SCWG) process to convert compost made from municipal solid wastes and sewage sludge to clean energetic gases.	Briefly review article
119	Syngas production by SCWG of biomass (pdf file)	ECN Biomass and Twente University	Class 2	The objective of this study was to evaluate the production of "Green Gas" (SNG) from relatively wet biomass/waste streams (70-95 wt. % water) by the supercritical (ca. 600°C, 300 bar) water gasification (SCWG) process.	Briefly review article

2.1.2 Task BO.2 - Literature Assessment

After the literature review, the team began contacting vendors to identify those that were viable for this project. Exhibit 2-2 presents a list of vendors contacted during the initial literature assessment, a summary of information from phone conversations, and information from their websites. The last column of the table presents whether or not a vendor will be considered for further action or, if not, why they were eliminated from further consideration. This evaluation is further explained below.

The following is a list of vendors contacted during this phase:

- Kopf AG
- MPM Technologies Inc.
- EBARA Corporation
- Energy Products of Idaho (EPI)
- Carbona, Inc.
- Infilco Degremont
- Primenergy, Inc.
- Innovative Technologies (Ireland) Ltd.
- US Centrifuge
- Taylor Biomass Energy
- Foster Wheeler Inc.
- Enerkem Technologies, Inc.
- Silvagas Corporation
- Thermochem Recovery International
- Emery Energy Company
- Uhde Corporation of America
- Waste to Energy, UK
- Community Power Corporation

EXHIBIT 2-2
List of Vendors Contacted During the Technology Assessment Phase

Vendor Name	Contact Information	Summary of Vendor Evaluation	Pilot Testing / Eliminate?
Kopf AG	Stützenstr. 6, 72172 Sulz-Bergfelden, Germany Contact: Mr. Michael Gaiffi (Email: m.gaiffi@kopf-alb.de, Phone: 011-49-7454-75-176), Mr. Christian Burgbacher (Email: c.burgbacher@kopf-alb.de, Phone: 011-49-7454-75-204) Website: http://www.kopf-albe.de	Developed a direct fired gasification technology called *Kopf Gasification.* The vendor built a biosolids gasification system for Balingan Sewage Works, Germany which is operational since October 2002. The vendor is building a new gasification plant in Mannheim, Germany.	The vendor meets the vendor assessment criteria and is selected for further evaluation.

EXHIBIT 2-2
List of Vendors Contacted During the Technology Assessment Phase

Vendor Name	Contact Information	Summary of Vendor Evaluation	Pilot Testing / Eliminate?
MPM Technologies, Inc.	199 Pomeroy Road Parsippany, NJ 07054 Phone: (973) 428-5009 Fax: (973) 428-5027 Contact: Mr. Frank Hsu (email: fh888@airpol.com) Website: www.mpmtech.com	The vendor developed a technology called *Skygas Gasification – a plasma arc technology.* They have a demonstration Facility in Naples, Italy and pilot plant in Libby, Montana. Both plants are not operational at present. The Libby, Montana plant has the required infrastructure and can be reactivated if required. Gasification tests using biosolids have been conducted at the Libby, Montana facility in the past.	The vendor does not meet the vendor evaluation criteria for the following reasons: Does not have a continuous feed air and/or steam blown fixed or fluidized bed gasification. Does not have an operational commercial or demonstration facility for biomass/biosolids gasification.

EXHIBIT 2-2
List of Vendors Contacted During the Technology Assessment Phase

Vendor Name	Contact Information	Summary of Vendor Evaluation	Pilot Testing / Eliminate?
EBARA Corporation	11-1 Haneda Asahi-cho, Ohta-ku, Tokyo 144-8510 Japan Phone: 81-3-3743-6111 Fax: 81-3-745-3356 US Contact: Mr. Lawrence Molloy (Email: Lawrence.molloy@Ebara-Seattle.org, Phone: (206) 622-1120) Website: www.ebara.co.jp/en/	The vendor developed two gasification technologies – *TwinRec Process* (atmospheric gasification) and *EBARA UBE Process* (pressurized gasification). The vendor has demonstrated significant experience with atmospheric biosolids and biomass gasification. The vendor provided a reference list of 150 gasification projects completed since 1975. Of these, 4 gasification projects have been completed for sewage sludge since 2002.	The vendor meets the vendor assessment criteria and will be considered for pilot plant testing.

EXHIBIT 2-2
List of Vendors Contacted During the Technology Assessment Phase

Vendor Name	Contact Information	Summary of Vendor Evaluation	Pilot Testing / Eliminate?
Energy Products of Idaho (EPI)	4006 Industrial Avenue Coeur d'Alene, Idaho 83815-8928 Phone: (208) 765-1611 Fax: (208) 765-0503 Contact: Mr. Patrick Travis Website: www.energyproducts.com	The vendor developed an updraft atmospheric fluidized bed gasification system. The vendor designed and built a biomass gasification facility in Cedar Rapids, Iowa that is operational. The vendor designed a biosolids gasification system for the City of Hoboken, NJ WWTP in 1991. However, the project did not proceed due to political reasons. The vendor has an operational pilot plant facility in Coeur d'Alene, Idaho.	The vendor meets the vendor assessment criteria and will be considered for pilot plant testing.

EXHIBIT 2-2
List of Vendors Contacted During the Technology Assessment Phase

Vendor Name	Contact Information	Summary of Vendor Evaluation	Pilot Testing / Eliminate?
Carbona, Inc.	PO Box 7067 Napa, CA 94558 Phone: (707) 553-9800 Fax: (707) 553-9820 Contact: Mr. Jim Patel (email: carbona@carbona.us)	Pressurized fluidized bed gasification technology. The vendor has designed and built several biomass gasification systems. The vendor has a demonstration plant in Skive, Denmark. Gasification of biosolids is not in accordance with the company's strategic business plan. Therefore, the vendor is not interested in the project.	The vendor indicated that gasification of biosolids is not in accordance with the company's business plan. Also, biosolids gasification trial runs conducted by the vendor have indicated that the syngas from biosolids is detrimental to the catalyst used in the gasification process. Therefore, the vendor will not be considered for further evaluation.
Infilco Degremont	8007 Discovery Drive Richmond, VA 23229 Phone: (804) 756-7600 Fax: (804) 756-7643 Contacts in France: Mr. Marcel Lesoille (Email: marcel.lesoille@degremont.com), Mr. Andre Haubry (Cell phone: 011-33-6-85-41-0436, Email: andre.haubry@degremont.com) Website: www.infilcodegremont.com	The vendor installed a biosolids gasification system for the Valenton WWTP; owned and operated by the Authority of Sewage and Waste Water Treatment for the area of Paris, France. The facility is still under construction. The Degremont system is a gasification multiple hearth with rotating shaft and arms.	The vendor meets the vendor assessment criteria and will be considered for pilot plant testing.

EXHIBIT 2-2
List of Vendors Contacted During the Technology Assessment Phase

Vendor Name	Contact Information	Summary of Vendor Evaluation	Pilot Testing / Eliminate?
Primenergy, Inc.	P.O. Box 581742 Tulsa, Oklahoma 74158 Phone: (918) 835-1011 Fax: (918) 835-1058 Contact: Mr. Kevin McQuigg (email: kmcquigg@primenergy.com) Website: www.primenergy.com	Fixed bed atmospheric updraft gasification technology. The vendor built a biosolids gasification system for the Philadelphia Water Department. The plant is currently not operational. The vendor has built a gasification system for a rice hulls facility in Arkansas, for wood processing residue facilities in Georgia and Minnesota.	The vendor meets the vendor assessment criteria and will be considered for pilot plant testing.

EXHIBIT 2-2
List of Vendors Contacted During the Technology Assessment Phase

Vendor Name	Contact Information	Summary of Vendor Evaluation	Pilot Testing / Eliminate?
Innovative Technologies (Ireland) Ltd.	47 Manse Road Bally Carry Carridefergus Northern Ireland BT38 9HP, UK Phone: +44 (0) 28 9337 3379 Fax: +44 (0) 28 9357 8039 Website: www.innovation-tech.co.uk	The vendor developed a gasification technology in collaboration with Fluidyne Gasification of New Zealand. The vendor markets modular gasification system of various sizes. The vendor built a demonstration and commercial gasification plants in Northern Ireland. The vendor has experience with gasification of wood waste and municipal derived fuel (MDF).	The vendor will not be considered for further evaluation as the Stamford gasification project is too big for their technology application. The largest commercial system marketed by the vendor is a 100 KW system.
US Centrifuge	4011 Championship Drive Indianapolis, IN 46268 Phone: 1-800-899-2040 Contact: Mr. Martin Nilsson Website: www.uscentrifuge.com	The vendor claims to have experience with gasification of sewage biosolids, hog manure sludge, waste paper pulp sludge, latex sludge, automotive paint sludge and industrial laundry sludge. The vendor has built a skid mounted pilot plant.	The vendor does not meet the vendor evaluation criteria for the following reasons: Does not have a continuous feed air and/or steam blown fixed or fluidized bed gasification.

EXHIBIT 2-2
List of Vendors Contacted During the Technology Assessment Phase

Vendor Name	Contact Information	Summary of Vendor Evaluation	Pilot Testing / Eliminate?
Taylor Biomass Energy	350 Neelytown Road Montgomery, NY 12549 Contact: Mr. Mark Paisley Email: Mark.Paisley@taylorbiomassenergy.com Phone: (614) 893-7312 Fax: (614) 459-8579 Website: www.taylorbiomassnergy.com	The vendor is in the process of building a commercial facility in Montgomery, NY. The Facility will produce 24 MW of power by processing 300 dry tons per day of construction and demolition materials and municipal solid waste (MSW) feedstock. The vendor is not interested in a developmental project. The vendor is only interested in commercial installations. They would be interested if the biosolids feedstock would be combined with MSW and/or construction & demolition materials. Mr. Paisley was the Biomass Gasification Program Manager at Battelle (www.battelle.org); Battelle manages the National Renewable Energy Laboratory for the Department of Energy.	The vendor does not meet the vendor evaluation criteria for the following reasons: Does not have an operational commercial or demonstration facility for biomass/biosolids gasification. The vendor is not interested in a project that involves bench scale and pilot scale testing. The vendor does not have experience with gasification of biosolids/biomass feedstock.

EXHIBIT 2-2
List of Vendors Contacted During the Technology Assessment Phase

Vendor Name	Contact Information	Summary of Vendor Evaluation	Pilot Testing / Eliminate?
Foster Wheeler, Inc.	Perryville Corporate Park Clinton, NJ 08809 Phone: (908) 730-4000 Fax: (908) 730-5315 Contact: Mr. Dave Wagner, Director of Strategic Initiatives Website: www.fwc.com	Developed an atmospheric fluidized bed gasification technology. The vendor supplied seven commercial biomass and refuse derived fuel (RDF) gasification systems producing low heat value gas for various applications.	The vendor is interested in the project but does not have the availability to assist at this time. As a result, the vendor will not be considered for further evaluation.
Enerkem Technologies, Inc.	615, boul. Rene-Levesque Ouest Suite 1220, Montreal, Quebec Canada H3B 1P5 Phone: (514) 875-0284 Fax: (514) 875-0835 Contact: Mr. Martin Gagnon (email: mgagnon@enerkem.com) Website: www.enerkem.com	Developed a technology called *BIOSYN* – bubbling fluidized bed pressurized gasification. Gasification systems operate around 30 to 35 psi pressure. Gasification demonstration plant in Sherbrooke, Quebec, CA. Meat, biomass, biosolids, MSW/RDF fuel and plastic have been gasified successfully at the demonstration plant. The plant is currently operational. Another gasification demonstration plant that gasifies plastic is currently operational in Spain.	The vendor is interested in the project but does not have the availability to assist at this time. As a result, the vendor will not be considered for further evaluation.

EXHIBIT 2-2
List of Vendors Contacted During the Technology Assessment Phase

Vendor Name	Contact Information	Summary of Vendor Evaluation	Pilot Testing / Eliminate?
Silvagas Corporation	One Overton Park 3625 Cumberland Blvd Suite 650 Atlanta, GA 30339 Phone: (770) 690-2450 Fax: (770) 690-2451 Contact: Mr. Sim Weeks Website: www.fercoenterprises.com	Developed a technology called the *SilvaGas Process*. First commercial demonstration gasification plant in Burlington, Vermont. The plant gasifies biomass (wood waste) to produce energy. Other biomass gasification demonstration plants in Winkleigh, Devon, United Kingdom and Forsyth County, Georgia. Vendor is not interested in a project that is less than 200 dry tons per day of feedstock processing capacity.	The vendor considers the Stamford project very small for their technology application. As the vendor is not interested in the project, the vendor will not be considered for further evaluation.

EXHIBIT 2-2
List of Vendors Contacted During the Technology Assessment Phase

Vendor Name	Contact Information	Summary of Vendor Evaluation	Pilot Testing / Eliminate?
Thermochem Recovery International (TRI)	3700 Koppers Street Suite 405 Baltimore, MD 21227 Phone: (410) 525-2400 Fax: (410) 525-2408 Contact: Mr. Ravi Chandran Website: www.tri-inc.net	The vendor claims to have developed a technology for gasification of black liquor (waste sludge produced during the paper manufacturing process). 115 tons per day (40% moisture) commercial installation in Trenton, Ontario, Canada. 200 tons per day demonstration project for Georgia-Pacific Corporation, Big Island, Virginia.	The vendor does not meet the vendor evaluation criteria for the following reasons: Does not have an operational commercial or demonstration facility for biomass/biosolids gasification.

EXHIBIT 2-2
List of Vendors Contacted During the Technology Assessment Phase

Vendor Name	Contact Information	Summary of Vendor Evaluation	Pilot Testing / Eliminate?
Emery Energy Company	159 West Pierpont Avenue Salt Lake City, Utah 84101 Phone: (801) 364-8283 Fax: (801) 746-3256 Contact: Mr. Ben Phillips, (email: bhillips@emeryenergy.com) Website: www.emeryenergy.com	Developed fixed bed atmospheric gasification technology. Two pilot plants in Utah currently operational. Two projects in the detailed design phase; one for municipal solid waste (MSW) in Europe and the other for mixed wood in the USA. Both projects are approximately 18 to 20 months away from completion. Does not have a commercial installation that is currently operational. The vendor provided a completed vendor evaluation questionnaire but requested not to be included in the Report.	The vendor does not meet the vendor evaluation criteria for the following reasons: Does not have an operational commercial or demonstration facility for biomass/biosolids gasification.

EXHIBIT 2-2
List of Vendors Contacted During the Technology Assessment Phase

Vendor Name	Contact Information	Summary of Vendor Evaluation	Pilot Testing / Eliminate?
Uhde Corporation of America	1370 Washington Pike USA-Bridgeville, PA 15017 Phone: (412) 257-8277 Fax: (412) 257-8344 Contact: Mr. Max Hooper (Cell: (713) 805-1647) Website: www.uhde.biz	Entrained air gasification system. The vendor has built a biomass gasification demonstration facility in Nuam, Buggem, Netherlands. In the USA, the vendor is interested in co-gasification projects only; i.e. gasification of biosolids/biomass with coal or petroleum coke. The vendor is not interested in a project that is less than 150 tons per hour of feedstock processing capacity.	The vendor is interested in co-gasification projects only, and considers the Stamford project very small for their technology application. Therefore, the vendor will not be considered for further evaluation.

EXHIBIT 2-2
List of Vendors Contacted During the Technology Assessment Phase

Vendor Name	Contact Information	Summary of Vendor Evaluation	Pilot Testing / Eliminate?
Waste to Energy	Melita House 124 Bridge Road Chertsey, KT16 8LH Tel: 01932 5758888 Fax: 01932 575889 Contact: N.A. Email: info@wastetoenergy.co.uk Website: www.wastetoenergy.co.uk	The vendor has developed a fixed bed gasification system. The vendor completed a biosolids gasification pilot project for Anglian Water, United Kingdom. The vendor has also completed a gasification project processing leather shavings, trimmings and tanned waste for British Leather Corporation.	Several attempts were made to establish contact with the vendor. The vendor has not responded yet. Therefore, the vendor will not be considered for further evaluation.

EXHIBIT 2-2
List of Vendors Contacted During the Technology Assessment Phase

Vendor Name	Contact Information	Summary of Vendor Evaluation	Pilot Testing / Eliminate?
Community Power Corporation (CPC)	8420 S. Continental Divide Road Littleton, CO 80127 Tel: (303) 933-3135 Fax: (303) 933-1497 Contact: Mr. Robb Walt, President Email: rwalt@gocpc.com Website: www.gocpc.com	The vendor has developed a modular gasification system called Biomax®. The size of the system ranges from 5 KW to 100 KW. The vendor has developed a fluidized bed gasification system but not large enough for the Stamford project application. The vendor has encountered problems gasifying biosolids in their system, and has decided not to consider biosolids feedstock for their technology application.	The vendor will not be considered for further evaluation as the Stamford gasification project is too big for their technology application. Their largest commercial system is 100 KW. Also, trial runs for gasification of biosolids have not been successful.

An introduction call was made to each vendor. Each vendor who expressed an interest in the project was provided with a one-page project description, and an evaluation questionnaire to complete.

The evaluation questionnaire was developed by the team to help identify if a vendor should be considered for further evaluation. The evaluation questionnaire was established based on the following criteria:

- Commercial biosolids/ biomass gasification facilities?
- Facilities in the US?
- U.S. representation?
- Location of the facility? When was it commissioned? Currently operational?
- Capacity? Feedstock?
- Quantity of Syngas? Impurities? Characteristics? How is it used?
- Gas purification process? Experience? Performance?
- Internal energy requirements?
- Safety issues?
- Cost?
- Footprint?

Eight vendors provided feedback with completed questionnaires. Of the eight, seven criteria sheets have been included in Appendix 2-B. Emery Energy Company provided the completed questionnaire but requested that their questionnaire not be included in the report because the firm preferred not to disclose details about its technology to the public at that time.

2.1.3 Conclusions of Technology Assessment

After the vendor information was collected, the CH2M HILL team reviewed each of the completed questionnaires. Each vendor was then evaluated based on the criteria in the questionnaire to determine which should be included in the next phase of this project. The results of this analysis are provided in the last column of Exhibit 2-2. Based on the review, CH2M HILL recommended the following five vendors for consideration for the pilot-scale testing:

- Kopf AG (Germany)
- EBARA Corporation (Japan)
- Energy Products of Idaho (EPI)
- Primenergy, Inc. (Oklahoma)
- Infilco Degremont (France)

It was determined the remaining vendors did not meet one of the project evaluation criteria. For example, they were eliminated if they did not have an operational or a demonstration facility for biomass or biosolids gasification; or, the vendor did not have a continuous feed air and/or steam blown fixed or fluidized bed gasification system.

After further conversations with the vendors, it was learned that EBARA, EPI and Infilco Degremont were not interested in a project of this size. A Request for Proposal (RFP) for

Pilot Testing and Preliminary Design was sent to Kopf AG and Primenergy. The details of this RFP are discussed in Section 4.

2.2 Continuing Technical Innovation

The literature review and subsequent vendor assessment clearly confirmed that biosolids gasification is an area of significant continuing research and vendor product development. It is therefore clear that ongoing assessment of this development is important to insure the SWPCA project incorporates the state-of-the-art as it develops. The criteria established in Task BO.2 above continue to provide the primary basis for evaluation, with additional criteria being:

- Compatibility of the innovation with technology concepts already incorporated into the design
- The status of existing project agreements with vendors by SWPCA
- The status of and potential impact on grants and other funding secured for the project

This process has become integral to the project development, with the following specific considerations being made to date:

- SWPCA investigation of potentially larger scale biosolids gasification facilities led to identification of Babcock & Wilcox (www.babcock.com) and Nexterra Energy (www.nexterra.ca) as vendors with recent commercial installations. While Babcock and Wilcox projects are focused on the larger scale market, Nexterra's work was determined to be consistent with the project criteria, warranting further consideration. (Discussed in further detail in Section 4).
- MaxWest approached SWPCA in April 2008 indicating their plans construct and operate a biosolids syngas facility during 2009. Evaluation of this vendor indicated inconsistencies of their technology configuration and business model, with plans of the SWPCA project (evaluation included in Appendix).

SECTION 3

Alternative Development and Testing

In order to evaluate the feasibility of converting the biosolids to syngas for electricity production, a series of tests were performed on the Stamford biosolids. The first test was to characterize the biosolids to determine if they were an appropriate fuel for the gasification process and would produce a quality syngas. In the second set of tests, Stamford biosolids were sent to the University of North Dakota Energy and Environment Center (UNDEERC) for bench-scale and pilot-scale gasification testing. In the third set of tests, a bench-scale gasifier was built at the SWPCF to test the Stamford biosolids and other potential biosolid fuels. This section summarizes the biosolids characterization, the onsite bench-scale testing performed by the SWPCA and Carlin, and the offsite bench-scale testing completed by UNDEERC.

3.1 Biosolids Characterization

The purpose of this test was to characterize the SWPCF biosolids to determine if gasification were viable. The data produced were used to develop the pilot-scale testing phase of the project and to establish the design criteria for the new gasification system.

The SWPCA collected grab samples of biosolids from the discharge end of the three belt filter presses (BFPs) on the third floor of the Sludge Processing Building (SPB). The samples were collected at equal intervals of approximately 2 hours during normal operating BFP hours.

Grab samples were collected on the following days:

- Week 1 – June 13, 2007 and June 18, 2007
- Week 2 – June 20, 2007, June 22, 2007 and June 25, 2007
- Week 3 – June 27, 2007, June 29, 2007 and July 2, 2007

Because the Dryer facility was not online yet, all grab samples were oven dried at 110°C for approximately 18 hours to reduce moisture. The dried samples were processed in a chopper to reduce particle size. Equal amounts of dried and processed samples from each sample collection day for that week were mixed together to prepare weekly composite samples. The samples were labeled Week 1, Week 2, and Week 3 and then sent to Hazen Research, Inc. (Hazen) in Golden, Colorado, for detailed characterization.

The following analyses were conducted on each of the composite samples by Hazen:

- Proximate Analysis; Method ASTM D3172
- Ultimate Analysis, Method ASTM D3176
- Heating Value, Method ASTM D5865
- Ash Slagging, Method ASTM D1857

- Metals "as received" and "in ash"; Method SW6010B; arsenic, mercury and selenium were analyzed using the oxygen bomb combustion method

Exhibit 3-1 summarizes the results of the biosolid characterization performed by Hazen. Complete results are presented in Appendix 3-A.

EXHIBIT 3-1
Summary of Biosolids Characterization Results

Parameter	Result
Ash Content	18.1%
Fusion Temperature (Reducing)	1974°F
Fusion Temperature (Oxidizing)	2042°F
Volatile Content	70.8%
Fixed Carbon	11.2%
High Heating Value (HHV; as received)	7,615 BTU/lb
Mercury	0.04 mg/kg

3.1.1 Analysis of Biosolids Characterization Data

CH2M HILL reviewed the characterization data provided by Hazen. The data were compared to similar biosolids data (not digested, dried and/or pelletized) from the Energy Research Center of the Netherlands (ECN). The ECN database PHYLLIS (http://www.ecn.nl/phyllis/) is an online database of characterization of different types of biomass and waste materials that have acquired significant attention in recent times as renewable fuel because of their high energy content. Copies of biosolids characterization retrieved from the PHYLLIS database for comparison to the SWPCF biosolids characterization are in Appendix 3-B. The following is an analysis of key parameters to the data available from the PHYLLIS database.

Ash Content (%) and Fusion Temperatures

The ash content of the SWPCF biosolids is less than other documented raw (not digested) municipal biosolids. The mean ash content of the three biosolid samples analyzed by Hazen is 18.1 percent. The documented ash content for raw municipal biosolids is between 25 percent and 30 percent. The typical ash content present in digested municipal biosolids is approximately 40 percent.

The ash content in biosolids represents inert material (mostly minerals) that does not combust upon gasification and exits the gasification reactor as bottom ash or fly ash. Ash reduces the overall efficiency of gasification systems. It is anticipated that the amount of bottom ash generated from the proposed SWPCF gasification system will be less than a similarly sized gasification facility. The ash residue is typically disposed of in a landfill, although there are some beneficial reuses such as soil conditioning, fertilizer, or as an ingredient in cement.

The ash fusion temperatures are above 1974°F and 2042°F for reducing and oxidizing atmospheres, respectively. Because typical operating temperatures of gasification reactors are between 1500 and 1700 °F, it is unlikely that the SWPCF biosolids will have clinkering in the reactor or the off-gas ducts. Clinkering is the result of the combustion process when the temperature is elevated to a point where the ash constituents will start to melt. The softened or melted matter then fuses into chunks when the temperature drops, and the resulting solids form an irregular lumps. As a result of this most furnaces, especially those with pneumatic ash handling, have a clinker grinder at the furnace exit for the ash.

Volatile Content and Fixed Carbon

The combustible content of the biosolids consists of the volatile content plus the fixed carbon content. The volatile content is the portion that readily converts to syngas (mostly carbon monoxide and hydrogen) during gasification. The fixed carbon is more difficult to gasify than the volatile content, and it is important to note the difference in the design of a gasifier. The tests selected for this analysis differentiate between volatile and fixed carbon. (Volatile content in the wastewater industry is usually measured using Standard Methods 209F, which reports the total combustible content as volatile matter).

The mean volatile content of the three biosolid samples analyzed by Hazen is 70.8 percent. This is greater than the typical volatile content of digested municipal biosolids, which is approximately 50 percent. The high volatile content is because the SWPCF biosolids are not digested.

High Heating Value (BTU/lb)

The heating value of the SWPCF biosolids is typical of other raw or digested municipal biosolids. The mean high heating value (HHV) of the three biosolid samples analyzed by Hazen is 7,615 BTU/lb (as received). It is anticipated that, based on the higher volatile content and similar HHV, the thermochemical energy of the syngas produced from the SWPCF gasification facility will be more than a similarly sized gasification facility that processes digested municipal biosolids.

Mercury (mg/kg)

The mercury concentration of the SWPCF biosolids is similar to other municipal biosolids. The mean mercury concentration of the three biosolid samples analyzed is 0.6 mg/kg. This falls within the range of the typical mercury concentration of municipal biosolids of approximately 0.5 mg/kg to 1.0 mg/kg. In the gasification reactor, almost all of the mercury present in the biosolids will stochiometrically convert to elemental mercury and leaves the gasifier with the syngas.

Based on previous experience, it is likely that mercury will be present in the syngas at measurable levels. However, it is also anticipated that the concentration will be low and will pass the current air emission standards. If the concentration of mercury in the syngas is higher than the allowable air emission standards technology to control this emission such as an activated carbon adsorption system can be used to adsorb mercury and remove it from the syngas.

Summary

The SWPCF sludge prior to drying is typical for a mixture of undigested primary and secondary wastewater sludge. Therefore, the resulting dried biosolids is anticipated to be well-suited for use as fuel for gasification, based on successful results with similarly treated sludges. This was further investigated in the bench scale testing and pilot testing phases as documented in Section 3.2, 3.3 and Section 4.

3.2 Offsite Bench-Scale and Pilot-Scale Testing

3.2.1 Introduction to UNDEERC

Bench-scale testing and pilot-scale testing were conducted at UNDEERC—a high-tech, nonprofit branch of the University of North Dakota (UND) that was once affiliated with the Department of Energy. Although a not-for-profit entity, UNDEERC operates in a business like environment and conducts research, development, demonstration, and commercialization activities.

UNDEERC's research portfolio consists of a wide array of strategic energy and environmental solutions, including clean coal technologies, CO2 sequestration, energy and water sustainability, hydrogen technologies, air toxics and fine particulate, mercury measurement and control, alternative fuels, wind energy, biomass, water management, flood prevention, global climate change, waste utilization, energy-efficient technologies, and contaminant cleanup.

For the past 20 years, UNDEERC has leveraged federal research dollars and developed working partnerships with private industry, state agencies, the research community, academic institutions, and government agencies. UNDEERC receives no state-appropriated funding, and the majority of UNDEERC contracts are from nonfederal entities.

3.2.2 UNDEERC Bench-Scale Equipment

Bench-scale testing includes gasification of biosolids to generate synthetic biogas (syngas) and gasification byproducts. The syngas and gasification byproduct is characterized to identify constituents and contaminants as well as unit gas production. Gas analyses are for carbon monoxide, hydrogen, methane, carbon dioxide, nitrogen, oxygen, hydrogen sulfide, total reduced sulfur compounds, siloxane compounds, tars/oils, and heating value. Gasification byproduct analyses include proximate analyses, heating value, ash fusion characteristics, and metal characterizations.

UNDEERC operates a 1- to 4-lb/hr continuous fluid-bed reactor (CFBR) bench-scale test unit previously used to pyrolyze/gasify coal, plastics, automotive shredder residue, and wood chips. The system is rated at 815°C (1500°F) and 170 psi. Various process gases and liquids can be used for reactants.

Data collection and process control are achieved with a process control software package. Sixty-two data points are stored every 30 seconds and are updated on the screen every 2 seconds. The data are stored in a Lotus format that can be downloaded or displayed graphically.

3.2.3 UNDEERC Pilot-Scale Equipment

UNDEERC operates a commercial demonstration facility (also called Truss Plant) that converts wood waste to electricity in Grand Forks, North Dakota. The gasifier is a downdraft gasifier consisting of a drying zone, pyrolysis zone, combustion zone and reduction zone. Fuel is fed from 55- gallon drums. The gasifier operates at temperatures between 900°C (1652°F) and 950°C (1742°F).The demonstration facility began operation in October 2007.

Electronic process control and data collection are limited. Emissions are continuously monitored and computer-logged. The gasifier bed temperatures, airflow rate into the gasifier, and syngas flow rate are measured manually.

3.2.4 Phase I Bench-Scale and Pilot-Scale Testing Scope

A request for proposal (RFP) was sent to UNDEERC in June 2007 to perform bench-scale and pilot-scale testing on the Stamford biosolids. The Scope of Work for Phase I of the UNDEERC testing consisted of two tasks, as follows:

Task 1 – Continuous Fluidized Bed Reactor (CFBR) Testing

Conduct five gasification test runs, including one (1) duplicate using UNDEERC's CFBR. A characterization of ash produced from various stages of the gasification process, and syngas flow rate and characterization is to be performed.

Task 2 – Downdraft Gasifier Testing at Commercial Demonstration Scale

Conduct one 8-hour gasification test run at UNDEERC's downdraft gasification demonstration facility. The goal for this task is to assess operational performance and maintenance characteristics using biosolid pellets.

For further details about the Scope of Work refer to UNDEERC's Proposal No. 2008-0105 dated October 23, 2007 in Appendix 3-C.

3.2.5 Phase I Bench-Scale and Pilot-Scale Testing Results

UNDEERC completed three bench-scale gasification test runs using the CFBR (bench-scale), and one 8-hour test run using the downdraft demonstration facility (pilot-scale). A summary of data produced from these tests was sent to CH2M HILL on January 11, 2008 and is presented in Appendix 3-D. The following sections provide CH2M HILL's opinion on test data available from UNDEERC. Table numbers refer to the Tables in the report.

Analysis of Continuous Fluidized Bed Reactor (CFBR) Testing (Bench Scale)

- The average operating temperature for the three test runs was 857°C (1,575°F) which is a lower temperature than typically noted in documentation of other biomass gasification facilities. These more typically operated at between 900°C (1,652°F) and 950°C (1,742°F). On December 18, 2007 CH2M HILL, WPCA and Carlin Contracting had a meeting with UNDEERC at the research facility in Grand Forks, North Dakota to discuss the preliminary results. During the meeting, CH2M HILL recommended UNDEERC increase the operating temperature in the CFBR for the remaining tests to temperatures between 900°C (1,652°F) and 950°C (1,742°F). UNDEERC notified the project team that the existing set-up of the CFBR prohibits conducting gasification test runs at temperatures requested by the project team.

- Reported Organosilicon analysis results indicated concentrations of three organosilicons compounds (siloxanes) present in the syngas: trimethylsilanol, hexamethylcyclotrisiloxane (D3) and tetraethylsilicate. Trace concentrations of siloxanes have become common in wastewater as they have become common in toiletries such as shampoo and hair spray. The presence of siloxanes in the gas is a significant design factor in the selection of the electrical generation equipment and determining requirements for gas conditioning systems. Both internal combustion engines and gas turbines are sensitive to siloxanes, while engines are more somewhat tolerant.

- Gas chromatograph analysis indicates the bench-scale results for combustible gas were lower than literature results as follows:

Gas	Gas Chromatograph Analysis (%)	Literature Results (%)
Hydrogen	4.4	14.9
CO	8.6	16.7
Methane	1.8	4.0
CO2	14.4	14.5

This situation indicates favored combustion to gasification in the reactor. It appears the air-to-fuel ratio used for CFBR testing (average of 3.15 lb/lb) is high, thereby driving the reactor operation away from optimum conditions.

- Solids Analysis indicates very low combustible residue present in the discharge ash from the cyclone and filter vessel downstream of the reactor. This is evident by low loss on ignition (LOI) data, which indicates that no carbonization (formation of elemental carbon) took place in the gasification reactor or the cyclone, or carbon combusted due to high air-to-fuel ratio.

- Analysis of syngas samples (Draeger sampling) collected before the quench stage during the three test runs showed ammonia concentrations ranging from 8,000 ppm to 18,000 ppm. The concentration of ammonia present in the syngas is very high when compared to concentrations encountered in syngas produced from other biomass feedstock, such as wood chips. CH2M HILL anticipated ammonia concentration in the syngas to be high because of the high concentration of nitrogen present in the biosolid pellets.

- Analysis Results for Cyclone and Filter Vessel Ash Samples indicates a very low concentration of mercury in the discharge ash from the cyclone downstream of the reactor. Biosolids fuel analysis indicates that the concentration of mercury present in the biosolids pellets is approximately 1.9 microgram per gram (μg/g). The average concentration of mercury present in the cyclone ash was measured at 0.02 μg/g. This indicates that the mercury present in the pellets was volatilized with the syngas.

- The average HHV of the syngas produced from the three test runs using CFBR was calculated to be 82 BTU/scf (BTU per standard cubic foot). CH2M HILL considers this HHV to be very low compared to HHV of syngas produced from biomass gasification reported in the literature (150 BTU/scf).Conclusion/Observation

- Overall, the gasification test data produced by UNDEERC using the CFBR are not what the team expected when compared to typical biomass gasification operation and analytical data reported in the literature.

Analysis of Demonstration Gasification Facility Testing (Pilot-Scale)

- The gas composition reported by UNDEERC is compared to values found in review of literature as follows:

Gas	Average Reported by UNDEERC (%)	Literature Results (%)
Hydrogen	14.7	14.9
CO	13.8	16.7
Methane	2.8	4.0
CO2	15.7	14.5

Therefore, percent volume of these compounds in the Stamford syngas is similar to the syngas from a typical biomass gasification facility.

- The gas samples were analyzed for benzene, toluene and xylene (BTEX). The presence of BTEX is an indicator of the presence of tars in the syngas produced. The total BTEX concentration was approximately 9.5 parts per million (ppm), which suggests that tar vapors are present in the syngas.

- Eight syngas samples were collected for analysis during the course of the run. The average HHV of the syngas was reported as 146 BTU/scf. CH2M HILL anticipated the HHV of the gas to be approximately 150 BTU/scf. Therefore, the syngas HHV is within the range expected.

- The approximate cold gas efficiency of the gasifier is 70 percent which is similar to gasifier efficiencies for biomass gasification reported in the literature.

- The operational temperature of the gasifier is between 649°C (1,200°F) and 982°C (1,800°F). The operational temperature range is very broad compared to operating temperatures reported in the literature. CH2M HILL expected the operating temperature of the gasifier to be between 900°C (1,652°F) and 950°C (1,742°F).

- While operational data was not provided, observations of use of the gas to power the on-site internal combustion engine/electrical generator provided encouraging results.

3.2.6 Phase II Pilot-Scale Testing

The tests completed by UNDEERC in the Phase I testing using the CFBR did not provide expected results. Therefore, CH2M HILL recommended no further testing using the CFBR and that the remainder of the testing focus on the pilot-scale unit. Because additional fuel was needed, a second batch of Stamford biosolids was sent to UNDEERC for this testing.

The Phase II testing at the pilot facility consisted of the following tests:

- Proximate and ultimate analysis of new biosolids. Calculate heating values and percent solids of biosolids.
- Two additional 8-hour to 12-hour test runs at steady state.
- Maintain the operating temperature in the gasifier between 900°C (1,652°F) and 950°C (1,742°F) during steady-state operation using biosolid pellets.
- Approximate temperatures in the gasifier before and after the syngas samples are collected.
- Approximate flow rate of air fed into the gasifier.
- Approximate flow rate of syngas produced when the gasifier is operating at steady state.
- Characterization of syngas composition and contaminants.
- Quantity of solid residue (char and ash) produced from the gasifier and the venturi scrubber.
- Conduct a Loss on Ignition (LOI) test on the solid residue.

3.2.7 UNDEERC Testing Results and Conclusions

On July 2, 2008, UNDEERC submitted the draft report entitled Biosolids Gasification Support for the City of Stamford, Connecticut. The final report was submitted on August 14, 2008 and is presented in Appendix 3-E.

The following observations and conclusions were made regarding the information in the report and the testing of the Stamford biosolids.

Type of Gasifier

A downflow gasifier is not appropriate for this application because reaction temperatures are difficult or impossible to control and keep below the ash fusion temperature. Therefore, the team will move forward with fluid bed or fixed bed upflow gasifiers. Operating temperatures should be controlled at approximately 1,560°F or lower.

Gas Formation

The composition and heating value, etc., of the dried biosolids appear to be consistent, based on the two sets of materials shipped to UNDEERC. A consistent composition of biosolids makes operating a gasifier system simpler.

It is unclear whether or not good conclusions can be drawn on the conversion rates and gas composition and heating value. Qualitatively, the conversion looks good, as well as the heating value in the 140 Btu/cubic ft range. The created syn-gas should work well in an internal combustion engine-generator.

Clinkering

As expected there was clinker formation in the downflow gasifier. The ash is stable below approximately 1,690°F.

Clinkering is typical of what has been observed in sludge furnaces such as multiple hearth furnaces (MHFs) that operate at varying temperatures as high as about 1,780°F.

Clinker formation may possibly be attributable to the high content of phosphorous and other minerals like iron and potassium in the sludge. This same issue occurs with sewage sludge incineration, when iron chelates in the wastewater sludge treatment process react with phosphorous and phosphates in the sludge, forming low-melting-point iron-phosphate compounds.

Tar Formation

Tar formation may be an issue. It is difficult to determine if the operating temperature had an impact.

Other Parameters

Siloxane is a component of the biosolids and may need to be treated prior to gasification. Siloxanes are partially or totally converted to silicon dioxide, which may cause damage to engines.

Hydrogen sulfide does not appear to be a problem in post-gasifier combustion devices. At the levels measured, gas engines or boilers should not experience operating issues, provided the proper system start-up and shutdown procedures are observed.

From a gasification/energy generation process perspective, ammonia should not be a problem in combustion equipment. However, issues with emission limits from NOx formation in boilers or IC engines are possible. This will need to be reviewed after vendor pilot-test results are obtained.

Mercury behaved in the expected pattern in the gasification tests. Mercury emissions may well meet local emission standards with no emission control equipment or, at worst, mercury can simply be controlled by activated carbon addition.

Siloxanes are now more prevalent in municipal residuals/biosolids due their increasing use in consumer products. These compounds will vaporize and manifest themselves in the gas stream of any gasifier. Syn-gas treatment for siloxane removal will be required prior to the syn-gas use in any conversion devices.

3.3 Onsite Bench Scale and Pilot-Scale Testing

In addition to off-site testing, SWPCA worked directly with Carlin Contracting to construct a small scale gasifier unit at the Stamford plant site. Testing of this unit was intermittent based on the availability of staff and other operational factors, and documentation of results was generally informal. The primary purpose of this facility was to provide SWPCA direct experience with a gasification facility fueled the SWPCA biosolids pellets. SWPCA did not provide quantitative results from operation of this unit, so none are considered in this report. However they did indicated they felt the experience and insight provided to staff was invaluable during subsequent testing, both to assist vendors and to validate the results they saw. This included which feed rates and operating temperatures typically provided the best results, and key qualitative indicators of gasifier performance, such as the appearance of well-converted ash.

SECTION 4

Technology Selection for 1 to 3 Megawatt WTE Facility

4.1 Vendor Selection and RFP Process

Section 2 provides a description of the process used to identify proven technologies, and the establishment and application of project criteria to provide a short list of five eligible vendors. Two of the five (Kopf AG and Primenergy) indicated interest in the project and were sent a Request for Proposal (RFP) for Pilot Testing and Preliminary Design. A third vendor (Nexterra) was subsequently identified and similarly provided information consistent with the RFP during 2009. A copy of the RFP is provided in Appendix 4-A. Section 4 summarizes the evaluation of proposals received and subsequent pilot testing.

The RFP was initially sent in April 2008 and consisted of a two-stage proposal. Stage 1 was to be submitted by the initial two vendors in May 2008 and Stage 2 was to be submitted in October 2008.

The Stage 1 proposals included:

- Preliminary information about each vendor's equipment
- The location, description, process flow diagram (PFD), quantity of biosolids required, and test procedures of existing plants that could be used for pilot testing.
- Identification and narrative description of a reference facility currently in operation that was similar to the proposed WTE facility.
- Preliminary design of the Stamford WTE facility including PFD, feedstock analysis, description of selection and sizing of trains, mass and energy balance, facility layout drawings, list of equipment, utility requirements, air emission treatment, and residual treatment.
- A "not to exceed cost" for providing the gasification facility.

The Stage 2 proposals contained information updated with pilot-scale testing results, and preliminary design and exhibits based on the collected data. It also included process guarantees based on feedstock, syngas quality and quantity, water consumption, air/oxygen consumption, steam consumption, chemicals, energy requirements, waste, and power generation. Finally, the proposals contained each vendor's best and final offer for the gasification equipment for the 1-3 MW WTE demonstration facility.

4.2 Primenergy

4.2.1 Introduction

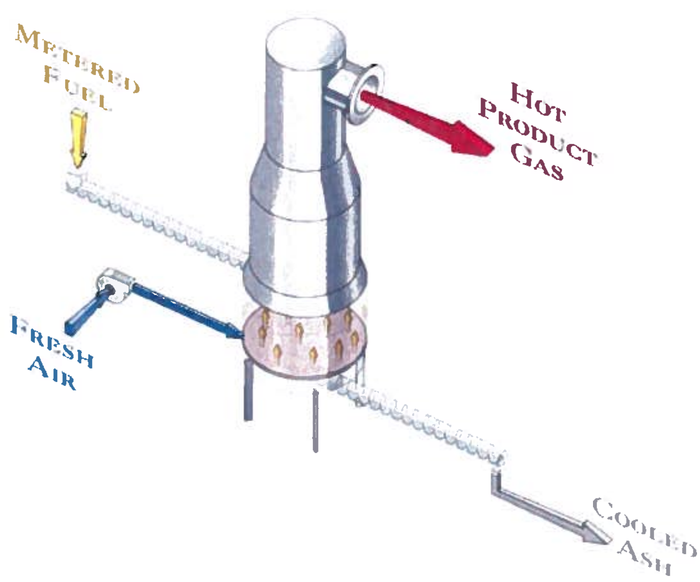
Primenergy is a firm based in Tulsa, Oklahoma, that specializes in engineering, procurement, and turnkey construction of biomass-fueled energy conversion facilities. Primenergy has several commercial-scale systems capable of processing between 70 and 550 tons of biomass per day. The systems are fed with a variety of biomass feedstocks, including rice husks, wood waste, and biosolids.

Primenergy's demonstration facility in Tulsa, Oklahoma is capable of processing up to 30 tons per day of feedstock and has been used to test more than 25 different types of biomass materials, including biosolids.

4.2.2 Overview of Primenergy WTE Technology

The Primenergy technology utilizes a fixed-bed, air-blown updraft gasification reactor operating at sub-atmospheric sub-stochiometric conditions to convert biosolids to energy. As shown in Exhibit 4-1, the gasification reactor consists of a vertical cylindrical steel shell, with a smaller diameter in the upper portion, and lined on the inside with a refractory. The cross-sectional area of the upper portion of the gasification reactor is reduced to provide the turbulence required to ensure complete mixing of the syngas. In a typical Primenergy application, the syngas is immediately combusted in a boiler to produce steam for electric power generation.

EXHIBIT 4-1
Primenergy Updraft Fixed-Bed Gasification Reactor



4.2.3 Commercial Status of the Primenergy WTE Process

The RFP required potential technology suppliers to provide information about a full-scale biomass-to-energy commercial facility that is currently operational (reference facility). Primenergy provided information about its commercially operating facility in Stuttgart, Arkansas.

The Stuttgart facility has been operational since 1996. The facility processes approximately 550 tons per day of rice husks. The syngas produced from gasification of rice husks is combusted in stages to produce steam for electric power generation and for use as process steam.

4.2.4 Pilot-scale Testing

As noted earlier, Primenergy operates a demonstration facility in Tulsa, Oklahoma, that is designed to process up to 30 DTPD of feedstock. The process train includes a feedstock feed system to control the rate of feedstock conveyed to the gasification reactor, a gasification reactor to produce syngas, and a staged combustion system to combust the syngas and produce low-grade steam. The demonstration facility was used to conduct the pilot-scale test using the Stamford biosolids.

The pilot-scale test using the Stamford biosolids was conducted at the demonstration facility on July 22, 2008. Project team representatives from the SWPCA, CH2M HILL, and Carlin Contracting witnessed the test. During the test, the facility was operated continuously for a period of approximately 8 hours. It was observed that the facility processed biosolids successfully to produce syngas, and the syngas was subjected to staged combustion to generate low-grade steam. The demonstration facility is not equipped with power generation equipment, so electric power was not produced during the test and the steam produced was vented to the atmosphere. Exhibits 4-2 through 4-5 present photographs of the pilot plant taken by the project team during the pilot-scale test.

EXHIBIT 4-2
Primenergy Pilot Facility

The facility houses (from left to right) a cyclone separator, gasification reactor, control room, steel access (ladder) structure, fuel bucket elevator and fuel hopper. An operator feeding biosolid pellets in the fuel hopper is visible in the bottom right portion of the photograph.

EXHIBIT 4-3
Close-up of Gasification Reactor

A close-up of the gasification reactor (vertical cylindrical chamber on the right side in the picture), cyclone separator (vertical cylindrical chamber on the left side of the picture), and interconnecting duct between the gasification reactor and the cyclone separator.

EXHIBIT 4-4
Primenergy Demonstration Facility Appurtenances

Appurtenances include (from left to right) the vent stack, firetube boiler (blue color horizontal cylindrical chamber), oxidizing chamber (gray color horizontal cylindrical chamber) and the combustion tube (gray color vertical cylindrical chamber). Steam produced from combustion of syngas is visible in the background.

EXHIBIT 4-5
Primenergy Demonstration Facility Char

Char produced during the gasification process is collected in a dumpster.

The Primenergy Stage 2 proposal provides a characterization (proximate and ultimate analysis) of the biosolids and a characterization of the char produced from the gasification reactor during the pilot-scale test. Char is defined as a solid residue mixture containing ash and fixed carbon that did not undergo conversion to gas during gasification. The char characterization data indicated that the percentage of fixed carbon in the char produced from the gasification process is approximately 18.8 percent. This is greater than the values encountered by the project team during the literature review. The project team anticipated the percentage of fixed carbon in the solid residue to be between 2.5% and 5%. The project team and Primenergy discussed options that could be implemented to reduce the fixed carbon content of the char.

Primenergy stated that the fixed carbon content could be reduced by modifying operating conditions such as the biosolids bed depth in the gasification reactor, increasing the residence time of biosolids in the gasification reactor, and adding substances to permit operation of gasification at higher temperatures. The characterization data also indicated that the char had a high heating value of approximately 5,600 BTU per pound, which is greater than the anticipated value of 4,000 BTU per pound. The higher heating value of the char is attributable to the presence of fixed carbon and volatiles in the char. The volatile content of the char was approximately 26 percent.

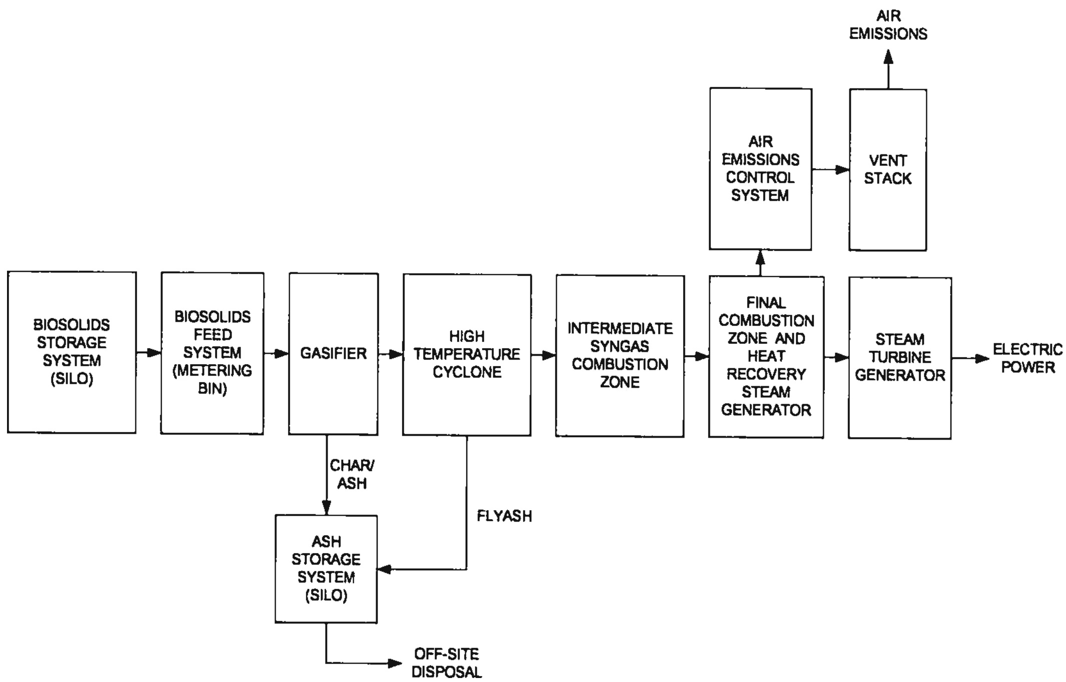
The Primenergy demonstration facility is of the same size as the Stamford WTE facility, and uses a process train similar to the Stamford process train. The results and biosolids-to-energy conversion efficiencies achieved during the pilot-scale test are representative of the expected performance to be achieved by the proposed Stamford WTE demonstration facility. Therefore, the mass and energy balance of the pilot-scale test is not discussed in this section but rather in Section 4.2.6.

4.2.5 Process Flow Diagram of the Primenergy WTE Process

This section describes the process flow diagram of the Stamford WTE facility using the Primenergy WTE process. The process is illustrated in Exhibit 4-6. The process train consists of a biosolids metering bin, a metered feeding system, gasification reactor, cyclone separator, staged combustion system, heat recovery steam generator, and a steam turbine to produce electric power.

Stored biosolids pellets are conveyed from the existing storage silo to the gasification system metering bin inlet bucket elevator. The bucket elevator conveys the biosolid pellets to the metering bin, and the metering bin conveys a known quantity of biosolids into the gasification reactor. In the gasification reactor, the biosolids undergo gasification, resulting in the production of syngas. As the syngas is produced, it leaves the gasification reactor and enters the high-temperature cyclone separator, where fly ash is removed. From the cyclone separator, the syngas enters the staged combustion system. The first step in the staged combustion system is partial oxidation of the syngas in an intermediate combustion zone for proactive control of nitrogen oxides. In the final oxidation step, the partially oxidized syngas is conveyed to a syngas burner for complete oxidation. The syngas burner fires into the furnace section of a heat recovery steam generator. Thermal energy produced from the combustion of syngas is used to produce high-pressure superheated steam, which is directed to a steam turbine generator to produce electric power.

EXHIBIT 4-6
Process Flow Diagram of the Stamford WTE Facility Using the Primenergy Process



4.2.6 Mass and Energy Balance of the Stamford WTE Facility Using the Primenergy Process

Exhibit 4-7 summarizes the design criteria and performance features of the Stamford WTE facility using the Primenergy WTE process. A more complete overview of the mass and energy balance of the Stamford WTE facility using the Primenergy process (which may be considered proprietary) is provided in the Appendix of this report.

EXHIBIT 4-7
Design Criteria and Performance Features of the Stamford WTE Facility Using the Primenergy Process

Design Features	Description	Value
Biosolids Feed Rate	Mass flow rate of biosolids fed to the gasifier	2,241 pounds per hour (lbs/hr)
Gasification Air Feed Rate	Mass flow rate of air fed to the gasification reactor	5,343 lbs/hr
Air–to-Fuel Ratio	Ratio of the mass flow rate of gasification air to the mass flow rate of biosolids	2.38
Syngas Production Rate	Quantity of syngas produced	1,389 standard cubic feet per minute (scfm)

EXHIBIT 4-7
Design Criteria and Performance Features of the Stamford WTE Facility Using the Primenergy Process

Design Features	Description	Value
Composition of Syngas	Hydrogen (H2), carbon monoxide (CO), methane (CH4), carbon dioxide (CO2) and nitrogen (N2)	6% H2 18% CO 5% CH4 13% CO2 58% N2
Syngas Heating Value	Low Heating Value	117 BTU/ standard cubic foot [scf]
Quantity of Syngas Produced	Standard cubic feet of syngas produced per short ton of biosolids	74,378 scf/short ton
Cold Gas Efficiency	Ratio of rate of energy input (estimated using low heating value of biosolids) in the gasification reactor to the rate of beneficial energy available from the gasification reactor in the form of syngas. The efficiency does not account for the sensible heat of the syngas produced by the gasification process.	62.1%
Gross Electric Power Production	Total quantity of electric power produced	659 kilowatts (kW)
Net Electric Power Production(1)	Quantity of net electric power produced after satisfying the electric demand of the WTE facility	523 kW
Gross Electric Power/Fuel Value Efficiency(2)	Ratio of the gross electric power produced to the rate of energy input to the WTE facility in the form of biosolids	14.4%
Net Electric Power/Fuel Value Efficiency(2)	Ratio of the net electric power produced to the rate of energy input to the WTE facility in the form of biosolids	11.4%
Electrical Energy Production Rate	Ratio of rate of net electrical energy produced to the biosolids feed rate	466.8 kilowatt hours [kWh]/short ton

Notes:

(1) – The electric demand of the Stamford WTE facility using the Primenergy process is 139 KW.

(2) – The low heating value of the Stamford biosolids is approximately 7,000 BTU per pound.

4.2.7 Dimensions of the Stamford WTE Facility Using the Primenergy Process

The Stamford WTE facility using the Primenergy WTE process has one process train. The process train is designed to process approximately 1-3 MW of biosolids.

The approximate dimensions of the Stamford facility are 175 feet x 125 feet. The approximate footprint of the facility is 21,875 square feet. The approximate height of the facility is 55 feet.

4.2.8 Utility Requirements for the Stamford WTE Facility Using the Primenergy Process

Exhibit 4-8 summarizes the expected water, natural gas, and electrical demands of the Stamford WTE facility proposed by Primenergy.

EXHIBIT 4-8
Utility Requirements of the Stamford WTE Facility Using the Primenergy Process

Utility Requirement	Description of Utility Use	Approximate Quantity
Water	Potable water is used as cooling tower makeup water and as boiler feed water makeup. A reverse osmosis treatment system is used to treat potable water to produce cooling tower makeup water and boiler feed water.	38,970 gallons per day (gpd) (potable water for cooling tower makeup water) 340 gpd (potable water for boiler feed makeup water)
Natural Gas(1)	A natural gas-fueled burner is used to pre-heat the refractory-lined equipment during each cold start. The time required to pre-heat the refractory-lined equipment during a cold start to reach operating temperature is approximately 48 hours. To estimate the quantity of natural gas needed per year, it was assumed that the facility is subjected to six cold starts per year.	92 scfm; 1,589,760 scf/year
Electricity	An electric load operates the conveyance systems (screw conveyors, bucket elevator, etc.), air blowers, air compressors, and pumps.	139 kW
Chemicals	Anti-scalants and anti-fouling chemicals in the reverse osmosis treatment system are used to treat potable water for producing cooling tower makeup water and boiler feed water makeup. The quantities of chemicals used by the reverse osmosis treatment system are not known at this time.	

Notes:

(1) – The natural gas demand does not include natural gas required to provide heat to the WTE building.

4.2.9 Solid Residue and Wastewater Produced by the Stamford WTE Facility Using the Primenergy Process

The Stamford WTE facility using the Primenergy process produces solid and liquid wastes. Gasification of biosolids results in the production of char, and processing of syngas through the high-temperature cyclone results in the production of fly ash. Air pollution control equipment on the exhaust of the boiler will also result in flyash production. Primenergy predicts that the solid residue produced by the Stamford WTE facility will be non-hazardous and could be disposed in a municipal landfill. SWPCA is investigating beneficial uses for the solid residue to be produced from the WTE facility. Information regarding potential beneficial uses for the solid residue is presented in Section 9.

As noted in Exhibit 4-8, the WTE facility uses potable water for cooling tower makeup water and boiler feed makeup water. A reverse osmosis treatment system is used to treat the cooling tower and boiler feed makeup water. Reverse osmosis treatment of potable water produces reject water as wastewater. In addition to reject water produced by the reverse osmosis treatment system, blow down (wastewater) is also produced from the boiler and cooling tower. Disposal of the wastewater produced from the boiler, cooling tower, and reverse osmosis treatment system will be conveyed to the head of the SWPCF. A characterization of the WTE facility wastewater is required to confirm that no additional treatment is necessary.

Exhibit 4-9 presents estimated quantities of solid and liquid wastes produced by using the Primenergy WTE process.

EXHIBIT 4-9
Approximate Quantities of Solid and Liquid Wastes Produced by Using the Primenergy Process

Waste Type	Description	Approximate Quantity
Solid Waste	Ash is produced from the gasification reactor, and fly ash is produced from the cyclone separator	6.1 tons per day
Wastewater	Wastewater is produced from the boiler (boiler blow down)	290 gpd
	Wastewater is produced from the cooling tower (cooling tower blow down)	4,970 gpd
	The reverse osmosis treatment system produces reject water as wastewater. Approximately 15% of potable water used to produce cooling tower and boiler feed makeup water is produced as reject water.	5,900 gpd

4.2.10 Best and Final Offer

Primenergy provided a best and final offer of $8,875,000 to provide engineering support services during detailed design, to supply process equipment, and to provide support during equipment installation (construction), startup, commissioning, and training of operations staff.

The scope of process equipment to be supplied includes a biosolids conveyance system, a gasification system and appurtenances (conveyors, valves, fans, etc.), a high-temperature cyclone separator, a staged combustion system, an ash storage silo and appurtenances (conveyors, valves, etc.), an air pollution control system on the exhaust of the HRSG (scope of technology not clear), a heat recovery steam generation system including appurtenances (fans, pumps, etc.), a re-conditioned steam turbine system, electrical system, and instrumentation and control system to operate the facility.

Primenergy's scope of supply does not include furnishing an electrical system to facilitate interconnection, i.e., convey the produced electric power to the electrical grid; a building to enclose the WTE facility; or travel and living expenses incurred by Primenergy staff to provide onsite support services.

Details of Primenergy's scope of supply can be found in the Primenergy Stage 2 proposal (Appendix 4-B).

4.3 Kopf AG

4.3.1 Introduction

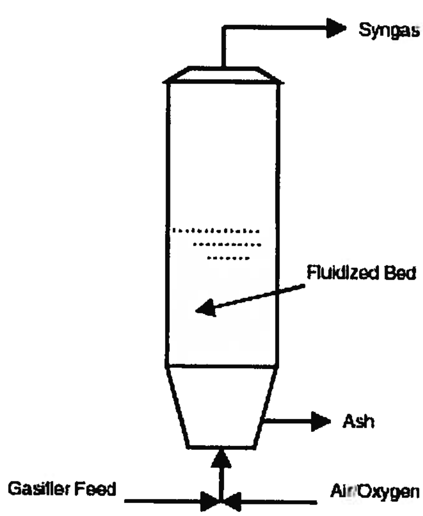
Kopf AG is a firm based in Sulz, Germany that specializes in providing engineering services for water and wastewater treatment facilities, solar (renewable energy) systems, and fabrication of steel and stainless steel equipment such as pipes and tanks. Kopf has developed a biosolids-fueled WTE process.

The commercial-scale Kopf WTE process is a modular design, designed to process approximately 12.5 DTPD of biosolids. A WTE demonstration facility using the Kopf process is currently operational at a wastewater treatment plant (WWTP) in Balingen, Germany. This demonstration facility is designed to process approximately 104.5 lbs/hr (approximately 5.5 tons per day) of biosolids. Kopf has no existing facility in North America and uses the Balingen facility to conduct pilot tests using other biosolids. All Kopf design, technical support, sales staff are currently located in Germany (with limited English proficiency), and they currently do not have a business partner or representative in North America.

4.3.2 Overview of Kopf WTE Technology

The Kopf process employs a fluidized bed, air-blown gasification system operating at sub-stochiometric conditions to convert biosolids to energy. Exhibit 4-10 presents a schematic of a typical fluidized bed gasifier, similar to the one used by Kopf.

EXHIBIT 4-10
Typical Fluidized-Bed Gasifier



The syngas produced by the Kopf gasifier is combusted in a boiler to produce steam for electric power generation, or is cooled, cleaned, and used as a gaseous fuel in internal combustion reciprocating engines to produce electric power.

4.3.3 Commercial Status of the Kopf WTE Process

The RFP required potential technology suppliers to provide information about a full-scale biomass-to-energy commercial facility that is currently operational. Kopf provided information about its commercially operating facility at the WWTP in Balingen, Germany.

The Balingen WWTP is designed to process approximately 7.2 million gallons per day (mgd) of municipal wastewater conveyed from cities and villages surrounding Balingen. Sewage sludge produced by the WWTP is digested and dried using solar drying beds. The dried biosolid residuals have a solids content of approximately 75 to 80 percent. The dried biosolids are stored in a silo and later used as a solids fuel in a WTE facility to produce heat and/or electric power.

The syngas produced from gasification of biosolids is cooled, conditioned and used as a gaseous fuel in an internal combustion reciprocating engine to produce approximately 70 kW of electric power and approximately 140 kW of thermal energy that can be used to heat the digesters at the WWTP. Of the total electric power produced, approximately 15 kW is used to operate the WTE facility and the remaining power is used to augment the WWTP's electric demand. . Surplus syngas that cannot be used in the internal combustion engines is disposed of in a post-combustion chamber.

4.3.4 Pilot-scale Testing

As noted earlier, the Kopf supplied a demonstration facility at the Balingen WWTP that is designed to process approximately 5.5 DTPD of dried biosolids. The WTE process consists of a feed system to control the rate of biosolids conveyed to the gasification system, a bubbling fluidized bed gasifier to produce syngas, and a syngas cooling and cleaning system to produce clean syngas for use as gaseous fuel in an internal combustion gas engine.

Pilot-scale tests using the Stamford biosolids were conducted on September 9, 2008, and November 7, 2008.

Project team representatives from the SWPCA, CH2M HILL, and Carlin Contracting witnessed the September 9 test. It was observed that the demonstration facility operated "intermittently" for a period of approximately 8 hours. A steady- state operation during the pilot test was aborted because of formation of clinkers in the gasification reactor. Clinkers were formed because the heat rate input (Stamford biosolids) to the gasification reactor exceeded the design capacity. The Balingen WTE facility is designed to process digested biosolids having a calorific value of approximately 3,015 BTU/lb. However the calorific value of the undigested Stamford biosolids is approximately 8,000 BTU/lb. Kopf was unable to compensate for the higher calorific value of the biosolids by lowering the feed rate to the gasification reactor due to speed limitations on the biosolids feed conveyance system and bed velocities. This condition caused the operating temperature in the gasification reactor to rise quickly above desirable levels, resulting in slagging, or the melting of the inorganic fraction (ash) of biosolids. Therefore, to prevent slagging in the gasification reactor and to avoid damage to equipment from high temperatures, Kopf terminated the test.

A second pilot-scale test using the Stamford biosolids was conducted on November 7, 2008. Representatives from the project team were not present to witness this second test. At this test Kopf modified the process by reducing the air feed rate in the gasification reactor, limiting combustion and thereby controlling the operating temperature within the reactor. To achieve the desired fluidizing velocity in the gasification reactor, a portion of the syngas produced during the pilot test was recirculated to the gasification reactor. A new post-combustion chamber was also added to the process for disposal of syngas unused as fuel in the gas engine.

Based on these modifications, the demonstration facility operated steadily for a period of approximately 8 hours using the Stamford biosolids. Kopf terminated the test after 8 hours when all Stamford biosolid pellets were consumed and the performance data (syngas composition) collected during the test was satisfactory. The syngas produced during the pilot test was cooled and cleaned with a Kopf syngas cleaning system, and used as fuel in an internal combustion gas engine to produce approximately 70 kW of electric power.

Exhibit 4-11 summarizes the design criteria and performance efficiencies achieved during the November 7 test.

EXHIBIT 4-11
Design Criteria and Performance Features of the November 7, 2008 Kopf Pilot-Scale Test

Stamford Waste to Energy Project

Design Features	Description	Value
Biosolids Feed Rate	Mass flow rate of biosolids fed to the gasifier	477.4 lbs/hr
Gasifier Air Feed Rate	Mass flow rate of air fed to the gasifier	528 lbs/hr
Air-to-Fuel Ratio	Ratio of the mass flow rate of gasification air to the mass flow rate of biosolids	1.1
Syngas Production Rate	Quantity of syngas produced	177scfm
Composition of Syngas	Hydrogen (H2), carbon monoxide (CO), methane (CH4), carbon dioxide (CO2) and nitrogen (N2)	9.9% H2 9.1% CO 2.3% CH4 14.3% CO2 64.4% N2
Syngas Heating Value	Low Heating Value	77.5 BTU/scf
Quantity of Syngas Produced	Standard cubic feet of sygnas produced per short ton processed biosolids	44,250 scf/short ton
Cold Gas Efficiency	Ratio of rate of energy input (through biosolids) in the gasifier to the rate of beneficial energy output (through syngas) from the gasifier. The efficiency is based on the available chemical energy (heating value) of the sygnas only.	23.6%

The heating value of the syngas produced during the November 7, 2008 pilot-scale test (77.5 BTU/scf) was less than the heating value reported in the literature for the syngas produced by the Kopf process.(approximately 130 BTU/scf). This was due to the modifications made to the Balingen WTE demonstration facility to compensate for the Stamford biosolids, without adjusting the biosolids feed rate to the reactor.

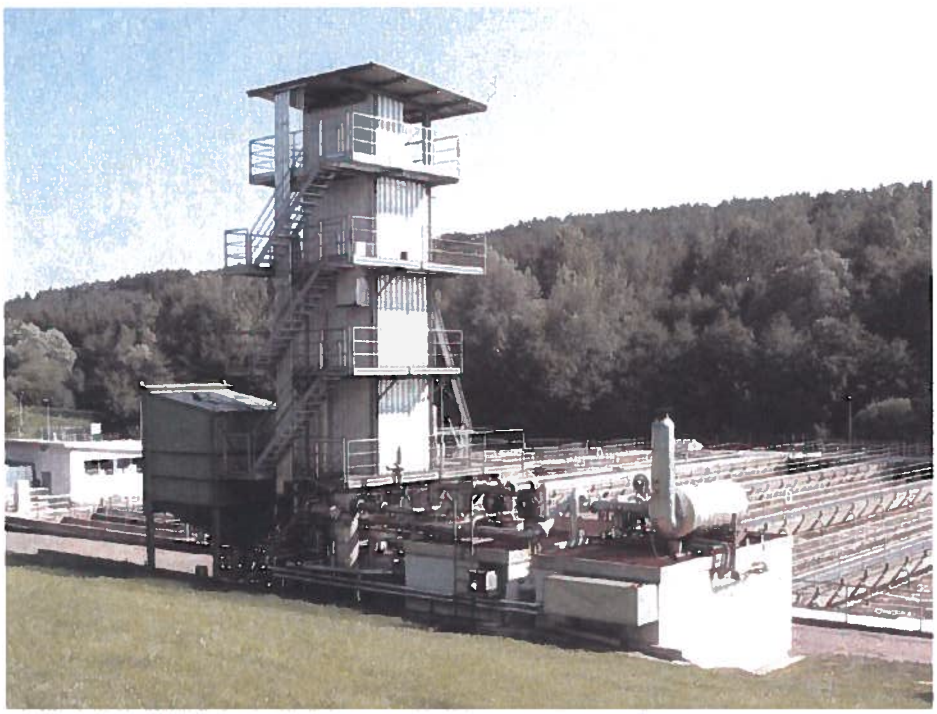
The cold-gas efficiency achieved during the November 7 test (23.6 percent) was less than the expected cold-gas efficiency of the Kopf process reported in the literature (approximately 70 percent). The cold-gas efficiency achieved during the November 7, 2008 pilot test is less than expected for the same reasons as the low heating value explained above.

Kopf did not conduct a proximate and ultimate analysis on the char (solid residue comprised of ash and fixed carbon) produced from the gasification reactor during the November 7, 2008 pilot-scale test. Therefore, the amount of fixed carbon remaining in the char is not known.

Exhibit 4-12 presents a photograph of the Kopf WTE demonstration facility at the Balingen WWTP.

EXHIBIT 4-12
Kopf WTE Demonstration Facility at Balingen WWTP

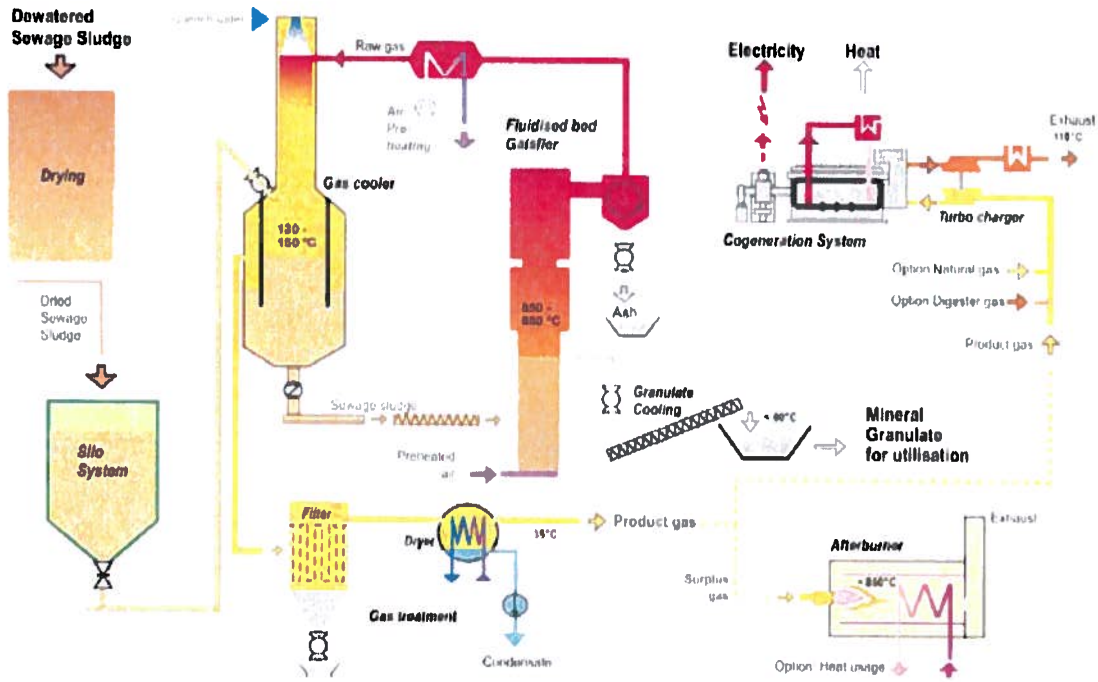
The gasification reactor is located in the tall corrugated metal building. The syngas cleaning system and the power generation equipment (gas engine) is located in the buildings adjacent (to the right) to the gasification reactor building.



4.3.5 Process Flow Diagram for the Kopf WTE Process

This section describes the process for the Stamford WTE Facility using the Kopf process. The process is illustrated in process flow diagram provided as Exhibit 4-13. The process train consists of a biosolids feed system, a gasification reactor, a gas cooler, and a gas cooling and cleaning system. The complete syngas cooling and cleaning system is illustrated in Exhibit 4-14.

EXHIBIT 4-13
Process Flow Diagram for the Stamford WTE Facility Using the Kopf Process

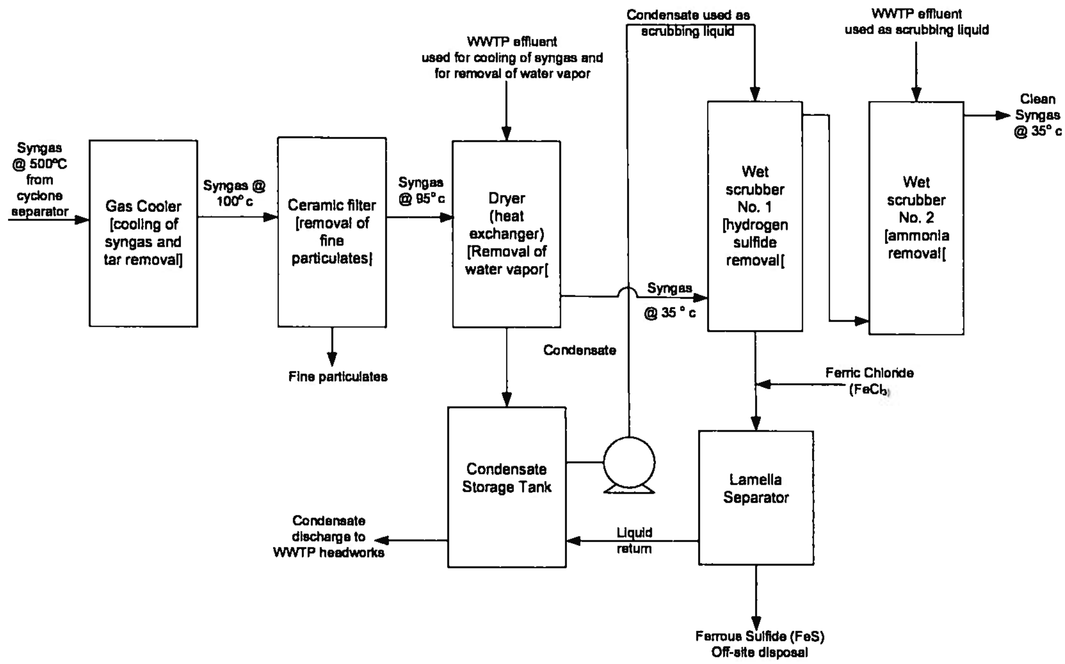


The biosolids dryer facility produces dried biosolid pellets that are stored in existing silos. From the storage silo, a screw conveyor carries the dried biosolid pellets to the gas cooler. In the gas cooler, the biosolid pellets come in contact with the tar-laden syngas leaving the bubbling fluidized bed gasification reactor. Water is sprayed in the top portion of the gas cooler. As the hot syngas comes in contact with the water droplets, the temperature of the syngas reduces and the tar vapors present in the syngas are condensed to liquid tar. As the tar-laden syngas passes through the biosolids bed, tar is adsorbed on the biosolid pellets and removed. From the gas cooler, a screw conveyor carries the biosolid pellets to the bubbling fluidized bed gasification reactor where syngas is produced. The gasification reactor also produces ash as a solid residue that is collected and stored.

As the syngas leaves the gasification reactor, it passes through a cyclone separator for fly ash removal. From the cyclone separator, the syngas passes through a heat exchanger before entering the gas cooler. In the heat exchanger, a portion of the sensible heat of the syngas is used to pre-heat the air fed in the gasification reactor.

After the syngas is cooled and tar is removed from the syngas in the gas cooler, the syngas enters the cleaning system shown in Exhibit 4-15. The first step in the syngas cleaning process is removal of fine particulates. A ceramic filter with a pore size of approximately 1.0 micron removes fine particulates from the syngas. From the ceramic filter, the syngas passes through a dryer (heat exchanger) for moisture removal, and through a dual wet scrubber system for removal of hydrogen sulfide, ammonia and hydrogen cyanide.

EXHIBIT 4-14
Kopf Syngas Cooling and Cleaning System



4.3.6 Mass and Energy Balance of the Stamford WTE Facility Using the Kopf Process

Exhibit 4-16 summarizes the design criteria and performance features of the Stamford WTE facility using the Primenergy WTE process. A more complete overview of the mass and energy balance of the Stamford WTE facility using the Kopf process (which may be considered proprietary) is provided in the Appendix of this report.

EXHIBIT 4-16
Design Criteria and Performance Features of the Stamford WTE Facility Using the Kopf Process (1)

Design Features	Description	Value
Biosolids Feed Rate	Mass flow rate of biosolids fed to the gasifier	2,677.4 lbs/hr
Gasification Air Feed Rate	Mass flow rate of air fed to the gasification reactor	4,620 lbs/hr
Air-to-Fuel Ratio	Ratio of the mass flow rate of gasification air to the mass flow rate of biosolids	1.73
Syngas Production Rate	Quantity of syngas produced	1,776 scfm
Composition of Syngas	Hydrogen (H2), carbon monoxide (CO), methane (CH4), carbon dioxide (CO2) and nitrogen (N2)	12% H2 13% CO 4% CH4

EXHIBIT 4-16
Design Criteria and Performance Features of the Stamford WTE Facility Using the Kopf Process (1)

Design Features	Description	Value
		13% CO2
		58% N2
Syngas Heating Value	Low Heating Value	112 BTU/scf
Quantity of Syngas Produced	Standard cubic feet of sygnas produced per short ton of biosolids	79,600 scf/short ton
Cold Gas Efficiency	Ratio (%) of rate of energy input (estimated using low heating value of biosolids) in the gasification reactor to the rate of beneficial energy available from the gasification reactor in the form of syngas. The efficiency does not account for the sensible heat of the syngas produced by the gasification process.	63.7%
Gross Electric Power Production(2)	Total quantity of electric power produced	1,223 kW
Net Electric Power Production(3)	Quantity of net electric power produced after satisfying the electric demand of the WTE facility	1,153 kW
Gross Electric Power/Fuel Value Efficiency(4)	Ratio of the gross electric power produced to the rate of energy input to the WTE facility in the form of biosolids	22.3%
Net Electric Power/Fuel Value Efficiency(4)	Ratio of the net electric power produced to the rate of energy input to the WTE facility in the form of biosolids	21%
Electrical Energy Production Rate	Ratio of rate of net electrical energy produced to the biosolids feed rate	861.3 kWh/short ton

Notes:

(1) The Design Criteria is based on the Kopf's estimated mass and energy balance presented in Exhibit 4-16. (2) For calculating the gross power produced, it is assumed that the efficiency of the gas engine is 35%.

(3) The electric demand of the Stamford WTE facility using the Kopf process is 70 kW.

(4) The low heating value of the Stamford biosolids is approximately 7,000 BTU/lb.

During review, it was observed that the mass flow rate of nitrogen in the syngas was approximately 17 percent more than the mass flow rate of nitrogen input to the WTE Facility. In addition, the mass flow rate of oxygen in the syngas (as carbon monoxide and carbon dioxide) was observed to be approximately 14 percent more than the mass flow rate of oxygen input to the WTE facility. The project team requested that Kopf explain these discrepancies, but was unable to obtain an appropriate explanation. Kopf stated that its estimate for the mass flow rate of nitrogen in the syngas is correct. It is CH2M HILL's opinion that Kopf's estimate for the quantity of air required for gasification is less by approximately 25 percent. These discrepancies should be resolved prior to initiating of future work with Kopf

4.3.7 Dimensions of the Stamford WTE Facility Using the Kopf Process

The Stamford WTE facility using the Kopf Process has two process trains. Each process train is designed to process approximately 12.5 DTPD of biosolids.

The dimensions of each process train are approximately 35 feet x 70 feet (2,450 square feet). Because the Stamford WTE facility has two process trains, the footprint of the WTE building is approximately 4,900 square feet. The building footprint does not include the area required to house the ash storage silo and gas storage tanks because these are located outside the building. The height of the WTE facility is approximately 80 feet.

4.3.8 Utility Requirements of the Stamford WTE Facility Using the Kopf Process

Exhibit 4-18 summarizes the water, natural gas, and electrical demands of the Stamford WTE facility using the Kopf process.

EXHIBIT 4-18
Utility Requirements of the Stamford WTE Facility Using the Kopf Process

Utility	Description of Utility Use	Approximate Quantity
Water	Potable water is used to produce spray water for the gas cooler. A reverse osmosis treatment system is used to treat potable water to produce spray water for the gas cooler.	3,730 gpd (potable water)
	The syngas cleanup process uses WWTP effluent to remove contaminants.	31,700 gpd (wet scrubbing process); 158,500 gpd (syngas drying process)
Natural Gas(1)	A natural gas-fueled system is used to pre-heat the refractory-lined equipment during each cold start. The time required to pre-heat the refractory-lined equipment during a cold start to reach operating temperature is approximately 24 hours. To estimate the quantity of natural gas needed per year, it was assumed that the facility is subjected to six cold starts per year.	59 scfm, i.e., 509,760 scf/ year
Electricity	An electric load operates the screw conveyors, air blowers and pumps. This auxiliary load does not include power required to operate a conveyance system to transfer biosolids from the existing storage silos to the gasification system.	70 kW
Chemicals	Ferric chloride is used to treat wastewater produced from the wet scrubber that removes hydrogen sulfide from the syngas.	2.2 pounds per day
	Anti-scalants and anti-fouling chemicals in the reverse osmosis treatment system are used to treat potable water for producing gas cooler spray water. The quantities of chemicals used by the reverse osmosis treatment system are not known at this time.	

Notes:

(1) – The natural gas demand stated represents demand beginning in Year 2 after the facility is commissioned and in service. The demand for the first year after commissioning is approximately 2 to 3 times greater than the demand beginning in Year 2 and from thereon. This is attributable to energy consumed to evaporate moisture present in the refractory lining. The demand also does not include natural gas required to provide heat to the

EXHIBIT 4-18
Utility Requirements of the Stamford WTE Facility Using the Kopf Process

Utility	Description of Utility Use	Approximate Quantity
WTE building.		

4.3.9 Solid Residue and Wastewater Produced by the Stamford WTE Facility Using the Kopf Process

The Stamford WTE facility using the Kopf process produces solid and liquid wastes. Gasification of biosolids results in production of char/ash, and processing of syngas through the high-temperature cyclone and ceramic filter results in the production of fly ash. Kopf predicts that the solid residue produced by the Stamford WTE facility will be non-hazardous and could be disposed in a municipal landfill.

As shown in Exhibit 4-18, the WTE facility uses WWTP effluent in the syngas cleaning process to remove water vapor and ammonia. The syngas drying process produces a condensate (wastewater) with a pH of approximately 8.5. Wet Scrubber No. 2 produces wastewater containing ammonia. The facility uses potable water that is treated using reverse osmosis to produce spray water for the gas cooler. The reverse osmosis treatment produces reject water as wastewater. Wastewater from the syngas drying process, the wet scrubbing process, and the reverse osmosis treatment system will be conveyed to the head of the SWPCF.

A characterization of the WTE facility wastewater is required to determine if additional treatment is required. Of importance is the quantity of ammonia that will be removed from the syngas in the syngas conditioning system. The ammonia present in the WTE Facility wastewater may impact the treatment efficiency of the WPCF's existing wastewater treatment processes. It is recommended that the hydraulic and treatment capacity of the existing wastewater treatment processes is evaluated to confirm if the WTE Facility wastewater can be treated through the main wastewater treatment plant.

The syngas drying process also uses WWTP effluent water as a source to transfer waste heat produced during cooling of syngas. Kopf stated that the drying process increases the temperature of the effluent by approximately 10°C. Because the effluent used in the drying process does not come in contact with the syngas, the composition of the WWTP effluent is unchanged. The high-temperature wastewater (WWTP effluent) produced from the syngas drying process can be combined with the remaining WWTP effluent and discharged in accordance with the SWPCF's current practice.

Exhibit 4-19 presents estimated quantities of solid waste and wastes produced by using the Kopf process.

EXHIBIT 4-19
Approximate Quantities of Solid and Liquid Wastes Produced by Using the Kopf Process

Waste Type	Description	Approximate Quantity
Solid Waste	Ash is produced from the gasification reactor.	8.4 tons per day
	Fly ash is produced from the cyclone separator	1.2 tons per day

EXHIBIT 4-19
Approximate Quantities of Solid and Liquid Wastes Produced by Using the Kopf Process

Waste Type	Description	Approximate Quantity
	and the ceramic filter.	
Wastewater	Wastewater with a pH of approximately 8.5 is produced from the syngas drying process	4,121 gpd
	Wastewater containing ammonia is produced from Wet Scrubber No. 2	31,700 gpd
	Wastewater (WWTP effluent) having a temperature greater than the WWTP effluent by approximately 10°C is produced from the syngas drying process	158,500 gpd
	The reverse osmosis treatment system produces reject water as wastewater. Approximately 15% of potable water used to produce gas cooler spray water is produced as reject water.	560 gpd

4.3.10 Best and Final Offer

Kopf quoted a best and final offer of €7,971,830 to provide engineering services during detailed design, to supply process equipment, and to provide support during equipment installation (construction), startup, commissioning and training of operations staff. This cost (in Euros) is equivalent to US$11,718,590, using a currency conversion rate of 1 Euro to 1.47 U.S. dollars (Oct 6, 2009 conversion rate).

The scope of process equipment to be supplied includes a biosolids conveyance system, gasification system and appurtenances (conveyors, valves, fans, etc.), high-temperature cyclone separator, heat exchangers, gas cooler, syngas cleaning system, electrical system, and instrumentation and control system to operate the Facility.

Kopf's scope of supply does not include furnishing an ash storage silo; electrical system to facilitate interconnection, i.e., convey the produced electric power to the electrical grid; a building to enclose the WTE facility; or travel and living expenses incurred by the Kopf staff to provide onsite support services.

Details of Kopf's scope of supply can be found in the their response to the SWPCA RFP (Appendix 4-C).

4.4 Nexterra Energy

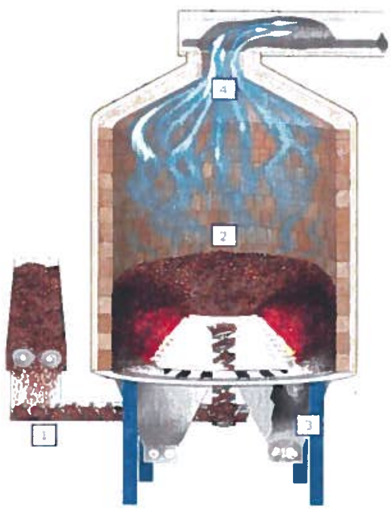
4.4.1 Introduction

Nexterra Energy (www.nexterra.ca) is a private company based in Vancouver, British Columbia, Canada and is a supplier of biomass gasification systems to produce heat and/or electric power for beneficial use.

4.4.2 Overview of Nexterra WTE Technology

Exhibit 4-20 is a schematic of Nexterra's gasification reactor.

EXHIBIT 4-20
Schematic of Nexterra's Gasification Reactor



The Nexterra Process utilizes the fixed-bed, updraft gasification technology. Biomass feedstock sized to 3 inches or less, is bottom-fed into the centre of the dome-shaped, refractory lined gasification reactor. Air, steam and/or oxygen are introduced into the base of the fuel pile. Partial oxidation, pyrolysis and gasification occur in the reactor at 1500 to 1800 °F, and the biomass is converted into "syngas" and non-combustible ash. The ash migrates to the base of the gasifier and is removed intermittently through an automated in-floor ash grate. The syngas produced from the gasification reactor can be combusted directly into boilers to produce steam for power generation, or can be conditioned and used as fuel in internal combustion engines to produce electric power.

Over the past two years Nexterra has tested and developed a proprietary syngas cooling and conditioning system to produce a clean syngas that meets specifications for use as gaseous fuel in internal combustion reciprocating engines. In their testing and development efforts, Nexterra has been supported by GE's Jenbacher gas engine division.

Over the next 24 months, Nexterra and GE plan to demonstrate operation of the Nexterra gasification and syngas conditioning system with GE Jenbacher gas engines. The demonstration is planned to be implemented in two phases. In the first phase, Nexterra's proprietary syngas conditioning technology and a GE Jenbacher J208 GS 250kW engine will be installed and tested at Nexterra's Product Development Center located in British Columbia, Canada in 2009. For the second phase, Nexterra plans to demonstrate a commercial scale 2 MWe power plant at a customer site. Discussions are underway with a number of candidate sites to host the demonstration facility.

4.4.3 Commercial Status of the Nexterra WTE Process

Nexterra Energy has supplied their gasification technology for two commercially operating projects; one for Tolko Industries, Ltd. based in Kamloops, British Columbia (BC), Canada (CA), and the other for the University of South Carolina (USC), South Carolina (SC). Nexterra Energy will also supply their gasification technology for two other projects; Dockside Green Development, Victoria, BC, CA, and for US DOE Oak Ridge National Laboratory, Oak Ridge, Tennessee (TN). In all the projects mentioned above the syngas produced from gasification is used to generate steam either for use as process steam or for electric power production.

Nexterra Energy in collaboration with Johnsons Controls completed a project in 2007 for the University of South Carolina (USC). The Facility is used as a cogeneration plant to provide heat and electric power for the university. The Facility uses wood residue (hog fuel) as feedstock. Exhibit 4-21 shows the gasification reactors and metering bin at the USC Facility.

EXHIBIT 4-21
Nexterra gasification reactors at the University of South Carolina Cogeneration Facility

4.4.4 Pilot-scale Testing

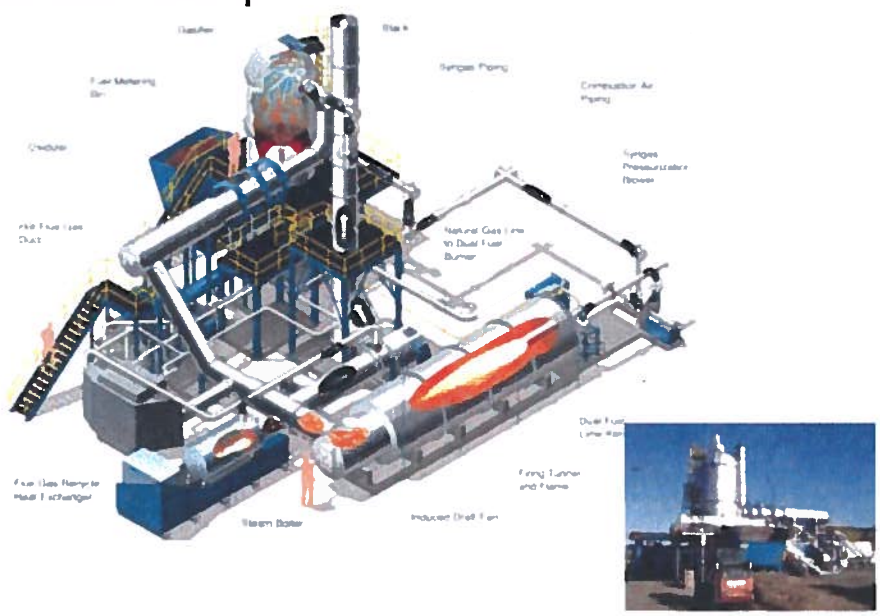
Nexterra Energy owns and operates a pilot plant facility in Kamloops, BC. It is called the Nexterra Product Development Center (PDC). The Nexterra PDC uses an updraft gasification reactor to produce syngas, and use the syngas to produce steam. Nexterra operates the PDC continuously for research and development in the areas of fuel testing, process optimization, and the development of new, higher-value applications for Nexterra's gasification technology.

Exhibit 4-22 shows Nexterra Energy's PDC in Kamploops, BC.

EXHIBIT 4-22
Nexterra Energy's Product Development Center (PDC) in Kamloops, British Columbia, 2009

The SWPCA team comprising Jeanette Brown, Jeff Fournier and Peter Burrows visited PDC on May 27, 2009. About 2 hours was spent at the site including a full tour of the gasifier system, the on-site lab and control room. The gasifier was processing Stamford pellets and had been in operation since about mid-day on May 25. Nexterra reported the unit had been started on sawdust on May 25, and when the unit had reached temperature, they began feeding SWPCA biosolids at about 50% of the estimated feed rate (1,000 lb/hr), increased to 70% on May 26, and were at about 90% during the visit. Stack testing of emissions was scheduled for May 28 and the unit was scheduled to operate at full load for the test. (Set-up of testing was under way during the visit.) Nexterra report that the syngas calorific value on May 26 was 140 BTU/scf (HHV).

Product Development Center



General observations during visit:

- Site staff appeared to be very knowledgeable in gasification and the operation of the pilot gasifier system. Overall, Nexterra appears to have good in their organization covering product development, product/project delivery, and marketing.
- The pilot gasification system appeared to be operating smoothly on SWPCA pellets. (Observations of the controls screen confirmed smooth operation.)
- A sound description of the operations of each process component was given followed by viewing of the observation ports at the gasifier and oxidizer. Although the gasifier port was fouled with tar, combustion in the oxidizer was clearly visible, with a distinct swirl of the syngas as it was combusted at the third set of secondary air injection nozzles.
- Ash consisted of small pellets of black or orange. The pellets typically retained their shape, but crushed easily, producing a powder. This is an indication of good

pyrolysis/gasification. Some clinkers were observed, which broke easily indicating temperatures were not excessive.

- Thermocouples located in the bed area indicated that active gasification was occurring in the middle of the bed, less active gasification was occurring near the walls, and ash was migrating downwards towards the bottom of the bed, where little thermal activity was occurring.

EXHIBIT 4-23
Design Criteria and Performance Features of the May 27, 2009 Nexterra Pilot-Scale Test

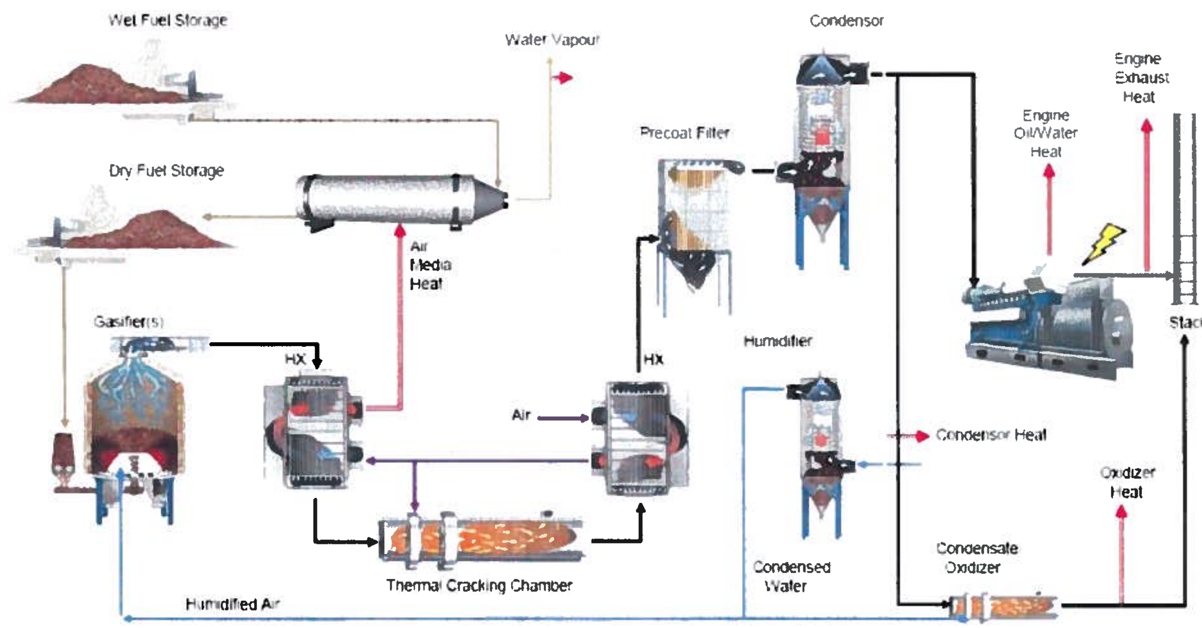
Stamford Waste to Energy Project

Design Features	Description	Value
Biosolids Feed Rate	Mass flow rate of biosolids fed to the gasifier	1,045 lbs/hr
Gasifier Air Feed Rate	Mass flow rate of air fed to the gasifier	2,213 lbs/hr
Air-to-Fuel Ratio	Ratio of the mass flow rate of gasification air to the mass flow rate of biosolids	2.12
Syngas Production Rate	Quantity of syngas produced	734scfm
Composition of Syngas	Hydrogen (H2), carbon monoxide (CO), methane (CH4), carbon dioxide (CO2) and nitrogen (N2)	12% H2 14.1% CO 2.9% CH4 16.6% CO2 53.6.4% N2
Syngas Heating Value	Low Heating Value	117 BTU/scf
Cold Gas Efficiency	Ratio of rate of energy input (through biosolids) in the gasifier to the rate of beneficial energy output (through syngas) from the gasifier. The efficiency is based on the available chemical energy (heating value) of the sygnas only.	69.4%

4.4.5 Process Flow Diagram for the Nexterra WTE Process

This section describes the process for the Stamford WTE Facility using the Nexterra process. The process is illustrated in process flow diagram provided as Exhibit 4-24. The process train consists of a biosolids feed system, a gasification reactor, gas conditioning including thermal cracking, gas filtration, condenser and feed to an engine.

EXHIBIT 4-24
Nexterra Energy's Gasification and Syngas Conditioning System



The system assumes the existing silos provide storage of the dry fuel which is fed to the gasifier. The resulting syngas is then partially combusted in a cracking unit to remove tars prior to filtration and treatment to remove contaminants that would contribute to combustion air pollutants. The filtered syngas is cooled in a condenser and then fed to the engine/generator.

4.4.6 Mass and Energy Balance Using the Nexterra Process

Heat Source *	Heat In (HHV)
Gross Heat Input	30 MM btu/hr
Electrical *	**Power Out**
Gross Electrical Output	1.94 MWe (equiv. 6.63 MM btu/hr)
Heat Source *	**Heat Out**
Engine Exhaust	5.15 MM btu/hr
Engine Oil Heat	0.96 MM btu/hr

Engine Cooling water	1.42 MM btu/hr
Intercooler Heat	0.95 MM btu/hr
Condensate Oxidizer	2.5 MM btu/hr (heat goes to dryer)
Air Media (summer, 25% mcwb)	2.7 MM btu/hr
Condenser Heat (difficult to recover)**	1.62 MM but/hr
Intercooler – stage 2 (difficult to recover)**	0.517 MM btu/hr
Humidifier Heat Required	-0.96 MM btu/hr
Total	12.7 MM btu/hr (14.8 MM btu/hr with **)

EXHIBIT 4-25
Design Criteria and Performance Features of the Stamford WTE Facility Using the Nexterra Process (1)

Design Features	Description	Value
Biosolids Feed Rate	Mass flow rate of biosolids fed to the gasifier	3695 lbs/hr
Gasification Air Feed Rate	Mass flow rate of air fed to the gasification reactor	4,616 lbs/hr
Air-to-Fuel Ratio	Ratio of the mass flow rate of gasification air to the mass flow rate of biosolids	1.25
Syngas Production Rate	Quantity of syngas produced	2,595 scfm
Composition of Syngas	Hydrogen (H2), carbon monoxide (CO), methane (CH4), carbon dioxide (CO2) and nitrogen (N2)	12% H2
		14.1% CO
		2.9% CH4
		16.6% CO2
		53.6% N2
Syngas Heating Value	Low Heating Value	117 BTU/scf
Quantity of Syngas Produced	Standard cubic feet of sygnas produced per short ton of biosolids	84,287 scf/short ton
Cold Gas Efficiency	Ratio (%) of rate of energy input (estimated using low heating value of biosolids) in the gasification reactor to the rate of beneficial energy available from the gasification reactor in the form of syngas. The efficiency does not account for the sensible heat of the syngas produced by the gasification process.	69.4%

EXHIBIT 4-25
Design Criteria and Performance Features of the Stamford WTE Facility Using the Nexterra Process (1)

Design Features	Description	Value
Gross Electric Power Production(2)	Total quantity of electric power produced	1,869 kW
Net Electric Power Production(3)	Quantity of net electric power produced after satisfying the electric demand of the WTE facility	1,623 kW
Gross Electric Power/Fuel Value Efficiency(4)	Ratio of the gross electric power produced to the rate of energy input to the WTE facility in the form of biosolids	24.3%
Net Electric Power/Fuel Value Efficiency(4)	Ratio of the net electric power produced to the rate of energy input to the WTE facility in the form of biosolids	21%
Electrical Energy Production Rate	Ratio of rate of net electrical energy produced to the biosolids feed rate	878 kWh/short ton

Notes:

(1) The Design Criteria is based on the Nexterra's estimated mass balance

(2) For calculating the gross power produced, it is assumed that the efficiency of the gas engine is 35%.

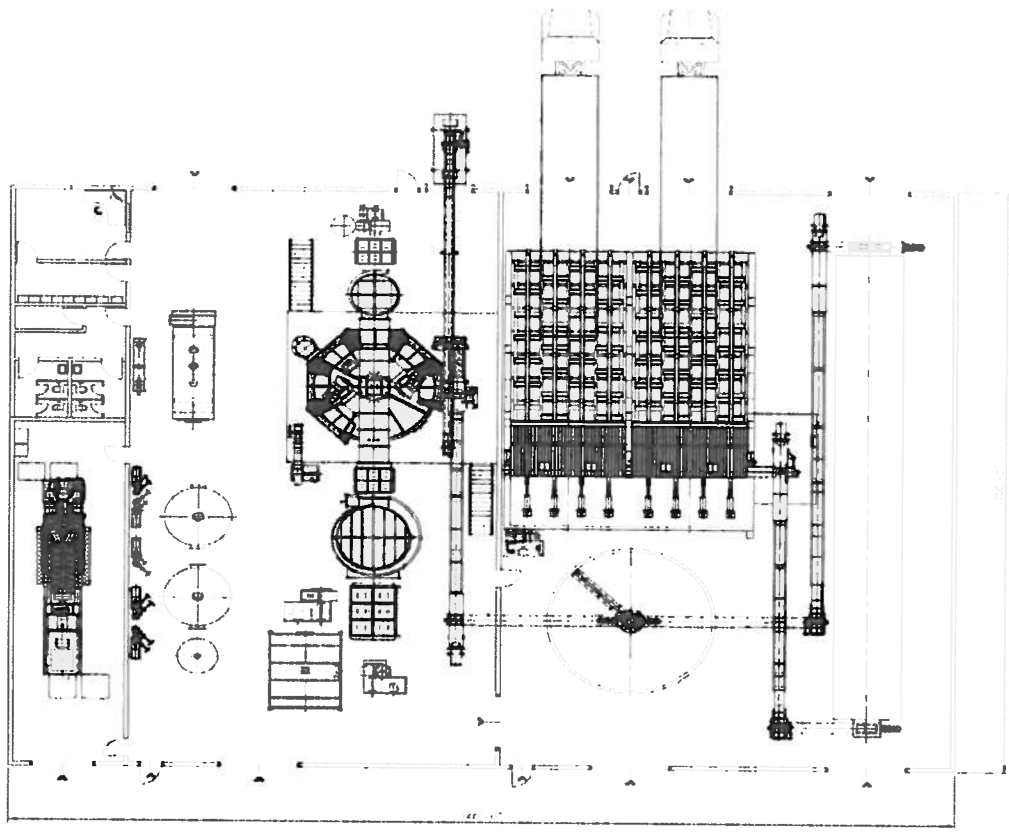
(3) The electric demand of the Stamford WTE facility using the Nexterra process is 246 kW.

(4) The low heating value of the Stamford biosolids is approximately 7,000 BTU/lb.

4.4.7 Dimensions of the Stamford WTE Using the Nexterra Process

A typical layout for the Nexterra Process is provided in Exhibit 4-26. The facility proposed for Stamford would utilize the existing sludge dryer and storage silos. Therefore the overall dimensions would be approximately one-half that shown or 110′x70′.

EXHIBIT 4-26
Typical Layout for the Nexterra Process



4.4.8 Utility Requirements of the Stamford WTE Using the Nexterra Process

Exhibit 4-27 summarizes the water, natural gas, and electrical demands of the Stamford WTE facility using the Nexterra process.

EXHIBIT 4-27
Utility Requirements of the Stamford WTE Facility Using the Nexterra Process

Utility	Description of Utility Use	Approximate Quantity
Water	A small amount of water would likely be required for make-up water to replace blow-down water discharged from the gas condenser.	Not specified
Natural Gas(1)	A natural gas-fueled system is used to pre-heat the refractory-lined equipment during each cold start. Assumed to be similar to Kopf.	59 scfm, i.e., 509,760 scf/ year
Electricity	An electric load operates the screw conveyors, air blowers and pumps based on submitted Phase 1 load summary. This auxiliary load does not include power required to operate a conveyance system to transfer biosolids from the existing storage silos to the gasification system.	145 kW

EXHIBIT 4-27
Utility Requirements of the Stamford WTE Facility Using the Nexterra Process

Utility	Description of Utility Use	Approximate Quantity
Chemicals	Pre-coat material for air emissions control in bag house.	50 pounds per hour

4.4.9 Solid Residue and Wastewater Produced by the Stamford WTE Using the Nexterra Process

The Stamford WTE facility using the Nexterra process produces solid and liquid wastes. Gasification of biosolids results in production of char/ash, and processing of syngas through the baghouse will produce particulate. Nexterra predicts that the solid residue produced by the Stamford WTE facility will be non-hazardous and could be disposed in a municipal landfill.

Exhibit 4-28 presents estimated quantities of solid waste and wastes produced by using the Nexterra process.

EXHIBIT 4-28
Approximate Quantities of Solid and Liquid Wastes Produced by Using the Nexterra Process

Waste Type	Description	Approximate Quantity
Solid Waste	Ash is produced from the gasification reactor.	6.2 tons per day
	Particulate from baghouse.	Not specified
Wastewater	Wastewater containing ammonia likely produced from condenser	Not specified

4.4.10 Nexterra WTE Proposal

Nexterra currently does not commercial offer a system using gasification of biosolids for generation of electricity. However, they are actively engaged in the development of technology for both the conditioning of syngas produced from biosolids, and the use of this gas in internal combustion engines. A part of this technology development is a strategic partnership established between Nexterra and GE Jenbacher, the engine manufacturer currently with the greatest level of experience with low BTU syngas fuels. Presentations and discussions regarding the Nexterra development program generally indicates they intend an extensive in-house testing program on these technologies prior to offering them with performance guarantees commercially.

Nexterra does, however, have significant experience with biomass gasification and has a separate strategic partnership with Andritz to use these in conjunction with the operation of their biosolids dryers, such as the one currently in operation at SWPCA. Discussions within SWPCA and the City of Stamford indicated they currently have an excess of woody waste materials potentially appropriate for use in a Nexterra gasifier. Based on this Nexterra provided an interim proposal and phased approach to implementing gasification at the SWPCA site.

Phase 1

- Use existing technology to generate required heating of the sludge dryer from wood waste supplied by the City of Stamford. This would serve as a permanent replacement of the existing natural gas burner as the primary heat source for the dryer.
- Wood to be supplied by the City of Stamford with processing provided prior to delivery to the site to provide 3" minus biomass and remove contamination.

Phase 2

- Utilize the Phase 1 gasifier to facilitate additional testing of the SWPCA biosolids pellets as a gasification fuel.
- Based on the results of testing consider potential modification of the Phase 1 facilities to be fueled on pelletized biosolids or some combination of wood and biosolids

Phase 3

- Construct a new gasifier to produce syngas using pellitized biosolids
- Construct a gas conditioning and engine/generator
- Evaluate and implement heat recovery as feasible

4.4.11 Best and Final Offer

While a Nexterra system fueled by biosolids to produce electrical power is not currently commercially available, they provided a planning level quotation. This lump sum quotation of $7,000,000 includes providing engineering services during detailed design, to supply process equipment, and to provide support during equipment installation (construction), startup, commissioning and training of operations staff.

The scope of process equipment to be supplied for the biosolids gasification phase includes a 16' diameter upflow air-blown gasifier, with a gas conditioning system, comprising thermal cracking chamber, heat exchangers, precoat baghouse and condensers. The scope of supply will include interconnecting ductwork and piping; access platforms; ash removal system; instrumentation and PLC controls; electric systems (motors, drives, VFDs, MCC); refractory; installation supervision and startup supervision.

Details of Nexterra's scope of supply can be found in their response to the SWPCA RFP (Appendix 4-C).

4.5 Basis for Recommendation

This section provides conclusions of the WTE study, and recommendations for path forward.

Gasification of Stamford biosolid pellets was successfully demonstrated using bench-scale and pilot-scale systems, and using different gasification configurations; downdraft, updraft and fluidized bed. There is only one known biosolids gasification facility that is operational at commercial scale. It is a 5 DTPD WTE facility at the Balingan WWTP in Germany that produces electric power using syngas produced from gasification of biosolids. The Balingan WTE Facility is smaller is size compared to the proposed Stamford WTE Facility. Other WTE facilities similar in size to the Stamford WTE Facility are still in planning and installation stages. It is concluded that gasification offers significant promise to produce electric power from dried biosolid pellets; however, gasification of biosolids is still in the developmental stage.

The syngas produced from gasification of Stamford biosolids has a low heating value (LHV) between 115 and 120 BTU/scf. The syngas produced from biosolids is considered a low heating value fuel compared to biogas produced from anaerobic digestion and natural gas. Biogas produced from anaerobic digestion and natural gas have heating values of approximately 550 BTU/scf and 950 BTU/scf respectively.

Syngas produced from gasification of biosolids contains contaminants such as tars, ammonia, hydrogen sulfide, siloxanes, fly ash and mercury. Conditioning of syngas to remove contaminants is required to facilitate its use as fuel in a gas engine. Syngas produced from gasification of biosolids contains higher concentrations of contaminants such as tars, ammonia, hydrogen sulfide and fly ash compared to syngas produced from gasification of woody biomass. Presence of siloxanes in syngas is a typical characteristic of gasification of biosolids, and is due to the presence of used personal care products found in municipal wastewater. Conditioning of syngas is required to permit its use as fuel in a gas engine. The WTE Facility at the Balingan WWTP has a syngas conditioning process that is currently operational; however, the syngas conditioning technology is still considered in the development stage. No other commercially proven syngas conditioning technologies to condition syngas produced from gasification of biosolids are known at this time.

Exhibit 4-29 provides a side-by-side comparison of performance and financial indicators for the Stamford WTE facility using the Primenergy, Kopf and Nexterra process.

EXHIBIT 4-29
Performance and Financial Comparison of the Primenergy, Kopf and Nexterra Processes

Performance Indicators	Description	Primenergy Process	Kopf Process	Nexterra Process
Gross Electric Power/Fuel Value Efficiency(1)	Ratio of the gross electric power produced to the rate of energy input to the WTE facility in the form of biosolids	14.3%	22.3%	24.3%
Net Electric Power/Fuel Value Efficiency(1)	Ratio of the net electric power produced to the rate of energy input to the WTE facility in the	11.3%	21.1%	21.1%

EXHIBIT 4-29
Performance and Financial Comparison of the Primenergy, Kopf and Nexterra Processes

Performance Indicators	Description	Primenergy Process	Kopf Process	Nexterra Process
	form of biosolids			
Electrical Energy Production Rate	**Ratio of net electrical energy produced to the biosolids feed rate**	**464 kWh/ton**	**862 kWh/ton**	**878 kWh/ton**
Net Electric Power (kW) (2)	Quantity of net electric power produced by the WTE Facility	520 kW	1,154 kW	1,623 kW
Cost ($) (3)	Budgetary cost for engineering services, equipment supply, installation, startup and commissioning services	$ 8,875,000	$ 14,218,590	$9,500,000
Cost to produce electric power ($/kW)	**Cost per net unit electric power produced**	**$17,100/kW**	**$12,300/kW**	**$5,900/kW**

Notes:

(1) Calculated using the low heating value of biosolids (7,000 BTU/lb)

(2) The biosolids feeding rate of the WTE Facility using the Primenergy Process, Kopf Process and Nexterra process is approximately 2,241 lbs/hr, 2,677 lbs/hr and 3,695 lbs/hr respectively.

(3) To facilitate a side-by-side comparison, equipment cost for a gas engine was added to the cost quoted by Kopf and Nexterra. It was assumed that one J620 GS Jenbacher gas engine is required to produce electric power. The equipment cost for one J620 GS Jenbacher gas engine is assumed to be $2,500,000.

The Primenergy process produces electric power by combusting syngas, using the heat of combustion to produce steam and operate a steam turbine. The Kopf and Nexterra process produces electric power using syngas in gas engines. It is concluded that electrical generation with syngas is best accomplished using gas engines; however, use of syngas in gas engines to produce electric power is still in the developmental stage. The WTE Facility at the Balingan WWTP is the only known commercially operating facility that produces electric power using gas engines.

Of the three technologies investigated the Nexterra process has the highest electrical energy production rate (kWh/ton) and the lowest cost to produce electric power ($/kW). It is concluded that the Nexterra process is the most efficient and cost effective compared to other technologies investigated.

The Nexterra process offers significant promise to maximize electric power production from biosolids in a cost effective manner. However, the Nexterra biosolids gasification and syngas conditioning process is still in the developmental stage and is yet to be proven at pilot-scale and commercial-scale. It is understood that the development of the Nexterra process for gasification of biosolids and the syngas conditioning process will take approximate 2 years. Nexterra has a strategic alliance with General Electric (GE) to develop a conditioning technology to produce clean syngas that can be used as fuel in a GE

Jenbacher gas engine. GE is the only known gas engine technology supplier that has commercially operating gas engines to produce electric power using syngas produced from gasification of biomass (wood and biosolids).

Since gasification of biosolids and the syngas conditioning process is still in the developmental stage it is recommended that the SWPCA withhold building a biosolids gasification facility for the next few years until the Nexterra technology is proven at pilot-scale and commercial scale. A phased approach for the project is recommended to allow the SWPCA incorporate state-of-the-art technology for the project.

A capital cost estimate of the 1-3 MW WTE facility based on using the Nexterra process is presented in Section 8.

Operating Parameters and Gasification Performance During Pilot Testing Using Stamford Biosolid Pellets:

Operating Parameter	Description	Primenergy	Kopf AG	Nexterra
Biosolids Feed Rate (lbs/hr)	Mass flow rate of biosolids fed to the gasifier	2,241	477	1,045
Biosolids Heating Value (BTU/lb)	Low Heating Value	6,993	6,985	7,108
Gasifier Air Feed Rate (lbs/hr)	Mass flow rate of air fed to the gasifier	5,343	528	2213
Air-to-Fuel Ratio	Ratio of mass flow rate of gasification air to mass flow rate of biosolids	2.38	1.11	2.12
Syngas Production Rate (scfm)	Quantity of syngas produced	1,389	177	734
Composition of Syngas	Hydrogen (H_2), carbon monoxide (CO), methane (CH_4), ethane (C_2H_6), carbon dioxide (CO_2) and nitrogen (N_2)	6% H_2, 18% CO, 5% CH_4, 13% CO_2, 58% N_2	9.9% H_2, 9.1% CO, 2.3% CH_4, 14.3% CO_2, 64.4% N_2	12% H_2, 14.1% CO, 2.9% CH_4, 0.73% C_2H_6, 16.6% CO_2, 53.6% N_2
Syngas Heating Value (BTU/scf)	Low Heating Value	120	77.5	117
Cold Gas Efficiency (%)	Ratio of beneficial energy output in the form of syngas from the gasifier to the energy input to the gasifier in the form of fuel. The efficiency is based on the available chemical energy (low heating value) of the syngas only.	63.8%	24.7%	69.4%

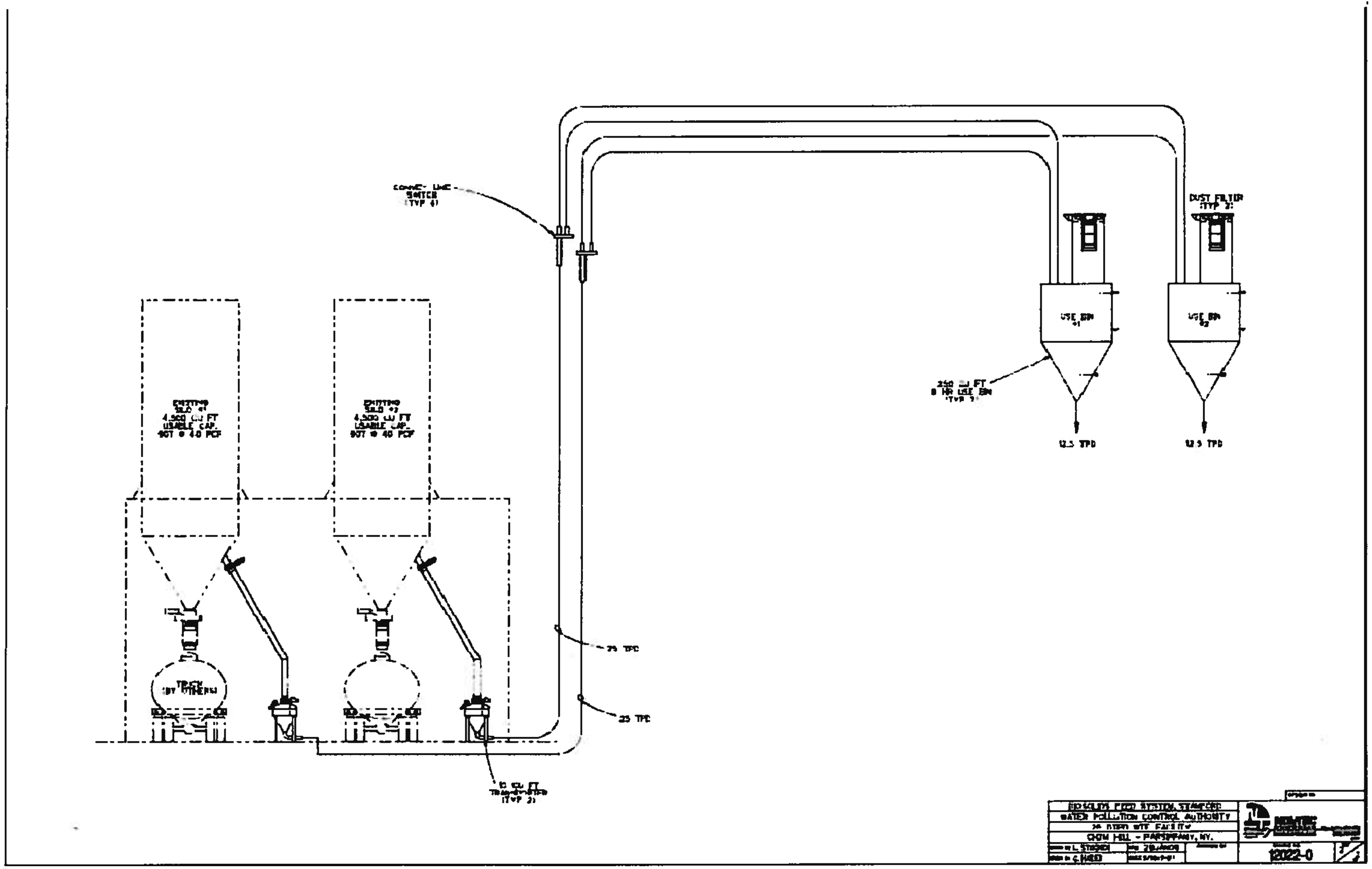
Operating Parameters and WTE Facility Performance Using Biosolid Pellets as Proposed by Vendors at the Stamford Site:

Operating Parameter	Description	Primenergy	Kopf AG	Nexterra
Biosolids Feed Rate (lbs/hr)	Mass flow rate of biosolids fed to the gasifier	2,241	2,677	3,695
Biosolids Heating Value (BTU//lb)	Low Heating Value	6,993	6,985	7,108
Energy Input Rate (KW)	Fuel energy input rate	4,593	5,481	7,698
Gasifier Air Feed Rate (lbs/hr)	Mass flow rate of air fed to the gasifier	5,343	4,620	4,616
Air-to-Fuel Ratio	Ratio of mass flow rate of gasification air to mass flow rate of biosolids	2.38	1.73	1.25
Syngas Production Rate (scfm)	Quantity of syngas produced	1,389	1,776	2,595
Composition of Syngas	Hydrogen (H_2), carbon monoxide (CO), methane (CH_4), ethane (C_2H_6), carbon dioxide (CO_2) and nitrogen (N_2)	6% H_2, 18% CO, 5% CH_4, 13% CO_2, 58% N_2	12% H_2, 13% CO, 4% CH_4, 13% CO_2, 58% N_2	12% H_2, 14.1% CO, 2.9% CH_4, 0.73% C_2H_6, 16.6% CO_2, 53.6% N_2
Syngas Heating Value (BTU/scf)	Low Heating Value	120	112	117
Quantity of Syngas Produced (scf/ton)	Standard cubic feet of syngas produced per ton of biosolids	74,378	79,600	84,287
Cold Gas Efficiency (%)	Ratio of beneficial energy output in the form of syngas from the gasifier to the energy input to the gasifier in the form of fuel. The efficiency is based on the available chemical energy (low heating value) of the syngas only.	63.8%	63.8%	69.4%
Gross Electric Power Production (KW)	Total Quantity of electric power produced	659	1,224	1,869
Nominal Electrical Consumption (KW)	Internal electric load of WTE Facility	139	70	246
Net Electric Power Production (KW)	Quantity of electric power available for beneficial use after satisfying the electric demand of the WTE Facility	520	1,154	1,623
Gross Electric Power / Fuel Value Efficiency (%)	Ratio of gross electric power produced to the rate of energy input the WTE Facility in the form of biosolids	14.3%	22.3%	24.3%
Net Electric Power / Fuel Value Efficiency (%)	Ratio of net electric power produced to the rate of energy input to the WTE facility in the form of biosolids	11.3%	21.1%	21.1%
Electrical Energy Production Rate (KWh/ton)	Ratio of rate of net electrical energy produced to the biosolids feed rate	464	862	878

4.6 Dryer System Interface

This section describes the design concept of the biosolids feed system recommended to convey biosolids from the existing storage silos to the new gasification process trains. Exhibit 4-30 presents a process flow diagram of the proposed biosolids feed system.

EXHIBIT 4-30
Biosolids Feed System Process Flow Diagram



A new biosolids feed system will convey biosolids from the two existing storage silos to the two new 12.5 DTPD gasification process trains (Kopf WTE process) pneumatically. Each existing storage silo will be modified to connect to a new pressurized transporter with a storage capacity of 10 cubic feet and will be configured to convey biosolids to both gasification process trains. A selector switch will be installed in the convey lines to convey biosolids from the transporter to either one of the two gasification process trains. The selector switch will not allow conveyance of biosolids to both gasification process trains simultaneously. Each gasification train will be equipped with a feed bin to allow storage of biosolids before being used as fuel in the gasification process. Each feed bin will have the capacity to store up to 250 cubic feet (5 short tons) of biosolids.

The biosolids feed system will include air compressor(s), air storage tank(s), and moisture removal equipment (not shown on the process flow diagram). The air compressor and air storage tank will deliver and maintain the system pressure required to convey biosolids to the gasification process trains. The moisture removal equipment will remove moisture from the pressurized air stream so that no moisture is absorbed by biosolids. The system operating pressure will be such that damage (breakage) to the biosolid pellets during conveyance is minimized.

The biosolids feed system will also be equipped with a gas monitoring system. The gas monitoring system will continuously monitor the atmosphere in the feed bins head space and in the convey lines to detect an explosive condition. If the gas detection system detects an explosive condition in any section of the biosolids feed system, the system will automatically shut down and will be purged with nitrogen until the explosive condition is overcome. The gas detection system will also sound a local alarm to notify the operator(s) of such a condition. The existing storage silos are equipped with a gas monitoring system. The gas monitoring system of the existing storage silos will be integrated with the new gas monitoring system for the biosolids feed system (not shown on the process flow diagram).

A new supervisory control and data acquisition (SCADA) system will be designed and installed for real-time monitoring and control of the new biosolids feed system (not shown on the process flow diagram). It will have a human-machine interface for the operator's use. The SCADA system will allow the operator to monitor system operating conditions, such as level of biosolids in the existing storage silos and use bins and the system operating pressure. It will also activate alarms for undesirable conditions, such as high and low levels of biosolids in storage silos and use bins, failure of the gas monitoring system, detection of explosive condition by the gas monitoring system, air compressor failure, low system operating pressure, etc. The operator will be able to optimize operating conditions, reset alarms, and set the system to operate under manual mode using the SCADA system. The biosolids feed SCADA system will be connected to the plant-wide SCADA system.

SECTION 5

Power Generation

5.1 Technology Evaluation

Both the Kopf and Nexterra gasification technologies have a product gas with potential for use in electrical power generation. This section provides an initial review of the electrical power generation technologies which could be considered, including fuel cells, gas turbines, and internal combustion (IC) reciprocating gas engines. This section describes the results of a general evaluation of these power generation alternatives applicable to both vendors.

Produced syngas from gasification of biosolids is a low-BTU (lower energy value) fuel compared to natural gas. Proposals by Kopf and Nexterra indicate the low heating value (LHV) of the syngas anticipated is 112 and 117 BTU/scf respectively. Vendor inquiries regarding power generation alternatives were made in early 2009, prior to receipt of Nexterra's proposal. Therefore, the gas quality projected to be produced by the Kopf Process (approximately 112 BTU/scf) was used for this initial analysis.

Fuel Cell

This technology was unfavorable for producing electric power using syngas based on the following:

- The state of the fuel cell technology to produce electric power from syngas is still in the research and development phase. No reference installations using syngas as fuel in fuel cells were found.
- The tolerance of commercially proven fuel cells to contaminants present in the syngas is low compared to gas engines and gas turbines. Therefore, the degree of conditioning (syngas cleaning) required to permit use of syngas in fuel cells will be much higher compared to degree of conditioning required to use syngas in gas engines and gas turbines.
- A single commercially available fuel cell can produce up to 400 KW of electric power. Approximately 3 to 5 fuel cells will be required to produce electric power using syngas. On the other hand, a single gas engine or gas turbine can be used to produce electric power from syngas. Therefore, the fuel cell alternative is not cost-effective.

Gas Turbine

This technology was also unfavorable to produce electric power using syngas based on the following:

- Discussions were held with Solar Turbines to evaluate the use of syngas as fuel in gas turbines. The minimum heating value of a fuel for use in a gas turbine should be 450 BTU/scf. As a result, syngas would have to be blended with natural gas to increase its heating value and make it a feasible fuel for a gas turbine.

- Typically, the fuel feed pressure for a gas turbine is approximately 350 psig. This requirement equates to expending a significant amount of energy (parasitic load) to pressurize the syngas.

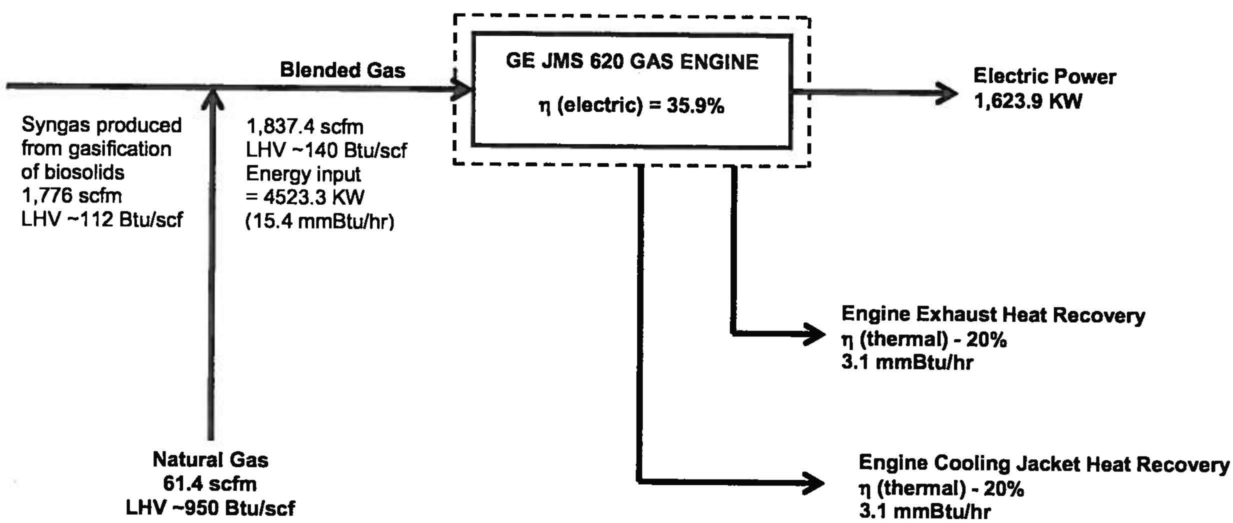
Internal Combustion Engines

A literature search and preliminary investigation confirmed extensive industry experience with IC engines generating electric power fueled with gas produced from biomass and biosolid feedstocks. Experience specific to the syngas produced from gasification, as likely to be produced at Stamford WTE, was identified for GE Jenbacher IC gas engines. Therefore, initial design concepts discussed in the subsequent paragraphs are based on generic specifications for applicable equipment by this vendor. Since these concepts are very preliminary, further coordination and specific equipment vendor recommendations should be obtained prior to any further design work.

Pilot testing indicated the syngas produced from Stamford biosolids using the Kopf gasification process demonstrated a low heating value of approximately 112 BTU/scf. Based on preliminary discussions with GE and after reviewing GE's January 19, 2009 proposal to the SWPCA, it was concluded that the minimum heating value of the syngas to be used as fuel in a GE gas engines is approximately 140 BTU/scf. Initial design concepts therefore include provisions for blending of the syngas with natural gas prior to supply to the engine, as a means of increasing the fuel quality.

Exhibit 5-1 provides a conceptual schematic for a blended gas operation and the estimated energy balance for operation of a single GE JMS 620 gas engine.

EXHIBIT 5-1
Conceptual Schematic and Estimated Energy Balance for a JMS 620 Gas Engine Using Syngas as Fuel



Approximately 61.4 scfm of natural gas will be required to blend with approximately 1,776 scfm of syngas to increase the heating value of syngas. The volumetric flow rate of the blended gas stream (syngas and natural gas) will be approximately 1,837 scfm. The LHV of the blended gas will be approximately 140 BTU/scf. Assuming an electrical conversion efficiency of 35.9 percent,, based on review of the GE January 19, 2009 proposal to the SWPCA, it is estimated that the engines will produce approximately 1,623 KW of electric power.

In order to maximize the economic benefit, the candidate project is assumed to include facilities to fully recover maximum available waste heat. Exhibit 5-2 provides the estimated quantity of waste heat that will be recovered by the engine exhaust heat recovery system and the engine cooling jacket heat recovery system.

EXHIBIT 5-2
Estimated Quantity of Energy Recovered as Waste Heat

Location	Heat Recovery Efficiency (approximate)	Approximate Quantity of Energy Recovered as Waste Heat (mmBTU/hr)
Engine cooling jacket	20%	3.1 mmBTU/hr
Engine exhaust	20%	3.1 mmBTU/hr

Note:
The heat recovery (thermal) efficiencies are assumed based on review of the GE January 19, 2009 proposal to the SWPCA and on a GE technical brochure for the Jenbacher Type 6 engines.

Options may exist for fueling an IC engine with syngas without blending it with natural gas. However, these options should be considered in coordination with the equipment manufacturers familiar with specific engine requirements. Such alternatives will be investigated during detailed design phase of the project.

5.2 Power Plant Switchyard

The WTE Facility will produce electric power at 4,160 volts, 3 phase, 60 hertz. Step-up transformers will be required to increase the voltage of the electric power produced to the voltage of the electrical distribution system at the project site. A tie-in connection application to the electrical utility (Connecticut Light & Power (CL&P)) will help determine the voltage required.

A concept for the power plant switchyard is not developed at this time because the total amount of electric power that will be produced is not known. The concept will be developed during the detailed design phase.

5.3 Interface with the Electrical Utility System

The project team met with CL&P on March 23, 2009 to discuss the process/logistics to feed electric power produced at the project site to the electrical distribution system. CL&P advised SWPCA the first step in evaluating a potential connection and defining the tie-in process would be submittal a tie-in connection application. CL&P would then review the application and advise the SWPCA about the process for completing the tie-in process and finalizing a power purchase agreement.

Subsequent to this meeting, SWPCA has also worked in cooperation with the local Energy Improvement District, as administered by Pareto Energy, regarding cooperative efforts to implement electrical supply to the local area and associated requirements. This includes concepts such as implementing net-metering, to provide credit for intermittent periods of excess power generation.

5.4 Budgetary Equipment Cost

This section summarizes the budgetary equipment cost for gas engines for the 1 to 3 MW WTE Facility.

The budgetary cost for one GE JMS 620 gas engine for syngas application is approximately $2.5 million. This includes the cost of the engine, generator package, emissions control system (selective catalytic reducer), cooling jacket and exhaust gas heat recovery systems, factory engineering, start-up and commissioning support, and training of operations staff. The budgetary cost is estimated based on review of the GE proposal of January 19, 2009 (see Appendix 6-A).

SECTION 6

Air Emissions

This section summarizes the projected air emissions from the 25 DTPD WTE Process and the 1.6 MW Power Generation Facility. The impact of the potential air emissions on the WPCF's existing air permit were also investigated and are described in the section.

6.1 Existing Air Quality

The Clean Air Act (CAA) and its associated 1977 and 1990 amendments established National Ambient Air Quality Standards (NAAQS) for six criteria pollutants: lead, carbon monoxide, nitrogen dioxide, sulfur dioxide, particulate matter and ozone. The NAAQS established primary standards, set at concentrations that protect human health, and secondary standards to protect the public welfare, particularly vegetation, livestock, building materials, and other elements of the environment. These standards are periodically reviewed and revised.

The City of Stamford, Connecticut is part of the New York - New Jersey - Connecticut Interstate Air Quality Control Region (AQCR). Fairfield County including the City of Stamford is in attainment of or better than the NAAQS for carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and respirable particulate matter with a diameter of less than 10 microns (PM10). The County is not in attainment for ozone (O_3) and condensable particulate matter with a diameter of less than 2.5 microns (PM2.5). The 1990 amendments to the CAA categorized the non-attainment ozone areas into five groups based on increasing severity of exceedance of the standard: marginal, moderate, serious, severe, and extreme. The Fairfield County and the City of Stamford have been designated as being in severe non-attainment for 1-hour ozone standard and moderate non-attainment of the 8-hour ozone standard.

To reduce ozone and PM2.5 concentrations and bring Fairfield County into compliance, the Connecticut Department of Environmental Protection (CT DEP) works cooperatively with the New York and New Jersey regulatory agencies in preparing a State Implementation Plan (SIP). The implementation plan must outline specific measures to be taken and a means of monitoring progress toward achieving the standards. Nitrogen oxides (NOx) and volatile organic compound (VOC) are precursors to ozone formation, thus, limits are placed on NOx and VOC emissions in order to reduce ambient ozone concentrations. Sulfur dioxide and NOx are considered to be precursors to PM2.5 formation.

The air permitting requirements for emission sources are based on the attainment status and the potential emissions from the new or modified source. The major new source and major modifications emission thresholds are summarized in Exhibit 6-1. The Stamford Water Pollution Control Facility (WPCF) is an existing minor source of air emissions. The proposed gasification process and power generation facility would be considered modifications to this existing minor source. If the air pollutant emissions from the proposed facilities exceed the major new source or modification thresholds, the facility would be subject to federal permit review including Prevention of Significant Deterioration (PSD) and Non-attainment New Source Review (NNSR). If the potential net increase in air emissions is less than the major modification threshold, the gasification process and power facility would be subject to review by the CT DEP.

EXHIBIT 6-1
Emission Threshold Levels for Major Sources and Major Modifications (tons per year)

Pollutant	Pollutant Attainment Status(1)	Major Source Threshold (2)	Major Modification Threshold (3)
CO	Attainment	100	100
SO_2	Attainment / Better than National Standards	100	40
PM-10	Unclassifiable/Attainment	100	15
PM-2.5	Nonattainment	100	10
NO_2	NO_2 - Cannot be Classified or Better than National Standards	100	40
	Ozone (8-hour standard) - Moderate Nonattainment	100	25
	Ozone (1-hour standard) - Severe Nonattainment	25	25
VOC (4)	Ozone (8-hour standard) - Moderate Nonattainment	50	25
	Ozone (1-hour standard) - Severe Nonattainment	25	25

(1) 40 CFR 81.307 Connecticut
(2) 40 CFR 51.165 (a) (1) (iv) Major Stationary Source
(3) 40 CFR 51.165 (a) (1) (v) Major Modification
(4) Volatile Organic Compounds

6.2 WTE Facility

For purposes of initial evaluation the proposed Facility is assumed to generate power using gasification using approximately 25 dry tons per day of biosolids. The syngas would be cooled, conditioned and used as fuel in internal combustion gas engines. The power generation island has two internal combustion gas engines; one duty and one stand-by.

6.2.1 Air Emissions

The operation of the gasification process is enclosed, producing a syngas used to power the engine generators and a char, a solid waste material. However, heating of the fluidized bed gasification unit to its operating temperature of 1550°F (850°C) is achieved using a natural gas-fired burner. For purposes of initial evaluation it is assumed this burner would operate for approximately 24 hours 4 to 6 times per year, as the system is restarted after maintenance. Annual gas usage is estimated at 509,760 standard cubic feet (scf). The annual emissions from the burner operation are presented in Exhibit 6-2 and are less than 1 ton per year from any of the criteria pollutants.

EXHIBIT 6-2
Emissions from the 25 DTPD WTE Process

Pollutants	Emission Factor (lb/10^6 scf)	Annual NG Usage (scf/yr)	Annual Emissions (tons/yr)	Major Modification Threshold (tons/yr)
NOx	140	509,760	0.036	25
VOC	5.5	509,760	0.0014	25
CO	84	509,760	0.0021	100
SO_2	0.6	509,760	0.00015	40
PM10	1.9	509,760	0.00048	15

Based on a low NOx burner for larger industrial boilers (AP-42)

The syngas produced would pass through several cleaning steps before being used as a fuel in the engines, used to remove ammonia, inorganic particulate matter, and other contaminants. The resulting syngas consists of hydrogen, carbon monoxide and methane as the primary combustible components. Nitrogen and carbon dioxide make-up the majority of the gas stream, but do not contribute to the energy value.

Test results provided by Kopf on other sludge tested at their facility shows that trace metal emissions are captured in the particulate filter and scrubbers. The compounds detected in the engine exhaust were extremely low. Compared to the sludge used in this set of tests, the Stamford sludge pellets have a lower ash content, potentially providing even lower exhaust emissions.

6.2.2 Air Permitting Requirements

The gasification facility and associated emissions from the burner used to heat the fluidized bed gasification unit are considered a minor modification to the existing wastewater treatment facility. A modification to the dryer facility permit needs to be submitted to the CT DEP for review. Likely permit conditions would be the use of a low NOx burner and limitation on the quantity of natural gas used on an annual basis. Operating conditions on the performance of the filtration and scrubbing systems may also be established as they are part of the process which prevents or controls air emissions from the engine.

6.3 Power Generation Facility

The proposed Facility consists of two (2) General Electric JMS620 GS gas engines. Syngas from the Kopf gasification process is used as fuel in the gas engines to produce electric power. Natural gas is used as a backup fuel and/or to enhance the quality of the syngas. Each engine produces approximately 1.6 MW of electric power.

6.3.1 Air Emissions

The air emissions from the power generation facility are based on vendor performance guarantees and emission limits established at similar facilities. To assess the limits established at other similar facilities, a search of emission limits established for large internal combustion engines (>500 HP) fired using natural gas or bio-gas including landfill gas in the RACT/BACT/LAER Clearinghouse was conducted.

Engines of the type proposed for this facility are widely used to combust landfill gas collected at solid waste landfills. The gas is often filtered to remove moisture and particulate matter and may also include the treatment of hydrogen sulfide in the raw gas stream. Engines of this type are also used by the natural gas industry to compress gas flowing though pipelines. However, no cases were found in the clearinghouse that used a bio-gas derived from sewage sludge solids or a syngas consisting primarily of hydrogen, carbon monoxide and methane as a fuel for the engines.

As a base case, the emissions estimates for the power generation facility are presented in Exhibit 6-3. The use of a blended syngas and natural gas fuel is being investigated. The emission estimates in Exhibit 6-3 are approximate and may be revised based on input from the engine vendor. The potential emissions show continuous operation of the two engines that are a lean burn design with controls to monitor and regulate the air-to-fuel mixture. This control strategy is considered the Best Available Control Technology (BACT) for large natural gas fired internal combustion engines and the Lowest Achievable Emission Rate (LAER) for engines firing landfill gas. Case-by-case determinations for landfill gas fired engines concluded that contaminants in gas stream, even with pretreatment, would damage an oxidative catalyst, so no selective catalytic reduction (SCR) requirements were imposed.

EXHIBIT 6-3
Emissions from the Power Generation Facility

Pollutant	Emission Factor (g/BHp-hr)	Engine Capacity (Bhp)	Hourly Emissions (lbhr)	No. of Engines	Annual Emissions (tons/yr)	Major Modification Threshold (tons/yr)
NOx	0.5	5595	6.2	2	54	25
VOC	0.3	5595	3.70	2	32	25
CO	2	5595	24.7	2	216	100
SO_2	0.09	5595	1.11	2	10	40
PM10	0.1	5595	1.23	2	11	15

Expected Average Emissions (Lean burn design, Air/Fuel ratio controls)

For natural gas fired engines that service the compressor stations along pipelines, additional requirements to install SCR technology was required. While the concentrations of trace metals and other potential contaminates in the engine exhaust are low when firing the syngas from the sludge solids gasification process, these potential contaminants could damage an oxidative catalyst if it were installed on this system.

6.3.2 Air Permitting Requirements

The base case emissions in Exhibit 6-3 exceed the major modification thresholds for NOx, VOC and CO. The major source thresholds for these compounds are also exceeded classifying the Stamford WPCF as a major source or air emissions.

Exceeding these thresholds triggers non-attainment new source review (NNSR) for NOx and VOC and Prevention of Significant Deterioration (PSD) review for CO. The permit review requirements would include an assessment of the viability of an oxidative catalyst for reducing VOC and CO emissions. An assessment of the potential impacts on ambient air quality may be required. Emission offsets for NOx and VOC emissions would need to be obtained. To avoid the classification of the Stamford WPCF as a major source, two permitting strategies are presented.

The facility can be classified as a synthetic minor source by accepting operating limitations as a part of their air permit which restricts their annual emissions. The facility would be able to provide 1.6 MW of generating capacity on a continuous basis. . The operating limitations would need to be specific, measureable and federally enforceable. Such a condition might limit operation to only one engine at a time. Limiting the number of hours per year or total volume of gas to be fired in the engines could also be accepted, reducing the potential annual emissions. Exhibit 6-4 shows how these additional limitations would reduce the annual emission rates and allow the Stamford WPCF to be classified as a synthetic minor source of air emissions.

As a synthetic minor source, the Stamford WPCF would be subject to state operating permit regulations and reporting of air emissions on an annual basis. The facility would avoid federal Title V operating permit requirements.

EXHIBIT 6-4
Facility Emissions Rates Compared to Major Source Thresholds

Pollutant	Dryer Facility Annual Emissions (tons/yr)	Power Generation Annual Emissions (tons/yr)	Total Emissions from WPCF (tons/yr)	Major Source Threshold (tons/yr)
NOx	3.0	21.9	24.9	25
VOC	0.982	16	16.98	25
CO	12.3	87.6	99.9	100
SO_2	0.56	10	10.6	100
PM10	1.8	11	12.8	100

The alternative permitting strategy is to use oxidative catalyst or selective catalytic reduction (SCR) to reduce the potential emissions from the facility. This permitting approach would remove the operational restrictions and allow the facility to operate both engines simultaneously resulting in a generating capacity of 3.2 MW. The use of SCR on a syngas produced from the gasification of sewage sludge solids has not been demonstrated. The presence of potential contaminants in engine exhaust needs to be investigated further in detailed design.

6.3.3 Best Available Control Technology for Emissions Control

As part of the state air permit review requirements, a best available control technology review would need to be conducted to determine the lowest achievable emission rate for NOx and VOC. Based on the emission limits established for natural gas fired engines, the potential emissions from an engine using SCR are summarized in Exhibit 6-5. Using SCR on the engines would reduce emissions below the major modification thresholds. This would allow the operational restrictions to be lifted.

EXHIBIT 6-5
Emission Rates from the Power Generation Facility with Supplemental Emission Control

Pollutant	Emission Factor (g/BHp-hr)	Engine Capacity (Bhp)	Hourly Emissions (lbhr)	No. of Engines	Annual Emissions (tons/yr)	Major Modification Threshold (tons/yr)
NOx	0.2	5595	2.5	2	22	25
VOC	0.2	5595	2.5	2	22	25
CO	0.5	5595	6.2	2	54	100
SO_2	0.09	5595	1.11	2	10	40
PM10	0.1	5595	1.23	2	11	15

Most Stringent Emission Limitations (Selective Catalytic Reduction/Oxidative Catalyst)

However, the use of SCR on an engine firing syngas from a gasification process has not been demonstrated. Potential trace contaminates in the exhaust gas could destroy the catalysts resulting in costly maintenance, repairs and replacements. During the detailed design further investigation is needed into the potential use of SCR while firing syngas.

SECTION 7
Solid and Liquid Wastes

This section discusses the potential wastes produced from a Stamford Waste to Energy facility using gasification and the options for disposal.

7.1 Solid and Liquid Waste Stream Generation

The Stamford WTE facility using gasification of biosolids to generate power would result in the production of char/ash. Conditioning of produced syngas using proprietary processes by either Kopf or Nexterra would also result in particulate waste requiring disposal. Both vendor anticipate that these solid residues would be non-hazardous and could be disposed in a municipal landfill.

Both vendors also anticipate that syngas conditioning will result in some liquid discharges either as the result of wet scrubbers or condenser blow-down. It is anticipated these would be discharged to the existing in-plant drainage system and treated with the wastewater. In each case this discharge will contain some concentration of ammonia, so care is needed to insure that no impact will be realized to the plants denitrification processes. Kopf has identified other liquid discharges from their syngas conditioning system including some with elevated pH. These discharges to the wastewater treatment system need to be considered during future design to determine if they have the potential to impact existing treatment systems.

The Kopf syngas drying process uses WPCF effluent water as a source for transferring waste heat produced during syngas cooling. Kopf stated that the drying process increases the temperature of the effluent by approximately 10°C. Because the effluent used in the drying process does not come in contact with the syngas, the composition of the WPCF effluent is unchanged. The high-temperature wastewater (WPCF effluent) produced from the syngas drying process can be combined with the remaining WPCF effluent and discharged in accordance with the SWPCF's current practice.

Exhibit 7-1 presents estimated quantities of solid and liquid wastes produced by using the Kopf process.

EXHIBIT 7-1
Approximate Quantities of Solid and Liquid Wastes Produced

Waste Type	Description	Approximate Quantity
Kopf		
Solid Waste	Ash produced from the gasification reactor.	8.4 tons per day
	Fly ash is produced from the cyclone separator and the ceramic filter.	1.2 tons per day
Wastewater	Wastewater with a pH of approximately 8.5 is produced from the syngas drying process.	4,121 gpd
	Wastewater containing ammonia is produced from Wet Scrubber No. 2.	31,700 gpd
	Wastewater (WWTP effluent) having a temperature greater than the WWTP effluent by approximately 10°C is produced from the syngas drying process.	158,500 gpd
	The reverse osmosis treatment system produces reject water as wastewater. Approximately 15% of potable water used to produce gas cooler spray water is produced as reject water.	560 gpd
Nexterra		
Solid Waste	Ash produced from the gasification reactor	6.22 tons per day
Wastewater	Blow-down from condenser	Quantity undetermined

7.2 Solids Characteristics

During the pilot testing of Stamford biosolids, Kopf and Nexterra did not characterize the char. The characteristics of the char will be investigated further during the design phase of the project.

The char produced from the Stamford biosolids should be similar to the char produced by the Kopf process in Kopf's Balingen facility, which is the same size as the Stamford Facility. In order to establish a basis for the char characteristics, Exhibit 7-2 presents the characteristics of char from the Balingen facility.

EXHIBIT 7-2
Characteristics of Balingen Char

	Volatile Matter (%)	Ash (%)	Fixed Carbon (%)
Gasification Char	39.74	57.69	2.58
Cyclone Ash	24.93	75.72	1.33

Data from Kopf AG. Samples taken 11/25/2002.

Analysis by the Institute for Process Technology and Steam Boilers of the University of Stuttgart.

Cost Estimate and Economic Analysis

8.1 Waste To Energy Facility, 25 DTPD

8.1.1 Equipment Cost Estimates

As part of their proposals, each gasification vendor supplied a budgetary cost estimate. This estimate was requested to include, not only the equipment supply, but also the scope of services they anticipated required from their company in support of their equipment supply, including engineering, installation support, start-up and commissioning services. Exhibit 8-1 provides a summary of this cost estimates. The particular nature of each vendor's product and unit sizing results is each vendor's proposal being rated to produce a different net electrical output. Therefore, the exhibit includes an estimate of the normalized costs per KW capacity.

Technology Supplier	Net Electric Power (KW)	Budgetary Cost for Equipment and Services	Approximate $/KW
Primenergy	520	$ 8,875,000	$17,100
Kopf	1,154	$ 14,218,590* **	$12,300
Nexterra	1,623	$9,500,000**	$5,900

* Kopf quotation was €7,971,830 (equivalent to $11,718,590 Oct 6; 1 Euro ~ 1.47 USD). Kopf later clarified this estimate likely includes structures and other items not included in the other two estimates.

** An estimate of $2,500,000 has been added to this quotation to account for the supply of a single gas engine.

8.1.2 Capital Cost Estimate

Exhibit 8-1 is a summary of the order of magnitude cost estimate for the overall project assuming a vendor cost of $9,500,000 for gasification, gas conditioning equipment, and engine/generator (and associated vendor services):

EXHIBIT 8-1
Order of Magnitude Cost Estimate Summary

Division	Division Subtotal	Percent of Total
Division 1 – General Requirements (See Below)	–	--
Division 2 – Site Work	$1,353,000	7%
Division 3 – Concrete	$1,424,000	7%
Division 4 – Masonry	$431,000	2%
Division 5 – Metals	$808,000	4%
Division 7 – Thermal and Moisture Protection	$84,000	0%
Division 8 – Doors and Windows	$114,000	1%
Division 9 – Finishes	$786,000	4%
Division 10 – Specialties	$74,000	0%
Division 11 – Equipment	$9,723,000	47%
Division 12 – Furnishings	$11,000	0%
Division 13 – Special Construction	$1,834,000	9%
Division 14 – Conveying Equipment	$31,000	0%
Division 15 – Mechanical	$392,000	2%
Division 16 – Electrical	$3,619,000	17%
Subtotal	$20,684,000	100%
General Conditions (~ 5%)	$1,035,000	–
Overhead and Profit (~ 15%)	$3,103,000	–
Mobilization/Bonding/Insurance (~ 5%)	$1,035,000	--
Contingency (~ 15%)	$3,103,000	–
Subtotal	$28,960,000	–
Escalation (~ 10% to midpoint of contract)	$2,896,000	–
Subtotal	$31,856,000	–
Engineering and Admin (~10%)	3,186,000	–
Contract Total	$35,042,000	–

Costs presented are considered "order-of-magnitude", or "Class 4, as defined by the Association for the Advancement of Cost Engineering. Actual construction costs can be expected to range from 50% above to 30% below the estimate presented. This level of accuracy is consistent with costs prepared to compare the relative merits of several alternatives using sketches, general assumptions, and historical costs from similar projects before an exact project definition and specific preliminary design drawings are available. Because of the accuracy of this type of estimate and the variable nature of a number of factors; including the final scope of the project, market conditions, and schedule and duration, this level of estimate is not a prediction of final construction costs. Final construction costs are expected to vary from those presented.

SECTION 9

Conclusions and Recommendations

Investigations documented in this report reflect the dynamic progress in the area of alternative fuels and resource recovery in recent years. It also confirms that there is commercial interest in development of biosolids as fuel for some of these technologies. In particular, gasification systems initially developed for application to biomass (wood waste) appear to be potentially well suited for adaption for use with biosolids. Many gasification systems are currently operating successfully using biomass fuel. This experience has resulted in systems that are mature in their development and commercially viable for use with biomass, particularly for providing process heating. Adaption of this technology to suit biosolids, particularly pelletized biosolids is demonstrating some success, with a few initial facilities currently sustaining operations.

Investigations of this report also indicate the greatest potential for use of syngas generated from gasification is fueling of internal combustion engines. The low heat value of syngas makes use in engines challenging, but manufacturers (particularly GE) appear committed to adapting their equipment for this use. Gasification of biosolids produces syngas which contains contaminants, including tars, which require conditioning prior to use in engines. Some initial successes have been documented in the development of these gas conditioning systems, in conjunction with use in engines.

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

- Since biosolids produced by SWPCA are not digested prior to drying, they retain a higher fuel value for gasification. The pelletize form of these biosolids also appears to be well suited to use in gasification systems.
- Gasification systems tested indicate encouraging results using biosolids, indicating there is significant promise to produce electrical power; however, difficulties remain and development is ongoing. Gasification of biosolids pellets for use in generating electrical power is therefore still considered in the developmental stage.
- Electrical generation with syngas is best accomplished using gas engines; however, conditioning technology for syngas produced from biosolids is in the developmental stage.
- The phased approach proposed by Nexterra represents a means to systematically further prove the viability of biosolids gasification for electrical power generation, while effectively managing SWPCA's project risks

Recommendations

- Continue design of a biomass gasification system for use with the existing biosolids dryer, based on financial evaluations by SWPCA indicating this is an economic alternative to the current natural gas heating system.
- Include in the design of the biomass gasifier provisions to allow testing of biosolids pellets as an alternative fuel.

- Continue to monitor development of conditioning systems for biosolids derived syngas and use of this gas in internal combustion engines for electrical power generation.