THE BENEFICIAL REUSE OF SLUDGE INCINERATOR EXHAUST GASES TO PRODUCE RENEWABLE ENERGY

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ABSTRACT

This paper reports on a unique plan to recapture exhaust waste heat from a sludge incinerator and convert that heat into electric power. The concept has shown itself to be technically viable, with low technical risk, and provides an economically attractive return on investment. The reuse of exhaust gases in a similar fashion at other wastewater treatment operations with sludge incineration could reduce long term operating cost for electric power as well as provide significant benefits to the ratepayer and the surrounding community. The equipment employed is proven, with a long-term history of reliability and inherently low risk, making the use of such technology readily available and easy to employ. In addition, in many cases, funding from Federal, State and other sources may be available to offset both capital cost and operating expenses, thus further reducing the amount of capital at risk. In an era of ever rising cost for electric power and continued concern over the effects of pollution emissions from electric power generating facilities, this concept may help other similar waste water treatment plant operators solve a number of problems.

KEY WORDS

Sludge incinerator, exhaust gases, waste heat recovery boilers, steam turbine generators, beneficial reuse, economic return and environmental benefits.

INTRODUCTION

About the GNHWPCA

The New Haven Water Pollution Control Authority has historically provided regional municipal wastewater collection and treatment services on a retail basis to customers in the City of New Haven, and on a wholesale basis to the Towns of East Haven, Hamden and Woodbridge. As a result of intensive study and research, these constituent municipalities collectively concluded that the creation of an independent regional authority to own, operate, manage and improve the regional assets, provided more effective and broad based protection of the environment at a lower cost.

The Greater New Haven Water Pollution Control Authority was created as an independent regional authority in August 2005 in accordance with Connecticut General Statutes 22a-500-519. The Authority will also continue to provide services to North Haven and North Branford through inter local agreements. These Statutes provide the Authority with extensive powers, including the power to purchase, own and operate a public sewer system, to levy assessments and sewer use fees, to place liens on real estate, and to issue revenue bonds. The Authority is also eligible for grants and loans under the State's Clean Water Fund (CWF) program. The Authority provides several key benefits including establishing for each of the municipalities a real stake in the regional wastewater system's finances, furthering the environmental protection laws of the State of Connecticut, enhancing service delivery and gaining efficiencies and economies of scale with respect to planning, design, construction, management, operation and maintenance.

The Authority is governed by a nine member Board of Directors appointed by the chief elected official and approved by the legislative body of each municipality. The Board consists of four representatives from New Haven, two each from East Haven and Hamden, and one from Woodbridge.

The Authority serves approximately 200,000 customers, including residential, commercial, government and non-profit, and oversees the operation and maintenance of an extensive 4-town regional wastewater system that includes 510 miles of pipeline, 30 pumping stations and a 40-million-gallon-per-day (MGD), advanced secondary water pollution control facility (WPCF). Wastewater treated by the Authority at its East Shore WPCF is discharged into Long Island Sound and is designed to meet both federal and state effluent quality standards.

Currently, the average daily flow at the WPCF is approximately 32 MGD. The WPCF has an average daily design flow capacity of 40 MGD and provides primary and secondary treatment for all wastewater influent up to 60 MGD. During high flow events all flow receives primary treatment; however, flow exceeding 60 MGD bypasses secondary treatment but receives disinfection along with the secondary effluent prior to discharge. The WPCF provides the following unit processes: screening and grit removal, raw waste pumping, three primary clarifiers, four aeration trains, eight secondary clarifiers, gravity thickeners and chlorine disinfection prior to discharge. Thickened sludge is delivered to a sludge storage tank for processing in the solids handling and disposal process. Thickened sludge from the sludge storage tank is dewatered and then disposed of in the multiple hearth furnace sewage sludge incinerator. The facility incinerates sewage sludge at a maximum feed rate of 1.67 dry tons per hour while firing natural gas fuel at an estimated firing rate of 11,000 cubic feet per hour (8,000 scfh and 3,000 scfh for the incinerator and RTO, respectively. The facility uses No. 2 fuel oil as a backup fuel typically when the natural gas supply is interrupted. The sewage sludge incinerator exhaust gases pass though an air pollution control system consisting of a venturi / impingement tray scrubber system followed by a wet electrostatic precipitator and a regenerative thermal oxidizer. The exhaust gases are vented through a 220 foot tall, 36-inch ID exhaust stack to the atmosphere.

The Authority assumed the 1997 contract of the NHWPCA with Operations Management International, Inc. (OMI). Under the contract, which expires in 2014, OMI is responsible for the operation and maintenance of the regional wastewater system including the WPCF and the New Haven collection system. The Authority compensates OMI under the contract at a flat annual fee with escalators and adjustments. The Authority entered into a second agreement with OMI to operate and maintain the collection systems of the Towns of East Haven, Hamden and Woodbridge.

Denver based OMI is a privately owned company and an affiliate of CH2M Hill Companies, Ltd. OMI describes itself as a global leader in water and wastewater management providing services to more than 130 million customers in government and industry all over the world.

The Authority also assumed the 1995 contract of the NHWPCA with Synagro-CT, Inc. Under the contract, which expires in 2014, Synagro is responsible for the receipt and disposal of sludge generated by the WPCF. The sludge is incinerated at the on-site incinerator. The Authority compensates Synagro under the contract at a flat annual fee with escalators and adjustments.

New Haven based Synagro is a wholly owned subsidiary of Synagro Technologies, Inc., a public company based in Houston, Texas. The parent describes itself as the largest recycler of bio-solids and other organic residuals in the United States with 600 municipal and industrial water and wastewater treatment accounts. Synagro operates three incinerators, including the incinerator at the WPCF.

The Waste Water Treatment Process

The Authority operates an advanced activated sludge secondary water treatment plant known as the East Shore Water Pollution Control Facility (the plant) in the outskirts of New Haven Connecticut.

It is the largest coastal Connecticut based wastewater treatment facility discharging into Long Island Sound. The plant is capable of treating 40 MGD of sewage on a typical dry weather day. Operating as a combined sewer system, one that conveys both sanitary sewage and storm water, the plant treats up to 100 MGD of sewage flow in periods of wet weather. In accordance with the recommendations of the Long Island Sound Study (LISS) the plant's secondary treatment process has been upgraded to include a Biological Nutrient Removal (BNR) system for removal of nitrogen.

Primary and waste activated sludge generated at the plant is ultimately delivered to an on site sludge incinerator for further processing. Primary sludge is delivered to gravity thickeners, with the thickener underflow passing to a sludge holding tank where it is mixed with belt thickened waste activated sludge and municipal sludge delivered from outside sources. The mixed sludge is then dewatered by a combination of belt presses and centrifuges. It is then fed to a seven hearth vertical incinerator. Based on current flows, excess capacity is available and the Authority's contract operator, Synagro, markets this excess capacity to outside sources to offset the sludge management cost, otherwise paid by the Authority. The objective is to run the incineration process at the permitted levels so as to maximize revenue from outside sludge sources

The Authority utilizes the onsite incinerator to meet its long-term sludge management and disposal needs. The contractor operates the sewage sludge incineration process, which is used to dispose of sewage sludge, fats oil and grease (FOG). In addition, FOG collected and disposed of at the facility can be used as supplement and or alternative fuel for the incinerator.

METHODOLOGY

The Problem

For over 30 years, incinerator exhaust gases, which exit at about 1200 degrees F, have been cooled and cleaned, then exhausted to the atmosphere unutilized. On an annual basis this is the equivalent to the energy of nearly 500,000 gallons of No.2 heating fuel being emitted to the atmosphere totally unutilized.

In addition to wasting the potential energy of the incinerator exhaust stream, the cost of electrical power in the Southern New Haven CT region has been steadily rising for the past eight years. The chief causes of these cost increases are the continuously increasing cost for generation and transmission services including, deregulation of commodity sales, inadequate transmission capacity, mandated state standards for a green component in the power mix and a steadily rising cost for natural gas, the major fuel component of electric power generation in Southern New England. The average delivered cost to the meter in this area has risen from about 8 cents per kWh in 2000 to over 20 cents per kWh in 2008, ***a 150 % increase***. These sharply rising costs have now made the capture and reuse of energy discharged from the incinerator economically viable.

If the incinerator exhaust gases could be successfully captured and converted to electric power, the equivalent of about 30% of the plant's electrical power needs would be generated internally, at lower cost and with the environmental benefit of reducing air pollution discharges from the local power generating plants.

The Procurement Process

After some initial in house analysis and conceptual design, the Authority elected to identify and contract with a turnkey design builder through a public solicitation involving an RFQ and RFP procedure. In March of 2006 the Authority issued a request for qualification and proposals for the beneficial reuse of the thermal energy available at the incinerator exhaust outlet. Potential vendors were required to use the thermal energy on site and propose either a reduction in the cost of the plant operations or a new revenue source from the sale of the recaptured energy, or a combination of both methods so as to reclaim the maximum value of the captured energy.

After short-listing and interviews, the Authority selected a consortium team consisting of the Dresser Rand Company as the prime contractor with American Heat and Power of Houston, TX as primary plant designer. In August 2007, the Authority entered into a multiphase/multiyear agreement for plant delivery. These steps included detailed feasibility and preliminary engineering, final detailed engineering design and equipment selection, major equipment procurement and construction, training, acceptance testing, and a five-year maintenance, replacement and warranty period. Construction completion and plant acceptance is scheduled for early December, 2008.

EXSITING CONFIGURATION OF WPCA SLUDGE INCINERATOR.

Figure 1 illustrates, in simple schematic form, the original sludge incineration process used at the WPCA.

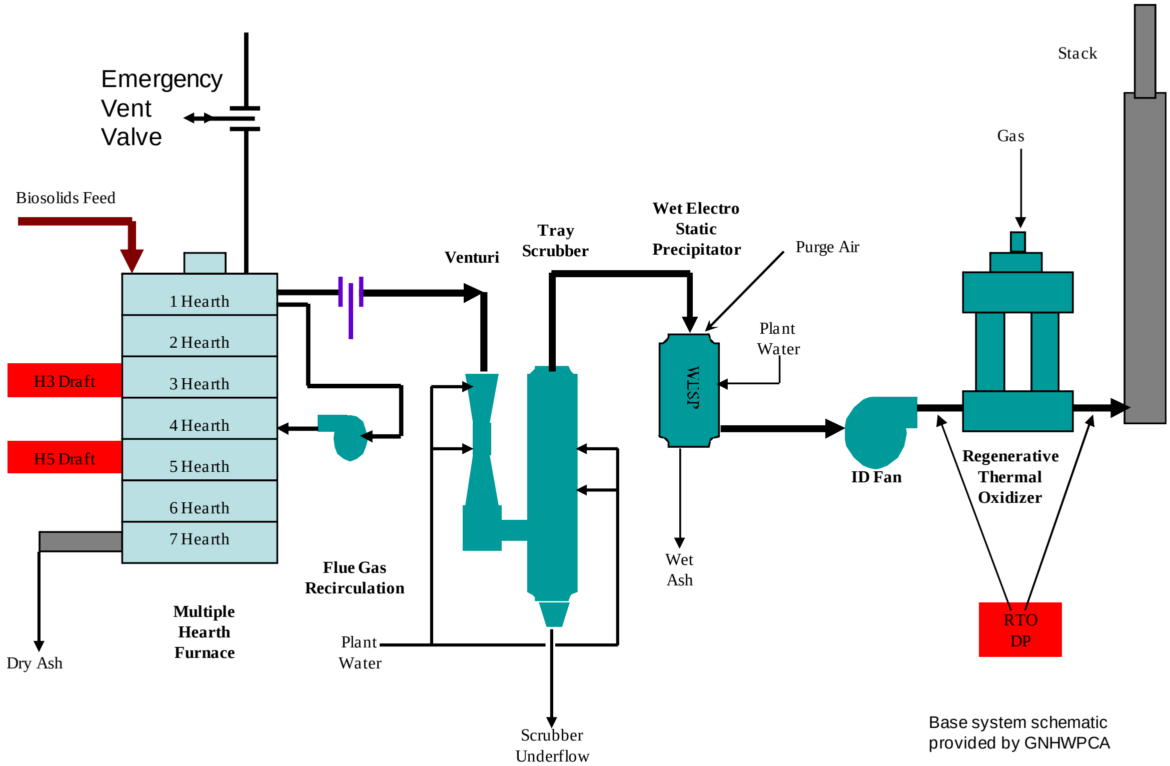

Figure 1 Original Incineration Plant Configuration

Typical operating statistics for the sludge incineration process are as follows:

Table 1 Sludge Operations and Incineration Process

Annual Run-time	**8177 hrs per year (93.3% uptime)**
Average exhaust temperature	**1200 degrees F**
Sludge average solids content	**26%**
Average sludge caloric content	**7800 Btu/lb**

Table 2 illustrates the sludge historical throughput rates and their frequency of occurrence, which is used to predict future performance.

[redacted]

Table 2 Annual Sludge Throughput Rates

Analysis of Incinerator Exhaust Gases for Potential Heat Generation and Capture

An exhaustive thermodynamic and combustion analysis of the New Haven multiple hearth furnace was conducted utilizing a computer model developed by American Heat and Power. The analysis, in which the model analyzes each hearth of the incinerator, was undertaken as part of the initial engineering design. The analysis was conducted using the recorded sludge throughput rates, sludge characteristics, such as moisture content, Btu content, and other variables in order to determine the recoverable heat output and the resulting steam production when the hot gases were passed through a waste heat boiler. In the final analysis, Table 2 summarizes the average and expected characteristics of the incinerator exhaust gases and their potential steam production rates.

TABLE 2 TYPICAL RESULTS FROM
THERMAL ANAYSIS OF INCINERATOR EXHAUST GASES (2)

- ***Sludge Characteristics***
  - Sludge Feed Rate 42 Dry Tons per day
  - Solids content 26%
  - Volatile Organics 78%
  - Ash 23 %
  - HHV of fuel (dry basis) 7,750 Btu/lb
  - LHV of Fuel (dry Basis) 7,260 Btu/lb
  - Total Natural Gas usage 2,850,000 BTU/hour
  - Total Natural Gas per Dry Ton 1,862 MMBTU/Dry Ton

- ***Exhaust Gases***
  - Exhaust Gas 9,038 SCFM
  - Exhaust Gas 28,846 ACFM
  - Excess Oxygen 29%
  - Sludge Combustion Air 4,561 SCFM
  - Inlet Air Temperature 60 Degrees F
  - Final Hearth Exit Temperature 1195 Degrees F

- ***Typical Steam & Power Production***
  - Steam Temperature 600 Degrees F
  - Steam Pressure 400 PSIA
  - Steam Production Rate 8,847.8 lbs/hour
  - Gross KW 628.2
  - Steam Output 7,687 lbs/hour
  - Net KW 512 KW

The exhaust gas analysis clearly indicated that the recaptured incinerator exhaust gases are sufficient to generate steam and electric power. Further economic analysis also indicated that this could be done with attractive return on investment to satisfy the economic thresholds needed by the Authority.

Incinerator Process Reconfiguration

Given the potential of capturing the incinerator exhaust gases with a positive economic outcome the incinerator plant was reconfigured as shown in Figure 2.

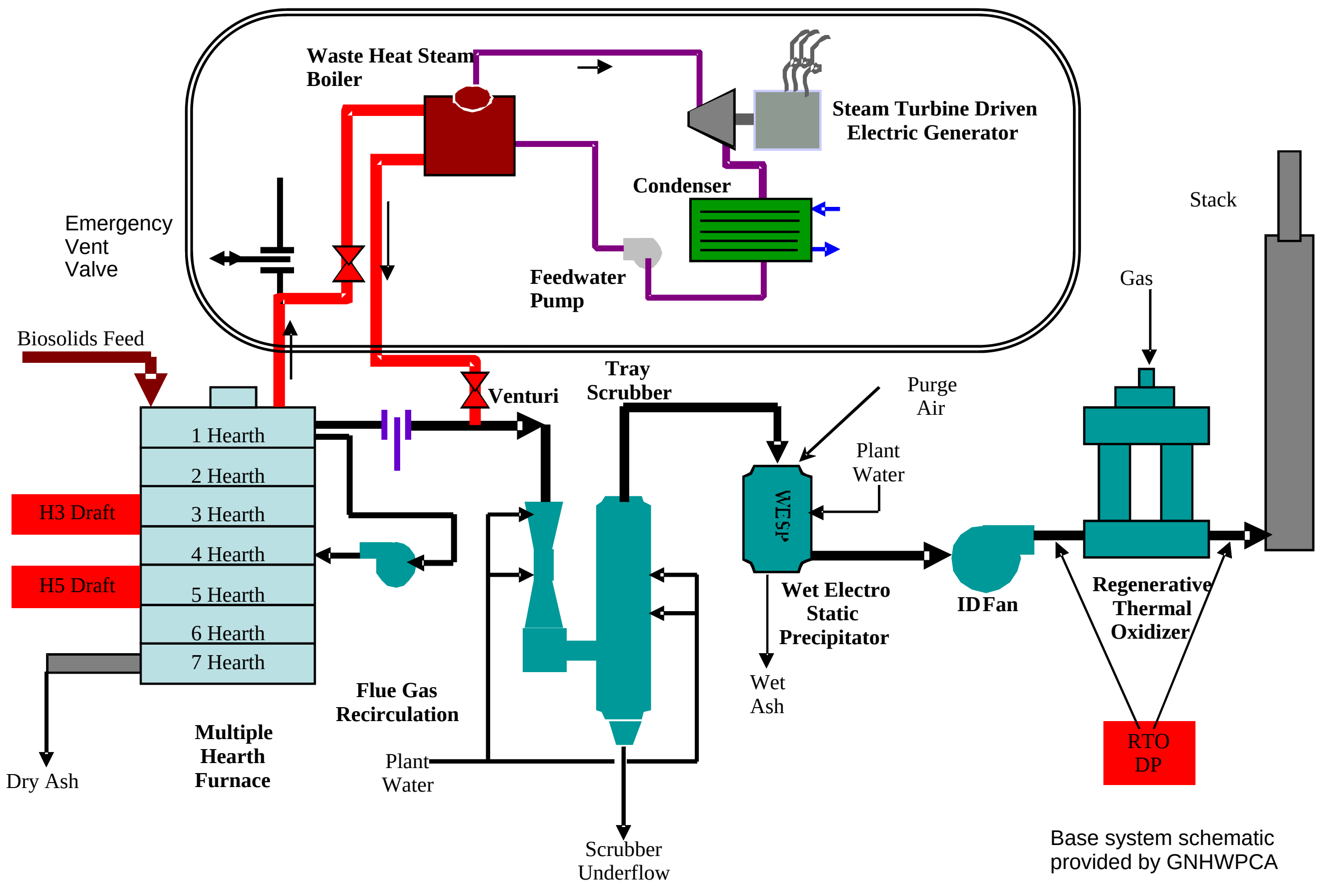

Figure 2 Reconfigured Incineration Plant with Steam Turbine Plant Added

A critical component of the design and engineering process centered around the concept of using conventional and proven technology and equipment, with` known reliability and low inherent risk. In addition, it was very important that the plant's ultimate configuration not further complicate an already difficult process of sludge handling and incineration. An additional concern was that maintenance and operations would require relatively low-tech procedures using a highly automated method of operation, alarming and safeties. This would let the existing plant contractor operate the existing sludge incineration operations and the waste heat recapture system with the least amount of added effort, cost and manpower.

The new plant is housed in a 48 Ft by 36 Ft by 22 Ft high building at grade consisting of steel frame and block construction. Figure 3 illustrates the main plant floor layout and component arrangement.

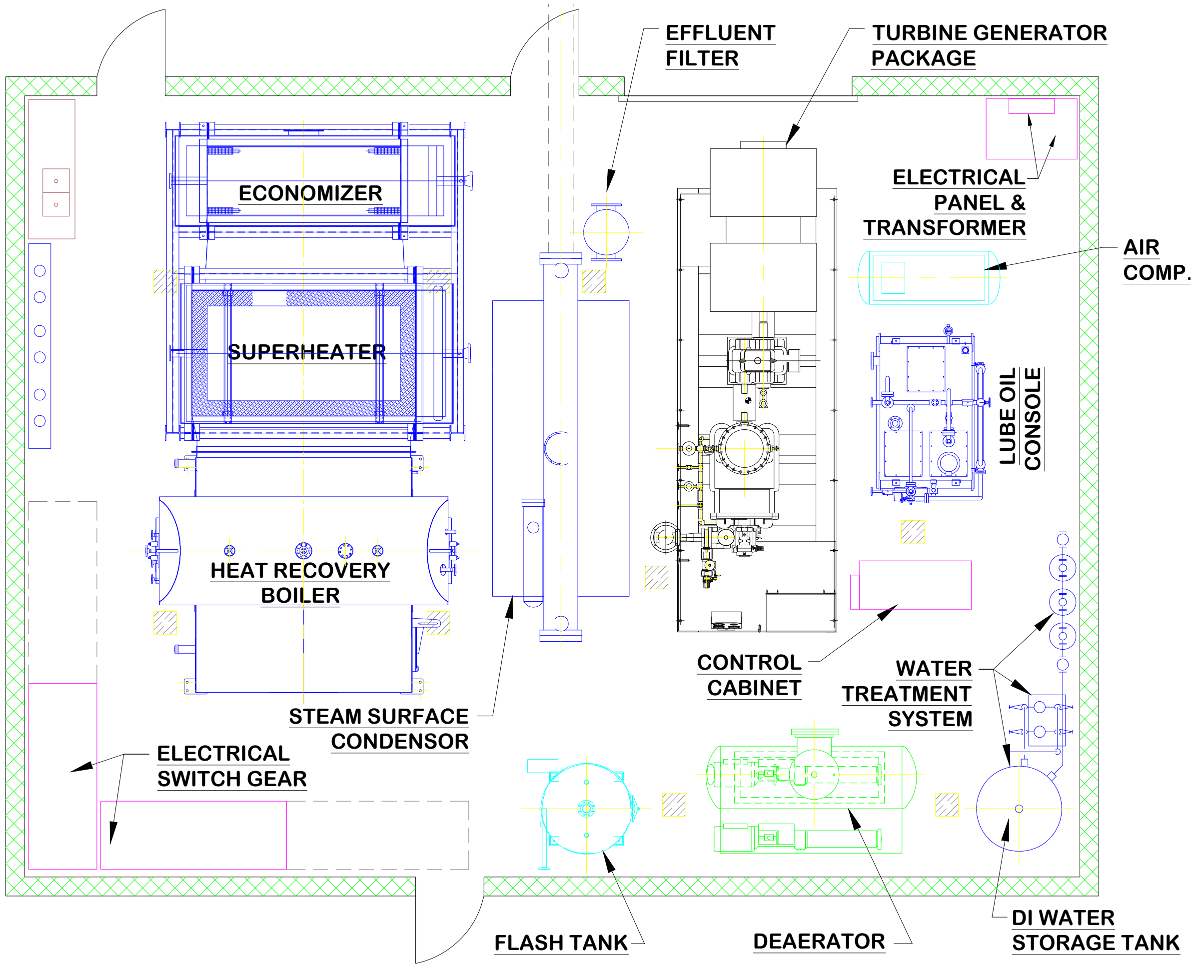

Figure 3 Renewable Energy Plant Floor Layout

The plant is relatively simple in design. Incinerator exhaust gases are directed to a waste heat boiler through a series of ducts and motorized dampers (See Figure-2). These dampers are opened or closed depending on incinerator operating conditions, waste heat boiler steam temperature and pressure, and turbine generator safeties. For example, should the turbine generator plant trip on one of its many internal safeties, the gases are immediately redirected around the waste heat boiler back through the original flow path of the incinerator exhaust gases. Ancillary systems and equipment include a de-aerator, condenser, soot blowers, water treatment, turbine lubrication and automated touch screen control alarm and safety system monitored in two on-site locations and one remote location.

The waste heat boiler is a water tube "O" type boiler equipped with an economizer and superheater. The design pressure is 500 PSIG and capacity is 12, 253 lbs/hr at 400 PSIG and 612 degrees F at NRV outlet. All tubes are 2-inch OD steel with varying wall thickness and material grade from 0.105 to 0.165 inches depending on location within the boiler. Ducting to and from the incinerator to the waste heat boiler is 14 gauge stainless steel with a 2 inch pre cast refractory lining, 6-inch external mineral wool insulation and a final external finish of an aluminum jacket.

The Dresser Rand Company manufactures the turbine generator set. This is an eight stage turbine rated for 400 PSIG at 600 Degrees F at the steam inlet with an exhaust pressure of 4 inches Hg vacuum with a steam flow of 10,740 lbs/ hr at 5,500 RPM with an 1800 RPM synchronous generator manufactured by Marathon rated at 750 KW.

Plant Economics

The ultimate test of the feasibility of this system is the ability of the plant to economically produce electric power at a rate that is less than can be purchased from the local utility after considering all capital, maintenance and operating costs.

Table 3 below summarizes the economic parameters used to analyze the economic issues and Table 4 illustrates the 25-year cash flow expected from this investment.

TABLE 3

ECONOMIC PARAMETERS

Project Economic Parameters	
Generation Output:	0.75 MW Gross Output
	0.70 MW Net Output
Generator Operating Schedule:	7 Days per week (24 hours at 0.70 MW with
	6 hours down time per week, 51 weeks per year
Annual KWh Output:	4,023,895 KWhs per year using actual 2005 operating
	Data with new centrifuge in operation
Base Year Electricity Rate:	$ 0.18564 per KWh (Represents January 2007 rate
	($0.17) plus 4.5 % escalation out to 2009 startup date plus
	Escalation for one year construction term
Additional Savings - Shaft Hear Recovery:	2,250 MBTU/year
Cost of Natural Gas:	$ 10/MCF
Yearly Savings	$ 22,500/year
Inflation Rates:	Electricity and Natural Gas – 4.5%
	Operations & Maintenance Costs – 3.0 %
Ongoing Services	
Equipment Maintenance Contract:	$ 10,130 per month
Available State of Connecticut Incentives	
Public Act 05-1, An Act for Energy Independence	
One Time Incentive:	$ 200 to $ 500 per KW
Connecticut Clean Energy Fund	Renewable Energy Generation Projects ($ 318,780)
Reduced Natural Gas Prices	Elimination of Natural Gas Distribution Charges for
	Customer Side Generation Resources ($ 62,000 per year)
Long Term Project Financing	Provides long term project financing.
Class 3 Renewable Energy Credits:	Provides ongoing renewable energy credits for electric
	Generation projects (Estimated annual credits $ 0.005/KWh
Available Federal Government Incentives	
$ 2,500,000 Clean Renewable Energy Bonds	

Project Financing	
Project Cost	$ 5,339,429.
Engineering & Oversight Costs	$ 200,000.
Bonding Costs	$ 250,000.
Total Project Initial Cost	$ 5,789,429.
Total Amount Financed	$ 5,789,429.
CREBs Bond Amount	$ 2,500,000.
Discount Rate	0.085 %
Term	16 Years
Bond Repayment Costs	$ 2,673,542
GNHWPCA Revenue Bonds	$ 2,839,429
Bond Coupon Rate	5 %
Term	20 Years
Yearly Amortization Costs	$ 224,867.

TABLE 4
25-YEAR SUMMARY CASH FLOW:

Capital Cost	**$5,339,429**
Net Positive Cash Flow over to Owner over 25 years	**$28,721,030**
Net Present Value of future cash flows at 3% inflation	**$17,851,448**
Simple Payback	**< 6 Years**
Internal Rate of Return	**34.13%**

Government Economic Support

Of significance importance with respect to economic performance for this plant is the additional capital contribution and operating cost incentives that were provide under Federal and State law. These included:

Capital Cost Incentives

- $2,500,000 in 0% financing using Treasury Department, Clean Renewable Energy (CREB's) Bonds.
- A cash grant of $318,780 from CT DPUC under its State of CT Energy Act 05-1 *An Act for Energy Independence*

Operating Cost Incentives

- The elimination of all natural gas transportation cost from the local supplier over the life of the project equivalent to $2,763,043.
- The potential income from the sale of the Class III Renewable Credits (REC's) associated with this project estimated at $502, 987 over the life of the project.

Environmental Benefits

In addition to the economic benefits enumerated above there are also some immediate and direct benefits to the local environment. While the addition of the waste heat boiler and steam turbine plant will not lower the emissions from the incinerator process significantly, the elimination of over 4 million kWh generated at the local power plant will reduce local pollutant emissions.

It is estimated that when this plant is running as scheduled the following pollutants will be eliminated from the local utility company power generating plant. These are:

Particulate	40.0	Tons per year
SO_2	3.7	Tons per year
NOX	1.3	Tons per year
CO	<1.0	Ton per year
CO_2	1,441	Tons per year

Table 5 Pollutants Eliminated

CONSTRUCTION, TRAINING ACCEPTANCE TESTING &LONG TERM MAINTENANCE

The Authority has contracted with Dresser Rand for the construction of the plant. It is expected to be complete and ready for acceptance testing by December 2008. Following completion of acceptance, testing and training will be conducted simultaneously. Authority and contract operator staff will be trained for a period of five consecutive days in startup, shutdown and maintenance routines on the actual equipment. Upon completion of training, a series of three days will be set aside in order to prove the systems capability to produce the rated power. The authority will test and stockpile acceptable sludge prior to each test. Each test will consist of a 24-hour continuous run period where all operating parameters as well as power output is continuously measured. The plant will be required to meet a minimum performance output as shown in Figure-5.

Actual expected performance is expected to exceed minimum acceptance criteria. The design build contractor and the Authority have also negotiated time allowances for corrective measures as well as penalty cost for failure to achieve minimum performance.

In addition to the training and acceptance testing the Authority has also contracted for a five-year Long Term Maintenance Contract with Dresser Rand which covers all routine and non-routine maintenance as well as repair and/or replacement of any component of the systems which fails in that period.

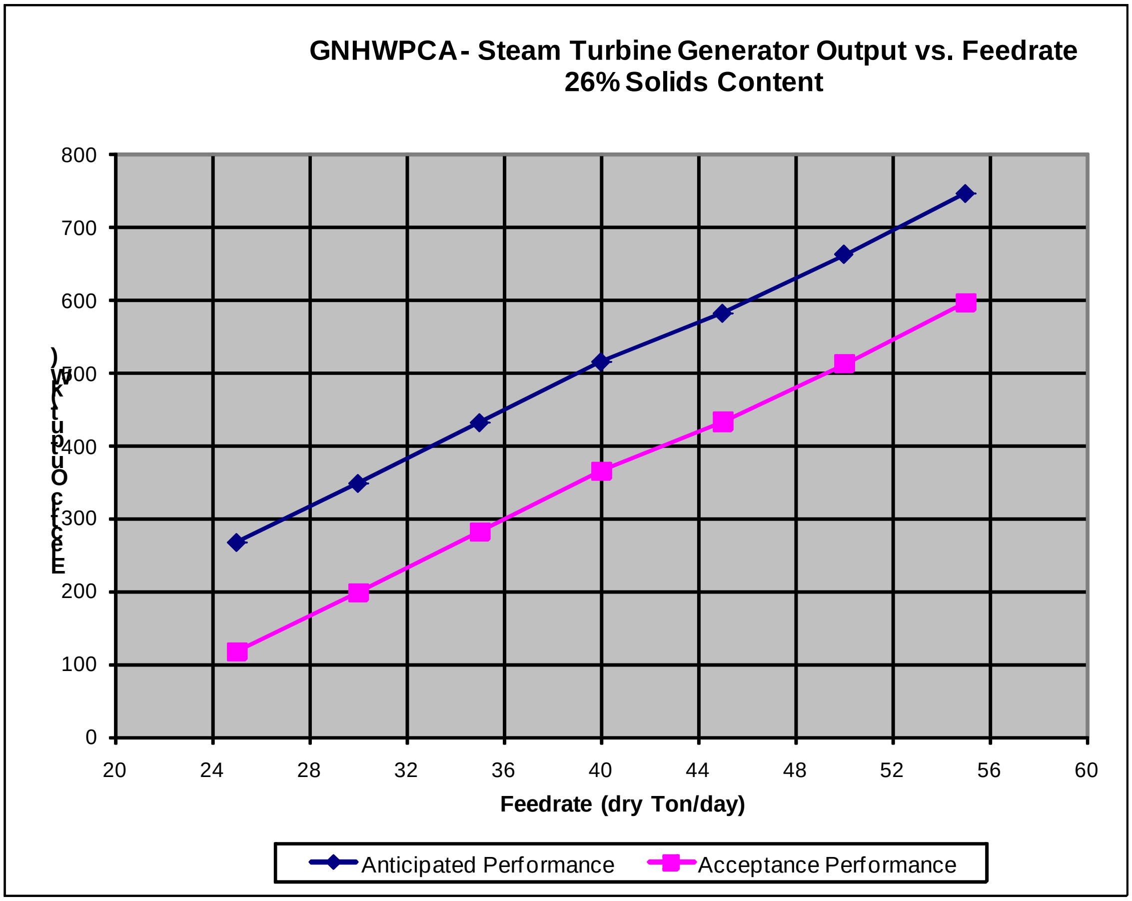

Figure 5 Waste Heat Recovery Acceptance Criteria

CONCLUSION

The plant configuration described above is currently under construction. Start up and acceptance testing is slated for December 2008 and full electric power production is schedule for January 2009. The capture and use of sludge incinerator exhaust gases in the case of this specific project has shown itself to be both technical and economically feasible. Among the many benefits, this renewable energy project concept:

- Utilizes conventional technologies with low inherent risk.
- Is economically advantageous and reduces operating cost and thus reduces cost to ratepayers.
- Supports the State of Connecticut and regional power generation plans.
- Provides the State and regional emission reductions.
- Establishes the Authority as an innovative, responsible and regional problem solving resource.

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