WASTE-TO-ENERGY / SLUDGE CO-DISPOSAL STUDY

For

CONNECTICUT RESOURCES RECOVERY AUTHORITY
Hartford, CT

CRRA Contract 020138

FOCUS FACILITIES

420 TPD Wallingford Facility
2,250 TPD Mid-Conn Facility

PREPARED BY

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1.0 INTRODUCTION

At the request of the Connecticut Resource Recovery Authority ("CRRA"), Halcyon Technologies LLC ("Halcyon") conducted a cursory review of two waste-to-energy facilities to evaluate their suitability for the co-disposal of municipal wastewater treatment residual biosolids ("sludge"). On February 13, 2002 representatives from Halcyon visited the following two CRRA facilities:

- ♦ 420 TPD, mass-burn facility in Wallingford, CT
- ♦ 2,250 TPD, RDF-fired Mid-Conn facility in Hartford, CT.

The purpose of this evaluation was to determine the preliminary feasibility for the co-disposal of sludge at one or both of these facilities and to develop a conceptual plan for future testing. The following activities were performed as part of this work effort:

- ♦ Project kick-off meeting held at the CRRA's office in Hartford on February 13, 2002.
  Attendees included:

  <u>CRRA</u>
  - John Clark
  - Peter Eagen
  - Chris Fancher

  <u>HALCYON</u>
  - Steve Cotta
  - Dave Wojichowski

- ♦ Toured of the Mid-Conn and Wallingford facilities with representatives of CRRA to become familiar with plant layout, operational practices and process parameters. Also, basic design drawings and equipment specifications were gathered and reviewed.
- ♦ Conducted brief review of potential regulatory hurdles presented by 40CFR503 "Standards for the Use or Disposal of Sewage Sludge".
- ♦ Contacted equipment suppliers, engineers and operators familiar with the storage, handling and processing of sludge.
- ♦ Established the most feasible options at both plants, illustrated by simple flow diagrams and mass balances.
- ♦ Defined a specific scope of work for a test burn, including equipment, plant modifications, interface with plant operations, quantities, duration, data collection, and cost.
- ♦ Summarized findings in report format.

2.0 EXECUTIVE SUMMARY

Both the Mid-Conn and Wallingford facilities were evaluated for the feasibility of co-firing municipal wastewater sludge with refuse. The evaluation results indicate that the co-disposal of sludge with refuse is possible at either facility. The sludge firing rates proposed for a test represent a starting point that will allow data to be collected to define the design and capacity of a permanent installation. For sludge cake, the recommended capacity is a weight ratio of 10 parts solid waste to 1 part wet cake. For liquid sludge, the recommended firing rate is a weight ratio of 12 parts solid waste to one part liquid sludge.

The net impact on boiler operation at the recommended test rates should be minimal. For sludge cake, the energy content of the dry solids (LHV of ~1,000 BTU/lb) is almost equally offset by the heat loss required to evaporate its water. Steam flow, solid waste throughput, and power generation will not be negatively impacted. The most important boiler parameter to review is ID Fan capacity – which must handle an additional 3-4% flow. A test burn program for sludge cake is estimated to cost approximately $150,000. For liquid sludge, additional thermal input is required to maintain the same boiler steam output, which creates the ability to fire more refuse while maintaining the same steam to the turbine. Handling liquid sludge is much easier, less costly and a lesser quantity of sludge can be processed. A test program utilizing liquid sludge would cost approximately $128,000. If the CRRA decides to proceed with a full scale sludge co-disposal initiative, we suggest that a 30 day test be conducted in order to gain an understanding of the technical, operational and environmental impacts of processing municipal wastewater sludge at the existing facilities.

3.0 BACKGROUND

The principal byproduct of a municipal wastewater treatment facility is a solid residual called sludge. This residual, also called biosolids, is a suspension of solids that settles in the bottom of tanks and basins in the wastewater treatment process. Because of its nuisance nature (odors, pathogens, etc.) sludge must be properly disposed. Sludge can be collected for beneficial reuse through land application or composting or it may be disposed of through land filling or incineration.

Approximately one-third of all wastewater sludge is disposed by means of incineration. Sludge incinerators are often located on the wastewater treatment plant site. These incinerators are either multiple hearth or fluidized bed combustors that have sufficient agitation and residence time to drive off the moisture and provide for proper combustion. Incineration of sludge provides for high temperature destruction of pathogens and toxic organics with a low residual content (ash represents about 1% by volume of liquid sludge). The co-disposal of sludge with municipal solid waste has the following additional benefits:

- Modern waste-to-energy facilities have state-of-the-art emission control systems, resulting in superior control of air pollutants compared with typical municipal sludge incinerators.
- Modern waste-to-energy facilities operate at a much higher temperature than dedicated sludge incinerators, reducing the emissions of volatile organic compounds and other products of incomplete combustion.

The incremental amount of ash produced with co-disposal would be a very small percentage of the total. The combined ash would be handled and disposed in secure landfills under existing environmental regulations.

3.1 Regulatory Considerations

The Federal EPA has enacted comprehensive rules governing the disposal of domestic sewage sludge in the form of 40 CFR Chapter I, Subchapter O, Part 503 – "Standards for the Use or Disposal of Sewage Sludge". However, Part 503.6(c) *Co-firing of sewage sludge* states that:

> "This part does not establish requirements for sewage sludge co-fired in an incinerator with other wastes or for the incinerator in which sewage sludge and other wastes are co-fired. Other wastes do not include auxiliary fuel, as defined in 40 CFR 503.41(b), fired in a sewage sludge incinerator."

The above exception leaves open the exact regulatory treatment that covers the co-firing of sewage sludge. Other federal rules which might be relevant are the NESHAP Beryllium and Mercury requirements. Our experience with these rules in a co-firing situation suggests that the issue is more administrative than substantive. Connecticut environmental regulations were not specifically reviewed as part of this evaluation. And while the existing air pollution control systems currently installed will most likely be sufficient to meet applicable emission regulations, the CT DEP will need to be contacted to provide guidance for this application.

3.2 Patent Considerations

While a detailed patent search was not done as part of this study, we are not aware of any issues that should interfere with the implementation of this test. A competent patent researcher or counsel should be retained for a more complete review of possible patent issues. The design for the injection nozzle apparatus would be the most likely area of invention, and the use of commercially available equipment should eliminate any potential for patent infringement.

4.0 SLUDGE CHARACTERISTICS

There are three forms of sludge, depending upon the level of de-watering, that could be utilized in a co-disposal application:

- Liquid sludge, which has a solids content of 3-6% by weight and is generated in settling tanks and basins.
- Sludge cake produced by the mechanical dewatering of liquid sludge, which has a dry solids content in the range of 15 – 30%.
- Dried sludge, greater than 90% solids, produced from the thermal drying.

The heat content of wastewater solids, when dried, is in the range of low-grade carbonaceous fuels such as peat or lignite. Wastewater sludge contains a higher percentage of volatile matter and lower fixed carbon content. Compared with coal, sludge combustion will produce more flaming as volatiles are oxidized. Table 1 provides the assumed ultimate and proximate analysis, as well as the heating value for the calculations in this report.

TABLE 1
Sludge & Waste Characteristics

	Combustible	**Dry Solids**	**Ultimate Analysis**		**Ref. RDF**	**Ref. MSW**
			5% Liquid	**25% Cake**		
C	57	34.2	1.7	8.6	34.7	30.8
H	7	4.2	0.2	1.1	4.1	4.1
O	30	18.0	0.9	4.5	23.5	25.9
N	5	3.0	0.2	0.8	0.5	0.6
S	1	0.6	0.0	0.2	0.23	0.1
Ash	-	40.0 (2)	2.0	10.0	14.0	20.1
Water	-	-	95.0	75.0	23.0	18.4
Total	100	100.0	100.0	100.0	100.0	100.0
HHV	10,300	6,200	200	1,250	5,785	5,000
LHV	9,635					

(1) Per 1992 WEF Manual of Practice F-19
(2) Info from Dr. Mark Girovich, SynaGro

4.1 Liquid Sludge Handling

Liquid sludge is relatively easy to handle with standard industrial pumping equipment. Liquid sludge is transported in tank trucks holding 3000-5000 gallons. The totally enclosed nature of these vehicles can provide optimum odor containment. Similarly, liquid sludge is processed in standard carbon steel or black iron piping with typical pumps, valves and instrumentation. Liquid sludge, which sits undisturbed for a period of time, will tend to settle, requiring a means of creating turbulence or solids removal. Liquid sludge also has a finite 'shelf life' due to its organic nature, which can result in changes in its physical, chemical and biological characteristics.

At the point of injection into the combustion chamber, it is important to atomize the liquid to facilitate evaporation and subsequent combustion in suspension. The location of injection and the design of the injector are critical to ensure good combustion. The location should be as directly above the grate as possible, with maximum residence time at the highest temperature. For MSW incinerators, this location is above the feed zone and before overfire air introduction. The injection nozzle itself must extend slightly inside the furnace zone as it is subjected to extreme temperatures and highly corrosive gasses. It is therefore essential to keep the exposed metal temperatures cool, which is usually done with air and/or liquid. The best arrangement is described as a pipe-within-a-pipe design. The inner pipe transports the sludge into the boiler, with an orifice nozzle on the end to create a desired spray pattern. The outer pipe carries either steam or air and serves a dual function – keeping the outer pipe cool, while providing energy to atomize the fluid. A suitable nozzle is available from Von Roll Inc., which would be custom fabricated for this purpose. The design is time proven and is derived from experience with injecting liquids into hazardous waste incinerators. See Nozzle Illustration in the Appendix for more detail. The nozzle requires 15-60 scfm of air at 20-30 psig for cooling/atomization.

4.2 Sludge Cake Handling

Sludge cake is quite awkward to handle, requiring special equipment and more extensive odor control provisions. Sludge cake is transported from the dewatering facility in dump trucks with liquid tight tail gates and air tight synthetic covers. A typical cake receiving design has at least two below grade receiving hoppers (for redundancy), each with shaftless screw live bottoms. Shaftless design is superior because the cake does not accumulate around the shaft – but therefore requires very thick flights to maintain structural strength and avoid "springing" in either a pushing or pulling mode. In addition, since the screws rest directly on the hopper bottom, hopper liners are essential. The live bottom screws are variable speed to effect process flow control, and feed forward to either shaftless screws, hydraulic piston-type pumps or progressive cavity pump. All three are essentially enclosed systems. The selection of a specific type depends upon the application, conveying length, and conveying path.

5.0 CO-DISPOSAL EXPERIENCE

Co-firing of solid waste with wastewater sludge is not a common practice in either Europe or North America. This may be more of an issue of separate entities being responsible for the disposal of these wastes as opposed to any technological issue. Where co-firing is used in Europe, the typical practice is to de-water or dry the sludge, and then mix the sludge in the pit or the refuse feed hopper. We could not confirm an operating facility in Europe utilizing direct injection in a co-disposal application. An operating concern associated co-firing sludge cake is particle size. Since a grate system has a finite residence time, large chunks of the cake will not burn out completely. The outside surfaces of the cake mass will burn and harden resulting in incomplete burnout.

Due to the high water content of the liquid sludge, external heat is required for complete combustion. As liquid sludge is added to the fuel, the firing rate of the refuse must be increased in order to maintain the selected steam output. Alternatively, the heat loss due to evaporating water must be provided by the addition of more fuel. The practical limit of how much water can be added is twofold – the ability to maintain good combustion in the furnace and the overall impact of the increased gas volumes passing through of the system, especially the ID Fan.

Domestically there are two facilities co-firing sludge that further support consideration of this application by the CRRA.

The ECO-Springfield facility has been co-firing liquid sludge with MSW since September 2001. It is our understanding that one train is processing the liquid sludge at a rate of 2500 gallon/day at a concentration of 5% solids. Each of the Springfield units has the same thermal rating as Wallingford, i.e., 59 MMBTU/hr. Their next step is to increase the firing rate to 5,000 GPD of 15% solids in all three units.

The Water Environment Foundation Manual of Practice for sludge incineration examines the ratio of thermal heat input to the heat loss in evaporating water in the sludge as a measure of the overall impact on the system heat balance. For the Springfield facility this heat ratio value calculates as 39. The implied meaning of this is that 39 times more energy is released from solid waste then is consumed heating/evaporating/superheating the sludge water. At their new co-disposal rate this ratio declines to 20. By comparison, the seven European co-incineration facilities cited by WEF had thermal ratios of 6 – 10. Hence, the projected firing rate at ECO-Springfield should be acceptable without negatively impacting overall combustion.

For the CRRA projects, a conservative recommendation would be to test at a rate close to the original thermal ratio of approximately 30. That would be 2 GPM per unit at Wallingford, which is a thermal ratio of 33 and a weight ratio of 12 parts solid waste to one part liquid sludge.

The evaluation of sludge cake is more appropriate on the basis of mass loadings. The Glen Cove facility has two mass burning furnaces, each designed for 110 TPD of refuse co-fired with 15 TPD of sludge cake at 15-25% solids. The sludge cake is mixed with the refuse manually in the refuse storage pit. On a weight ratio basis, the thermal heat ratio is approximately 30, which translates to a firing rate of 7 parts refuse to 1 part cake. For the CRRA projects, it is suggested that a weight ratio of 10:1 would be reasonable if injected directly in a even manner. Since the fuel value of the sludge cake is fairly proportional to that of the refuse, there is no appreciable temperature suppression.

The primary focus of this evaluation was somewhat geared towards defining an approach for co-disposal that would be readily tested. There are a number of other approaches that could be considered including a dedicated sludge incinerator or combination drying/injection technology as offered by Induction Drying Technologies Inc. and thermal oxidation systems offered by Von Roll Inc. These and other options could be reviewed and evaluated as part of another study.

6.0 CALCULATIONS – FIRING RATE

The actual sludge co-firing rate that would be acceptable can ultimately only be determined through testing and evaluation of a specific boiler unit. Short of actual testing we attempted to estimate the impact on predicted gas flows and boiler efficiency for co-firing liquid sludge and also for co-firing cake. Combustion calculations were performed in accordance with the methodology described in STEAM / its generation and use, Chapter 6. For each plant evaluated, a base case of refuse firing only, was used to compare the calculation results with the original plant data provided by the system designers. Then a mixed fuel analysis was determined by a ratio of the refuse and sludge, weighted by the co-firing rate. A reiterative calculation was then performed to maintain the original base steam output. The data from these calculations is summarized in Table 2 and more complete information is presented for each case in the flow charts included in the Appendix. A brief description of the specific parameters for Mid-Conn and Wallingford is also presented below.

TABLE 2
CALCULATION SUMMARY

	Mid-Conn		**Wallingford**	
	Cake	**Liquid**	**Cake**	**Liquid**
Sludge Dry Solids (%)	25	5	25	5
Sludge Disposal/Unit	68 TPD	9.6 GPM	14 TPD	2.0 GPM
Disposal Rate (Dry TPD)	17.0	2.9	3.5	0.6
Steam Flow (lb/hr)	231,000	231,000	35,400	35,400
DELTA RDF/MSW	0	+13 TPD	0	+4 TPD
Increase in Gas Flow	3.6%	3.4%	3.9%	4.4%

6.1 Wallingford Load Calculations

The Base Case, Appendix Chart 1-1 labeled Wallingford Refuse Firing, reflects the baseline conditions of current operation. The calculations are based on a firing rate of 140 TPD of refuse with a predicted higher heat value of 5,000 BTU/lb. The calculated steam flow, boiler efficiency, and gas flow is approximately 35,300 lb/hr, 68.1%, and 86,900 lb/hr respectively.

Chart 1-2, the Liquid Sludge Case, illustrates a weight ratio of 12 parts MSW to 1 part sludge. In order to maintain the steam flow set point of 35,300 lb/hr, the calculations indicate that the boiler controls will increase the demand for MSW to 144 TPD. The corresponding boiler efficiency and gas flow is approximately 66.2% and 90,745 lb/hr. The boiler exit gas flow is increased by a factor of 4.4%.

Chart 1-3, the Sludge Cake Case, illustrates a weight ratio of 10 parts MSW to 1 part sludge. In order to maintain the steam flow set point of 35,300 lb/hr, the calculations indicate that the boiler controls will not require the addition of additional MSW – reflecting the near autogenous heating value of 25% dry solids cake. The corresponding boiler efficiency and gas flow is approximately 66.3% and 90,324 lb/hr – very similar effects as to that of the Liquid Sludge Case.

6.2 Mid-Conn Load Calculations

The Base Case, Appendix Chart 2-1 labeled MID-CONN – RDF Firing, reflects the baseline conditions of current operation. The calculations are based on a firing rate of 675 TPD of RDF with a predicted higher heat value of 5,785 BTU/lb. The calculated steam flow, boiler efficiency, and gas flow is approximately 231,000 lb/hr, 74.7%, and 413,000 lb/hr, respectively.

Chart 2-2, the Liquid Sludge Case illustrates a weight ratio of 12 parts RDF to 1 part sludge. In order to maintain the steam flow set point of 231,000 lb/hr, the calculations indicate that the boiler controls will increase the demand for RDF to 688 TPD. The corresponding boiler efficiency and gas flow is approximately 73.1% and 427,520 lb/hr. The boiler exit gas flow is increased by a factor of 3.5%.

Chart 2-3, the Sludge Cake Case illustrates a weight ratio of 10 parts RDF to 1 part sludge. In order to maintain the steam flow set point of 231,000 lb/hr, the calculations indicate that the boiler controls will not require the addition of additional RDF – reflecting the near autogenous heating value of 25% dry solids cake. The corresponding boiler efficiency and gas flow is approximately 73.2% and 428,146 lb/hr – once again very similar effects as to that of the Liquid Sludge Case.

7.0 TESTING

A successful test will allow the following information to be collected:

1. Observe any significant impacts on boiler operation. Does the sludge add significantly to boiler fouling or furnace slagging?
2. Observe burn-out. The sludge should be completely burnt out in the ash. This requires proper atomization and dispersion, as well as nozzle location.
3. Measure / determine impact of elevated gas volumes.
4. Environmental data should be collected to prove no adverse effect on emissions performance. CEM data should be collected and analyzed.

Ideally, the duration of the test should be long enough to complete one boiler fouling cycle – approximately 3 months. During that period of time, the boiler could consume approx 14,000 gallons of liquid sludge each day – about 3 trucks. However, the thermal and mechanical efficacy of the technique could to be observed without 24 / 7 operation. For practicality and cost considerations, it is recommended that multiple 12-hour test runs occur during a 30-day period. During these tests the performance of the ID Fan should be monitored to estimate effect of additional gas flow, and to determine a new design basis for any permanent modification. CEM data must be collected to statistically determine if there are any noticeable changes to CO emissions. SNCR reagent consumption should be monitored to compare before/after, and a manual stack sampling test should be conducted to measure impact on mercury and trace metals.

Liquid sludge is relatively straightforward to handle with standard pumping and piping systems. A simplified flow diagram, Sketch 001, which would be applicable for either facility is included in the Appendix. For the purposes of a test, a tank truck can be used as a storage vessel and be refilled from incoming tanker trucks delivering liquid sludge for the test. The sludge would be pumped up at moderate pressure to an injection nozzle, which utilizes compressed air or steam for droplet atomization.

Sludge Cake is more difficult and expensive to handle, but greater quantities of sludge can be processed. An enclosed and odor controlled location must be available to receive cake in dump trucks. A simplified flow diagram, Sketch 002, which would be applicable for either facility is included in the Appendix. The area must also have the ability to wash down the truck tailgates and collect the wash water. A small loader would charge the sludge to a feed hopper with live bottom screws. The screws would force feed the positive displacement pumps, which transports the cake through piping to the injection nozzle(s). A portable sludge pump suitable for this application is available for rental from Schwing America Inc., an illustration of the pump is included in the Appendix. The nozzle would act very much the same as for liquid, using compressed air to size-reduce and disperse the cake inside the boiler unit. A nozzle for this task is available from Von Roll Inc. The Appendix also illustrates the operation of Von Roll's dual-fluid nozzle with sludge. For both facilities, a new opening in the boiler wall is needed to accommodate the 4" barrel of the injector.

7.1 Wallingford Test Recommendation

Since the Wallingford facility currently adds water to its solid waste for slag control, it should be relatively straightforward to test fire liquid sludge at the Wallingford facility. The stationary tanker could be located at grade just outside of the boiler building, with the pump skid adjacent. Piping could be routed to any of the three boilers, although the closest boiler would be most logical. The use of liquid injection at Wallingford is particularly appropriate since they currently spray excess water onto the MSW for furnace temperature/slag reduction. The amount of water proposed is less than what the facility was using at the date of visit – so there should be no new negative impact onto the ID Fans. It should be noted that during periods of wet trash, there might be a net effect if sludge spraying continues.

Sludge Cake could be injected directly into the Wallingford units either in the primary combustor or possibly onto the refuse in the feed-lock area. The Von Roll nozzle could be used in either application to facilitate breaking the sludge cake into smaller pieces. For firing in the hot combustor it is recommended that the nozzle penetrate down through the combustor roof above the second hearth. The roof of the combustor is a steel casing/refractory lined enclosure, which should easily facilitate the nozzle port. The penetration would need to be made during an outage. A final design needs to be completed to firmly establish location and pipe routing.

7.2 Mid-Conn Test Recommendations

As with Wallingford, the handling of liquid sludge should not be a problem at the Mid-Conn facility. A stationary tanker could be located at grade on the riverside of the boiler building, with the pump skid adjacent. Piping could be routed to any of the three boilers, although boiler 13 might be preferred due to the existence of the rear wall overfire air plenum. Again, it is our recommendation to use a dual fluid nozzle available from Von Roll Inc. Due to the diameter of this nozzle a new opening in the furnace sidewall will be necessary to be installed in the boiler. A final design needs to be completed to firmly establish location and pipe routing.

There are several options to be considered for firing sludge cake at the Mid-Conn facility. As mentioned earlier, sludge cake requires a greater amount of materials handling equipment and the RDF aspect of the Mid-Conn facility creates additional considerations.

One option is to carefully mix the cake on top of belt at RDF storage building. On the plus side, this is relatively simple for purpose of a test and the tipping floor would provide ample area for dump truck tipping, feed hopper and bobcat maneuvering. On the downside, this approach would contaminate the surfaces of the belts and idlers over a long distance and create an odor issue inside of the process building.

A second option that was considered is to set up receiving/feeding/pumping at grade in the boiler building, pump up under pressure and size reduce at point of discharge to one of the RDF air swept chutes. This is the technique most often used for feeding cake to a conventional sludge incinerator – the end of the pipe is flattened to an approx ½" width and the cake is introduced in ribbon form. This approach would have the minimal contamination of the conveyor equipment, but it is not immediately obvious where tipping/receiving can be set up. Real potential for plugging in chute/spout exists that must be evaluated during testing.

A third option that was examined is to set up receiving/feeding/pumping at grade in the boiler building and pump up and ribbon discharge to the RDF surge bin. This would allow additional mixing with RDF fuel while reducing the possibility of plugging the chutes/spout and it would disperse the sludge over multiple chutes. On the downside this could create a bridging problem in the RDF feed chutes while also increasing the amount of sludge contamination to material handling equipment (live bottom screws).

A fourth option would be to directly inject the sludge cake with the dual-fluid injection nozzle, as suggested for Wallingford. This nozzle injection method is commercially proven at multiple locations and uses compressed air or steam for size reduction method. The outside barrel would be approximately 4" diameter. An inner pipe would carry the pumped sludge cake. The compressed air requirement for the test is estimated to be 60 scfm using 30-psig air.

7.3 Test Cost

Table 3 on the following page provides a summary of the cost estimate for conducting a test. The costs should be applicable for either Walling ford or Mid-Conn. As much equipment as possible would be rented, but there are some permanent costs that would be incurred for modifying equipment or purchasing components.

TABLE 3

TEST BUDGET ESTIMATE

	LIQUID SLUDGE TEST					SLUDGE CAKE TEST			
	Qty	Units	Unit $	Total		Qty	Units	Unit $	Total
MATERIAL									
Equip. Rental	4	WKS	2,250	$ 9,000		4	WKS	4,000	$ 16,000
Material	1	LOT	20,000	$ 20,000		1	LOT	20,000	$ 20,000
Installation	1	LS	15,000	$ 15,000		1	LS	20,000	$ 20,000
LABOR									
Operations	160	HR	50	$ 8,000		240	HR	50	$ 12,000
Engineering	60	HR	115	$ 6,900		60	HR	115	$ 6,900
Furnace Mods.	1	LS	6,000	$ 6,000		1	LS	6,000	$ 6,000
TESTING									
Technical	50	HR	115	$ 5,750		50	HR	115	$ 5,750
Emission Tests	1	LS		$ 25,000		1	LS		$ 25,000
Report	30	HR	115	$ 3,450		30	HR	115	$ 3,450
CONTINGENCY	30	%		$ 29,730		30	%		$ 34,530
TOTAL				$ 128,830			$		$ 149,630

1	Liquid case equipment rental is demurrage for stationary tank trailer, $300/day
2	Cake case equipment rental is for solids pump ($2500/wk) + Bobcat ($1000/wk)
3	Test duration is 1 month - day shift only
4	Material Purchase incl. nozzle, pump, valves, pipe, hose, fittings
5	Assumes adequate compressed air both locations
6	Stack Testing for Mercury and Heavy Metals, 2 operating cases
7	Combustor modifications - 2 men x 24hrs, plus material

APPENDIX

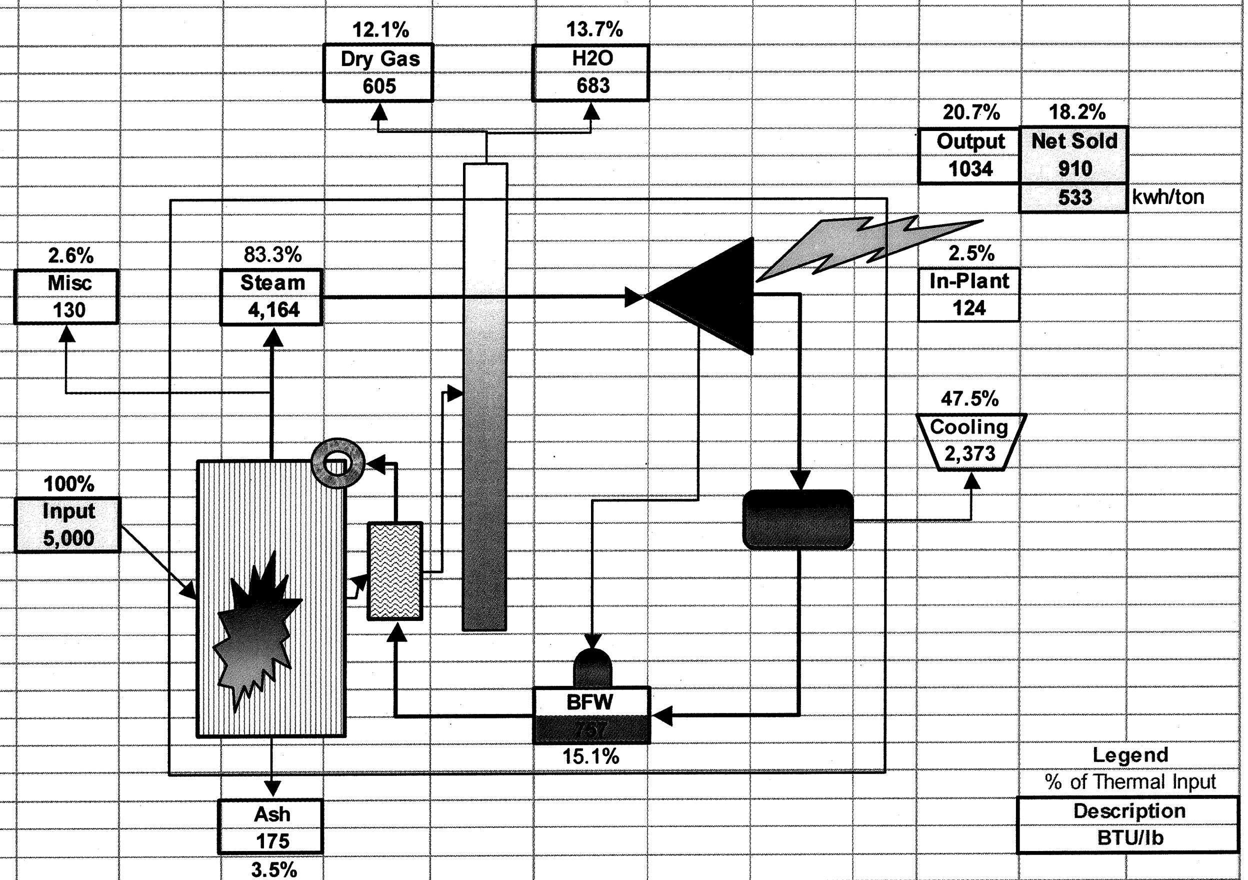
CRRA Sludge Co-Disposal Study

Chart 1-1

Wallingford Refuse Firing

INPUT		
HHV	5000	btu/lb
Firing Rate	140	TPD
Excess Air	75%	%
Air Temp.	80	F
Air Heater EGT	450	F
Steam Press.	655	psig
Steam Temp.	750	F
BFW Temp.	280	F
T/G Stm Rate	12.0	lb Stm/mwh

OUTPUT		
Steam Flow	35,333	lb/hr
Thermal Input	58	mmbtu/hr
Ent. Air Flow	76,694	lb/hr
Gas Lvg. Boiler	86,894	lb/hr
Evap. Rate	3.03	lb stm/lb ref
Boiler Effic.	68.1%	



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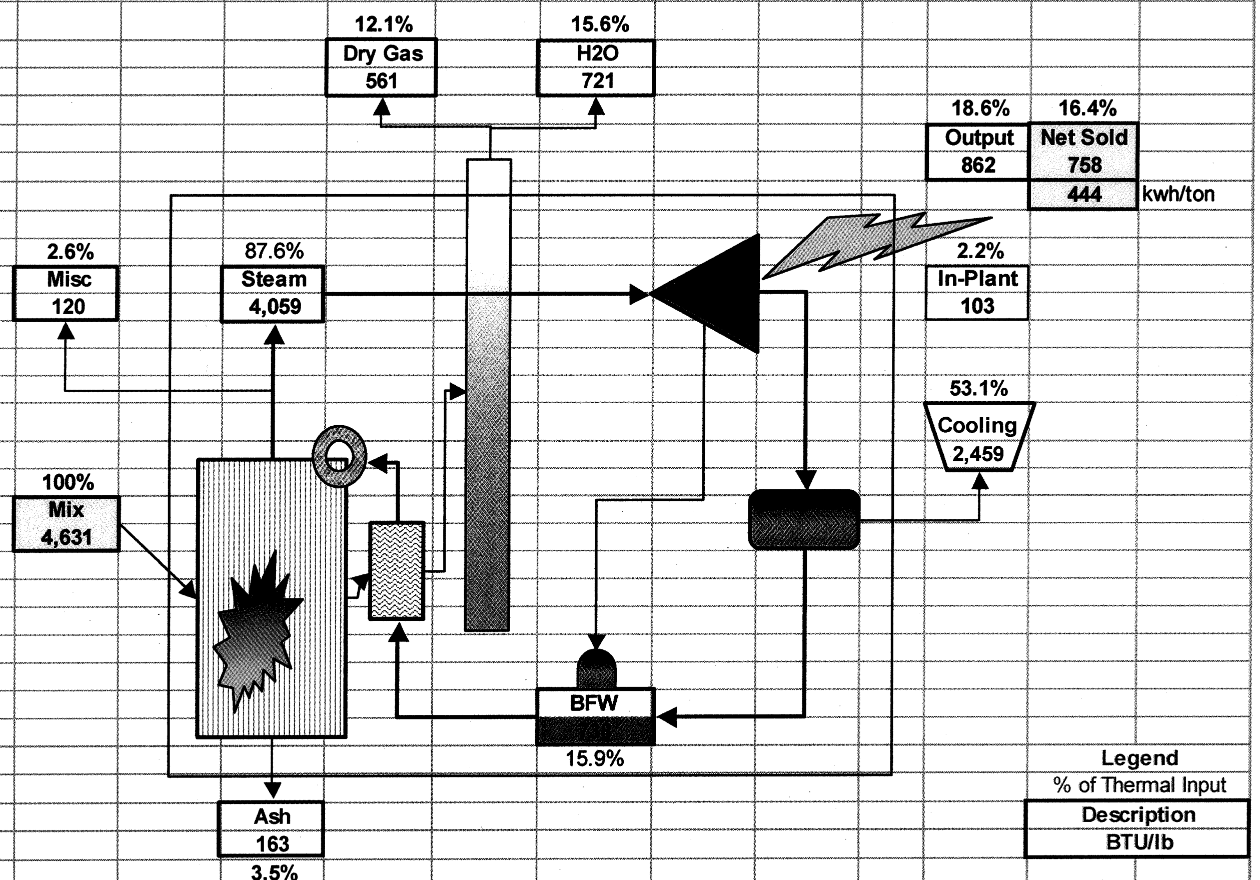
CRRA Sludge Co-Disposal Study

Chart 1-2

Wallingford 12 :1 REF: Liq. Sludge

INPUT		
HHV	5000	btu/lb
RDF Rate	144	TPD
SLUDGE Rate	2.0	GPM
Excess Air	75%	%
Air Temp.	80	F
Air Heater EGT	450	F
Steam Press.	655	psig
Steam Temp.	750	F
BFW Temp.	280	F
T/G Stm Rate	12.0	lb Stm/mwh

OUTPUT		
Steam Flow	35,422	lb/hr
Thermal Input	60	mmbtu/hr
Ent. Air Flow	79,269	lb/hr
Gas Lvg. Boiler	90,745	lb/hr
Evap. Rate	2.95	lb stm/lb ref
Boiler Effic.	66.2%	



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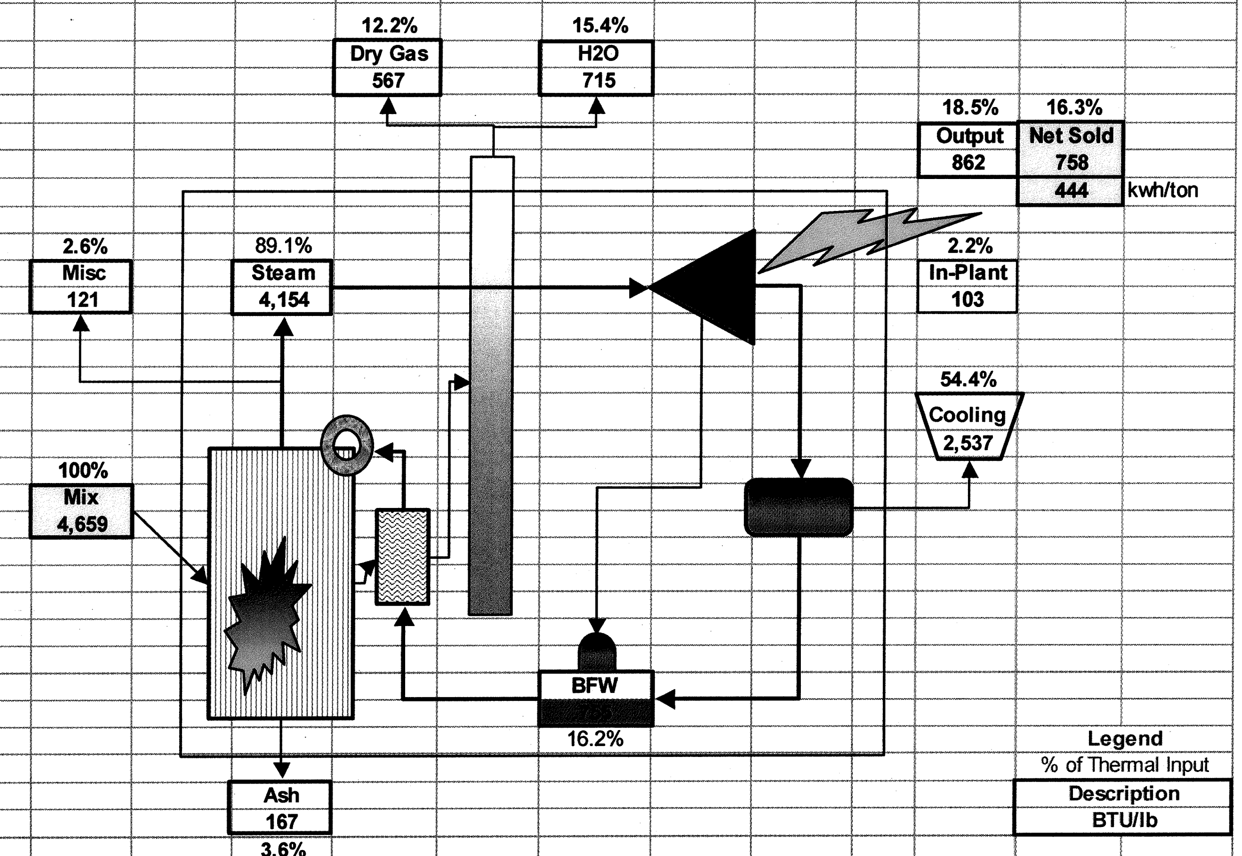
CRRA Sludge Co-Disposal Study

Chart 1-3

Wallingford 10 :1 REF: Sludge Cake

INPUT		
HHV	5000	btu/lb
RDF Rate	140	TPD
SLUDGE Rate	14	TPD
Excess Air	75%	%
Air Temp.	80	F
Air Heater EGT	450	F
Steam Press.	655	psig
Steam Temp.	750	F
BFW Temp.	280	F
T/G Stm Rate	12.0	lb Stm/mwh

OUTPUT		
Steam Flow	35,242	lb/hr
Thermal Input	58	mmbtu/hr
Ent. Air Flow	79,047	lb/hr
Gas Lvg. Boiler	90,324	lb/hr
Evap. Rate	3.02	lb stm/lb ref
Boiler Effic.	66.3%	



Halcyon Technologies, LLC

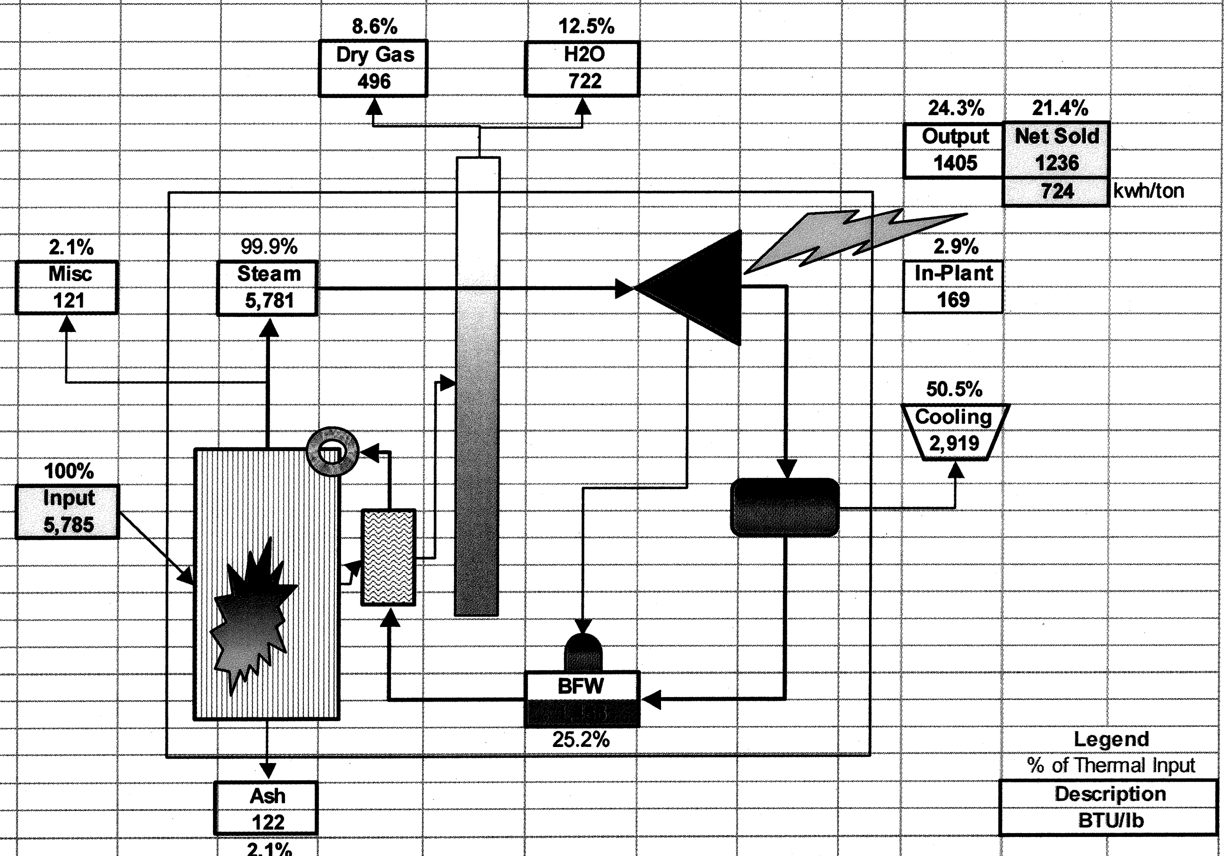
CRRA Sludge Co-Disposal Study

Chart 2-1

MID-CONN - RDF Firing

INPUT		
HHV	5785	btu/lb
Firing Rate	675	TPD
Excess Air	50%	%
Air Temp.	80	F
Air Heater EGT	390	F
Steam Press.	880	psig
Steam Temp.	825	F
BFW Temp.	384	F
T/G Stm Rate	10.0	lb Stm/mwh

OUTPUT		
Steam Flow	231,428	lb/hr
Thermal Input	325	mmbtu/hr
Ent. Air Flow	360,629	lb/hr
Gas Lvg. Boiler	413,298	lb/hr
Evap. Rate	4.11	lb stm/lb ref
Boiler Effic.	74.7%	



Halcyon Technologies, LLC

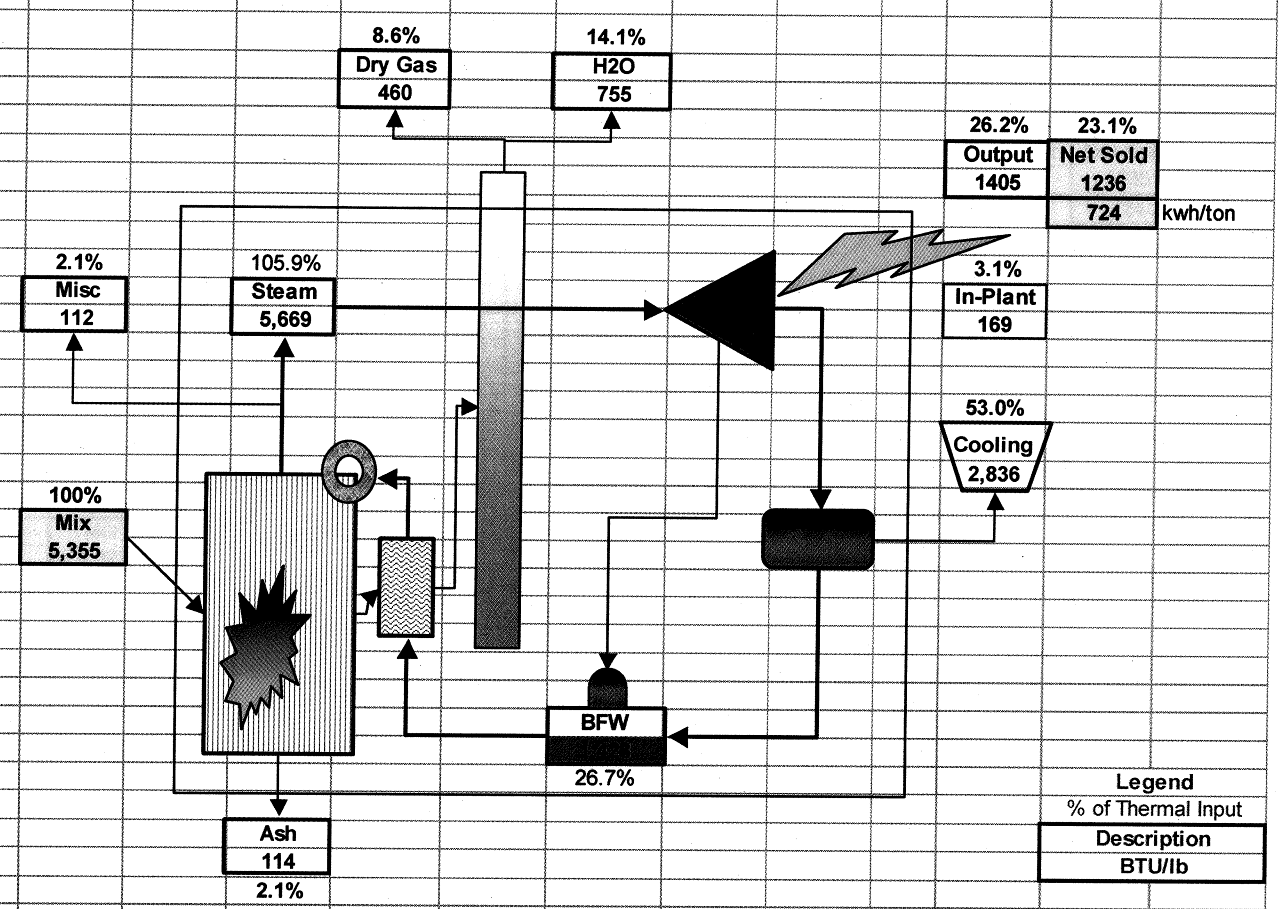
CRRA Sludge Co-Disposal Study

Chart 2-2

MID-CONNN 12 :1 RDF: Liq. Sludge

INPUT		
HHV	5785	btu/lb
RDF Rate	688	TPD
SLUDGE Rate	9.6	GPM
Excess Air	50%	%
Air Temp.	80	F
Air Heater EGT	390	F
Steam Press.	880	psig
Steam Temp.	825	F
BFW Temp.	384	F
T/G Stm Rate	10.0	lb Stm/mwh

OUTPUT		
Steam Flow	231,347	lb/hr
Thermal Input	332	mmbtu/hr
Ent. Air Flow	369,139	lb/hr
Gas Lvg. Boiler	427,520	lb/hr
Evap. Rate	4.04	lb stm/lb ref
Boiler Effic.	73.1%	



Halcyon Technologies, LLC

Dual Fluid Nozzle

Von Roll

16% Sludge
1 1/2" Lance
~ 2 psig air
tip atomized

16% Sludge
1 1/2" Lance
~ 10 psig air
tip atomized

16% Sludge
1 1/2" Lance
~ 10 psig air
tip atomized