

The Power of Sludge
Maximizing Energy Recovery at the Woodward Avenue WWTP in Hamilton, Ontario

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INTRODUCTION

The Woodward Avenue WWTP is a secondary wastewater treatment plant with a rated capacity of 409 ML/d, serving a population of approximately 450,000 in the City of Hamilton. Wastewater is treated through primary clarifiers, aeration, secondary clarifiers and chlorine disinfection. Effluent is discharged through an outfall pipe to Red Hill Creek upstream of Hamilton Harbour, in Lake Ontario.

Residual sludge from the wastewater treatment process is biologically stabilized anaerobic digesters and dewatered in centrifuges. Biosolids cake is stored seasonally, and ultimately applied to agricultural land. The Woodward Avenue WWTP currently generates 33 tonnes per day (as dry solids) of biosolids, equivalent to about 130 cubic metres per day of biosolids cake. Most of the digester gas is currently used as fuel to a 1.6 MW cogeneration engine. Electricity is fed back to the power grid, generating revenue for the City.

The City recently completed Master Plan (KMK, 2006) and Class Environmental Assessment (AECOM, 2008) studies to plan for projected growth in the City of Hamilton. Those planning studies recommended expansion of the plant from 409 to 500 ML/d to serve an estimated population of 600,000 in the by the year 2031. With the projected growth, biosolids quantities are projected to increase due to growth in the Woodward Avenue WWTP service area. A separate Master Plan (Hydromantis et. al, 2007) and Class Environmental Assessment (EA) (AECOM, 2010) study was completed to plan for the management of biosolids. Raw and waste activated sludge generation is projected to increase from the current rate of 66 dry tonnes per year to 94 dry tonnes per year by 2031 with the planned growth. The Master Plan and Class EA recommended continued digestion and cogeneration of digester gas, and construction of a new fluidized bed incineration facility.

The Province of Ontario's Feed-In-Tariff (FIT) program provides \$0.138 per kW.h of electricity generated from biogas, compared to the cost of purchasing electricity, ranging from \$0.05 to \$0.09 per kW.h depending on demand and time of day. In light of this potential revenue stream, and the success of the existing cogeneration facility, the City was interested in investigating other options to realize more revenue from the inherent energy value from biosolids, while also demonstrating a more sustainable biosolids facility with less dependency on purchase of energy and reducing the carbon footprint of the biosolids management facilities operation.

ANAEROBIC DIGESTION

Anaerobic digestion at the Woodward Avenue WWTP occurs in three existing mesophilic primary digesters in the North Digester Complex, providing approximately 23,000 m³ digestion capacity. At current flows, the digesters are operating at slightly less than the minimum 15 days retention time required for land application of biosolids. With future growth, the digesters would not provide adequate capacity for digestion and maximum gas generation. Furthermore, given the significant plant expansion required, the implementation of the new fluidized bed incineration facility was planned to be deferred for 5 to 10 years, so land application would continue to be practised for biosolids management.

The South Digester Complex includes 2 additional primary digesters, which would provide capacity for the projected biosolids generation. However, a separate study estimated that it would cost approximately \$25 million to upgrade these digesters.

SLUDGE PRE-CONDITIONING

In consideration of City's goals for increased gas generation and digester capacity needs, a thorough review pre-conditioning options was undertaken. Pre-conditioning involves the application of chemicals, heat and/or pressure to break apart the microorganisms and exposing biodegradable carbon for anaerobic digestion.

A range of commercially available technologies for pre-conditioning was reviewed, to identify appropriate technologies for consideration for the Woodward Avenue WWTP. Thermal hydrolysis technology was selected for assessment at the Woodward Avenue WWTP. With this technology, sludge is dewatered prior to digestion. The lower volume sludge stream would mean that the South Digester Complex for future use would not be required.

Thermal hydrolysis uses temperature and pressure to cause hydrolysis and break open cellular material. Research into thermal hydrolysis for improved anaerobic digestion was started in the 1970's. However, at that time, the technology faced a number of operational and maintenance problems, including high pressure pumping of the feed sludge, fouling of heat exchangers and wear on equipment. In the 1990's thermal hydrolysis was evaluated in Norway, and has since developed in to a viable technology, using newer technology, such as direct steam injection rather than heat exchangers. This process has received considerable attention in Europe..

The systems that have been commercialized to date are based on a batch operation mode. Continuous thermal hydrolysis systems are being developed, but are in the early stages. Due to the high temperature and pressure conditions that occur in thermal hydrolysis, the cost of the equipment is high, and means that demonstration-scale equipment requires a significant investment and may not be cost effective if it is done at a small scale. The technology may be retrofitted ahead of existing digesters, or may be incorporated into new facilities. Key advantages of thermal hydrolysis include the ability to operate digesters at high feed solids concentrations, of around 10 percent, due to improvements in viscosity through the process, improved biosolids dewaterability and the ability to achieve Class A pathogen reduction through operation of a batch treatment process.

Hydrolysis of the feed solids provides for improved gas production and solids destruction. However, the cost of high-pressure stainless steel tanks, heating and the need for operators trained in high pressure systems has impacted the cost and the acceptability of this process in North America. It has been realized that the cost of the system and some of the complexity may be reduced by treating only the WAS, rather than the primary and waste activated sludge combined. This provides some important advantages over the previous approach, including:

- Smaller system as only the WAS is treated, reducing costs
- Treating only the WAS focuses the costs on the portion of sludge with the highest return for improved digestion.
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With the use of cogeneration engines to generate electricity from the digester gas, waste heat from the engine cooling jacket and exhaust provide most if not all of the steam and hot water heating needs to operate the thermal hydrolysis process and supplement any additional digester heating.

There are 13 Cambi® thermal hydrolysis process (THP) installations in Europe. In the Cambi® THP process, shown in Figure 1, a three tank system is typical. Pre-dewatered solids, up to 15 percent solids concentration, are added to the feed tank. The feed tank is heated by the steam from the reactor and the flash tank. The solids are held in the feed tank until the reactor is ready for a batch. Solids are pumped to the reactor where they are held for a minimum of 20 minutes at 170 °C and 8 bar pressure. Live steam is added to achieve this temperature and pressure. Steam is vented to the feed tank. At the end of the batch, solids are allowed to flow to the flash tank where the rapid expansion causes the cells to rupture and the resulting solids have considerably lower viscosity. The temperature is also reduced by flashing, so the temperature in the digester is about 37°C. By the addition of the water in the steam and the cell rupture, the resulting solids concentration to digestion is 10 to 12 percent. Due to the cell rupture, the solids are now easily pumped to the digestion process.

The BioThelys® process is a similar thermal hydrolysis process, commercialized by Veolia. This process was installed in 2006 at two cities in France: Saumur (60,000 pe) and Chateau-Gontier (38,000 pe). A process schematic is provided in Figure 2. The Saumur WWTP is an extended aeration process without primary treatment.

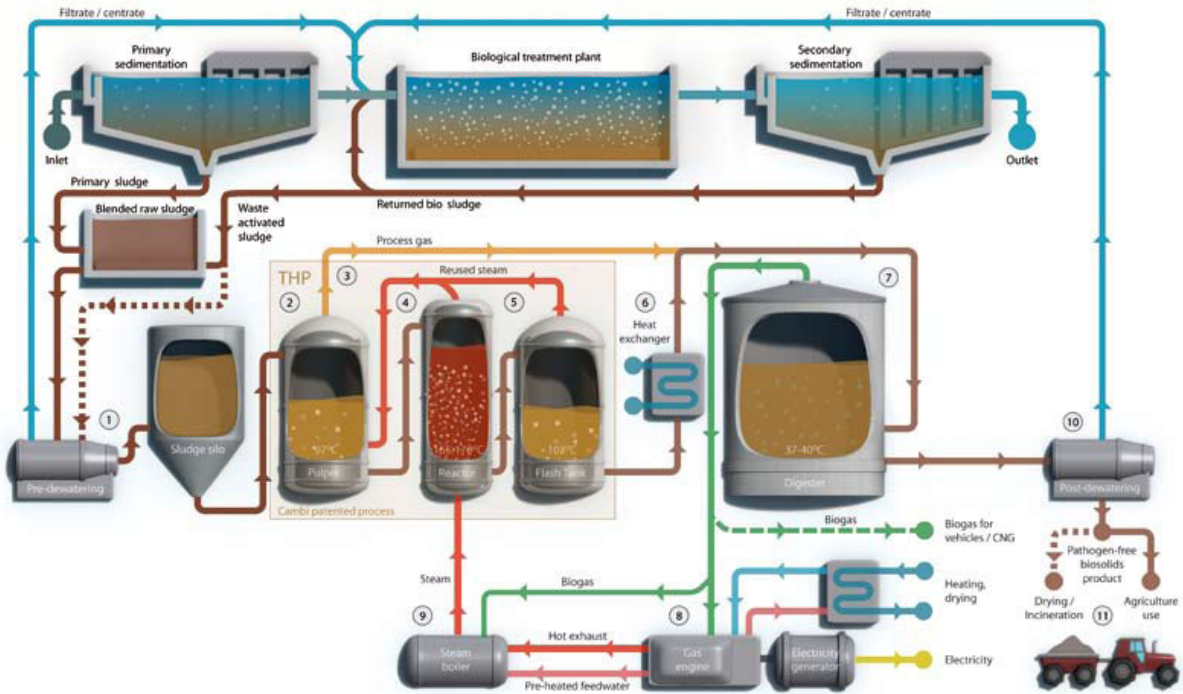


Figure 1 Cambi® THP Schematic (from Cambi AS literature)

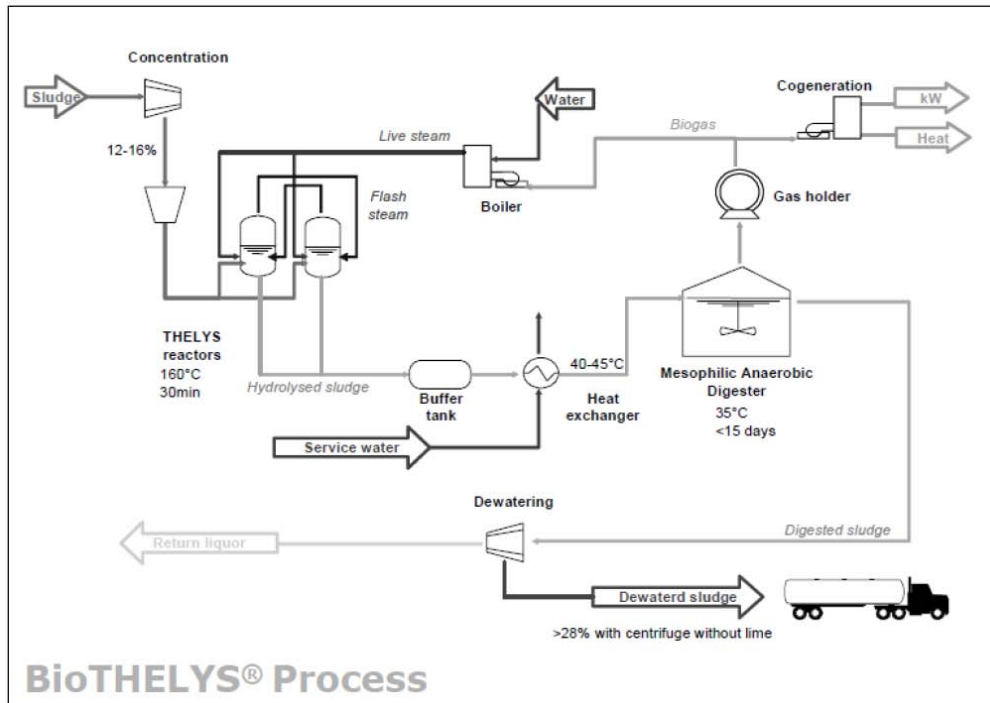


Figure 2 BioThelys® Thermal Hydrolysis Process (Chauzy, et. al., 2007)

ENERGY AND COST ANALYSIS

For the purposes of assessing thermal conditioning as a potential option for the Woodward Avenue WWTP, energy balances and costs were developed for two potential digester upgrading scenarios to provide capacity for future growth, as follows:

- Base Case: Expand digestion capacity by upgrading the South Digester Complex, and continue to use cogeneration to generate revenue from digester gas. A new 0.8 to 1.0 MW cogeneration engine would be required to maximize electricity generation from digester gas.
- Pre-Conditioning: Install a thermal hydrolysis pre-conditioning process to pre-treat waste activated sludge and just enough primary sludge such that a digester capacity expansion would not be required. In this case, another 1.6 MW engine would be required to maximize electricity generation, based on the 2031 projected flows.

Heat balance and cost benefit analyses were completed, considering land application of biosolids which will continue to be practised in the short-term, and also considering fluidized bed incineration. The analysis was based on the following:

- In both cases, waste heat from the cogeneration exhaust would be used to produce steam for the thermal hydrolysis process, and waste heat from the engine cooling jacket would be used for pre-heating the sludge
- Thermal hydrolysis would result in digested biosolids that dewater better using the existing centrifuge dewatering; for the base case, the historical value of 27% solids was used, and for pre-conditioning, 30% of used.
- Thermal hydrolysis would increase volatile solids reduction (and corresponding gas generation) to 50%, compared to 44% for the base case.

Table 1 presents the energy and cost comparison based on land application of biosolids. The following may be noted from the information in Table 1.

- Without preconditioning/pre-thickening, 5 primary digesters would be required
- Significantly more energy can be generated by pre-conditioning sludge, such that the net energy for pre-conditioning, digestion, and downstream dewatering is an output, taking advantage of the energy value of the sludge, compared to digestion only, which results in a net energy input.
- With the excess gas generated, there is more than enough heat to satisfy heat the pre-conditioning or digestion (depending on the process) heat input needs, compared to digestion only, which requires about 50% of the heat to be provided by natural gas.
- The capital costs for pre-conditioning are higher, to provide for pre-thickening and pre-conditioning processes.
- The life-cycle costs with pre-conditioning are similar to the base case, though with significantly lower energy input (and greenhouse gas generation).

Table 1 Comparison of Base Case and Thermal Hydrolysis Based on Land Application of Biosolids, based on 2031 flow of 500 ML/d)

		Base Case	Thermal Hydrolysis
Energy			
Energy Input			
Pre-dewatering energy	kW.h/d	0	2,835
Pre-conditioning	kW.h/d	0	1,089
Mixing	kW.h/d	11,095	6,934
Heating (supplemental to cogen heat)	kW.h/d	38,180	0
Dewatering energy	kW.h/d	3,942	3,745
Total Energy Input		53,217	14,603
Energy Generated	kW.h/d	50,212	62,660
Net Energy Generated	kW.h/d	-3,005	48,057
Net Energy Generated	kW.h/tonne	(36)	572
Net Energy Generated	MW	(0.13)	2.00
Annual Operating Costs in 2031			
Electricity (0.08/kW.h)	\$/y	\$439,080	\$344,685
Natural Gas (\$9.00 per GJ)	\$/y	\$451,523	\$0
Primary Sludge Thickening Polymer (\$6/t)	\$/y	\$0	\$0
Pre-dewatering polymer (\$6/t)	\$/y	\$0	\$683,280
Pre-conditioning chemical	\$/y	\$0	\$0
Thickening and Dewatering Polymer (\$6/t)	\$/y	\$1,868,070	\$1,587,860
Land Application (\$55/t)	\$/y	\$4,416,500	\$3,284,772
Labour (65\$/t)	\$/y	\$379,600	\$474,500
Maintenance	\$/y	\$50,000	\$360,000
Annual O&M Cost including land app.	\$/y	\$7,604,774	\$6,735,096
Annual Revenue from electricity (\$0.138/kW.h)	\$/y	\$2,529,178	\$3,156,184
Net Operating Cost	\$/y	\$5,075,595	\$3,578,912
Net Operating Cost	\$/t	\$148	\$104
Capital Cost			
Preconditioning Facility			
Yard Piping		\$0	\$800,000
Roads, miscellaneous		\$0	\$200,000
Preconditioning facility including pre-dewatering and ancillary equip.		\$0	\$22,000,000
Structural		\$0	\$3,500,000
Sub total		\$0	\$26,500,000
Existing Upgrades/Replacement			
Cogeneration		\$3,500,000	\$4,200,000
Digester (South rehabilitation)		\$17,200,000	\$0
Subtotal Facility Costs		\$20,700,000	\$30,700,000
General Contractors Overhead, Profit, etc.	15%	\$3,105,000	\$4,605,000
Design Contingency	15%	\$3,105,000	\$4,605,000
Construction Contingency	5%	\$1,035,000	\$1,535,000
Engineering	15%	\$3,105,000	\$4,605,000
Total Cost Estimate		\$31,050,000	\$46,050,000
Life Cycle Cost (20 years) based on 2% inflation and 4.5% interest			
Based on land applicaton @ \$55/ wet tonne		\$102,108,333	\$96,154,768

Table 2 presents the same comparison based on fluidized bed incineration of biosolids. Table 2 presents the same base case and preconditioning scenarios, using a downstream fluidized bed incineration process with waste heat recovered to run steam power generators. The results of this analysis show that greater advantages would be realized with a downstream fluidized bed incineration process because preconditioning, with less sludge mass and volume, would require a smaller incinerator (lower capital cost, lower energy required for fluidizing air blower). And, with less water (in the thermal hydrolysis 'high' scenario), there would be no natural gas required for supplemental combustion fuel.

CONCLUSIONS

An energy and cost evaluation of two options for anaerobic digestion at the Woodward Avenue WWTP was completed. For the base case, digester capacity would be expanded by upgrading existing digesters at the site that currently not used, to address existing capacity limitations and provide for future growth. For the alternate case, a thermal hydrolysis process would be installed, and waste activated sludge and a small portion of primary sludge would be pre-treated prior to digestion. With pre-treatment, the volume of sludge to digestion would be reduced such that additional digestion capacity would not be required. In both cases, the cogeneration facilities would be expanded to generate electricity from all of the digester gas.

Analyses of the two cases were completed considering land application of biosolids, and also considering potential future incineration of biosolids. The following conclusions can be drawn from the analysis:

- The 20-year life-cycle cost of both options for both land application and incineration are similar; however, the pre-conditioning costs were lower for both biosolids management approaches
- With thermal hydrolysis, there is a net energy output from the biosolids process; compared to the base case, which has a net energy input. Based on land application, the energy requirements are about 2 MW more for the base case; based on incineration, this difference increases to approximately 4 MW.
- The capital cost for the base case is considerably lower, by approximately \$15 to 20 million. With incineration, the capital cost advantage reduces because a smaller incinerator can be constructed for the pre-conditioned sludge.
- A thermal hydrolysis process introduces more complexity into the operation of the biosolids facilities at the plant
- A thermal hydrolysis process offers a more sustainable long term solution with less operating cost risk than the base case, because it has no reliance on natural gas (except during start-up).

Table 2 Comparison of Base Case and Thermal Hydrolysis Based on Fluidized Bed Incineration of Biosolids, based on 2031 flow of 500 ML/d)

		Base Case	Thermal Hydrolysis
Energy			
Energy Input to Digestion and Dewatering			
Pre-dewatering energy	kW.h/d	0	2,835
Pre-conditioning	kW.h/d	0	1,089
Mixing	kW.h/d	11,095	6,934
Heating (supplemental to cogen heat)	kW.h/d	38,180	0
Dewatering energy	kW.h/d	3,942	3,745
Energy Input to Incineration			
Electricity		44,291	28,297
Natural gas	kW.h/d	36,564	0
Total Energy Input		134,072	42,900
Energy Generated	kW.h/d	77,874	81,053
Net Energy Generated	kW.h/d	-56,198	38,153
Net Energy Generated	kW.h/tonne	(669)	454
Net Energy Generated	MW	(2.34)	1.59
Annual Operating Costs in 2031			
Electricity (0.08/kW.h)	\$/y	\$1,732,378	\$1,138,107
Natural Gas (\$9.00 per GJ)	\$/y	\$451,523	\$0
Pre-dewatering polymer (\$6/t)	\$/y	\$0	\$683,280
Pre-conditioning chemical	\$/y	\$0	\$0
Thickening and Dewatering Polymer (\$6/t)	\$/y	\$1,868,070	\$1,587,860
Labour (65\$/t) (excluding incinerator labour)*	\$/y	\$379,600	\$474,500
Maintenance (excluding incinerator maintenance)*	\$/y	\$50,000	\$360,000
Annual O&M Cost	\$/y	\$4,481,571	\$4,243,747
Annual Revenue from electricity (\$0.138/kW.h)	\$/y	\$2,529,178	\$4,082,640
Net Operating Cost	\$/y	\$1,952,392	\$161,107
Net Operating Cost	\$/t	\$57	\$5
* Incinerator maintenance and labour would be the same for all options.			
Capital Cost			
Preconditioning Facility			
Yard Piping		\$0	\$800,000
Roads, miscellaneous		\$0	\$200,000
Preconditioning facility including pre-dewatering and ancillary equip.		\$0	\$22,000,000
Structural		\$0	\$3,500,000
Sub total		\$0	\$26,500,000
Existing Upgrades/Replacement			
Cogeneration		\$3,500,000	\$4,200,000
Digester (South rehabilitation)		\$17,200,000	\$0
Sub total		\$20,700,000	\$10,700,000
New Incineration Facilities with Steam Power Generation			
Incineration facility and building		\$70,000,000	\$66,000,000
Subtotal Facility Costs		\$90,700,000	\$103,200,000
General Contractors Overhead, Profit, etc.	15%	\$13,605,000	\$15,480,000
Design Contingency	15%	\$13,605,000	\$15,480,000
Construction Contingency	5%	\$4,535,000	\$5,160,000
Engineering	15%	\$13,605,000	\$15,480,000
Total Cost Estimate		\$136,050,000	\$154,800,000
Life Cycle Cost (20 years) based on 2% inflation and 4.5% interest			
Based on incineration		\$163,383,494	\$157,055,500

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