DISCUSSION PAPER

Capital Regional District
Core Area Wastewater Management Program

Integrated Resource Management Strategy

Discussion Paper: Investigation of Examples of Integrated Resource Management in Sweden
031-DP-2

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1 Introduction

The CRD is moving forward with developing a plan for implementing secondary wastewater treatment. Secondary wastewater treatment will create solids that will need handling, treatment and disposal. Secondary treatment also creates the opportunity for energy recovery through biogas and/or heat recovery from the treated effluent.

At the same time as secondary treatment is moving forward, the CRD is continuing with its plans to further divert materials from its Hartland Road landfill. In addition to the on-going 3Rs program, i.e. reduction, reuse and recycling, the CRD is looking at a recovery and enhanced residuals management program. Recovery would involve source separated organics and their conversion to a useful and beneficial product. Up until recently, recovery was thought to be using in-vessel composting to create a product that could be used in agriculture.

Because of a need to handle materials that cannot be recycled or recovered, the CRD has some interest in enhanced residuals management which, in this case, would be some form of thermal destruction, i.e. incineration with complete air pollution control and energy recovery. This would be called a municipal solid waste (MSW) waste-to-energy (WTE) plant.

There are several real or potential "touch-points" between liquid waste management and solid waste management. For example, wastewater treatment plants create screenings and sludges. The screenings need to be disposed of, typically at a solid waste management facility such as a landfill or, in some cases, in a MSW WTE facility, if one exists. Energy in both the wastewater and the heat from an MSW WTE facility can be used to supply heat to local industry or residences through heating loops. The sludges from a wastewater treatment plant can be either dried and used as a fuel in the MSW WTE facility or they can be anaerobically digested to create a methane-rich biogas that can be used to create heat and electricity in a cogeneration facility. Similarly, the biogas from a landfill can used in a cogeneration facility, such as that already established at the Hartland Road landfill. Alternatively, the biogas from both wastewater treatment plants and landfills can be cleaned and enriched (by removing the carbon dioxide) to create a vehicle fuel suitable for use in specially-equipped buses, cars and/or trucks. Furthermore, fats, oils and greases (FOG) and/or source-separated kitchen and restaurant wastes can be diverted from the wastewater treatment plant and landfills or composting facilities and anaerobically digested. This digestion can either be co-digestion with wastewater treatment plant sludges or in purpose-built digestion systems without wastewater sludges. In both cases, the resulting treated solids are nutrient rich and can be used as a soil amendment. However, in some jurisdictions, even though treated wastewater biosolids meet all current standards for beneficial reuse, they are not applied to land for food production.

With the knowledge of these real and potential touch-points, the CRD needed to investigate the options first hand to see how solid and liquid resources can be integrated as the CRD moves forward with the secondary treatment program. Since it was known that Sweden was a leader in such integration, a fact-finding mission was arranged to visit both solid waste management and liquid waste management facilities in Sweden. The focus of this mission was to learn more about energy extraction from liquid and solid waste, the extent and practicality of district heating and various ways that solid and liquid waste-derived biogas is utilized in Sweden.

The fact-finding mission involved three Swedish locations: Göteborg, Stockholm and Västerås. The participants included the following people:

- Mayor Alan Lowe, City of Victoria (for the Göteborg facilities)
- Mayor Chris Clement, Corporation of the Township of Esquimalt
- Kelly Daniels, CRD, Chief Administrative Officer
- Alan Summers, CRD, Sr. Manager of Solid Waste
- Deborah Rasnick, Provincial Ministry of Community Services
- David Forgie, Ph.D., P.Eng., Associated Engineering, wastewater planning team

The facilities toured or meetings held in Sweden included the following:

- Göteborg:
  - Göteborg Rya AB (aka “Gryaab”) Wastewater Treatment Facility with biogas production and effluent heat extraction
  - Renova MSW WTE facility with electricity generation and heat production for a portion of the Göteborg district heating system
  - Biogas Max – a European program being developed to promote the use of biogas from anaerobic digestion and landfills as a vehicle fuel

- Stockholm:
  - Fortum Energi – MSW WTE facility with electricity generation and heat production for a portion of the Stockholm district heating system

  - Hammerby Heat Pump Facility (as a Forum Energi video) – extracts heat from wastewater treatment plant effluent for use in the Stockholm district heating system
  - Henriksdal Reningsverk (wastewater treatment plant (WWTP)) with biogas production and biogas upgrading for use in specially-equipped Stockholm buses; biosolids are pumped off-site to a dewatering facility and then taken away for land application.

- Västerås:
  - Svensk Växkraft purpose-built source separated kitchen waste organics digestion to create biogas
  - Biogas upgrading facility
  - Biogas utilization at the local bus company in specially-equipped buses

The remainder of the report is not chronological but instead is divided up into MSW WTE and Biogas generation and utilization sections.

2 Municipal Solid Waste Waste-to-Energy Facilities

As mentioned above, two MSW WTE facilities were visited: the Renova facility in Göteborg and the Fortum Energy facility in Stockholm. The following sub-sections describe these two facilities.

2.1 The Renova MSW WTE Facility in Göteborg

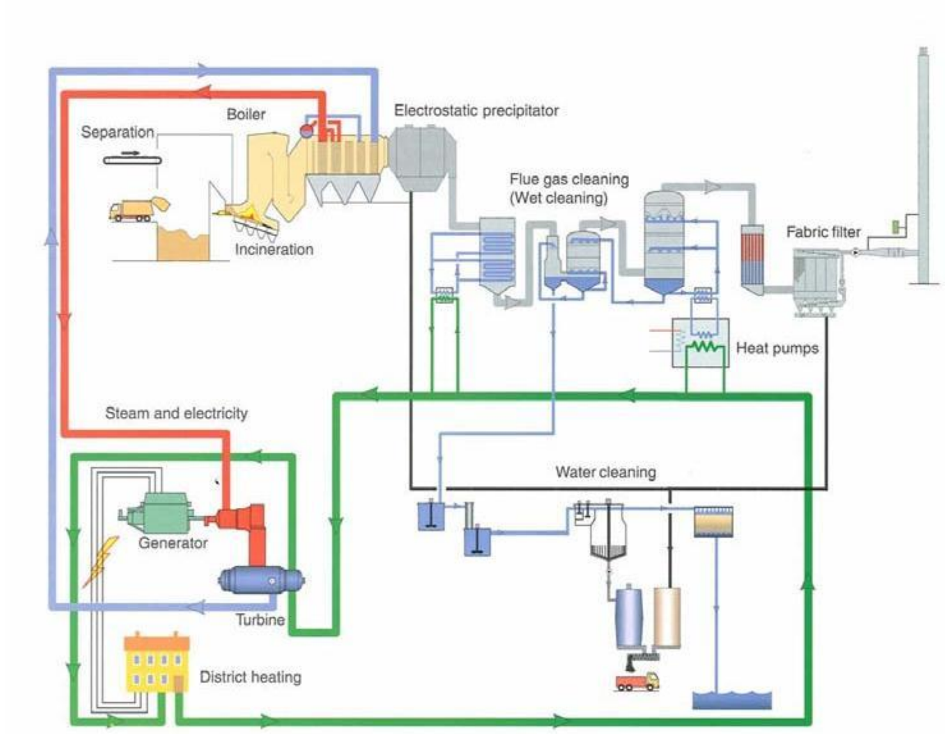
The Renova is a large waste management company owned by the 11 municipalities that it serves. Renova provides collection, recycling, composting, waste-fueled district heating and power generation (via a MSW WTE facility) and landfilling of residuals. The MSW WTE facility began in 1972 and is located in the northern part of Göteborg in a primarily industrial area. The facility serves a population of approximately 800,000 persons in the Greater Göteborg area. Of the approximately 709,000 tonnes of solid waste that are collected each year, approximately 444,100 tonnes (50% household, 50% commercial and industrial) are processed in the WTE facility on a 24/7 basis. (The remainder is diverted through recycling or direct discharge (e.g. non-combustible construction waste) to landfill). A view of the Renova plant, taken from the train to Stockholm, is shown in Figure 1.

Figure 1
The Renova MSW WTE Facility
(Note the lack of visible plume from the stack)

The Renova MSW WTE facility is based on three mass-fired water-walled boilers, two with 22 tonnes/hour capacity and one with 15 tonnes/hr capacity. On average, each of these water-walled boilers operates for approximately 8000 hours per year for an approximate total throughput potential of 472,000 tonnes per year. There is no pre-sorting, other than that done at the curb during collection, i.e. bulky items like couches and mattresses are not brought to this facility but all other wastes that have not been recycled are discharged to the tipping pit.

The plant operators manipulate and mix the materials in the tipping pit with large grapple cranes. As required, they use the grapples to lift a load of mixed waste into the feed hopper to both charge the boiler with material and create a seal against the flames inside the boiler. Grates in the boiler move the material down the boiler, taking the wastes through various stages of drying, burning, burn-out and ash. The heat from the burning is used to heat water in tubes in the walls of the boiler to create steam. The steam is then used to drive steam turbines and create electricity. The heat in the hot flue gases and condensing the steam back to water is extracted in heat exchanges and heat pumps. This heat is used as one of the heat sources for the Göteborg district heating loop system. A schematic of the Renova facility is shown in Figure 2.

Figure 2
A Schematic of the Processes at the Renova MSW WTE Facility



The fuel gases from the boiler are cleaned in various steps including electrostatic precipitators, wet Venturis, wet precipitators and bag filters so that Renova can meet its air pollution discharge permit requirements. The scrubbing liquid is treated and then conveyed by pipeline to ocean discharge (because of its high salt content, it can not be discharged into the local river). The cleaned flue gases are discharged to the atmosphere via a 126 m high stack. Approximately 90,000 tonnes per year of bottom ash (slag) is processed to remove recyclable metals and then is hauled away for use in road building as a gravel substitute. The fly ash from the scrubbers and precipitators is mixed with cement powder and water and formed into concrete blocks (to immobilize any heavy metals) which are then taken to Renova's secure landfill for disposal.

Overall, the Renova facility creates approximately 235,500 MWhr of electrical power (enough for about 23,000 homes) and the equivalent of approximately 1,437,000 MWhr of heat per year or about 3.24 MWh/tonne of waste processed. The heat represents approximately 25% of the total input of heat into the Göteborg district heating system or about enough to heat 100,000 homes.

Because the district heating requirements in the summer are much less than in the winter, Renova actually stockpiles non-putrescible wastes over the summer months (June through October). To do this, they create bales of burnable, non-putrescible wastes that are then shrink-wrapped in white plastic bags. These bagged bales are taken to the local landfill site where they are stockpiled. As the heating requirements ramp up in the late Fall, these bales are brought back to the Renova MSW WTE for thermal conversion.

General observations of the plant include the relative lack of odours except when very close to the actual boilers. There are no odours from the collection truck receiving hall/tipping floor because the combustion air system is arranged to draw its air from above the waste tipping pit which in turn draws air from the receiving hall/tipping floor. Other observations include the significant size and complexity of the facility. As such, the decision to construct and operate an MSW WTE must not be taken lightly. Once committed, the time to design and construct the initial phase of the facility would likely be significant, e.g. four to five years. Subsequent phases could be added as demand required.

2.2 The Fortum Energi Facility in Stockholm

The Fortum Energi Högdalen MSW WTE facility is located in the southwestern portion of Stockholm, about 8.5 km from downtown Stockholm. The facility first began in 1970 and there has been a series of expansions and upgrades since that time. The 100 plus staff facility currently serves a population of approximately 800,000 persons and processes approximately 700,000 tonne/yr of waste. The size of the facility is significant, as shown in Figure 3.

Figure 3
Fortum Energi Högdalen MSW WTE Facility in Southwest Stockholm

Like the Renova MSW WTE facility in Göteborg, the Fortum Energi Högdalen facility uses mass-fired water wall boilers for MSW WTE. As such, much of the plant is very similar to the Renova plant. However, instead of three units at Renova, the Fortum Energi Högdalen facility has four water-walled boilers totaling 170 MWh capacity. However, the Högdalen facility also has a separate single 90 MWhr fluidized bed combustion unit that is used to combust pre-processed industrial solid wastes. Like the Renova facility, the steam from the water-walled boilers and fluidized bed combustion unit is used to drive steam turbine-generators for electricity generation. Heat from the hot fuel gases and condensing of the steam back to water is extracted using heat exchangers and heat pumps and is used to serve part of the heat requirements of the Stockholm district heating system. The heat from the Högdalen plant provides the heating and hot water requirement of approximately 80,000 to 200,000 dwelling units (depending on the season), according to Fortum Energi information. The electrical generation is approximately 2,280,000 MWhr per year.

It was noted that like the Renova facility, the Fortum Energi MSW WTE facility did not have any noticeable odour, primarily due to the combustion air being drawn from the tipping hall.

Fortum Energi is apparently very successful at the operation of its MSW WTE facilities because they mentioned that they are looking to expand into the other Baltic nations, including Poland, in the near future.

2.3 Summary of MSW WTE

Both the Renova facility in Göteborg and the Fortum Energi facility in Stockholm illustrate how, if the desire and need is there, MSW WTE can provide a multiple benefit solution to solid waste management. Not only do the facilities significantly reduce the volumes of material that needs to go to landfill, they also create heat and electricity that can be beneficially used, especially in a situation where fossil fuel and energy costs will be increasing in the future.

The operation of the two facilities appeared to be environmentally responsible. The flue gases from the combustion process were handled and treated well in both cases and we were informed that the final air quality easily met or exceeded the Swedish regulatory requirements. The bottom ash was “mined” for recyclables metals and then taken away for beneficial reuse as a gravel substitute in road building. Scrubbing liquid from the flue gas cleaning was treated and then released in an environmentally compatible manner. Fly ash was treated using cement powder to prevent heavy metals in the fly ash from being leached out. The resulting blocks are landfilled in a lined landfill.

Construction of an MSW WTE facility could be phased, with initial construction based around a two or three boiler system with subsequent boilers added in the future as demand requires.

When we asked, we were told that neither of the two MSW WTE facilities that were visited was receiving any dewatered wastewater treatment plant sludges as a disposal/ reuse method.

3 Biogas Generation and Utilization

3.1 Gryaab

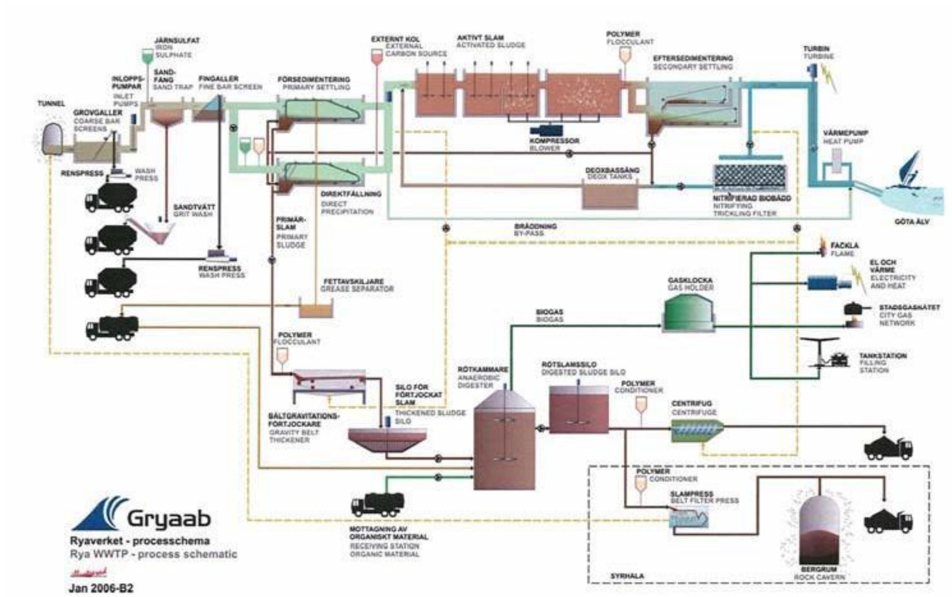
The Göteborg Rya AB “Gryaab” wastewater treatment plant in Göteborg is one of two treatment plants serving the greater Göteborg area. Gryaab treats wastewater from its joint owners, the municipalities of Ale, Göteborg, Härryda, Kungälv, Mölndal and Partille on the Swedish west coast. The connected population in 2007 was approximately 635,000 persons and the population equivalents, including industry, was about 827,000. Wastewater is conveyed to the plant from outlying areas and Göteborg itself through a series of gravity flow tunnels measuring a total of 120 km. Although the tunnels are in granite, they are unlined, which results in significant quantities of infiltration and inflow, resulting in a relatively dilute influent wastewater. They have previously determined that the cost of building the treatment plant to accommodate this extra wastewater flow is less than the cost of preventing the I&I from occurring in the tunnels.

Figure 4
The Gryaab WWTP
(Note: nearby petroleum refineries)

The treatment plant is relatively conventional in that they have primary sedimentation followed by activated sludge aerobic secondary treatment, followed by final clarification, as shown in Figure 5. What is relatively unusual is they use ferric sulphate ($Fe_2(SO_4)_3$ as a means of precipitating out phosphorus to prevent eutrophication of the ocean bay into which the final effluent is discharged.

On a related note, in order to decrease impacts on fish due to ammonia toxicity, they have a separate post-secondary nitrifying trickling filter to convert the ammonia to nitrate. They are currently in the process of adding filters to further clean the post-nitrification effluent.

Figure 5
Schematic of the Gryaab WWTP Process



The resulting effluent is very high quality and they are proud of the positive impacts the improved treatment has had on their local portion of the ocean. To illustrate this fact, they have developed a very extensive education program, including an award-winning video that is targeted at children 10 to 12 years old, with the intent that they will both educate their siblings and their parents and become life long “Aqua Angels”.

The sludges from the primary treatment and secondary treatment process are sent to two 11,375 m^3, 29.5 m high, 23.5 m diameter anaerobic digesters. These digesters are relatively tall and narrow cylinders (compared to the typical North American “pan cake” digester), with a conical top and a flat bottom. The digesters are mixed mechanically rather than with gas lances. Gryaab’s operators are not concerned about the corners of the flat bottom filing in with grit because they know that although there is volume loss the resulting internal shape will closely approximate an “egg” shape which is very efficient for mixing. As shown in Figure 6, the digesters are aesthetically quite pleasing, clad in porcelain-coated steel panels, resembling a pixilated photo of trees and the sky.

Figure 6
The Anaerobic Digesters at the Gryaab WWTP

In addition to the treatment plant sludges, the Gyraab digesters also receive about 9000 wet tonnes of FOG from local restaurants and commercial kitchens. This FOG significantly improves the gas production but is not without its challenges, e.g. the need to grind the materials as it comes in (to prevent clogging), the need to heat the lines carrying the FOG to prevent it from congealing in the pipes and also have the ability to hot water flush the lines to make sure they don't plug.

The gas from the digesters is approximately 65% methane and 35% carbon dioxide with very little hydrogen sulphide (H_2S) (the $FeSO_4$ used for phosphorus removal also ties up the sulphides as FeS, a very insoluble precipitate). The annual production of biogas is the equivalent of about 60 Giga Watt hrs (GWh) or the energy to drive about 4000 cars each once around the world. The biogas is sold to Göteborg Energi AB for about 20,000,000 Swedish Kronar (sek) or about CDN$3.6 million. The raw biogas piped to a facility off-site where it is upgraded and compressed for use in "Biogas" buses in the Greater Göteborg area. The treatment is primarily based on removal of carbon dioxide and moisture, bringing the methane content up to at least 97%. If need be, the raw biogas can be used in the Gryaab plant in three 770 kW cogen engines for heat and electricity.

The biosolids from the digestion process are dewatered on-site. These biosolids are currently used for large scale landscaping situations like highway ditches to help establish vegetative growth (grasses) to prevent soil erosion. None of the biosolids from the Gryaab treatment plant are used on agricultural land used for food production.

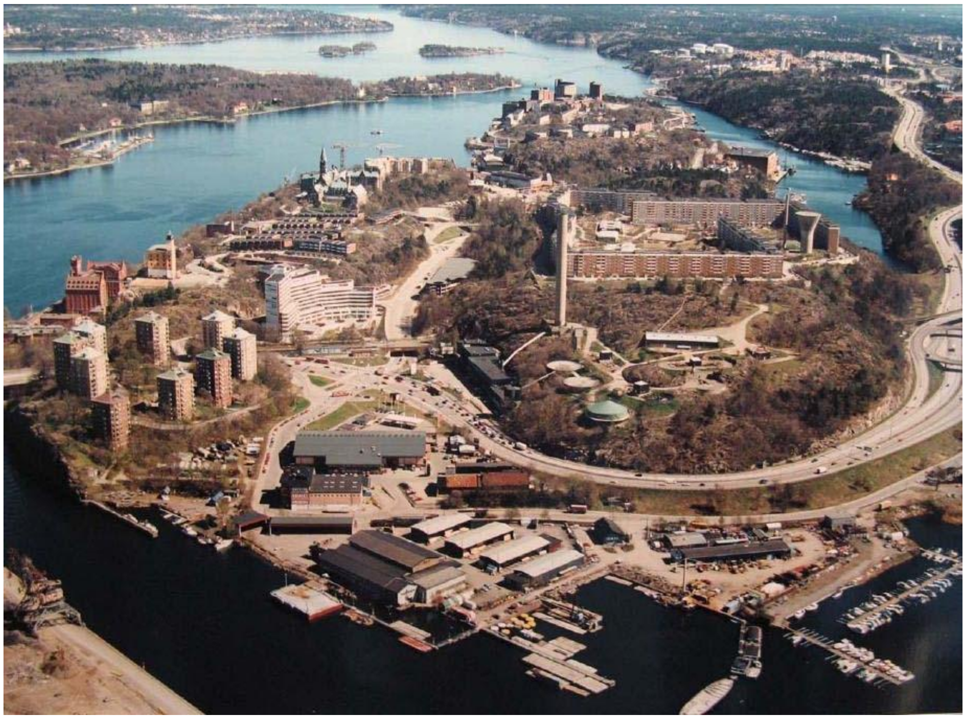
In discussing the overall Greater Göteborg wastewater collection and treatment scheme, the question was asked about any move to more distributed treatment, i.e. having more treatment plants in the local areas rather one centralized treatment facility. The response was that rather than having more smaller treatment plants, in fact, they were moving to eliminate some existing smaller treatment plants. For example, a smaller community, Lerum, within the Greater Göteborg area had chosen to be connected to the Gryaab system so that they could reuse the valuable lake front property that their current treatment plant is located on. This was no small undertaking because, to do this, an 8.5 km long tunnel through the bedrock is required.

3.2 Henriksdal Reningsverk, Stockholm

The Henriksdal Reningsverk is one of three secondary wastewater treatment plants that serve the Greater Stockholm area (down from a former five plants). The treatment plant began in 1942 and has been expanded and upgraded almost continuously since then. The treatment plant currently serves a population of approximately 800,000 people but because the collection system is much tighter than the Göteborg system, the influent wastewater strength is much higher (and closer to the North American norm). With the exception of the office and maintenance buildings shown in Figure 7, the majority of the treatment plant is constructed completely inside a granite “mountain” (large outcrop), in tunnels, unseen from above, as shown in Figure 8.

Figure 7
The Entrance and Office Buildings at the Henriksdal Reningsverk
(Note flow measurement beside the plant name)

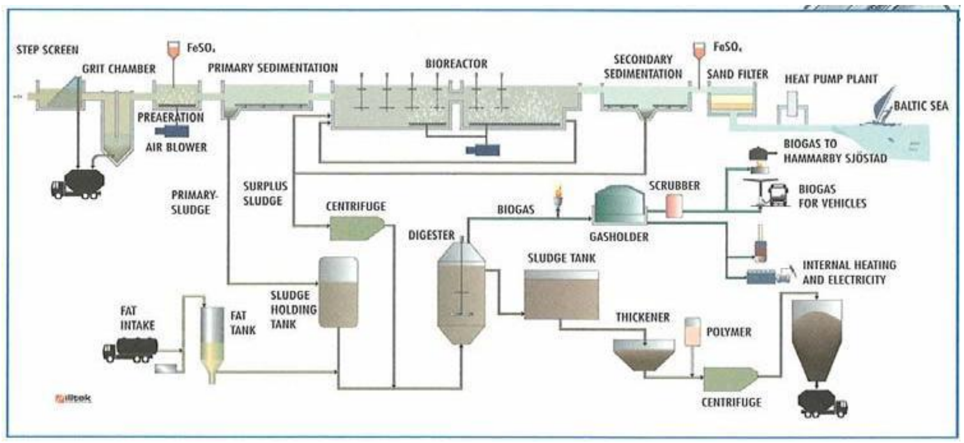
Figure 8
The Henriksdal Reningsverk from the air
(Note the apartments are built above the secondary treatment portion of the plant which is deep in the rock)



The treatment process is fairly convention with preliminary screening followed by grit removal and primary sedimentation tanks. After primary treatment, the flow is directed to deep and long secondary biological activated sludge aeration tanks and then long rectangular secondary clarifiers. The effluent from these clarifiers is sent to sand filtration and the final result is an effluent with less than 2 mg/L BOD and less than 2 mg/L TSS with remarkable clarity. Like the Göteborg Gryaab facility, Henriksdal uses $FeSO_4$ for phosphorus removal. Final effluent from the Henriksdal Reningsverk is conveyed by pipe about 1.5 km to the Fortum Energi Hammerby Heat Pump plant where it is used to supply heat into part of Stockholm's extensive district heating system.

A schematic of the Henriksdal plant is shown in Figure 9.

Figure 9
A Schematic of the Henriksdal Reningsverk WWTP



The primary and secondary sludges from the Henriksdal clarifiers are thickened, blended and sent to seven mesophilic (37°C) anaerobic digesters along with 30,000 m^3 per year of FOG and 1000 m^3 per year of restaurant waste that has been brought to the site from restaurants and commercial food processing establishments. The Henriksdal digesters are constructed in the rock, from the top of the outcrop, down. The digestion process is fairly conventional, using pressurized gas lances for mixing the digester contents. The resulting biosolids after about 21 days digestion are pumped approximately 1 km away to a centrifuge dewatering facility. After dewatering, the resulting dewatered biosolids are loaded into empty copper ore rail cars for backhauling to a large mine in northern Sweden where the biosolids are used to rehabilitate the mined areas. Again, none of the wastewater biosolids goes to land application for food production.

The biogas from the Henriksdal facility is processed on-site. As with the Gryaab biogas, H_2S is not an issue because of the use of iron salts for phosphorus removal. The CO_2 is removed through the use of water scrubbing within a pressurized packed bed scrubbing tower. This process takes advantage of the higher solubility of CO_2 in water than methane (CH_4) in water and Boyle's Law which uses the higher pressure to "push" more CO_2 into the water. The result is taking the biogas from about 63% methane to at least 97% methane. Additional treatment includes moisture and particulate removal. Once processed, the cleaned biogas (now "biomethane") is pumped via pipeline about 1.5 km where it is used to fuel approximately 60 of Stockholm's transit buses, particularly the ones that operate in downtown Stockholm. Figure 10 shows the size of the gas upgrading facility at the Henriksdal Reningsverk.

Figure 10
The Biogas Upgrading Facility at the Henriksdal Reningsverk
(Stack at left is part of the plant odour control system, not related to the biogas upgrading facility)

It was pointed out that once the buses are built to run on biomethane, they can not run on anything other than biomethane or natural gas. As a result, the Henriksdal biogas processing plant is equipped with a liquified natural gas (LNG) storage tank and evaporator system to provide a back-up fuel source should there be a sustained problem with the digesters or biogas processing facility. The tip of the white LNG tank is shown just above the top of the left hand side of the building in Figure 10.

The gas processing facility at Henriksdal has a capacity to treat enough gas for about 120 buses. However, since the buses are purpose-built to run on biogas, the Stockholm transit authority is only slowly replacing the diesel buses as their service life is reached. As a consequence, when the weather is warmer and the heating needs of the treatment plant and digesters are down, there is an excess of biogas in the current biogas utilization system. As a result, at the time of the site visit, they were flaring some biogas. This was despite the fact that the Henriksdal plant is also equipped with an 80 GWhr per year cogen facility. Once again, there was not sufficient need for the heat to justify the operation of the cogen facility at the time of the site visit.

The Henriksdal plant receives approximately 14,000,000 sek (about CDN$2.52 million) per year for the heat energy from the effluent heat extraction at the Hammerby heat pump plant. There is also revenues of about 200 sek per tonne of FOG for about 28,000 tonnes/year or about 5,600,000 sek (CDN$1.01 million). The biogas is sold at about 6 to 10 sek/m^3, but there are costs of about 6 sek/m^3 to process the gas. Overall, the treatment plant has gross revenues of about 35,000,000 to 40,000,000 sek (CDN$6.3 million to 7.74 million) per year. These revenues help to offset the cost of the plant operation, e.g. 160,000,000 sek (CDN$28.8 million) for the Operation and Maintenance costs for the Henriksdal and Bromma WWTPs, but they do not result in an overall profit.

3.3 Västerås Svensk Växtkraft AB

Västerås is a small(er) city of about 130,000 people located about 92 km (or about an hour by train) from Stockholm. Västerås is relatively unique in that Svensk Växtkraft AB has developed a purpose-built anaerobic digester system to process source-separated kitchen and restaurant waste, supplemented by a “Ley” forage crop (comprised of red clover, timothy grass and rye grass) grown by 17 local farmers who are partners in the facility and some FOG.

Approximately 14,000 tonnes per year source-separated organics and 4000 tonnes per of FOG come from approximately 300,000 persons in the Greater Västerås area. At the home and apartment (“flat”) level, the source-separated organics are saved in the home in special paper bags, sized so that they fill up relatively quickly, i.e. a day or two. When the bags are full they are taken to perforated plastic rolling tote bins (individual bins at the home level and larger communal bins in apartment/townhouse developments). Once every two weeks, the stored source-separated organics are collected and taken to the digester facility that is located at the Västerås regional landfill site, located at the northern edge of Greater Västerås. Figure 11 shows one load of these source separated organics on the Svensk Växtkraft receiving hall tipping floor.

Figure 11
A Load of Source Separated Organics Bags on the Svensk Växtkraft Tipping Floor

The Ley crop is harvested twice per year, June and August, and is loaded into a series of 3 m diameter by 85 m long white sillage bags for storage. Approximately 5000 tonnes per year from these silage bags is fed into the digestion system separately from the source-separated organics. Figure 12 shows a front end loader removing the sillaged Ley crop from the bag and loading into a transport trailer for delivery to the digester.

Figure 12
Loading the Stored Ley Crop into a Trailer for Delivery to the Digester

The source-organics are processed prior to being introduced into the digester. This processing includes screening, grinding, slurrying to 6% to 8% dry solids, re-grinding and pasteurization (to kill pathogenic bacteria, like salmonella). After batch pasteurization at 70°C, the resulting slurry is passed through a heat exchanger to bring the temperature down to the 37°C mesophilic digestion range at which point the source-separated organics slurry is introduced into the single digester. The process schematic for this plant is shown in Figure 13.

Figure 13
Process Schematic for the Västerås Svensk Växtkraft AB Biogas Facility

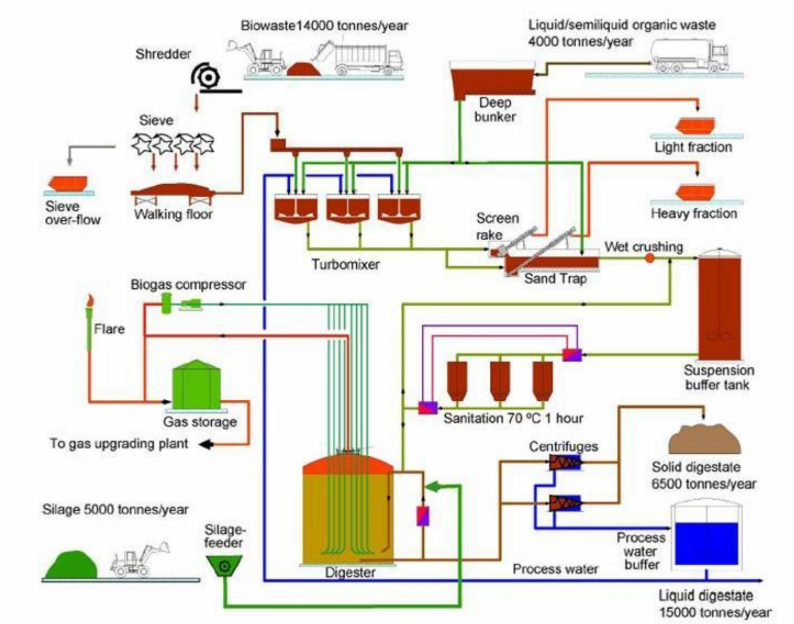


Figure 14 shows the digester and the Ley trailer at the Ley sillage feeder facility.

Figure 14
Västerås Svensk Växtkraft Digester with the Ley Sillage Feeding Facility

The resulting 6000 tonnes/year of dewatered biowaste residual from the combined digestion of the source-separated organics and the Ley crop are dewatered by centrifuge and then hauled out to the 17 participating farmers for storage and eventual land application in the fall. The soils in the Västerås are clay-rich glacial till and the source-separated organics biowaste solids provide both organic structure and nutrients, primarily phosphorus, to the soil. At the time of the site visit, the facility was in the final steps of a process to have the digested biowaste residuals certified for use on certified organic farms. Figure 15 shows some of the dewatered biowaste residuals being removed from the Västerås Svensk Växtkraft facility and deposited on farm land for subsequent storage and land application.

Figure 15
Handling and Reuse of Dewatered Biowaste Residuals from the Växtkraft Facility
(Courtesy of Svensk Växtkraft)

Approximately 16,000 tonnes (16,000 m^3) of liquid from the dewatering of the biowaste residuals, i.e. the “centrate”, is not returned to a wastewater treatment plant, as is the typical North America situation. Instead, the ammonia-rich centrate is hauled out to several covered storage lagoons strategically located near several of the participating farms. In the spring, this ammonia-rich liquid is extracted from the storage lagoons by the 17 farmers and applied to the crops after planting as an additional fertilizer replacement, as shown in Figure 16.

Figure 16
Applying Västerås Svensk Växtkraft Ammonia-rich Centrate to Land as an Ammonia-rich Fertilizer

In the background to this source-separated organics digestion process, Västerås also has a large wastewater treatment plant that has mesophilic anaerobic digesters that digest primary and secondary treatment sludges as well as fats, oils and greases from restaurants and commercial food processing facilities. The resulting approximately 8000 MWh per year of biogas is pumped approximately 8.5 km to the Svensk Växtkraft source-separated organics digester facility.

The combined biogases from the Svensk Växtkraft facility and the Västerås WWTP are processed at the Växtkraft facility to remove carbon dioxide (CO_2), moisture and particulates. A schematic of the gas upgrading process is shown in Figure 17. Figure 18 shows the size of the gas upgrading facility. The resulting product, biomethane is at least 97% methane represents approximately 23 GWh (23,000 MWh) per year or about 2.3 Million litres of gasoline or diesel equivalent.

Figure 17
A Schematic of the Biogas Upgrading Process at the Västerås Svensk Växtkraft Facility

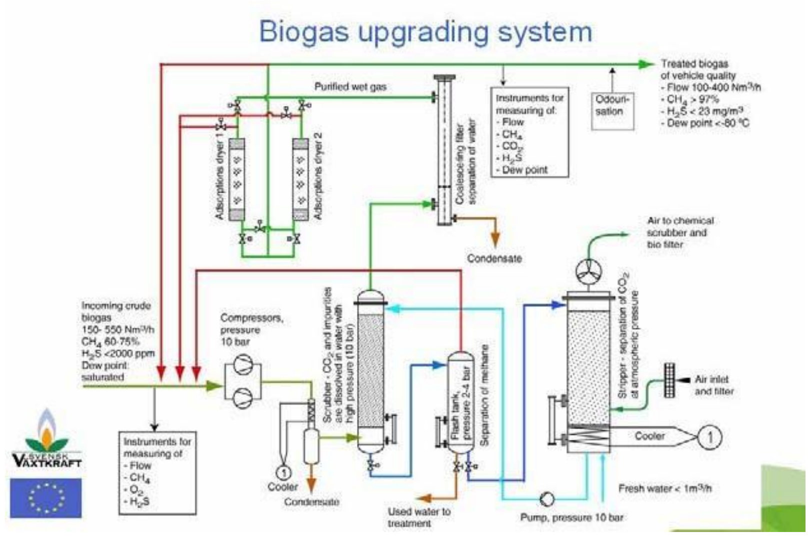


Figure 18
The Västerås Svensk Växtkraft Biogas Upgrading Facility

Once the gas is cleaned, it is then compressed and pumped via pipeline to the local bus company's bus yard. Some of the biomethane is also compressed and pumped into portable biomethane fueling units that are subsequently picked up by trucks and hauled to Stockholm to supplement the supply of biomethane from Stockholm's wastewater treatment plants.

At the bus yard, the gas is further compressed and stored in 16, 2 m^3 fibreglass pressure tanks where it is available to the fueling station. The fueling system, as shown in Figure 19, is designed to fill the biomethane storage tanks on each bus in the same five minutes that it used to take to fuel the diesel buses. As a back-up, like the Henriksdal facility in Stockholm, the Västerås bus facility has a liquified natural gas (LNG) storage tank and evaporator system, should there be a problem with the biogas/biomethane system. This LNG back-up system is shown in Figure 20.

Figure 19
Examples of Biogas Fueling in Västerås
(Courtesy of the Svensk Växtkraft)

Figure 20
The LNG back-up System at the Västerås Bus Facility

Just outside the fenceline of the bus yard, there is also a fueling facility for private vehicles that have been designed or converted to run on biomethane, as shown in Figure 21. This part of an overall program in Sweden to provide biomethane fueling points within reasonable distances. This program is called Biogasmax and is discussed in Section 3.4 below.

Figure 21
A Växtkraft Biomethane Fueling Point for Private Vehicles in Västerås

The bus company pays the equivalent of what diesel would cost them. The pubic pays 80% of the pump price of 95 octane (RON) gasoline (which at the time of the site visit to was approximately 13 sek/litre or about CDN$2.34/litre, about double Canadian fuel costs at the time of the site visit. In contrast, if the biogas was converted to heat and electrical power the revenue would be about 0.016 Euros/kWh (about CDN$0.026/kWh, substantially less than would be paid in BC to independent power producers). As a result, the use of biogas as a fuel in Sweden makes sense both environmentally and economically.

3.4 Biogasmax

Biogasmax is a European project intended to create a network of biogas-related demonstration projects in Europe, with the aim of sharing experiences in terms of the best practises in managing urban transportation. The principles of Biogasmax include:

- Production of biogas from various sources of waste including:
  - supermarkets, farmers markets
  - restaurants
  - kitchens
  - gardens
  - farms
  - wastewater treatment

- Upgrading the biogas to a high-quality fuel (by removing H_2S, CO_2, moisture and particulates)
- Distribution for transport and injection in natural gas grids
- Use in vehicles to increase the number of biomethane-fueled vehicles

The Biogasmax project includes demonstration projects in Sweden, Holland, France, Italy, Switzerland, Germany and Poland. In Sweden, the main participating areas are Göteborg and Stockholm. In the Göteborg area, Biogas Väst (Biogas West) is being promoted by the Business Region Göteborg (BRG). The partners in Biogas Väst are Fordons Gas Sverige (Sweden), Göteborg Energi and the Municipality of Falkoping. The 2006 targets were for 35 vehicle fueling stations, 7000 gas vehicles and at least 120 GWh of biogas production. Both buses and some solid waste collection vehicles in Göteborg are fueled by biomethane. There are now 11 fueling stations in Göteborg, with 30 in the study area, including four bus fueling stations.

In Stockholm, biomethane has been produced and used as fuel since 1996. By the end of 2006, there were approximately 3000 biomethane cars, 30 buses and 30 solid waste collection trucks. At the time of the 2008 site visit, these numbers had increased, e.g. 60 buses instead of 30. Stockholm Vatten, the operator of the three treatment plants, including the Henriksdal Reningsverk that was visited, is working with Svensk Biogas.

One other component of the Biogasmax project is the Växtkraft facility in Västerås, which, as previously discussed, uses source-separated organics and agricultural crops as the feed stock for the digester.

One subproject of the Biogasmax project, has been the development of a "Biogas Highway" to facilitate the use of biomethane vehicles between the western and eastern parts of Sweden. AGA Gas and Fordons Gas were the main financiers of the Biogas Highway. By the end of 2007 there were approximately 110 methane filling stations in Sweden including 83 stations for cars and 27 for buses. This included ten stations in Göteborg, three in Helsingborg, two in Kristianstad, five in Linkoping, two in Lund, four in Malmo, three in Norrkoping, two in Orebro, ten in Stockholm and at least two in Västerås.

Volvo, which is headquartered in Göteborg, was, up until recently, a leader in developing and providing bi-fueled gasoline-biomethane-fueled passenger vehicles and trucks. However, in the last year, Volvo's parent company, Ford, recently stopped Volvo from providing further biomethane-fueled passenger vehicles so they could concentrate on ethanol-fueled vehicles. While the wisdom of this policy change could be questioned, the loss of Volvo as a provider does not significantly impact the program since many other manufacturers including Mercedes, Volkswagen, Opel, FIAT, Peugeot and Citroën are developing and/or marketing bi-fuel gasoline-methane passenger vehicles. For biogas-fueled light duty trucks, Iveco, FIAT, Ford, Mercedes, VW and Volvo are in the market. For buses, the manufactures supplying biogas-fuelled buses include Ekobus, Irisbus, Iveco, MAN, Mercedes and Volvo. Volvo is currently working on a diesel truck engine that runs on 10% diesel and 90% biomethane.

In general, biogas (biomethane) fueled cars cost about 20,000 sek (CDN$3600) more than a normal diesel or gasoline fuelled vehicle. However, there is a rebate of 10,000 sek (half the cost) available to encourage biomethane vehicle purchase. It is hoped that the Biogasmax program will be eventually be able to replace 25 to 35% of the fossil fuel used for road transport in Europe.

3.5 Summary of Biogas Generation and Utilization

The use of biogas from wastewater treatment plants and purpose-built digestion facilities for vehicle fuel in Sweden is expanding. One of the drivers for this is the cost of importing petroleum fuels. The other driver is green house gas-based. Petroleum fuels like gasoline and diesel are significant contributors to green house gas production because they are fossil fuels and burning them adds carbon dioxide to the atmosphere. In contrast, biogas as both methane and carbon dioxide is derived from plant material (either directly or indirectly (through meat-animals fed grains and grasses)) that recently used to be carbon dioxide in the atmosphere. As a result, the use of biogas as a fuel source simply returns CO_2 to the atmosphere but does not add new CO_2 to the atmosphere, as does the use of fossil fuel. While this is understood in North America, the relative abundance and cost of fossil fuels in North America (about half the cost of fossil fuels in Sweden), coupled with a significant amount of coal-fired electricity generation has typically lead to the use of biogas from wastewater treatment plants being used in cogeneration facilities to produce electricity and heat for the treatment plant and, in doing so, displacing the use of fossil fuel-derived electricity.

In Sweden, their electricity primarily comes from hydropower and nuclear power, both of which have relatively small carbon footprints per kWh. As a result, since fossil fuels for vehicles have a significant carbon footprint, there is very little incentive to use the biogas to fuel cogen engines at wastewater treatment plants. It is much more beneficial from a carbon footprint viewpoint to use the biogas as a vehicle fuel. The situation in BC is similar to that in Sweden in that most of our electrical energy is generated by hydropower. However, we do create or import some fossil fuel-derived electrical energy so our electricity does have some carbon footprint. At this point, it is not clear whether the Swedish biomethane model is the correct one for BC and the CRD. This will merit further investigation.

4 District Heating and the Use of Energy from MSW WTE Facilities and WWTPs

It is clear that MSW WTE facilities can and do provide heat to district heating systems. It is also possible to extract heat from wastewater since wastewater contains heat energy. The amount of energy available is dependent on the wastewater flow and the wastewater temperature. In the lower Mainland, e.g. the Annacis Island WWTP, the average influent wastewater treatment plant influent temperature is about 18°C year round, with slightly higher temperatures in the summer and slightly lower temperatures in the winter. Lower winter temperatures would be due to snow melt and infiltration and inflow into sanitary sewers or combined sewers.

The situation in Sweden is not too much different than the lower Mainland of BC, except like other areas in Canada, they do experience winters. As a result, the influent temperatures can drop down to the 8 to 10°C range in under some conditions. Summer influent temperatures would be similar to those in most of Canada, e.g. about 18°C.

Heat can be extracted from wastewater through the use of heat exchangers and heat pumps. Heat pumps work very similar to a refrigeration system, using the heat in the wastewater to evaporate a liquid and then an electrical-powered compressor to compress the evaporated fluid and, in doing so, creating heat that can be extracted for use in various ways. The typical Swedish application involves extracting heat from treated effluent and then using the heat as part of district heating or cooling system. The resulting effluent is chilled down to the 1 to 4°C range and is either discharged as such or used as a source of chilling water for chilling loops operated in the summer, serving large buildings.

District heating systems in Sweden are typically high temperature loops, running initially in the 80°C range. The heating loops are based on insulated pipes in the streets with tapping off-points leading into buildings equipped with hot water radiators for heating and hot-water heat exchangers for heating of waters used in bathing and washing. These heating loops have been developed over many decades, some going back to the 1950's and 60's when the source of heat was coal, wood or oil. In the 1970's as a result of the 1973 oil "crisis", there were concerted efforts made to expand the district heating systems by adding new lines and combining existing smaller systems into a larger overall community system and adding new heat sources like MSW WTE plants.

By the time of the 2008 visit, Göteborg had a district heating system that served the majority of the residents in the Göteborg area. The annual heating requirements were approximately 3940 GWhr per year. The sources for the energy for this district heating system include waste heat from at least two petroleum refineries, MSW WTE facilities including the Renova facility, localized natural gas heating plants (typically used for peak heating demands), a new natural gas-fired cogeneration facility located very near the Gryaab wastewater treatment plant and a heat pump system operated by Göteborg Energi that extracts heat from the Gryaab plant effluent. Overall, about 28% of the energy requirements are supplied by the Renova MSW WTE facility, 28% by the refineries, 29% by the natural gas-fired facilities and 5% from the Gryaab treatment plant effluent. At the time of the site visit, in mid-April 2008, Göteborg Energi had more than enough heat for its district heating system. One of the reasons for this is the recent addition of the natural gas-fired cogeneration plant. As a result, the effluent from the Gryaab plant was being pumped from the treatment plant about 400 m to the Göteborg Energi heat pump system but the effluent heat pump plant was not being used and the energy was not being extracted. The effluent simply was pumped to the facility and then discharged as normal. During the winter, the situation would change. The operators of the Gryaab treatment plant were not too concerned because, even though the heat was not being extracted from their effluent, they were still paid by Göteborg Energi as if it was being extracted.

In Stockholm, the situation was different. The final effluent from the Henriksdal Reningsverk WWTP is pumped approximately 1.5 km to the Hammerby Heat Pump facility operated by Fortum Energi. The effluent is either used as a source of heat or a source of chilling water, depending on the season. While we did not have a chance to visit the plant, we were shown a video by Fortum Energi while at the Högdalen MSW WTE facility. What was noted was the Henriksdal WWTP provides enough heat for approximately 95,000 two bedroom apartments.

One of the interesting points that came out during the presentation and discussion of the Hammerby Heat Pump plant was the fact that the wastewater effluent flow and the requirements for heat are out of sync by several hours. For example, in the winter, in the early morning, people are getting up, turning up the thermostat and having showers and bathes, etc. However, it can take several hours for the morning wastewater to reach the treatment plant then several more hours for the wastewater to make it through the treatment plant and then some additional time to be processed by the Hammberby heat pumps. As a result, heat pump plants, like the Hammerby facility have to be equipped with large heat storage tanks that store heated water overnight for delivery in the early morning. This adds cost and complexity to the system.

There are actually three heating districts in Stockholm, North, South and Central. Almost all of Stockholms larger buildings and about 90% of the single family dwellings are on district heating. Fortum Energi alone, serves about 600,000 to 700,000 people or about a 60% market penetration.

It was noted that in Stockholm, in addition to the sources of heat from the MSW WTE facilities and the wastewater treatment plants (via heat pumps), any time the ambient air temp is less than 7°C, additional heat is required. Most typically this extra heat is supplied by low sulphur bio-oil fired boilers. This was different than in Göteborg that currently has the advantage of the nearby petroleum refineries as a source of non-wastewater, non-MSW WTE derived heat.

Although the facility was not visited, it was noted that the Västerås district heating system is fueled in part by wood chips of various types. On the train trip to and from Västerås and Stockholm, fields of willow were being grown as coppice for this purpose. Coppice is when the wood is harvested in an on-going sustainable fashion, which, in the case of willow, is harvesting (cutting down the tree growth but leaving the roots to regrown new shoots) every three years. An advantage of this process is wastewater treatment biosolids can be used to fertilize the coppice and increase the rate of growth. Wastewater effluent and dewatering centrate could also be used to irrigate the coppice crops and further enhance tree growth.

During these site visits, there was no mention of any heat recovery systems that were based on raw, untreated, wastewater. All the facilities we heard of or saw used treated secondary treatment effluent as the feed to the heat pump systems.

Overall, it is clear that, while heat can be successfully extracted from treatment plant effluent for beneficial reuse, there is cost both in the heat pump facility and the district heating system. Of the two costs, the heat pump facility would likely be relatively inexpensive compared to the cost of developing a district heating system in an existing developed area based on the cost of the installation and the disruption involved with excavating streets to install the piping and building connections. Furthermore, there would be significant additional costs to install hot water radiators in the buildings and residences or replacing the hot air furnaces with individual heat pumps to extract the heat from the district heating loop water.

5 Overall Summary and Conclusions

The investigation into integrated resource recovery in Sweden lead to site visits to MSW WTE facilities, wastewater treatment plants and a purpose-built source-separated organics digestion facility. Along the way, there were discussions about the use of heat pumps for energy extraction from wastewater, district heating systems, biogas utilization as vehicle fuel and the land application of biowaste from the source-separated organics digestion system and biosolids from the wastewater treatment plants. The conclusions that can be drawn from these Swedish investigations include the following:

- The use of MSW WTE facilities as a means of generating electricity and heat from non-recyclable solid wastes is well established in Sweden.
- Swedish MSW WTE facilities are operated in what appears to be an environmentally responsible manner with respect to odour control, air pollution control and process wastewater treatment.
- The energy from these facilities is a significant contributor to the overall heat and electricity requirements of the populations that are served.
- Heat pumps are being used to extract significant quantities of energy from wastewater treatment plant effluents for use in district heating systems.
- In some cases, the cost of running the heat pump systems is higher than alternative forms of energy and, therefore, the heat pumps are not always used.
- District heating systems in the two larger cities that were visited is extensive and well established and has evolved in various phases since the 1950’s with significant expansions in the 1970’s. This is a distinct advantage over many cities in Canada, including those that comprise the CRD.

- Even with heat from MSW WTE facilities and heat pumps extracting heat from wastewater treatment plant effluent, there are still times when other heat sources, e.g. fossil fuels or wood waste are needed to supplement the district heating supply in the winter.
- In Sweden, fossil fuels are relatively expensive when compared to the cost of electricity.
- In Sweden, the use of digester biogas, after upgrading to biomethane, for use as vehicle fuel is seen as a better use of the resource from economic and environmental (greenhouse gas credit) viewpoints, when compared to burning biogas in a cogen engine system to create electricity and heat.
- It is possible to set up a technically and economically successful purpose-built biogas generation system built around source-separated organics, supplemented by agricultural wastes.
- The products of the source-separated organics digestion, i.e. biogas, dewatered biowaste and dewatering centrate, are almost completely used in an environmentally friendly manner with the biogas used to fuel vehicles, the dewatered biowaste used as a soil supplement and phosphorus source and the dewatering centrate used as an ammonia-rich liquid fertilizer.
- No dewatered wastewater treatment plant biosolids were being incinerated as a means of disposal and/or energy production at the MSW WTE facilities visited.
- Wastewater treatment plant biosolids are typically land-applied in large scale landscaping and mine reclamation operations; Swedish farmers do no want wastewater treatment biosolids to be land applied on their food and forage crop lands.
- Dewatered biowaste residuals from the source-separated organics digestion process are readily accepted by farmers and, in some cases, may be certified for application to organic crops.
- No trends towards decentralized wastewater treatment were observed, in fact, the opposite, increased centralization, both in Göteborg and Stockholm, was noted.

Based on the above, the following could apply to the CRD situation:

- Some or all of these Swedish examples of integrated resource management opportunities could be applicable to the CRD situation. However, it should not be expected that all of the Swedish technologies and programs would be directly applicable to the CRD situation because the siting conditions, economics and social acceptance are likely to be different than in Sweden.

- There is definite merit in the CRD continuing with a program for separate handling and processing of source-separated organics. The possibility of following the Swedish (Västerås Svensk Växtkraft) biowaste digestion process should be investigated further because it provides the possibility of a triple benefit of biogas, centrate and dewatered biowaste production and utilization when compared to the current composting option.

- Biosolids from any CRD wastewater treatment plants would likely be better kept separate from the source-separated organics residuals. Options for beneficial use of these biosolids would include non-food related land application, e.g. forestry, or as feed material to an MSW WTE facility or a fluidized bed combustion WTE facility or a cement kiln facility.

- The use of biogas in a cogeneration situation to create heat and electricity should be examined in light of the possibility that upgrading the biogas to biomethane and using the biomethane as fuel for vehicles, including CRD vehicles and BC Transit buses, could make more sense from both economic and environmental (green house gas credits) viewpoints.

- The biogas from the biosolids digestion could be mixed and upgraded with biogas from a source-separated organics digestion system. In contrast to Sweden, Canada and the CRD has a much more elaborate natural gas pipe network that could also allow the introduction of upgraded CRD biogas, i.e. biomethane at multiple locations, with multiple extraction points, not unlike the way in which Green electrical energy from independent power producers is put into the electrical grid and then utilized at various extraction locations by users who have subscribed to the Green energy. For example, it might be possible to introduce biomethane from both a source-separated organics digester at the Hartland Road landfill and a biosolids digestion system in the Macaulay Point area into the natural gas pipeline grid for subsequent extraction at the BC Transit facility to fuel buses that operate in the CRD core area.

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