Treatment Through Resource Recovery:
Options for Core Area Sewage

Prepared for:
SETAC Review Panel
Capital Regional District Liquid Waste Review

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April 6, 2006

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Introduction

Stephen Salter is a professional engineer and independent environmental consultant, working as a volunteer with the Victoria Sewage Alliance. The Victoria Sewage Alliance is a group of like-minded individuals and organizations working to reduce all forms of pollution associated with sewage, and to expand the discussion concerning options for treatment in the Core Area. We do not stand to gain personally from decisions to move ahead with sewage treatment.

There is a significant gap between innovations in wastewater treatment adopted by industry and municipalities in other parts of Canada and the world, and the limited number of traditional treatment options which have so far been discussed with the public here. An unintended benefit of the delay in implementing treatment in the Core Area is that technologies for resource recovery have become more advanced and attractive in the context of rising energy process and our understanding of climate change.

This submission provides information showing how other municipalities and industries are recovering renewable energy and other resources from wastewater. This submission provides examples of the most commonly-used strategies as well as links to more information.

The Resource Recovery Option

When issues of sewage, municipal solid waste, air pollution and climate change are considered in isolation, we limit the scope and creativity of our solutions. European municipalities are showing how green energy can be derived from several waste streams at the same time, and how waste-to-energy infrastructure can effectively treat sewage and also reduce inner-city air pollution and greenhouse gases. Countries like Sweden are dealing with sewage and municipal solid waste in concert, so that energy recovery plants convert organic materials from garbage, offal from abattoirs, and sludge from sewage plants in single processes.

For example:

- There are 3,000 biogas plants in Europe, producing methane from sewage treatment plants and from organic municipal waste (1,2).
- Sweden runs 5,300 vehicles and much of its transit system on biogas (1,3). Replacing diesel with biodiesel or biogas (natural gas) in buses and cars in Victoria will reduce particulate emissions and will also reduce greenhouse gases by 30,000 tonnes/year (*please see Appendix I Energy and Greenhouse Gas Calculations*).
- Sweden is enacting environmental legislation which will require that 60% of phosphates be recovered from municipal sewage (4).

In Victoria and the Core Area, discussions concerning sewage treatment have become polarized into two camps; no treatment versus traditional aerobic treatment. The third option of treatment designed for resource recovery has not been discussed or explored. The public has been given very little information about the benefits of treating sewage through processes designed to recover resources, despite the fact that resource recovery is well established elsewhere: searching Google with the keywords "sewage" + "biogas" yields 400,000 pages.

We have an opportunity to take a more holistic approach to pollution by dealing with liquid and solid waste streams, and reducing their combined environmental impacts on water, land, and air. Ironically, while one section of the CRD has discouraged sewage treatment, another section (Greenhouse Gas Emissions Subcommittee: http://www.crd.bc.ca/rte/greenhse.htm) is actively seeking greenhouse gas reduction opportunities. The CRD's Regional Planning page, Greenhouse Gas Emissions section states: "*The CRD is currently looking for partners to fund co-ordination of a community energy program for the CRD area, which will include a greenhouse gas inventory.*" (5)

The CRD's *Wastewater and Marine Environment Program 2003 Annual Report* (6) shows the size of the resource recovery opportunity which the region's untreated sewage represents. We can recover:

- Biodiesel from approximately 5 million kgs/year of fat, oil and grease
- Biogas from approximately 16 million kgs/year of other organic material
- Biodiesel from residual sludge
- Fertilizers and metals from the approximately 2 million kgs/year of inorganic materials
- District heating through sewage-source (water-source) heat pumps
- Water for reuse from the 38 billion litres of water discharged per year

The Social Context of Treatment with Resource Recovery

A survey of 1,500 households conducted by the CRD in 2004 showed that 75% of the public believe that it's simply unacceptable to dump untreated sewage into the ocean (7). Support for sewage treatment is high, in spite of the fact that the public has been told treatment would cost $447 million, would cause other problems such as sludge disposal, and is unnecessary from an environmental point of view.

What would a survey show if citizens understood that sewage could power all the region's buses and whale watching boats, thus reducing greenhouse gas emissions and dependence on fossil fuels? What would the levels of support for treatment be if residents understood that the cost would equal what other BC residents pay - about $9 per home per month (8)? (*please see Appendix II - Cost Estimates*).

How can we measure the long-term value of improving greater Victoria's reputation as a sustainable city, and of showing the next generation of citizens how we can live more sustainably?

The Regulatory Context of Treatment with Resource Recovery

In 1999, the United Fishermen and Allied Workers Union, represented by Sierra Legal Defence Fund, initiated a private prosecution against the CRD, alleging violations of the federal Fisheries Act prohibition against depositing deleterious substances into fish-bearing waters (9).

On April 27, 2004, Sierra Legal Defence Fund submitted a Petition to the Auditor General of Canada concerning municipal wastewater discharges and pollution of the marine environment, raising the concern that CRD's discharge of raw sewage into Juan de Fuca Strait fails to comply with the federal Fisheries Act or with the Stockholm Convention on Persistent Organic Pollutants (10).

In November 2005, Sierra Legal Defence Fund made an urgent request the BC Ministry of Environment to designate the immediate vicinity of the Clover and Macauley Point sewage outfalls as contaminated sites, pursuant to the Ministry's powers under the British Columbia Environmental Management Act, S.B.C. 2003 c. 53. This request was based on my analysis of the CRD's own benthic sediment samples for the years 2000-2004. The analysis demonstrated unsafe levels of 19 of 31 substances prescribed in Schedule 9 of the Contaminated Sites Regulation, BC Reg. 375/96. I understand that Sierra Legal Defence Fund will be forwarding to SETAC the submission it made to the BC Ministry of Environment, along with my analysis. I urge the Panel to consider this submission and scientific analysis carefully (11).

It's interesting that when environmental regulations are enforced with respect to industrial pollution, industry responds with creative solutions. When treatment becomes necessary for the Core Area, we should explore the kind of treatment which minimizes all forms of pollution: resource recovery.

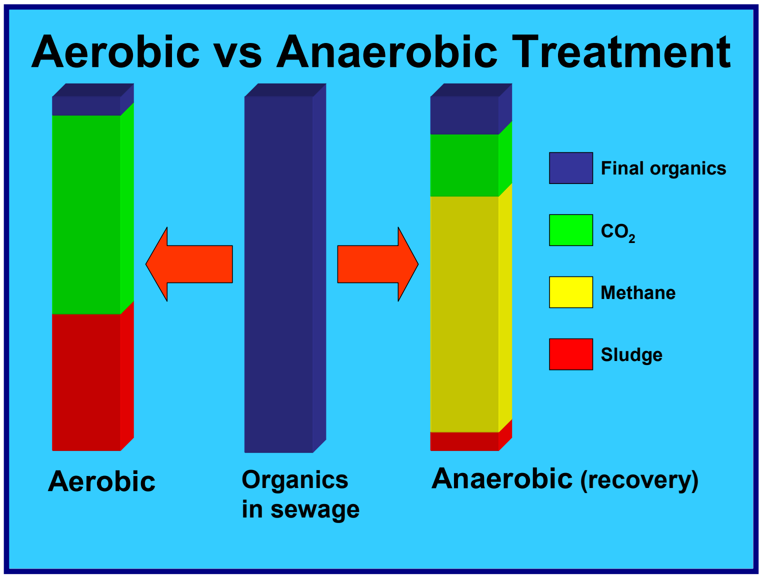
The Cost of Treatment Through Resource Recovery

Sewage treatment plants designed for resource recovery are less expensive to build and operate (more compact, require less electricity and chemicals) than traditional aerobic plants (12). Even in the worst case, basing our costs on comparable traditional plants (GVRD treatment plants, the Saanich Peninsula WWTP, pulp mill secondary treatment plants), there is no reason to believe the cost will be higher than the $9 per home per month paid by most BC residents for secondary treatment (*please see Appendix II - Cost Estimates*).

Discussions of treatment costs must also take into account the actual and potential benefits, including;

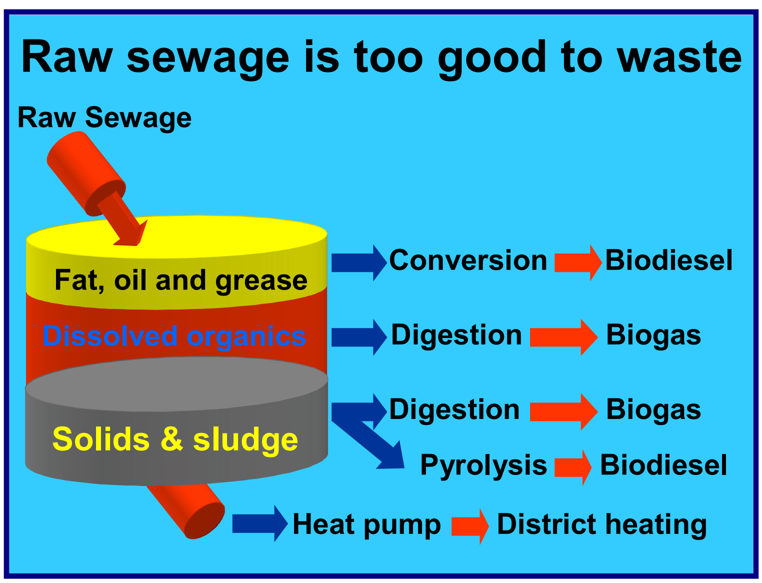
- The opportunity to displace fossil fuels with biofuels which can be recovered from sewage, amounting to enough biodiesel to run 200 buses and enough biogas to run 5,000 cars. This energy is worth $6 million/year at 2006 prices.
- The value of approximately $300,000/year of greenhouse gas credits
- Protection and enhancement of the region's $1 billion/year tourism industry
- Recovery of the currently closed shellfish and swimming scallop fisheries
- Protection of salmon, orcas, and other species from pollution
- Protection of marine habitats, including sediments, from further contamination

Direct Benefits of Treatment Designed for Resource Recovery



We need the right kind of sewage treatment. Traditional treatment relies on aerobic micro organisms to convert the organic energy in wastewater to carbon dioxide and biomass (sludge). The process consumes significant amounts of chemicals and electricity, but consuming electrical energy to get rid of organic energy is senseless; producing the electricity and chemicals used in traditional treatment causes upstream pollution. Current practices of land-farming sludge from aerobic plants or sending the sludge to landfills (as is the current practice for existing wastewater treatment plants in the CRD) is wasteful and unsustainable.

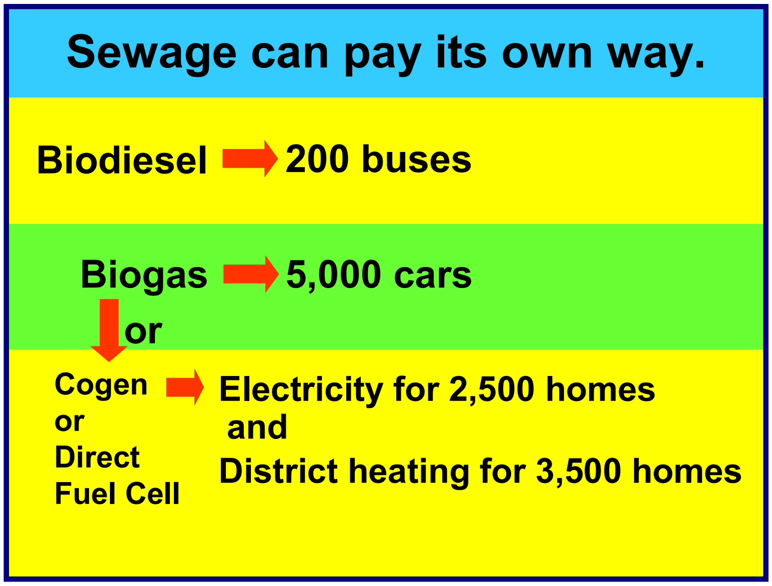
Dr. David Bagley, a scientist at the University of Wisconsin, has calculated that sewage contains almost 10 times the energy required to treat it (13). Dr. Bagley has submitted his paper on the energy content of sewage to the SETAC Review Panel website.



In anaerobic treatment plants on the other hand, methanogenic bacteria digest organic materials and produce raw biogas - a mixture of roughly 1/3 CO_2 and 2/3 methane. When the raw gas is stripped of CO_2 and trace sulphur compounds (using treated wastewater) the resulting natural gas can be distributed for use in homes or cars.

Anaerobic treatment plants cost less to build since they do not require aeration equipment, and they require less space since they use closed vessels rather than open settling tanks. They also cost less to operate since they do not consume electricity for aeration and use fewer chemicals; aerobic plants require settling agents such as alum and commonly use chlorine to disinfect sludge and effluent. Finally, anaerobic plants produce one fifth to one twentieth of the sludge produced by aerobic plants, since a significant proportion of the energy in the wastewater is converted to methane. Since anaerobic treatment takes place in closed vessels, odours are contained and it becomes practical to co-locate treatment with other land uses.

For example, Victoria's planned Dockside Development will convert sewage and other organic waste from 2,000 tenants into biofuels, electricity, and compost through an anaerobic plant in the basement. The treated effluent will flow in a creek within the development, providing aesthetic value (14).



CRD reports (6) show that Core Area sewage contains enough energy to provide pure biodiesel for 200 buses and 5,000 cars; the greenhouse gas reductions would equal 30,000 tonnes/year (*please see Appendix I - Energy and Greenhouse Gas Emission Calculations*.) Applying the right kind of treatment to Core Area sewage will not only remove up to 95% of contaminants from the effluent, but can also help counter inner-city air pollution and climate change: biodiesel and biogas burn more cleanly than fossil fuels. Resource recovery plants can be designed to accept and process solid municipal organic waste as well as sewage, further reducing pollution of air, soil, groundwater, and the ocean. The *Examples of Resource Recovery From Sewage* section below show how sewage and sludge can provide the Core Area with biodiesel, biogas, minerals, and district heating.

Conclusions: What the Core Area Can do Now

Pollution is often a misplaced resource, and that's certainly the case with the oils, bio-energy, and metals we're currently flushing out to sea. We're also fortunate that innovative technologies have put these resources within reach. Given the rising cost of energy and the pressing need to reduce greenhouse gas emissions and air pollution, it makes environmental and economic sense to take the resource recovery route to sewage treatment.

We have no reason to believe treatment through resource recovery will cost more than residents pay for treatment through existing CRD plants. To settle the question of cost, the Capital Region can hold a design competition or initiate a "Request for Expression of Interest" to solicit the best resource recovery options from across Canada and around the world. In 2003, Toronto's RFEI process yielded fifty modern waste-to-energy options for its municipal solid waste and sewage sludge (15). Core Area governments can display the responses in an open forum to help the public learn the pros, cons, and costs of each option. This kind of open process is needed to give the public a clearer picture of the many possible solutions.

When Core Area communities run buses and whale-watching boats on biofuels, we will replace our environmental stigma with a reputation as an innovative, sustainable community. Resource recovery is an idea that's just too good to waste.

If you have any questions about this brief, please feel free to reach Stephen Salter PEng at (250) 370-9664 or by email at Stephen_VSA@telus.net.

Examples of Resource Recovery from Sewage

Biodiesel from Fat, Oil & Grease in Sewage

City bus on biodiesel in Cedar Rapids, Iowa (link 3)

Montreal Tourist Craft Powered by Biodiesel (link 2)

What's being done elsewhere:

The City of Victoria and BC Transit have both run pilot biodiesel programs (personal communication with Patrick O'Reilly PEng, Director of Engineering, City of Victoria on October 28, 2005.)

Biodiesel is also being used to power the tourist boats operated by a number of Quebec firms (link 2). The vessel pictured below is reported to carry fifty passengers at up to 50 knots, on B100 - 100% biodiesel.

Biodiesel is being used in municipal vehicles (for example in Hennepin County Minnesota; link 6) and in transit buses (for example in Cedar Rapids, Iowa; link 3).

Biomass to biodiesel conversion technology is developing rapidly in Canada (links 4, 5). Fat, oil, and grease (FOG) from sewage can be collected from sewage treatment and commercial grease traps, and converted to biodiesel through esterification and hydrogenation (link 7).

What we can do here:

CRD reports for 2003 show untreated sewage from the Macaulay Pt. and Clover Pt. outfalls contains 5 million kgs/year of oil & grease per year, which could provide enough pure biodiesel to run all of Victoria's 200 buses (6). When grease from commercial grease traps is also converted the figure will significantly higher.

We could also sell biodiesel from sewage to whale-watching companies, showing tourists from the world over how we've turned pollution into a resource.

Links to more information:

1) http://www.epa.gov/region09/waste/biodiesel/california.html
2) http://www.biomer.ca/en/ContFlotte.html
3) http://www.biodiesel.org/resources/users/stories/CRtestimony.shtm
4) http://www.ensyn.com/what/renewable.htm
5) http://www.bcsea.org/sustainableenergy/biodiesel.asp
6) http://www.biofuels.coop/archive/MN_wastefatsuofm.pdf
7) http://205.168.79.26/docs/fy99osti/26141.pdf

Biogas from Sewage


Biogas Plant, Kristianstad Municipality, Sweden

What's being done elsewhere:

In 1999 the executive committee of Kristianstad Municipality (pop. 75,000) declared themselves a Fossil Fuel Free Municipality, to help the district meet fifteen environmental goals set by the Swedish Parliament (3). Biogas from the sewage treatment plant is used to fuel buses and other vehicles; 22 buses ran on biogas as of December 2002.

In 2002 the biogas cost CND$0.32 per litre, and the Kristianstad Municipality further encourages the public to buy cars that run on biogas by:

- providing free parking places for biogas-powered cars
- subsidizing 50% of the cost of converting cars to run on biogas

Another benefit of anaerobic digestion is that certain anaerobic bacteria have been found to degrade persistent organic pollutants (link 8) such as:

- chlorinated biphenyls (Burkholderia (Pseudomonas) strain LB400)
- dioxins and chlorobenzenes (Dehalococcoides)

What we can do here:

CRD reports show sewage contains 16,000,000 kgs/year of organic materials, which could produce enough biogas to run about 5,000 cars, or heat 3,500 homes, or generate electricity for 2,500 homes (*please see Appendix I Energy and Greenhouse Gas Emission Calculations*).

Links to more information:

1) http://www.energie-cites.org/db/stockholm_113_en.pdf
2) http://www.managenergy.net/indexes/I59.htm
3) http://www.biomatnet.org/secure/Other/S919.htm
4) http://www.draaisma.net/rudi/anaerobic_wastewater_treatment.html
5) http://www.undp.org.in/programme/GEF/dec%2002/dec02/news.htm
6) http://www.techmonitor.net/techmon/03may_jun/was/was_persistent.htm
7) http://www.ias.unu.edu/proceedings/icibs/mansson/paper.htm
8) http://www.techmonitor.net/techmon/03may_jun/was/was_persistent.htm

Biogas from Sludge

Biogas Plant in Switzerland

What's being done elsewhere:

Anaerobic digestion is commonly used in Canadian sewage treatment plants to "stabilize" sludge resulting from the traditional aerobic treatment processes (16).

A modern method used in Hamar, Norway is to "cook" the sludge at 180 ºC before a final digestion stage. This approach (which has not yet been used in Canada) ruptures cell walls, killing pathogens and making the conversion to biogas more efficient. Thermophilic anaerobic digestion at 70 ºC then converts the sludge to biogas (17). The biogas (methane, or natural gas) can then be used to run vehicles, or to produce electricity and heat from cogeneration plants or Direct Fuel Cells.

What we can do here:

Treatment plants in the Core Area could also accept and convert other organic waste, including as much as possible of the 46,000,000 kgs/year of organic waste currently sent to the Hartland Landfill (18). This solid organic waste stream includes sludge produced by existing CRD secondary sewage treatment plants such as the Saanich Peninsula Wastewater Treatment Plant, as well as the Sooke Treatment Plant.

Small, local resource recovery/treatment plants could digest their own sludge on site, producing biofuels.

As an alternative, a sludge processing facility could be built at the Hartland Landfill site which could also accept sludge from Saanich Peninsula WWTP, Sooke WWTP, a new landfill leachate treatment system, and organics diverted from landfill.

The Ministry of Environment has required the CRD to seek solutions for treatment plant sludge processing; discussions should be expanded to include sludge-to-energy options (19).

Links to more information:

1) http://www.energie-cites.org/db/linkoping_113_en.pdf
2) http://www.cambi.com/publications/sludge/five%20years%20exp%20HIAS.pdf
3) http://www.sgc.se/nyheter/resources/ReportAltener.pdf
4) http://www.managenergy.net/indexes/I59.htm
5) http://www.italocorotondo.it/tequila/module3/treatment/sludge_treatment.htm

Biodiesel, Metals, and Minerals from Sludge

Sludge to Oil Reactor in Colton, California

What's being done elsewhere:

Sludge (and other organic waste) can be converted to biodiesel and minerals through plasma gasification or pyrolysis, processes which heat and decompose the waste in the absence of air. The Dockside Development project will use pyrolysis as a final treatment stage to reduce the residual sludge to biofuels and mineral ingots. Pyrolysis is being used extensively in the USA; the Sludge-To-Oil Reactor System (STORS) in Colton, California also converts ammonia in the sludge to fertilizer.

The Tembec high-yield pulp mill in Chetwynd, BC uses resource recovery strategies to achieve zero effluent operation. Sludge from the treatment plant is processed into fuel and ash consisting of metals and minerals. The ash is sent to a mine and blended with ore for refining (20). Interestingly, the trace metals present in sludge act as catalysts in pyrolysis.

A biodiesel conversion plant at the Hartland Landfill could also provide fuel for commercial and municipal vehicles such as recycling trucks.

What we can do here:

Anaerobic treatment processes produce 1/5 to 1/20 of the sludge produced by aerobic processes, but pyrolysis can be used to convert the remaining sludge to fuel and minerals. A pyrolysis plant could also accept sludge produced by the region's existing traditional sewage treatment plants in North Saanich, Sooke, and so on. This sludge has been applied to farmland, but is currently going to the CRD's Hartland landfill.

CRD reports show that sewage includes 2,000,000 kgs/year of metals and minerals (6). These could be recovered as ash or solid ingots through the sludge-to-oil process, and included with ore from mines for refining.

The Ministry of Environment has required the CRD to seek solutions for treatment plant sludge processing; discussions should be expanded to include sludge-to-energy options (19).

Links to more information:

1) http://www.thermoenergy.com/munistors2.htm

2) http://www.thermoenergy.com/enhancedBiogasProcess.html

Electricity & Heat from Co-generation

Cogeneration at the Lethbridge sewage plant

What's being done elsewhere:

In Kristianstad, Sweden biogas cogeneration plants are located close enough to housing developments to provide heat - district heating.

The GVRD's Annacis Island secondary treatment plant uses biogas cogeneration from their sludge treatment process to produce 4 megawatts of electricity from 50,000 m^3 of biogas per day (link 1).

The Lethbridge sewage treatment plant generates 1.5 megawatts of electrical power and recovers 1.7 megawatts of thermal energy from their cogen process (link 2).

What we can do here:

We could consider co-locating closed-vessel, anaerobic treatment (similar to the Dockside Development process) with developments for market and social housing. DND has an interest in ensuring low-cost housing is available in Esquimalt, and residents are concerned about odours from a traditional treatment plant.

A community development which integrates resource recovery with other land uses could have lasting benefits for the community.

The region is facing pressure to develop waterfront property which could also be used for sewage treatment (e.g. Macaulay Point), but perhaps the question should be "and" rather than "or". Developers could be required to integrate a resource recovery plant into a new community, as the Dockside Development will do in Victoria's inner harbour.

Links to more information:

1) http://www.gvrd.bc.ca/sewerage/plans.htm
2) http://www.ae.ca/aetoday/020302.html

Electricity from Biogas-Powered Fuel Cells

US DOE's 250 kilowatt- Direct Fuel Cell

What's being done elsewhere:

The US Department of Energy is testing Direct Fuel Cells which convert methane to hydrogen internally, and then convert hydrogen to electricity (link 1).

Two 500 kilowatt Direct Fuel Cell power plants have been installed at the El Estero Wastewater Treatment Facility in California. These cells generate electricity directly from methane gas (biogas) recovered from sewage treatment (links 2 and 3).

A New York wastewater treatment plant has installed a 200 kilowatt Direct Fuel Cell (link 4).

Portland, Oregon has also installed a 200 kilowatt Direct Fuel Cell to produce power using anaerobic digester gas from a waste water facility (link 5).

The South Treatment Plant in Renton, Washington has installed a 1 megawatt Direct Fuel Cell which produces enough electricity for 1,000 homes. Other King County sewage treatment plants use internal combustion engines and microturbines to produce electricity and heat (link 6).

What we can do here:

This technology could be considered as an alternative to the more traditional internal-combustion engine/generator approach (as used by the Greater Vancouver Regional District's Annacis Island plant, the Lethbridge plant, and others).

Links to more information:

1) http://www.netl.doe.gov/publications/press/2000/tl_fce1year.html
2) http://www.fuelcellsworks.com/Supppage2128.html
3) http://www.aiada.org/article.asp?id=33888
4) http://www.epa.gov/globalwarming/greenhouse/greenhouse17/benefits.html
5) http://www.chpcenternw.org/NwChpDocs/ColumbiaBlvdWastewaterCaseStudyFinal.pdf
6) http://dnr.metrokc.gov/wtd/energy/index.htm and
http://dnr.metrokc.gov/wtd/fuelcell/index.htm

Water-Source Heat Pumps

What's being done elsewhere:

Sewage-source (water-source) heat pumps are being used by the Osaka Municipal Government (link 1) and by the Tokyo sewage treatment plant (link 2) to extract residual heat energy from sewage after treatment and before it is discharged.

The 2010 Olympics Athlete's Village in Vancouver will be heated by sewage-source heat pumps (21).

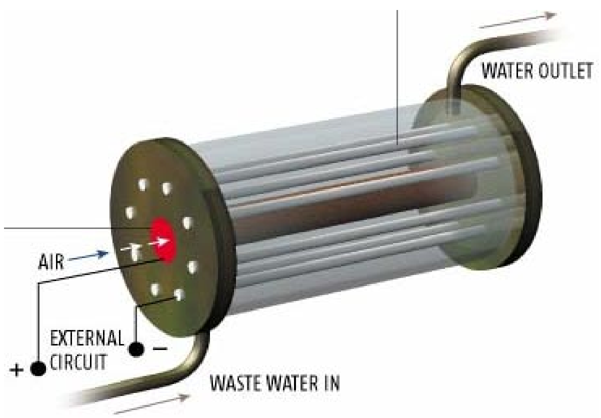
What we can do here:

Sewage temperatures average 16 ºC in winter months (3), and the tremendous volume of sewage (38 billion litres per year) means it contains significant energy. If a resource recovery plant is co-located with new housing or even social housing, a sewage-source (water-source) heat pump could recover enough energy to heat several thousand homes (*please see Appendix I Energy and Greenhouse Gas Emission Calculations*).

Links to more information:

1) http://www.unep.or.jp/ietc/Publications/Water_Sanitation/wastewater_reuse/Booklet-Wastewater_Reuse.pdf
2) http://etis.net/caddet/ee/D033.pdf

Electricity from Sewage-Powered Fuel Cells



What's being done elsewhere:

Researchers at Pennsylvania State University are developing a fuel cell which produces electricity directly from sewage: *"The microbial fuel cell could provide a modern solution to two worrying problems - how to reduce the energy costs involved in treating raw sewage and how to produce power without relying on non-sustainable resources."* (links 1-3)

What we can do here:

Senior government could encourage research to commercialize the fuel cells in BC.

Links to more information:

1) http://www.newscientist.com/article.ns?id=dn4761
2) http://www.psigate.ac.uk/spotlight/issue20/farming.html
3) http://www.physorg.com/news3840.html

Water From Sewage

Membranes for recovering water from sewage in King County, Washington

What's being done elsewhere:

The sewage treatment system for the planned Dockside Development LEED Silver project will recover water from treated sewage. The water will be purified by passing through ultrafiltration membranes which remove bacteria, and recovered water will be used for grey water applications such as flushing toilets (link 1).

The World Health Organization has published standards for water recovered for reuse from wastewater (link 2).

The Tembec high-yield pulp mill in Chetwynd, BC incorporates a zero-effluent wastewater treatment system, which uses vapour recompression technology to recover process water for reuse in the pulping process. Vapour recompression produces distilled water by recycling the latent heat of evaporation in the compression process (link 3).

The King County, Washington treatment plant is installing ultrafiltration membranes to recover water from sewage (link 4).

What we can do here:

Water can be recovered through membrane ultrafiltration, vapour recompression, or multiple effect evaporators. Recovered water could be diverted for use in irrigation or grey water systems.

Links to more information:

1) http://www.docksidegreen.ca/
2) http://www.who.int/water_sanitation_health/norms/en/
3) http://www.norlandintl.com/multiple_effect_vapor_compression_distillation.asp
4) http://dnr.metrokc.gov/dnrp/press/2005/0317membrane.htm

Appendix I - Energy and Greenhouse Gas Emission Calculations

The calculations below are intended to show the size of the resource recovery opportunity, bearing in mind Dr. Bagley's research showing that sewage contains about ten times the energy required to treat it (13).

Part 1: The Sources of Energy Available From Sewage

a) BOD as Sugar	$C_{12}H_{22}O_{11}$ (s) + 12 O_2 (g) → 12 CO_2 (g) + 11 H_2O(l) +5,792 kJ/mol		
Mass of BOD per year from sewage:	**7,992,498**	kg/year	Source: CRD 2003 Annual Report
Molecular weight of sucrose:	342	g/mol	This calculation makes some simplifying assumptions:
Molecular weight of oxygen:	32	g/mol	1) BOD indicates the organic content of sewage
Molecular weight of CO2:	44	g/mol	2) The organics in sewage are mostly cellulose
Mols of oxygen per year:	249,765,576	mols/year	3) Fat Oil Grease is oleic acid
Mols of sugars per year:	20,813,798	mols/year	
Mols of CO2 produced:	249,765,576	mols/year	
Energy value per mol of sucrose:	5,792	kJ/mol	
Energy value from sugars (as nat. gas):	120,557,681	MJ/year	
b) TSS as Cellulose	$C_6H_{10}O_5$ (s) + 6 O_2 (g) → 6 CO_2 (g) + 5 H_2O(l) +2,783 kJ/mol		
Mass of TSS per year from sewage:	**8,331,182**	kg/year	*Source: CRD 2003 Annual Report*
Molecular weight of cellulose:	162	g/mol	
Mols of cellulose per year:	51,427,051	mols/year	
Mols of CO2 produced:	308,562,308	mols/year	
Energy value per mol of cellulose:	2,783	kJ/mol	
Energy value from cellulose (as nat. gas):	143,129,712	MJ/year	
c) Fat, Oil & Grease as Oleic Acid	$C_{18}H_{34}O_2$ (l) + 25.5 O_2 (g) → 18 CO_2 (g) + 17 H_2O(l) +10,000 kJ/mol		
Mass of FOG per year from sewage:	**5,111,832**	kg/year	*Source: CRD 2003 Annual Report*
Molecular weight of oleic acid:	282.47	g/mol	
Mols of oleic acid per year:	18,096,904	mols/year	
Mols of CO2 produced:	325,744,266	mols/year	
Energy value per mol of oleic acid:	10,000	kJ/mol	
Energy value from oleic acid:	180,969,036	MJ/year	
Total energy from biomass (a+b+c):	**444,656,429**	MJ/year	

Appendix I - Energy and Greenhouse Gas Emission Calculations (continued)

Part 2: Potential Uses for Energy From Sewage

a) Biodiesel component:	**3,407,888**	litres/year	Assume recovery of: **60%** of fat/oil/grease	
Value as biodiesel =	**$3,407,888**	/year		
Average buses cover:	65,000	km/year	1.047	m3 natural gas/litre of diesel
At a fuel efficiency of:	4.21	km/litre, or 4.41 km/m3 of biogas		
(hybrid buses achieve up to 18 mpg)	15,438	litres/year/bus	16,169	m3 natural gas/year
Which provides enough fuel for:	**221**	buses (or **2,392** cars at 14.0 km/litre)		
b) Remaining oil and biogas:	**336,075,007**	MJ/year		
Natural gas equivalent:	**8,844,079**	m3/year		
Value as natural gas:	**$4,442,911.60**	per year at the rate of $13.22 $/GJ		
Which provides enough fuel for:	**5,926**	cars, or **547** buses, or **6,371** homes		
Assuming electricity conversion at 35%:	**32,673,959**	kw.hrs/year		
Value as electricity =	**$1,797,067.75**	per year	at the rate of $ 0.055 $/kwhr	
ref. BC Hydro fact sheet:	**10,000**	kw.hrs/home/year		
Provides enough electricity for:	**3,267**	homes		
Plus heat for:	**4,141**	homes *(The value of waste heat from generators)*		
c) Heat energy (via Heat Pump)		ref.	http://etis.net/caddet/ee/D033.pdf	
Flow rate (October-March):	118,117	m3/day	*Source: CRD 2003 Annual Report*	
Temperature in (October-March)	17.3	C		
COP:	5.3			
Heat energy available:	5.73E+12	joules/day		
Can provide enough heat for:	**39,636**	homes at 52,750 MJ/home/year (ref. BC Hydro)		

Part 3: Greenhouse Gas Calculation

The calculation is conservative, since it does not account for the carbon equivalent of any methane which could be produced by decomposing sewage in the ocean. Methane has a 21x stronger greenhouse has effect than CO_2.

Mols of CO_2 displaced by biofuels:	884,072,149	mols/year	(BOD, Solids, Oil and Grease)
Tonnes of CO_2 displaced by biofuels:	**38,899**	tonnes/year	
Value of carbon credits:	**$388,992**	at the rate of $10 per tonne as of January, 2006	

Part 4: Metals and Minerals in Sewage

It is expected that resource recovery technologies will only recover a portion of this material. The summary is included to show the size of the opportunity (6).

	Macaulay (2003) kg/year	**Clover (2003)** kg/year	**Total** kg/year	**2005 Prices** ($/kg)	**Value** ($/year)
Aluminum	22,307	23,873	46,179	$1.87	$86,494
Chromium	43	48	91	$8.54	$776
Copper	1,769	2,538	4,307	$3.83	$16,474
Iron	21,059	21,430	42,489	$0.15	$6,480
Lead	186	219	406	$0.88	$357
Magnesium	98,265	128,342	226,607	$1.95	$442,336
Manganese	1,564	1,054	2,617	$0.73	$1,916
Nickel	96	72	168	$14.52	$2,438
Total kjeldahl nitrogen	616,845	670,442	1,287,287	$0.49	$631,337
Phosphorous	98,982	112,539	211,521	$0.24	$51,611
Potassium	200,833	239,444	440,277	$0.18	$80,571
Silver	38	66	104	$228.60	$23,808
Tin	25	36	61	$7.30	$443
Zinc	1,488	1,750	3,238	$1.28	$4,132
		Totals:	**2,265,351**		**$1,349,171**

Appendix II - Cost Estimates

	CRD Estimate (July 6, 2005)	**Victoria Sewage Alliance Estimate**
Capital cost	**$447 million** before grants Based on: 1. One quotation for a traditional treatment technology from one consultant. The traditional treatment approach was not geared toward resource recovery. 2. Constraints include underground construction, sized and priced for a population twice as large as the current Core Area equivalent population of 350,000. 3. Engineering & administration fees of $62 million. 4. Contingency fees of $47 million. 5. No cost sharing was assumed in the CRD's July 6, 2005 estimate, although three-way cost sharing is anticipated in the CRD's LWMP.	**$250 million** before grants Based on: 1. $90 million paid by BC pulp mills for secondary treatment plants in the early 1990s, for flows which are approximately 80% higher than the total from Clover and Macaulay point (22). 2. $20 million paid by the CRD in 2000 for the Saanich Peninsula Wastewater Treatment Plant, designed to serve a population of 50,000 (23). Scaling this cost up by a factor of seven to serve an equivalent population of 350,000, discounting for economies of scale and the use of newer technologies, and adding for the effects of inflation leads to an estimate of $180 million. 3. Construction costs have increased, but newer treatment technologies require less equipment and space. For example, the electro-oxidation and electro-coagulation plant operating in Ladysmith BC will cost $9.4 million, require only 200 m^2 of space, and will serve 9,000 people. 4. Resource recovery plants do not require aeration equipment and large settling tanks, and are therefore less expensive than traditional designs. 5. 1/3 cost-sharing with the federal government, and 1/3 shared with the province. Both levels of government have indicated their willingness to help solve the sewage treatment problem, but senior government has indicated that discussions cannot begin without a request from the CRD. Given the federal interest in encouraging sustainable energy initiatives, it is possible that further R&D grants could be available for resource recovery.
Carrying cost	**10%** interest rate	**4.75%** interest rate based on the cost of 30-year municipal loans at the time of the estimate.

	CRD Estimate (July 6, 2005)	**Victoria Sewage Alliance Estimate**
Operating cost	**$16.7** million/year	**$9** million/year Based on: 1. BC pulp mills spend $7-8 million/year to operate secondary treatment plants which process 80% more flow than Clover and Macaulay Points combined (24). 2. The existing CRD Saanich Peninsula Wastewater Treatment Plant has an operating budget of $1 million/year. Note that the estimate of $9 million/year does not take into account the value of resources which can be recovered and sold. At current energy prices, the biogas and biodiesel which could be recovered from Core Area sewage are worth $6 million/year. If the fuel savings in the regional transit system are passed on to commuters through lower fares, the region can further encourage the use of (biofuel-burning) transit.
Net annual cost per household	**$573.02** per home/year	**$76** per home per year Based on: 1. Calculations factoring in the capital costs, cost-sharing, interest rates, and operating costs explained above. 2. The actual rate of $108 per home per year currently paid to the CRD by residents of North Saanich and Sidney for treatment through the CRD's Saanich Peninsula Wastewater Treatment Plant (8).

In conclusion there is no reason to believe secondary treatment based on resource recovery should cost more than the $108 per home per year which residents of North Saanich and Sidney already pay for secondary treatment through the CRD.

The only way to know the costs and resource benefits of secondary treatment with resource recovery will be to open the process to a wide range of sources through a design competition or a Request for Expression of Interest (15).

Appendix III - Links to Resource Recovery Websites

Current Technologies	
Anaerobic Bacterium Degrades Dioxins	http://www.techmonitor.net/techmon/03may_jun/was/was_persistent.htm
Anaerobic Digestion, Enhanced	http://www.thermoenergy.com/thermoFuelProcess.html
Anaerobic Treatment Advantages	http://www.draaisma.net/rudi/anaerobic_wastewater_treatment.html
Anaerobic Treatment Theory	http://www.biotank.co.uk/anaerobic_digestion.htm
Anaerobic USB Reactors	http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/T0541E/T0541E08.htm
Australian Bioenergy from Sewage	http://reslab.com.au/resfiles/waste/text.html
Biodiesel Association of Canada	http://www.biodiesel-canada.org/
Biodiesel Buses Running in Iowa	http://www.biodiesel.org/resources/users/stories/CRtestimony.shtm
Biodiesel Process by Ensyn	http://www.ensyn.com/what/renewable.htm
Bio-fuel Links - European Commission	http://www.managenergy.net/indexes/I59.htm
Bio-fuel Projects in Europe	http://www.energie-cites.org/page.php?lang=fr&dir=3&cat=3&sub=3
Bio-fuels for Transportation in France	http://www.trendsetter-europe.org/index.php?ID=542
Bio-fuels for Transportation in Sweden	http://www.ias.unu.edu/proceedings/icibs/mansson/paper.htm
Biogas for Transportation in Sweden	www.fv-sonnenenergie.de/fileadmin/fvsonne/publikationen/ws2003/02_d_biogas_01.pdf
Biogas in Finland	http://www.biomatnet.org/secure/Other/S919.htm
Biogas in Sweden	http://www.cardiff.ac.uk/archi/programmes/cost8/case/watersewerage/bromma.html
Biogas Powering Norwegian Buses	http://www.newconnexion.net/article/05-01/theroad.html
Canada's First Biodiesel Plant	http://www.rothsaybiodiesel.ca/en/
Canadian Biogas Association	http://www.biogas.ca/
Canadian Renewable Fuels Assoc.	http://www.greenfuels.org/
Cellulose Materials to Ethanol	http://www.iogen.ca/
Cellulose Waste to Ethanol	http://www.gaianbioenergy.com/Gaian%20Process%2001.htm
Dockside Project - Resource Recovery	http://www.docksidegreen.com/project_overview/index.php
Ecological Wastewater Treatment	http://online.caup.washington.edu/courses/udpsp00/udp508b/overview.html
Fuel Cells Powered by Sewage Biogas	http://www.fuelcells.org/basics/faqs.html
Micronizer dewatering technology	http://www.fasc.net/
Nanaimo Sewage Power Project	http://www.rdn.bc.ca/cms.asp?wpID=470
Sludge-to-oil process	http://www.water-technology.net/projects/stors/
Sludge-to-oil process	http://www.thermoenergy.com/munistors2.htm
Toronto RFEI	http://www.toronto.ca/wes/techservices/involved/swm/net/pdf/oct15_review.pdf
Water Reuse - Membrane Filtration	http://dnr.metrokc.gov/dnrp/press/2005/0317membrane.htm
Water Reuse - Vapour Recompression	http://www.norlandintl.com/multiple_effect_vapor_compression_distillation.asp
Westport Innovations	http://www.westport.com/

Sewage Treatment - Emerging Technologies	
Farming Power by Sewage	http://www.psigate.ac.uk/spotlight/issue20/farming.html
Fuel Cells Powered by Sewage	http://www.wasteage.com/mag/waste_technology_fuel_cells/
Hydrogen from Y19 Bacteria	http://www.undp.org.in/programme/GEF/dec%2002/dec02/news.htm
Microbial Fuel Cells	http://www.acfnewsource.org/science/sewage_power.html
Penn State Hydrogen Fuel Cell	http://www.physorg.com/news3840.html
Plugging into Sewage Power	http://www.newscientist.com/article.ns?id=mg18124383.000

Appendix IV - References

1) *Alternative Transportation, Helen Isaac, University of Calgary, Calgary, Alberta*
http://www.cseg.ca/recorder/pdf/2005/09sep/sep05_05.pdf

2) *Biogas as transportation fuel*
http://www.fv-sonnenenergie.de/fileadmin/fvsonne/publikationen/ws2003/02_d_biogas_01.pdf

3) *Fossil Fuel Free Kristianstad*
http://www.energie-cities.org/meels/documents/case_studies/kristianstad_se.pdf

Swedish Biogas Industry Education Tour 2004: Observations and Findings
http://www.westernuniteddairymen.com/USDA%20Grant/WestStart-Calstart%20Swedish%20Biogas%20Tour%20Trip%20Report%206-04.pdf

4) *Phosphorous Recovery from Phosphate Rich Sidestreams in Wastewater Treatment Plants*
http://www.lwr.kth.se/forskningsprojekt/Polishproject/JPS10s47.pdf

5) *CRD's Managing Natural Resources and the Environment Sustainably*
http://www.crd.bc.ca/regionalplanning/growth/toolbox/naturalresources.htm

6) *CRD's Macaulay and Clover Point Wastewater and Marine Environment Program 2003 Annual Report*

7) *CRD Liquid Waste Management Study – 2004. The study was conducted by Ipsos-Reid from February 27th to March 3rd 2004, and included 1,515 interviews of CRD residents; overall results ± 2.6%, 19/20. Obtained through a Freedom of Information Request.*

8) *Personal communication with Jim MacIsaac, resident of North Saanich, 2005*

9) *Private prosecution under Section 36 (3) of the Fisheries Act*
http://www.sierralegal.org/m_archive/1998-9/pr99_02_04.htm
http://www.sierralegal.org/m_archive/1998-9/bk99_02_04.htm

10) *Sierra Legal Defence Fund, Petition No. 112 - Municipal wastewater discharges and pollution of the marine environment, April 27, 2004*
http://www.oag-bvg.gc.ca/domino/petitions.nsf/viewe1.0/cb5a8a2dc76cd57985256f0f0050a588?OpenDocument&Click=

11) *Sierra Legal Defence Fund, Clover and Macaulay Point outfalls – contaminated sites?*
http://www.sierralegal.org/reports/crd_sewage_analysis_10_15_2005.pdf

12) *Anaerobic Treatment Advantages*
http://www.draaisma.net/rudi/anaerobic_wastewater_treatment.html

13) *Experimental Determination of Energy Content of Unknown Organics in Municipal Wastewater Streams Ioannis Shizas 1 and David M. Bagley, Journal of Energy Engineering, Vol. 130, No. 2, August 1, 2004 and*
http://www.psigate.ac.uk/spotlight/issue20/farming.html

14) *Dockside Development Website*
http://www.docksidegreen.com/project_overview/index.php

15) *Summary of Individual Responses to Toronto's REOI on New and Emerging Waste Management Technologies* *http://www.toronto.ca/wes/techservices/involved/swm/net/pdf/oct15_review.pdf*

16) *Environmental Operators Certification Program* *http://www.eocp.org/plants.html*

17) *Enhanced stabilisation of sewage sludge through thermal hydrolysis – three years of experience with full scale plant, U. Kepp, I. Machenbach, N. Weisz and O.E. Solheim* *http://www.cambi.com/publications/sludge/cambi-athen10.99.PDF*

18) *Solid Waste Publications, Reports & Presentations* *http://www.crd.bc.ca/es/sw/publications.htm*

19) *Core Area Liquid Waste Management Committee Minutes* *http://www.crd.bc.ca/minutes/corearealiquidw_/index.htm*

20) *Personal conversation with Tembec's Environmental Manager, March 27, 2006*

21) *Heat from sewage could warm athletes' village, Vancouver Sun, March 22, 2006* *http://www.canada.com/vancouversun/news/story.html?id=5030534e-e92e-4336-8f52-ba891fafee4a&k=74067*

22) *Personal communication with three BC pulp mills in 2005*

23) *Saanich Peninsula Wastewater Treatment Plant* *http://www.eocp.org/spwwtp.html*