

**Bennett Environmental Inc**  
**Proposed Kirkland Lake Thermal**  
**Oxidizer Facility**

**Proposed Terms of Reference**

Pursuant to the Environmental Assessment Act

Background Document 3  
Rationale for the Chosen Technology

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## 1 INTRODUCTION

BEI has received requests from stakeholders to provide a rationale for the hazardous waste destruction technology proposed for the Kirkland Lake facility.

This document evaluates alternative treatment technologies for organic contaminated solids. For the proposed Kirkland Lake facility, Bennett Environmental Inc. (BEI) proposes to treat site remediation generated contaminated soil and debris. BEI is also proposing to treat organic contaminated solids generated from clean up and industrial activities such as spent activated carbon, packaging material, prompt wastes, etc. The main intent of the proposed facility is to thermally treat contaminated solid wastes and divert treatable waste from landfills.

Contaminated soil treatment technologies can be categorized into two major classifications namely ex situ and in situ. For industrial and prompt wastes ex situ technologies are the only options considered in this discussion.

Discussion in Section 2.1 leads BEI to conclude that the remediation of Persistent Organic Pollutant (POP) contaminated sites with in situ technologies is not viable at this time. There are ex situ treatment technologies that may be feasible under the appropriate circumstances and they are discussed in Table 1.

We focussed the evaluation on the following ex situ technologies:

- Enhanced Bioremediation
- Solidification/Stabilization
- Biopiles
- Slurry Phase Biological Treatment
- Chemical Extraction
- Chemical Reduction/Oxidation
- Dehalogenation (Catalyzed Dechlorination, APEG)
- Soil Washing
- Incineration
- Plasma Energy Pyrolysis
- Thermal Desorption
- Landfilling - Excavation, Retrieval, and Off-site
- Gas Phase Chemical Reduction (EcoLogic)
- Molten Metal/Molten Salt Oxidation
- Solvated Electron Technology

This list was generated based on public feedback to BEI to explore and review alternative technologies. BEI also reviewed a number of literature sources for information.<sup>1</sup>

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<sup>1</sup> The USEPA has consolidated the performance reporting of various treatment technologies under the Federal Remediation Technologies Roundtable ([www.frtr.gov](http://www.frtr.gov)). Case studies on 210 different sites are reported in the Federal Remediation Technologies Roundtable. Site remediation information has been compiled by the EPA Hazardous Waste Clean-up Information Web Site <http://www.clu-in.org>. The U.S. Department of Defense has summarized various ex situ remediation technologies at [www.em.doe.gov](http://www.em.doe.gov). A very good summary of ex situ treatments is discussed in an article at: [www.em.doe.gov/define/techs/exsitu2.html](http://www.em.doe.gov/define/techs/exsitu2.html)

The evaluation of each technology was based a number of criteria including:

1. Decontamination targets
2. Technology flexibility
3. Impact to host community
4. Permanence of Cleanup
5. Competitive Clean-up Costs
6. State of commercialization

The criteria for the technology assessment are based on BEI's experience as an equipment supplier and as an operator of waste treatment units.

### **1.1 Decontamination (clean up) Targets**

For POP or hazardous organic species present in the waste, the clean up target must be non-detect or less than the residential soil concentrations specified in the "*Guideline for Use at Contaminated Sites in Ontario*". Achieving this target clean up allows for maximum reuse of treated solids and total elimination of liability.

Of all the technologies examined, only high temperature thermal oxidation (incineration) in a rotary kiln and high temperature desorption were found to consistently achieve target clean up standards for all chlorinated and non-chlorinated organic compounds in all solid matrices. However, the high temperature desorption produces a concentrate residue that must be transferred to a licensed incineration facility to complete the destruction process. Incineration is the technology that can complete the job in one process.

### **1.2 Technology Flexibility**

Technology flexibility is important to:

- Treat a wide range of chemical compounds including POPs, hazardous organic semi-volatile and volatile wastes such as PAHs, PCBs, PCPs etc with equal success;
- Deal with a variety of physical matrices such as rocks, soil, aggregate, sediment, clay, rubble, debris, wet, and sticky materials encountered in clean up projects; and
- Treat low concentrations of hazardous organic compounds in a mixture of organic materials such as peat, plastics, coal, activated carbons, sawdust, wood-chips etc.

Certain technologies such as base catalyzed dechlorination and APEG are effective on chlorinated compounds but are less effective on non chlorinated and high boiling point compounds such as PAHs (Polycyclic Aromatic Hydrocarbons).

Certain processes such as bioremediation, APEG, dechlorination and chemical reduction/ oxidation, have difficulty penetrating the interior of porous media such as wood, rock, bricks etc.

Low temperature thermal desorption is effective only on low boiling point organic contaminants in a variety of solid matrices.

Incineration is effective on a wide range of organic contaminants in a variety of solid matrices.

### **1.3 Impact to Host Community**

Individual unit processes must be simple, reliable and robust. The technologies must be protective of employees, the community and the environment in the event of upsets such as power failures, spills, fires or operator errors. When taken together these factors represent the risk to the community.

Most of the technologies meet the low risk criterion. The only processes that are somewhat more risky due to the following factors include:

- Hydrogen reduction - due to potential explosion risks with hydrogen, and potential fugitive emissions due to positive pressure in the operating chamber.
- Solvated Electron Technology - due significant risk of fire and chemical reactivity from the use of ammonia and liquid sodium metal in the process.
- Solvent Extraction - due to risk of spill and fire when flammable solvents are utilized

### **1.4 Permanence of Clean Up**

The technology must offer a permanent and final solution to the contamination problem in order to prevent the transfer of the problem to future generations.

### **1.5 Competitive Treatment Costs**

The technology must offer affordable clean up solutions in order to be a commercial success.

Technologies must be shown to be reliable with an operating track record in the commercial market.

### **1.6 Conclusion**

Upon evaluation of the alternatives, BEI has selected high temperature thermal oxidation as the most suitable treatment technology for the anticipated market opportunity to treat organic contaminated soils and solids.

The U.S. EPA supports this conclusion:

*“In its development of UTS [Universal Treatment Standards], EPA identified incineration as BDAT [best demonstrated available technology] for all constituents identified for treatment standard development for K173 (except for the hepta- and octa- dioxins and furans, where UTS were not established). EPA similarly expects BDAT to be incineration for the remaining hepta- and octa- dioxin and furan compounds, based on their similar structure to the other dioxin and furan constituents.”<sup>2</sup>*

*“Treatment technologies are alternatives to on-site containment and off-site land disposal. Established treatment technologies are those for which cost and performance information is readily available. The most frequently used established technologies are on- and off-site incineration,*

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<sup>2</sup> USEPA, *Proposed Best Demonstrated Available Technology (BDAT) Document for Chlorinated Aliphatics Production Wastes – K173, K174, K175*, Section 4.3.4 Identification of BDAT for Nonwastewater Forms of K173, July 14, 1999. These are wastes that are generated from the production of Chlorinated Aliphatics. These wastes frequently contain pentachlorophenol, dioxins and furans

*solidification/stabilization, soil vapor extraction (SVE), thermal desorption, and pump-and-treat technologies for groundwater”<sup>3</sup>*

## **2 Remediation**

In general terms, remediation projects are categorized according to the following treatment regime:

- Ex situ soil remediation
- on site treatment
- off site treatment
- In situ soil remediation
- Debris/solid media treatment
- Groundwater remediation

BEI's primary business covers ex-situ remediation and prompt industrial debris/solid media treatment, and this discussion will be limited to the two market sectors.

### **2.1 In Situ Soil Remediation**

In situ soil remediation is outside of BEI's current core business plan. BEI has no plans to enter the in situ treatment field at this time.

There are organizations offering in situ treatment technologies for light hydrocarbon contaminated soils. The main advantage of the in situ process is that it allows soil to be treated without being excavated and transported, resulting in less disturbance at the site.

If in situ technologies such as enhanced bioremediation can reach the cleanup goal in a compatible time frame, it can save significant costs over methods involving excavation and transportation. Also, both contaminated ground water and soil can be treated simultaneously, providing additional cost advantages. In situ processes generally require longer time periods, however, and there is less certainty about the uniformity of treatment because of the inherent variability in soil and aquifer characteristics and difficulty in monitoring progress. Air emissions may result from certain types of in situ treatment.

The EPA has recorded 60 case studies of in situ soil remediation. In situ soil remediation technologies include phytoremediation, vitrification, bioventing, and electrokinetics, just to name a few. In situ treatment is widely utilized for the removal of chlorinated and non-chlorinated volatile species.

#### BEI's Evaluation

- Remediation times depend mainly on the degradation rates of specific contaminants, site characteristics, soil composition, treatment regime and climate.
- There is a risk of increasing contaminant mobility and leaching of contaminants into ground water.
- Regulators often do not accept the addition of nitrates and other nutrients or non-native microorganisms to contaminated soils.

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<sup>3</sup> Annual Status Report (Ninth Edition) Treatment Technologies Annual Status Report 1998, U.S. EPA, Technology Innovation Office <http://www.clu-in.org/products/asr/index2.html>

- BEI is not aware of the commercialization of in situ PCB soil remediation technologies that can consistently reduce high PCB concentrations (>100 ug/g PCBs) to the 5 ug/g concentration standard listed in Table A and B for residential soil in the "*Guideline for Use at Contaminated Sites in Ontario*".

## 2.2 Ex Situ Soil Remediation

Ex situ soil remediation involves the excavation of soil from the site and the subsequent treatment in an on site or off site treatment facility. A large number of ex situ soil remediation technologies exist for various contaminants. These technologies are in varying stages of commercialization.

The U.S. Federal Remediation Technologies Roundtable lists the following soil sediment and sludge treatment technologies: (<http://www.frtr.gov/matrix2/section1/toc.html>) The technologies marked with an \* are ex situ technologies and are reviewed in this document.

Bioventing	Chemical Reduction/Oxidation *
Enhanced Bioremediation *	Dehalogenation *
Land Treatment	Separation
Natural Attenuation	Soil Washing *
Phytoremediation	Soil Vapor Extraction
Electrokinetic Separation	Solar Detoxification
Fracturing	Solidification/Stabilization *
Soil Flushing	Hot Gas Decontamination
Soil Vapor Extraction	Incineration *
Soil Vapor Extraction, Thermally Enhanced	Open Burn/Open Detonation
Biopiles *	[Plasma Energy] Pyrolysis *
Composting	Thermal Desorption *
Fungal Biodegradation	Landfill Cap
Landfarming	Landfill Cap Enhancements
Slurry Phase Biological Treatment *	Excavation, Retrieval, and Off-Site Disposal *
Chemical Extraction *	

Public comments received during the draft Terms of Reference Consultation contained requests that the following technologies be considered:

1. Gas Phase Chemical Reduction (EcoLogic),
2. Molten Metal/ Molten Salt Oxidation,
3. Plasma Energy Pyrolysis

During literature review, BEI found Solvated Electron Technology as a possible candidate and included this technology to the list of technologies to be evaluated.

Each of the technologies reviewed has a niche in the impacted solids treatment marketplace. For the treatment market that BEI serves, BEI ranks the most environmentally, and economically viable technologies in the following order:

### Commercial Technologies:

1. High Temperature Thermal Treatment

2. Base Catalyzed Decomposition (form of Dehalogenation)

Emerging Technologies:

3. Gas Phase Chemical Reduction (EcoLogic Inc.)

4. Solvated Electron Technology (Commodore Applied Technologies)

The remaining technologies do not achieve the treatment goals or are still at the innovative (laboratory) stage of development.

Table 1 summarizes the capabilities of various ex situ treatment technologies.

## 2.3 Summary of Ex Situ Hazardous Waste Organic Treatment Technologies

Table 1: Summary of Ex Situ Hazardous Waste Organic Treatment Technologies

Technology	Concentration in decontaminated soil based on 500 ug/g of PCBs in feed	Estimated Treatment Cost (\$/Tonne)	High destruction efficiency for a Wide Range of Compounds	Effective on a wide variety of solid matrices, ie clay, debris, granular etc.	Effective on organic matrices such as peat, activated carbon, wood	Safety / Environmental Risk	State of Commercialization
Incineration (High Temperature Thermal Oxidation)	<0.001 ppm PCB <0.001 ppm for virtually all organic compounds	\$500 to \$1000	Yes	Yes	Yes	Negative pressure and simple, robust unit operations. No dangerous reagents involved. Public perception of risks.	Well proven technology. 30 permanent hazardous waste operations in the US, two in Canada.
Base Catalyzed Dechlorination	~10 ppm for PCBs	Sydney Australia Olympic Site proposed cleanup: CND\$4750/ Tonne	Not satisfactory for PAHs	No	Wastes that pyrolyze at low temperatures may produce excessive off gas flows	Process must be operated under nitrogen Atmosphere to prevent ignition of heated hydrocarbon.	Demonstrated on chlorinated materials
Glycolate / Alkaline Polyethylene Glycole (APEG) Dechlorination	~10 ppm for PCBs	US\$200 to \$500	Not satisfactory for PAHs	No	Yes	Produces a polyethylene contaminated wastewater	Demonstrated on chlorinated materials. Does not treat hydrocarbons.
Hydrogen Reduction (EcoLogic Inc.)	~2 ppm for PCBs	CND\$3508 to \$5263 for soil (Price listed in Australia: converted to Canadian \$.)	Yes – reaction must be monitored to ensure complete hydrogenation	Yes	High hydrogen usage rates	Hydrogen system is under positive pressure: risk of hydrogen leak or explosion. EcoLogic's attempt to clean soil in southern Ontario was abandoned.	One plant (Australia) currently in commercial operation. Presently can only treat small volumes of material.

<b>Technology</b>	<b>Concentration in decontaminated soil based on 500 ug/g of PCBs in feed</b>	<b>Estimated Treatment Cost (\$/Tonne)</b>	<b>High destruction efficiency for a Wide Range of Compounds</b>	<b>Effective on a wide variety of solid matrices, i.e. clay, debris, granular etc.</b>	<b>Effective on organic matrices such as peat, activated carbon, wood</b>	<b>Safety / Environmental Risk</b>	<b>State of Commercialization</b>
Solvated Electron Technology (Commodore Applied Technologies)	~10 ppm	Not yet operating commercially. No cost information available.	Not satisfactory for PAHs	Highly organic matrices require very large quantities of sodium or potassium reagent	Highly organic matrices require very large quantities of sodium or potassium reagent	System uses flammable potassium or sodium metal and anhydrous ammonia. These reagents are very reactive.	Capacity of single operational plant is 1 tonne per hour.
Low Temperature Desorption	~5 ppm for PCBs	\$40 to \$280	Not satisfactory for PAHs,	Yes	No	Negative pressure and simple-robust unit operations results in safe operation	Not recommended for POPs
High Temperature Desorption	No info?	Energy losses during Indirect Heat Transfer result higher operating costs than incineration	Concentrates organics into a liquid waste stream that must be transported and incinerated .	As indirect heating is utilized, feed must be crushed to a smaller feed size than incineration.	Wastes that pyrolize at low temperatures may produce excessive off gas flows.	Similar operation risks as high temperature incineration. Concentrated residue has to be transported off site.	Very few units in operation. Requires very exotic alloys for heat transfer kiln. Unit processing capacity low as indirect heat transfer is less efficient than incineration.
Enhanced Bio-Remediation (Including slurry phase bioremediation, biopiles etc.)	~100 ppm for PAHs and PCBs	\$30 to \$100	Destruction rates for POPs and PAHs are less than 90 %. Not satisfactory in cold weather.	Sticky, clayey materials do not allow permeability for oxygen transfer, bacteria contact, nutrition diffusion.		Potential odours to community unless site is completely contained. Breakdown product may be volatile and emitted to atmosphere.	Not recommended for POPs

<b>Technology</b>	<b>Concentration in decontaminated soil based on 500 ug/g of PCBs in feed</b>	<b>Estimated Treatment Cost (\$/Tonne)</b>	<b>High destruction efficiency for a Wide Range of Compounds</b>	<b>Effective on a wide variety of solid matrices, i.e. clay, debris, granular etc.</b>	<b>Effective on organic matrices such as peat, activated carbon, wood</b>	<b>Safety / Environmental Risk</b>	<b>State of Commercialization</b>
Chemical reduction / oxidation	~50 ppm for PCBs	\$200 to \$1000	Not satisfactory for PAHs	Depends on intimate mixing of chemical with solids. Pretreatment often required.	Certain organics may have too high of a chemical oxygen demand.	Certain reagents may be dangerous	Not recommended for POPs
Soil Washing	~100 ppm for PCBs	\$50 to \$250 plus disposal of concentrate	Not satisfactory for PAHs	No	Certain organic wastes may be too soluble and create too much waste. Fines create mud not recoverable	Concentrates sent to incinerator for destruction. Spill of contaminant laden liquids	It is Concentrating technology
Solvent Extraction (Chemical Extraction)	~10 ppm	US\$110 to \$440 for production of a concentrate. Disposal of concentrate?	Concentration Technology does not destroy contaminants. Requires a destruction technology	No	If the waste contains excessive quantities of soluble organics, treatment will not be feasible. fines slurry into mud and not recoverable	System uses solvents that may be flammable and or toxic, and hazardous to employees in case of leak. Concentrates incinerated	It is a Concentrating technology
Molten Salt Oxidation				Inert fraction of soil dilutes molten salt			
Plasma Energy Pyrolysis (Vanguard Research Inc.)				Inert fraction of soil produces enormous volumes of slag, high energy usage			
Molten Metal Oxidation (Molten Metal Inc.)				Inert fractions of soil dilutes molten metal			Molten Metal Inc. is bankrupt

<b>Technology</b>	<b>Concentration in decontaminated soil based on 500 ug/g of PCBs in feed</b>	<b>Estimated Treatment Cost (\$/Tonne)</b>	<b>High destruction efficiency for a Wide Range of Compounds</b>	<b>Effective on a wide variety of solid matrices, ie clay, debris, granular etc.</b>	<b>Effective on organic matrices such as peat, activated carbon, wood</b>	<b>Safety / Environmental Risk</b>	<b>State of Commercialization</b>
Solidification / stabilization			No destruction			Not appropriate for organic contaminants	Commonly used to stabilize heavy metals
Landfilling	Cannot accept PCB's over 50ppm	\$60 to \$300	No destruction	Yes	yes	Organic compounds are not destroyed	Fully Commercialized

### **3 Evaluation of Selected Ex-Situ Technologies**

#### **3.1 Incineration (High Temperature Thermal Oxidation)**

High temperatures, 870 to 1,200 °C (1,400 to 2,200 °F), are used to volatilize and combust (in the presence of oxygen) halogenated and other refractory organics in hazardous wastes. Often auxiliary fuels are employed to initiate and sustain combustion. The destruction and removal efficiency (DRE) for properly operated incinerators exceeds the 99.99% requirement for hazardous waste and can be operated to meet the 99.9999% requirement for PCBs and dioxins.

Incineration is a well-proven technology with simple, robust unit operations. It has proven to be effective on a wide variety of solid and organic matrices. There are no dangerous reagents involved. If operated with state of the art emissions control, environmental and health impacts are negligible. There are 30 permanent hazardous waste operations in the US and two in Canada. Incineration has been used for over 150 Superfund site remediation projects.

High treatment rates are achieved at fixed facilities. POP concentrations in treated solids are usually non-detect.

A detailed discussion of the specific High Temperature Thermal Oxidation (Incineration) technology selected by BEI is included in background document Background Document 4: Rationale for Incinerator Design.

##### BEI's Evaluation

- There is negative public perception surrounding emissions from incineration and dioxins in particular.
- Old technology and improperly operated facilities may produce unacceptable quantities of emissions.

#### **3.2 Dehalogenation**

##### **3.2.1 Base-catalyzed Dechlorination (BCD)<sup>4</sup>**

The BCD process involves the addition of an alkali or alkaline earth metal carbonate, bicarbonate or hydroxide to the contaminated medium containing one or more halogenated or non-halogenated organic contaminant compounds. The alkaline chemical may be added to the contaminated medium in an aqueous solution, or in a high boiling point solvent. Alkali is added to the contaminated medium. A hydrogen donor compound (eg. carbohydrate) is added to the mixture to provide hydrogen ions for reaction with the halogenated and non-halogenated contaminants, if these ions are not already present in the contaminated material or solvent.

The mixture is heated to totally dehydrate the medium and further heated at a temperature between 200°C and 400°C for a time sufficient to effect reductive decomposition of the halogenated and non-halogenated organic contaminant compounds, typically 0.5 to 2 hours. At this temperature the carbon source (eg. the

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<sup>4</sup> The reference for the material contained in this section is <http://www.environment.gov.au/epg/swm/swtt/base.html> et al.).

carbohydrate) acts as a catalyst for the formation of a reactive hydrogen ion from the hydrogen donor compound. The reactive hydride ion then reacts with the halogenated organic compounds contained in the contaminated medium to reduce the contaminated compound. Finally, the mixture is neutralized by the addition of an acid. Depending on the nature of the feed material, the reagent additions and the site use, it may be possible for the treated material to be returned to the site if desired, although this may not be possible if the treated material is oily or has a high salt content.

The treatment is usually carried out as a batch process with all steps completed within a single reactor.

The potential to form dioxins and furans in the BCD process is low, particularly when the system is operating under an inert atmosphere. In addition, any dioxins formed in the process should be subsequently dechlorinated in the system. As such, the risk associated with emissions from the normal operation of the system is relatively low, although in general the destruction efficiencies are not as high as can be achieved by high temperature combustion systems. However, as the system is operated on a batch basis, the treatment efficiency can be controlled by extending the treatment time when required.

### BEI's Evaluation

- The treatment of chlorinated aromatic hydrocarbons by the removal of chlorine atoms results in an increased concentration of lower chlorinated species (eg higher chlorine congeners are replaced by lower chlorine congeners). This is not a problem with contaminants such as PCBs. However, with constituents such as dioxins the lower congeners (e.g. TCDD) can have a higher toxicity than the more highly chlorinated congeners (e.g. OCDD). Therefore the process must be monitored to ensure that the reaction continues to completion.
- This technology is not satisfactory for the treatment of PAHs.
- Air in leak could result in auto ignition of the oil phase at the reaction temperature resulting in a uncontrolled emission to air. The provision of a nitrogen atmosphere over the reactor is designed to ensure that this cannot occur. The occurrence of a fire in 1995 at the Victorian (Australia) BCD facility operated by Technosafe was apparently the result of operation of a storage vessel without a nitrogen blanket.
- When contaminated soil is treated directly by the BCD process, the resulting soil is likely to be oily and disposal options may be limited. For example, the soil may require disposal in a secure landfill.
- To avoid the oily soil problem, some suppliers of the BCD process now propose the use of a thermal desorption unit (TDU) to remove these contaminants, to concentrate them into a liquid phase for separate treatment by the BCD process. As such, the soil is not treated directly by the BCD process and the BCD reagents (including alkali and hydrocarbons) are not added directly to the soil. Thermal Desorption systems are subject to the limitations discussed in the section on Low Temperature Thermal Desorption.
- This technology is limited by its high cost. For example,

*The [Australian] Olympic Co-ordination Authority has chosen ADI as the preferred tenderer to treat 400 tonnes of excavated soil containing chemical waste on-site... will use two safe, proven technologies to destroy the waste. These include:*

- *Heating to separate chemicals from the soil - a process known as indirect thermal desorption (ITD);) and*
- *Decomposition to destroy the chemicals through reversing the process by which they were made. This is known as base catalysed decomposition (BCD).*

*The proposed clean-up methods require approval from the NSW Environment Protection Authority, following which a plant will be commissioned on-site to carry out the clean-up at a cost of around \$2.3 million [Australian Dollars].*<sup>5</sup>

This works out to approximately CDN\$4,750 /tonne.

### 3.2.2 Glycolate/Alkaline Polyethylene Glycol (APEG)

Glycolate Dehalogenation is a technology in which an alkaline polyethylene glycol (APEG) reagent is used to dehalogenate halogenated aromatic compounds. Potassium polyethylene glycol (KPEG) is the most common APEG reagent. Contaminated soils and the reagent are mixed and heated in a treatment vessel. In the APEG process, the reaction causes the polyethylene glycol to replace halogen molecules and render the compound nonhazardous or less toxic. The reagent (APEG) dehalogenates the pollutant to form a glycol ether and/or a hydroxylated compound and an alkali metal salt, which are water-soluble byproducts.

The contaminant is partially decomposed rather than being transferred to another medium.

Glycolate process has been used to successfully treat contaminant concentrations of PCBs from less than 2 ppm to reportedly as high as 45,000 ppm. This technology has received approval from the EPA's Office of Toxic Substances under the Toxic Substances Control Act for PCB treatment.

The APEG process has been used for cleanup of PCB-contaminated soils at a small number of Superfund sites: Wide Beach in Erie County, New York (September 1985); Re-Solve in Massachusetts (September 1987); and Sol Lynn in Texas (March 1988).

A continuous feed, full-scale PCB treatment system completed a remediation project in Guam.

The concentrations of PCBs that have been treated are reported to be as high as 45,000 ppm. Concentrations were reduced to less than 2 ppm per individual PCB congener [There are 109 PCB congeners, total PCB concentration not given]. PCDDs and PCDFs have been treated to nondetectable levels at parts per trillion sensitivity. The process has successfully destroyed PCDDs and PCDFs contained in contaminated pentachlorophenol oil. For a contaminated activated carbon matrix, direct treatment was less effective, and the reduction of PCDDs/PCDFs to concentrations less than 1 ppb was better achieved by first extracting the carbon matrix with a solvent and then treating the extract.

The cost for full-scale operation is estimated to be in a range of \$220 to \$550 per metric ton and does not include excavation, refilling, residue disposal, or analytical costs. Factors such as high clay or moisture content may raise the treatment cost slightly.

#### BEI's Evaluation

- The treatment process produces a polyethylene contaminated wastewater which must be treated by chemical oxidation, biodegradation, carbon adsorption, or precipitation.
- The technology is less effective on certain halogenated VOC's (Volatile Organic Compounds) and is not satisfactory for the treatment of PAHs.

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<sup>5</sup> Ref: [http://www.adi-limited.com.au/newsletter/41/onsi\\_clea.html](http://www.adi-limited.com.au/newsletter/41/onsi_clea.html)

- The treatment of chlorinated aromatic hydrocarbons by the removal of chlorine atoms results in an increased concentration of lower chlorinated species (eg higher congeners are replaced by lower congeners). This is not a problem with contaminants such as PCBs. However, with constituents such as dioxins the lower congeners (eg TCDD) can have a higher toxicity than the more highly chlorinated congeners (eg OCDD). Therefore the process must be monitored to ensure that the reaction continues to completion.

### 3.2.3 Solvated Electron Technology

Commodore Applied Technologies is attempting to commercialize a “solvated electron treatment”(SET™) process (a.k.a SoLV™ process.) Currently the process is in the pilot plant stage with a plant capacity of one tonne/hour.

This process is a version of based catalyzed dechlorination, and uses sodium metal or calcium-metal generated solvated electrons as a reducing agent. Solvated electrons are formed when alkali or alkaline earth metals dissolve, with no net reaction, in solvents such as ammonia, amines, and ethers, forming metal ions and free electrons. Commodore employs sodium as the reactant in its processes and has developed its technology using anhydrous ammonia as the solvent because it is easily recycled.

Soil is prepared by excavation, screened to remove debris, and dewatered to <30% (if required). The prepared soil is placed into the treatment vessel, liquid anhydrous ammonia is added to the sealed vessel at room temperature, and the vessel rotates, tumbling the soil like a cement mixer.

After mixing to form a soil/ammonia slurry, elemental calcium or sodium is added to the slurry and mixing continues until the slurry conductivity indicates the reaction is complete.

Commodore’s promotional literature claims that for PCBs, ions of chlorine combine with ions of sodium, and sodium chloride is formed, leaving no toxic agents whatsoever. It is not clear to BEI what happens to the carbon.

The reacted slurry is transferred to an ammonia/soil separation vessel where the ammonia is separated from the soil as a liquid until most of the ammonia is removed. The separator is then rotated, warming the soil and driving off the remaining ammonia as a vapor, which is collected, along with the liquid, in the ammonia/water separator. Water is separated from the ammonia for return to the cleaned soil. The ammonia is returned to the main ammonia storage tank for reuse.

#### BEI’s Evaluation

- The treatment of chlorinated aromatic hydrocarbons by the removal of chlorine atoms results in an increased concentration of lower chlorinated species (eg higher congeners are replaced by lower congeners). This is not a problem with contaminants such as PCBs. However, with constituents such as dioxins the lower congeners (eg TCDD) can have a higher toxicity than the more highly chlorinated congeners (eg OCDD). Therefore the process must be monitored to ensure that the reaction continues to completion.
- The process is not satisfactory for PAHs.
- The process requires handling of anhydrous ammonia.<sup>6</sup>

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<sup>6</sup> Anhydrous ammonia is an irritant that is corrosive to skin, eye, respiratory tract and mucous membranes. It may cause severe burns, eye and lung injuries (Eye: lachrymation, edema, blindness. Skin: irritation, corrosive burns, blister formation). Contact with the liquid will freeze the tissue, then produce a caustic burn. Heavy, acute exposure

- Ammonia contact with chemicals such as mercury, chlorine, iodine, bromine, silver oxide, or hypochlorites can form explosive compounds. There are special hazards with chlorine that result in the formation of chloramine gas.
- This process utilizes sodium metal, which is extremely reactive and may ignite spontaneously on exposure to air. Sodium Metal must be stored under an inert atmosphere in an oxygen-free liquid (e.g. certain petroleum oils).

### **3.3 Gas Phase Chemical Reduction (EcoLogic Process)**

Gas Phase Chemical Reduction is a process patented by ELI EcoLogic Inc. EcoLogic currently operates a treatment facility in Kiwanas, Australia.

Environment Australia published an evaluation of the EcoLogic Kiwanas facility<sup>7</sup>. The following is paraphrased from this evaluation:

The ECO LOGIC Process involves the gas-phase chemical reduction of organic compounds by hydrogen at temperatures of 850°C or greater. Organic compounds are ultimately reduced to methane, hydrogen chloride, and minor amounts of low molecular weight hydrocarbons (benzene and ethylene). The hydrochloric acid is neutralized by addition of caustic soda during initial cooling of the process gas.

Since the Eco Logic technology is a hydrogenation process and will add hydrogen atoms to any incompletely hydrogenated organic molecule, it will dechlorinate molecules and break down aromatic rings, and is therefore indiscriminate in its treatment of organic substances. For this reason, it can be expected to treat PCP similarly to PCB, HCB and dioxins, and can also extend to other non-halogenated compounds such as PAHs. However, throughput will be determined by the total contamination of organics in the waste rather than just the scheduled components.

EcoLogic's technology achieves excellent destruction efficiencies on a wide range of concentrated organic compounds in liquid or gas form, or in small volumes of solid matrix.

#### BEI's Evaluation

- EcoLogic was contracted by an industrial company in Ontario to destroy PCB liquids and to treat a large quantity of PCB impacted soil. EcoLogic's process successfully treated the PCB liquids, however attempts to treat the impacted soil failed and the project was abandoned. The soil was ultimately sent to BEI's Récupère Sol Inc. facility where it was successfully treated.
- The process operates under slightly positive pressure with a danger of contaminant escape if leak develops.
- Air ingress could form an explosive hydrogen / air mixture. At process temperatures this mixture could ignite explosively. This situation could potentially result in a large atmospheric release of contaminants, and endanger worker safety.

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by inhalation may result in severe irritation of the respiratory tract, glottal edema, bronchial spasm, pulmonary edema and respiratory arrest. Chronic effects can include bronchitis. Extreme exposure (5000 ppm) can cause immediate death from spasm, inflammation or edema of larynx.

<sup>7</sup> Reference: *CMPS&F - Environment Australia: Appropriate Technologies for the Treatment of Scheduled Wastes Review Report Number 4 - November 1997*

[http://www.environment.gov.au/epg/swm/swtt/eco\\_logic.html](http://www.environment.gov.au/epg/swm/swtt/eco_logic.html)

- A reliable source of hydrogen is also required.
- The system is complex, increasing the risk of failure or operator error.
- Treatment of highly organic matrices (wood, peat, humus etc.) may require enormous quantities of hydrogen.
- This technology is limited by its high cost (\$4000-\$6000/tonne – AUD; \$3508-\$5263/tonne Cdn)
- Given its size, the plant is not readily transportable and a significant set up time would be required for its relocation. As such, it is likely the unit would be operated from a fixed location within a region and waste transported to the facility.
- In principle, the Eco Logic process can be applied to volatile solvent mixtures. However, care would be required to avoid high rates of gas generation that could over-pressurize the systems. As the process has limited surge capacity, over pressurization could result in a release of waste material.
- The treated gas may contain products of incomplete reaction such as benzene.
- The treatment of chlorinated aromatic hydrocarbons the removal of chlorine atoms results in an increased concentration of lower chlorinated species (eg higher congeners are replaced by lower congeners). This is not a problem with contaminants such as PCBs. However, with constituents such as dioxins the lower congeners (eg TCDD) can have a higher toxicity than the more highly chlorinated congeners (eg OCDD). Therefore the process must be monitored to ensure that the reaction continues to completion.
- When treating high organic containing solids, the competing demands for reduction chemicals may reduce the removal of the more refractory POP compounds.
- There are no commercial operations treating large volumes of contaminated solids.

The Eco Logic is proposing to precede the gas-phase chemical reduction system with a thermal desorption unit in order to overcome the limitations when treating solid wastes. To this end, EcoLogic has an agreement with Torftech (Canada) Inc. to use Torftech's proprietary Torbed fluidized bed reactor technology in order to separate contaminants from solids with the evolved gasses to be treated by EcoLogic's process.

- As the Torbed thermal desorption step has not yet been tested in full operation, the efficiency of the thermal desorption unit (Torbed) and its ability to completely desorb organic contaminants in a wide variety of solid matrices must wait assessment. The application of the thermal desorption unit to irregular solids such as concrete (containing reinforcing materials) is uncertain. Material sizing is critical in any fluidized bed technology. Material handling considerations for such wastes may restrict the application of the process.
- There is low throughput on existing units. The Kiwanas facility is expected to increase capacity to 100 Tonnes/ month in 2000.<sup>8</sup>

### **3.4 Enhanced BioRemediation<sup>9</sup>**

Enhanced bioremediation is a process in which indigenous or inoculated micro-organisms (e.g., fungi, bacteria, and other microbes) degrade (metabolize) organic contaminants found in soil and/or ground water, converting them to volatile shorter chain compounds or innocuous end products. Nutrients, oxygen, or other amendments may be used to enhance bioremediation and contaminant desorption from subsurface materials.

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<sup>8</sup> Ref. EcoLogic website: [www.eco-logic-intl.com/Kiwana.html](http://www.eco-logic-intl.com/Kiwana.html). The proposed BEI facility will be capable of treating this mass of (low concentration) solid wastes in two hours.

<sup>9</sup> The reference for this section is (Ref: [http://www.frtr.gov/matrix2/section4/4\\_2.html](http://www.frtr.gov/matrix2/section4/4_2.html)).

Bioremediation techniques have been successfully used to remediate soils, sludges, and ground water contaminated with petroleum hydrocarbons, solvents, pesticides, wood preservatives, and other organic chemicals. Bench- and pilot-scale studies have demonstrated the effectiveness of anaerobic microbial degradation of nitrotoluenes in soils contaminated with munitions wastes. Bioremediation is especially effective for remediating low level residual contamination in conjunction with source removal.

Typical costs for enhanced bioremediation range from \$30 to \$100 per cubic meter (\$20 to \$80 per cubic yard) of soil. Variables affecting the cost are the nature and depth of the contaminants, and use of bioaugmentation.

Where biological treatment of the contaminated material is effective, the generator, due to the significantly lower cost of treatment, will normally select biological treatment where available. Incineration of this material will only be selected where time, space or climate constraints limit the use of biological treatment, or where the generator wishes to achieve more stringent cleanup criteria.

Biological treatment may be aerobic or anaerobic or a combination of the two.

### ***Aerobic***

In the presence of sufficient oxygen (aerobic conditions), and other nutrient elements, microorganisms will ultimately convert many organic contaminants to carbon dioxide, water, and microbial cell mass.

### ***Anaerobic***

In the absence of oxygen (anaerobic conditions), the organic contaminants will be ultimately metabolized to methane, limited amounts of carbon dioxide, and trace amounts of hydrogen gas. Under sulfate-reduction conditions, sulfate is converted to sulfide or elemental sulfur, and under nitrate-reduction conditions, nitrogen gas is ultimately produced.

### **BEI's Evaluation**

- Persistent Organic Pollutants are by definition not readily treated by biodegradation. Most chlorinated compounds and some non-chlorinated compounds are biocides and are not readily destroyed by biological treatment. Destruction rates for POPs and PAHs are less than 90%.
- Sometimes contaminants may be degraded to intermediate or final products that may be less, equally, or more hazardous than the original contaminant. For example, TCE anaerobically biodegrades to the persistent and more toxic vinyl chloride. To avoid such problems, most bioremediation projects are conducted in situ. Vinyl chloride can easily be broken down further if aerobic conditions are created.
- Although successful in situ bioremediation has been demonstrated in cold weather climate, low temperature slows the remediation process. For contaminated sites with low soil temperature, heat blankets may be used to cover the soil surface to increase the soil temperature and the degradation rate.
- Cleanup goals may not be attained if the soil matrix prohibits contaminant-microorganism contact.
- Mass transfer limitations in certain matrices may restrict the ability of the biological agent (bacteria, fungus, plant, enzyme etc.) to reach the contaminant. For example, the nutrients and bacteria may not have access to contaminants located in the center of clay lumps.

- The circulation of water-based solutions through the soil may increase contaminant mobility and necessitate treatment of underlying ground water.
- Preferential colonization by microbes may occur causing clogging of nutrient and water injection wells.
- Preferential flow paths may severely decrease contact between injected fluids and contaminants throughout the contaminated zones. The system should not be used for clay, highly layered, or be a heterogeneous subsurface environment because of oxygen (or other electron acceptor) transfer limitations.
- High concentrations of heavy metals, highly chlorinated organics, long chain hydrocarbons, or inorganic salts are likely to be toxic to microorganisms.
- Remediation times are often measured in years, depending mainly on the degradation rates of specific contaminants, soil characteristics, site characteristics, and climate.
- There is a risk of increasing contaminant mobility and leaching of contaminants into ground water.
- Regulators often do not accept the addition of nitrates, bulking agents or non-native microorganisms to contaminated soils.
- In certain situations, biological breakdown of contaminants is not necessarily complete nor predictable. The contaminants may be broken down to more volatile compounds that are vented to the atmosphere. Breakdown products may also be more hazardous due to their volatile nature.

Bioremediation may occur in situ (soil treated in place) or ex situ (soil excavated for treatment). In situ treatment is compared with ex situ treatment in 2.1.

Ex Situ Bioremediation technologies include BioPiles and Slurry Phase Biological Treatment. Each is discussed below.

### 3.4.1 BioPiles

Biopile treatment<sup>10</sup> is a full-scale technology in which excavated soils are mixed with soil amendments and placed on a treatment area that includes leachate collection systems and some form of aeration. It is used to reduce concentrations of petroleum constituents in excavated soils through the use of biodegradation. Moisture, heat, nutrients, oxygen, and pH can be controlled to enhance biodegradation.

The treatment area will generally be covered, inside a shelter, or contained with an impermeable liner to minimize the risk of contaminants leaching into an uncontaminated soil. The drainage itself may be treated in a bioreactor before recycling. Soil piles may be covered with plastic to control runoff, evaporation, and volatilization and to promote solar heating. If there are VOCs in the soil that will volatilize into the air stream, the air leaving the soil may be treated to remove or destroy the VOCs before they are discharged to the atmosphere.

Duration of operation and maintenance may last a few weeks to several months.

Bennett Environmental's Récupère Sol Inc. (RSI) facility was a BioPile soil treatment facility prior to installation of the Thermal Oxidizer. The Thermal Oxidizer was installed at RSI originally in response to the fact that the BioPile technology did not work for many types of organic contaminated soils, especially those contaminated with heavier hydrocarbons such as PAHs and aromatic compounds.

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<sup>10</sup> The reference for this section is [http://www.frtr.gov/matrix2/section4/4\\_12.html](http://www.frtr.gov/matrix2/section4/4_12.html).

### 3.4.2 Slurry Phase Biological Treatment<sup>11</sup>

An aqueous slurry is created by combining contaminated soil, sediment, or sludge with water and other additives. The solids are maintained in suspension in a reactor vessel and mixed with nutrients and oxygen. If necessary, an acid or alkali may be added to control pH.

Microorganisms also may be added if a suitable population is not present. When biodegradation is complete, the soil slurry is dewatered. Dewatering devices that may be used include clarifiers, pressure filters, vacuum filters, sand drying beds, or centrifuges.

Slurry Phase Bioremediation techniques have been successfully used to remediate soils, sludges, and sediments contaminated by explosives, petroleum hydrocarbons, petrochemicals, solvents, pesticides, wood preservatives, and other organic chemicals. Sequential anaerobic/aerobic slurry-phase bioreactors containing cometabolites and specially adapted microorganisms are used to treat PCBs, halogenated SVOCs, pesticides, and ordnance compounds found in excavated soils or dredged sediments.

Bioreactors are favored over in situ biological techniques for heterogenous soils, low permeability soils, areas where underlying ground water would be difficult to capture, or when faster treatment times are required.

Slurry-phase bioreactors are both used to treat halogenated VOCs and SVOCs, pesticides, and PCBs in excavated soils and dredged sediments.

#### BEI's Evaluation

- Excavation of contaminated media is required, except for lagoon implementation.
- Sizing of materials prior to putting them into the reactor can be difficult and expensive. Nonhomogeneous soils and clayey soils can create serious materials handling problems.
- Dewatering soil fines after treatment can be expensive.
- An acceptable method for disposing of non-recycled wastewaters is required.
- Bioreactor off-gas has to be further treated because of the presence of volatile compounds.
- Long treatment times are necessary. Residence time in the bioslurry reactors will vary depending on the nature of the contaminants, their concentrations, and the desired level of removal. Residence time is typically 5 days for PCP-contaminated soil, 13 days for a pesticide-contaminated soil, and 60 days for refinery sludge.

Treatment costs using slurry reactors range from \$130 to \$200 per cubic meter (\$100 to \$150 per cubic yard). Costs ranging from \$160 to \$210 per cubic meter (\$125 to \$160 per cubic yard) are incurred when the slurry-bioreactor off-gas has to be further treated because of the presence of volatile compounds<sup>12</sup>.

### 3.5 Chemical Extraction<sup>13</sup>

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<sup>11</sup>The reference for this section is [http://www.frtr.gov/matrix2/section4/4\\_16.html](http://www.frtr.gov/matrix2/section4/4_16.html).

<sup>12</sup> The reference for these costs is [http://www.frtr.gov/matrix2/section4/4\\_16.html](http://www.frtr.gov/matrix2/section4/4_16.html).

<sup>13</sup> The references for this section are [http://www.frtr.gov/matrix2/section4/4\\_17.html](http://www.frtr.gov/matrix2/section4/4_17.html), and <http://enviro.nfesc.navy.mil/esc414/Techinfo/shortlist/shortlist.htm>

Contaminated soil and extractant are mixed in an extractor, dissolving the contaminants. The extracted solution is then placed in a separator, where the contaminants and extractant are separated for treatment and further use.

Chemical extraction does not destroy wastes, but is a means of separating hazardous contaminants from soils, sludges, and sediments, thereby reducing the volume of the hazardous waste that must be treated. The technology uses an extracting chemical and differs from soil washing, which generally uses water or water with wash-improving additives such as detergents. Commercial-scale units are in operation. They vary in regard to the chemical employed, type of equipment used, and mode of operation.

Physical separation steps are often used before chemical extraction to grade the soil into coarse and fine fractions, with the assumption that the fines contain most of the contamination. Physical separation can also enhance the kinetics of extraction by separating out particulate heavy metals, if these are present in the soil.

### 3.5.1 Solvent Extraction

Solvent extraction is a common form of chemical extraction using organic solvent as the extractant. It is commonly used in combination with other technologies, such as solidification/stabilization, incineration, or soil washing, depending upon site-specific conditions.

Solvents used include various alcohols, and various amine compounds.

Solvent extraction has been shown to be effective in treating certain sediments, sludges, and soils containing primarily organic contaminants such as PCBs, VOCs, halogenated solvents, and petroleum wastes.

#### BEI's Evaluation

- The solvents used are typically flammable. The flammability of the solvent produces the unacceptable risk of fire. An uncontrolled fire of POP contaminated solvent would not reach the temperatures required for complete destruction of the POP and solvent molecules resulting in the potential release of significant quantities of furans and dioxins into the environment.
- Solvent extraction does not destroy wastes, but is a means of separating hazardous contaminants from soils, sludges, and sediments, thereby reducing the volume of the hazardous waste that must be treated. The solvent is typically distilled to create a POP concentrate that is ultimately sent for incineration.
- Some soil types and moisture content levels will adversely impact process performance.
- Higher clay content may reduce extraction efficiency and require longer contact times.
- Organically bound metals can be extracted along with the target organic pollutants, which restricts handling of the residuals.
- The presence of detergents and emulsifiers can unfavorably influence the extraction performance.
- Solvent remains in the treated solids; the toxicity of the solvent is an important consideration.
- Solvent extraction is generally least effective on very high molecular weight organic and very hydrophilic substances.
- After acid extraction, any residual acid in treated soil needs to be neutralized.
- Capital costs can be relatively high and the technology may be more economical at larger sites.
- The technology has not proven effective on soils with high clay content, high moisture content or with large fractions of humic matter.

- Meeting highly stringent heavy metals criteria (e.g. passing the California WET test) may prove uneconomical.

The technology is available from select vendors. Cost estimates for this technology range from US\$110 to US\$440/metric ton (US\$100 to US\$400/ton) plus the cost of treatment or disposal of the concentrates.

### **3.6 Chemical Reduction / Oxidation**

Reduction/oxidation (redox) reactions chemically convert hazardous contaminants to nonhazardous or less toxic compounds that are more stable, less mobile, and/or inert. Redox reactions involve the transfer of electrons from one compound to another. Specifically, one reactant is oxidized (loses electrons), and one is reduced (gains electrons).

The target contaminant group for chemical redox is inorganics. The technology can be used but may be less effective against nonhalogenated VOCs and SVOCs, fuel hydrocarbons, and pesticides.

There are three major methods by which Chemical Oxidation is achieved:

- permanganate
- Fenton's reagent
- Ozonation.

Other oxidizing agents that can be used for treatment of hazardous contaminants are hydrogen peroxide, hypochlorites, chlorine, and chlorine dioxide.

#### BEI's Evaluation

- Incomplete oxidation or formation of intermediate contaminants may occur depending upon the contaminants and oxidizing agents used.
- The process is not satisfactory for PAHs or recommended for POPs.
- The process is not cost-effective for high contaminant concentrations because of the large amounts of oxidizing agent required.
- Oil and grease in the media should be minimized to optimize process efficiency.
- There is difficulty in mass transfer of oxidants in soil matrices, especially clay.
- It requires extensive soil preparation and handling.
- Certain reagents may be dangerous.

### **3.7 Thermal Desorption**

Thermal desorption is a physical separation process and is not designed to destroy organic contaminants. Wastes are heated to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system. The bed temperatures and residence times designed into these systems will volatilize selected contaminants but will typically not oxidize them.

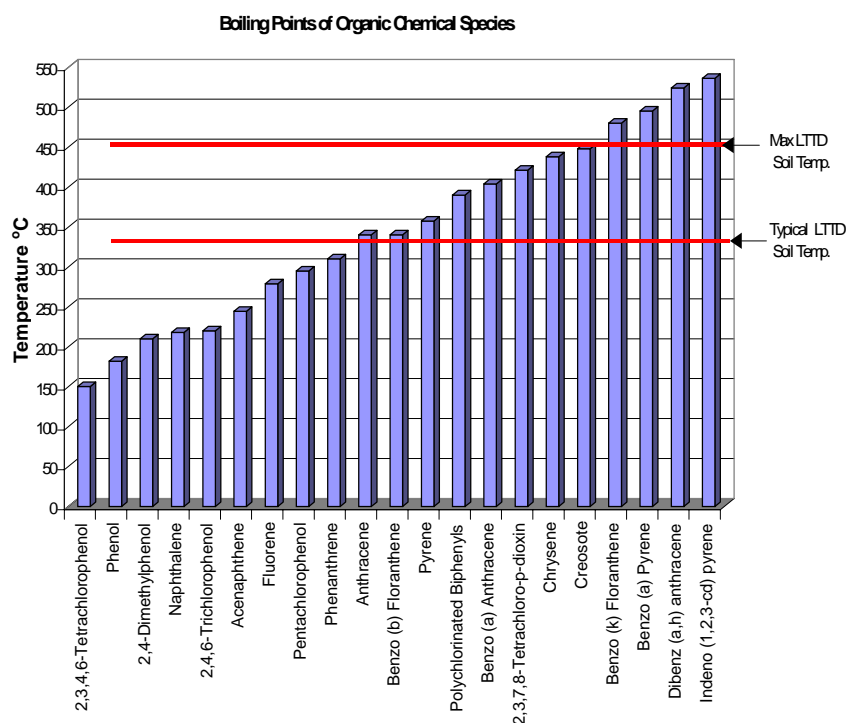
Two common thermal desorption designs are the rotary dryer and thermal screw. Rotary dryers are horizontal cylinders that can be indirect- or direct-fired. The dryer is normally inclined and rotated. For the thermal screw units, screw conveyors or hollow augers are used to transport the medium through an

enclosed trough. Hot oil or steam circulates through the auger to indirectly heat the medium. All thermal desorption systems require treatment of the off-gas to remove particulates and contaminants. Particulates are removed by conventional particulate removal equipment, such as wet scrubbers or fabric filters. Contaminants are removed through condensation followed by carbon adsorption, or they are destroyed in a secondary combustion chamber or a catalytic oxidizer. Most of these units are transportable.

Based on the operating temperature of the desorber, thermal desorption processes can be categorized into two groups: high temperature thermal desorption (HTTD) and low temperature thermal desorption (LTTD).

Figure 1 illustrates the limitations of Thermal Desorption Systems. In order to indirectly heat the soil, the shell of the desorber must be able to handle the high temperatures required without warping, while still providing efficient heat transfer across the shell. The solid must then be capable of efficiently transferring the heat throughout the matrix. Many solid matrices such as clays have insulating properties. To overcome the insulating properties, a large residence time and/or a high temperature differential are required. These heat transfer limitations limit the capability of LTTD units to desorb higher boiling organic contaminants. Solid matrix temperatures typically achievable by indirect heating are typically limited to about 450°C. Most Desorption systems achieve even lower temperatures. These temperatures are not sufficient to desorb all species organic contaminants.

Figure 1- Boiling Points of Organic Chemical Species



Rates charged to remediate petroleum hydrocarbon contaminated soil range from \$45 to \$330 per metric ton (\$40 to \$300 per ton) of soil. Of this cost, approximately \$20 to \$35 per metric ton (\$15 to \$30 per ton) is required for direct operating costs such as utility consumption and repair. Vendors typically perform preventive maintenance, such as lubrication, on a daily basis. Unit transportation and setup costs are typically \$3.30 to \$5.50 per metric ton (\$3 to \$5 per ton), seldom exceeding a mobilization cost of \$200,000.

### 3.7.1 High Temperature Thermal Desorption (HTTD)

HTTD is a full-scale technology in which wastes are heated to 320 to 560 °C (600 to 1,000 °F). HTTD is frequently used in combination with incineration, solidification/stabilization, or dechlorination, depending upon site-specific conditions. The technology has proven it can produce a final contaminant concentration level below **5 mg/kg** for the target contaminants identified.

#### BEI's Evaluation

- The technology has higher operating costs and a lower processing capacity than incineration.
- The technology concentrates organics into a waste stream that must be processed separately.
- As indirect heating is used, the feed must be crushed to a smaller feed size than incineration.
- Wastes that pyrolyze at low temperatures may produce excessive off gas flows. However, it is quite safe because volumes of off gases are minimal.
- There is a limited commercial track record since there are very few units in operation.
- It requires exotic alloys in the kiln.

### 3.7.2 Low Temperature Thermal Desorption (LTTD)

In LTTD, wastes are heated to between 90 and 320 °C (200 to 600 °F). LTTD is a full-scale technology that has been proven successful for the remediation of light petroleum hydrocarbon contamination in all types of soil. Contaminant destruction efficiencies in the afterburners of these units are greater than 95%. The same equipment could probably meet stricter requirements with minor modifications, if necessary. Decontaminated soil retains its physical properties. Unless being heated to the higher end of the LTTD temperature range, organic components in the soil are not damaged, which enables treated soil to retain the ability to support future biological activity.

Low Temperature Thermal Desorbers (LTTD) attempt to clean soil by directly or indirectly heating the soil. LTTDs are frequently used for hydrocarbon contaminated soils, however heat transfer limitations have limited the ability of these units to clean the soils to below target levels for POP compounds.

Various off gas treatment technologies have been applied to LTTD units, each varying in efficacy.

#### BEI's Evaluation

- There are specific particle size and materials handling requirements that can impact applicability or cost at specific sites.
- Dewatering may be necessary to achieve acceptable soil moisture content levels.
- Highly abrasive feed potentially can damage the processor unit.
- Heavy metals in the feed may produce a treated solid residue that requires stabilization.
- Clay and silty soils and high humic content soils increase reaction time as a result of binding of contaminants.
- LTTD is not satisfactory for PAHs or PCBs, or POPs.

## 3.8 *Molten Salt Oxidation*

Molten Salt Oxidation reacts solid, liquid and other waste feeds with slightly more air than that required for oxidation, simultaneously injecting the waste into a bath of molten salt (usually  $\text{Na}_2\text{CO}_3$ ). The waste reacts to form carbon dioxide, steam and salt residues.

Molten Salt Oxidation is targeted at concentrated liquid waste streams.

#### BEI's Evaluation

- Soil is too high in inerts to put into the molten salt bath. The inert fraction would dilute the salt bath, produces large volumes of residue, and use excessive amounts of energy.<sup>14</sup>
- MSO cannot treat contaminated soil as it would produce more waste than the original soil feed.
- To treat contaminated soil, the soil would have to be desorbed in a kiln and the off gas would then be treated by MSO.

### **3.9 Molten Metal Oxidation**

The Molten Metal Oxidation “*process uses a normal steel converter with molten iron or slag to heat a waste. Molten iron, which is the heat source for the process, has a high heat capacity, that is, it heats relatively slowly, retains heat, and cools slowly. The following description of the process has been adapted from information contained in the Report from the Independent Panel on Intractable Wastes (1992) and further information on the process obtained from MMT (1995).*

*The molten metal process is called "Catalytic Extraction Processing" (CEP), although it is not primarily a catalytic process or an extraction process, rather it may be described as a 'fluid-phase, high temperature combustor'. It uses a molten iron bath at a temperature of about 1650°C to dissociate wastes into their atomic constituents. The waste is injected with oxygen into a reactor containing the molten metal. The waste is bottom fed through tuyeres (or nozzles) and must therefore be either gas, liquid or finely divided solids [low inerts]... The bath is initially raised to the required temperature by electrical energy following conventional smelting practice, and the temperature can be maintained by the addition of organic waste and oxygen. Three products can be recovered depending on the waste feed: metals; gases such as chlorine, fluorine, hydrogen, and oxygen; and a ceramic slag phase that may be used as an aggregate or may require disposal by landfilling...*

*The technology is applicable to a range of chlorinated wastes which are in reasonably homogeneous phases. The process is able to treat wastes containing iron and was developed to treat tyres and complete transformers. Wastes comprising predominantly inert material such as soil cannot be treated”<sup>15</sup>*

Molten Metal Technology Inc. filed for Bankruptcy protection in 1997. Allied Technology Group Inc. of California purchased the technology in 1998. In Sept. 2000 BEI reviewed ATG's website, <http://www.atgusa.com>. BEI found no mention of Molten Metal Technology.

#### BEI's Evaluation

- Wastes comprising predominantly inert material such as soil cannot be treated.

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<sup>14</sup> Danny Ponn, VP Engineering, COO Bennett Environmental contacted Molten Salt Oxidation Corp. (MSO) of Warminster, PA. Kim Warley, VP Engineering on July 21, 2000.

<sup>15</sup> <http://www.environment.gov.au/epg/swm/swtt/molten.html>

### **3.10 Plasma Energy Pyrolysis<sup>16</sup>**

The Plasma Energy Pyrolysis System™ (PEPS™) is used as a means to convert problem waste streams into a clean fuel gas and construction aggregate. Organics are converted to a clean-burning fuel gas, and inorganics are economically recovered as metals or immobilized in a non-leachable vitreous slag.

PEPS is designed for concentrated wastes and liquids, and would not be suitable for contaminated soils as the volume of slag produced would be extremely large, and the energy consumption would be very high. To treat contaminated soil, the soil would have to be desorbed in a kiln and the off gas treated by PEPS.

They do not have a commercially operating system yet, but they are close. The estimated operating cost of their 10 ton/day fixed unit in Virginia is 20-25 cents/lb (US). (CD\$660/tonne).

Their air pollution control currently consists of a quench column using caustic, followed by a packed tower wet scrubber. BEI has been advised that in order to meet their particulate emission standards, they are switching to a quench tower followed by lime/carbon injection followed by a fabric filter, followed by a polishing packed tower.

#### BEI's Evaluation

- The technology is not proven and there is no commercial operating system yet.
- It is not suitable for contaminated soils as the volume of slag produced would be extremely large and the energy use would also be very high.
- Because it is a new technology, initial applications are expected to be very expensive.
- There are current operational problems with particulate emissions.

### **3.11 Soil Washing<sup>17</sup>**

Soil washing is a water-based process for scrubbing soils *ex situ* to remove contaminants. The process removes contaminants from soils in one of two ways:

- by dissolving or suspending them in the wash solution (which can be sustained by chemical manipulation of pH for a period of time); or
- by concentrating them into a smaller volume of soil through particle size separation, gravity separation, and attrition scrubbing (similar to those techniques used in sand and gravel operations).

Soil washing systems incorporating most of the removal techniques offer the greatest promise for application to soils contaminated with a wide variety of heavy metal, radionuclides, and organic contaminants. Commercialization of the process, however, is not yet extensive.

The concept of reducing soil contamination through the use of particle size separation is based on the finding that most organic and inorganic contaminants tend to bind, either chemically or physically, to

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<sup>16</sup> Mr. Danny Ponn, Bennett Environmental obtained the information on this technology presented in this report in a telephone conversation with Mr. Allan Anderson, Vanguard Research, Inc. on August 3, 2000

<sup>17</sup> The reference for this section is [http://www.frtr.gov/matrix2/section4/4\\_21.html](http://www.frtr.gov/matrix2/section4/4_21.html).

clay, silt, and organic fine soil particles. The silt and clay, in turn, are attached to sand and gravel particles by physical processes, primarily compaction and adhesion.

Washing processes that separate the fine (small) clay and silt particles from the coarser sand and gravel soil particles effectively separate and concentrate the contaminants into a smaller volume of soil that can be further treated or disposed of. Gravity separation is effective for removing high or low specific gravity particles such as heavy metal-containing compounds (lead, radium oxide, etc.). Attrition scrubbing removes adherent contaminant films from coarser particles. However, attrition washing can increase the fines in soils processed. The clean, larger fraction can be returned to the site for continued use.

Complex mixture of contaminants in the soil (such as a mixture of metals, nonvolatile organics, and SVOCs) and heterogeneous contaminant compositions throughout the soil mixture make it difficult to formulate a single suitable washing solution that will consistently and reliably remove all of the different types of contaminants. For these cases, sequential washing, using different wash formulations and/or different soil to wash fluid ratios, may be required.

Soil washing is generally considered a media transfer technology. The contaminated water generated from soil washing is treated with the technology(s) suitable for the contaminants. It is a concentration technology; it does not destroy compounds. The technology is not generally effective for POPs.

Soil washing is a water-based process for scrubbing soils *ex situ* to remove contaminants. The process removes contaminants by dissolving or suspending them in the wash solution, which is later treated by conventional wastewater treatment methods or ultimately incineration. Detergents may be used in the process.

Cost varies, typically \$50-\$250 Cdn/tonne.

#### BEI's Evaluation

- Complex waste mixtures (e.g., metals with organics) make formulating washing fluid difficult.
- High humic content in soil may require pretreatment.
- The aqueous stream will require treatment at demobilization.
- Additional treatment steps may be required to address hazardous levels of washing solvent remaining in the treated residuals.
- It may be difficult to remove organics adsorbed onto clay-size particles.
- The process creates contaminated water stream that must be treated. Ultimate disposal is incineration of concentrated contaminants.
- Clay type soils, peat soils and soils with large fractions of humic matter are not washable.
- It is not effective on organic molecules that have low solubility in water.

### **3.12 Solidification / Stabilization<sup>18</sup>**

Contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility (stabilization).

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<sup>18</sup> The reference for this section is [http://www.frtr.gov/matrix2/section4/4\\_10.html](http://www.frtr.gov/matrix2/section4/4_10.html).

Solidification/stabilization (S/S) reduces the mobility of hazardous substances and contaminants in the environment through both physical and chemical means. Unlike other remedial technologies, S/S seeks to trap or immobilize contaminants within their "host" medium (i.e., the soil, sand, and/or building materials that contain them), instead of removing them through chemical or physical treatment. Leachability testing is typically performed to measure the immobilization of contaminants.

S/S techniques can be used alone or combined with other treatment and disposal methods to yield a product or material suitable for land disposal or, in other cases, that can be applied to beneficial use. These techniques have been used as both final and interim remedial measures.

Solidification / Stabilization does not remove or destroy the organic contaminant and is therefore not an appropriate technology for consideration.

#### BEI's Evaluation

- Does not destroy contaminants
- Does not stabilize organic contaminants

### **3.13 Landfilling – Excavation, Retrieval and Off-site Disposal**

Landfill disposal is a common means of disposing of hazardous solid waste. Contemporary landfills incorporate liner systems, leachate collection, leak detection, proper excavation and placement procedures, capping, and long term monitoring. There are three basic approaches to building a landfill: above grade, partially below grade, and below grade. The liner system typically involves a geotextile and clay liner, although some jurisdictions also require an additional layer of impermeable foundation soils. The leachate collection system is usually a series of linear trenches filled with gravel and perforated drainage pipe, which diverts leachate from the bottom of the disposal cell to collection areas. Landfill site conditions sometimes require a network of surface interception trenches to control drainage and reduce leachate.

#### BEI's Evaluation

- Does not destroy contaminants
- Long term liability not eliminated
- Potential for leakage to groundwater
- Ongoing monitoring costs
- Organic compounds breakdown anaerobically volatilizing into the air
- Vegetation that has a tendency for deep root penetration must be eliminated from the cap area.

## **4 Conclusion**

Upon evaluation of the alternatives, Bennett Environmental Inc. concludes that a High Temperature Rotary Kiln thermal treatment system is the Best Demonstrated Available Technology for treatment of the array of wastes presented to BEI by customers seeking waste destruction services.

The US EPA is mandated to study alternatives to thermal incineration. The US EPA report, “*Strategy for Hazardous Waste Minimization and Combustion*” concludes that incineration is the preferred technology for the treatment of hazardous waste. The report states<sup>19</sup>:

*“However, of the limited alternative treatment technologies commercially available today, or those expected to be available over the next 5 to 10 years, none have been shown to provide a standalone alternative that is entirely comparable to combustion in the degree of toxicity reduction, process efficiency, permanence, and adaptability to a wide variety of waste matrices. A few existing technologies provide some of these characteristics, but not all”.*

The report further concludes that,

*“In addition, unlike many other waste treatment processes, combustion in incinerators and boilers and industrial furnaces (BIFs) can accommodate a wide variety of waste matrices -liquids, solids, and sludges. Residues from combustion are generally amenable to land disposal, often more so than the original waste streams. Finally, combustion is a demonstrated and commercially available technology for which considerable design and operational experience exists.”*

The conclusions of the US EPA report are consistent with BEI’s experience and knowledge of the remediation industry. BEI believes that it will be some time before companies offering alternative technologies will be in the position to offer commercial treatment capacity for the Ontario market.

Currently, there are a number of hazardous waste thermal incinerator units operating in Canada. None of the hazardous waste thermal destruction units in Ontario continuously treat organic contaminated solid materials. For example, Material Resource Recovery Inc.’s Cornwall facility is based on batch thermal treatment and is limited to small quantities of specific waste streams. As a result, BEI’s facility will be filling a unique market niche for the continuous treatment of large volumes of organic contaminated solid materials.

Several alternative contaminated site treatment technologies are under development. Some of these technologies are currently effective for certain classes of POP wastes, primarily liquid wastes. As discussed in the previous sections, however, contaminated sites are rarely remediated unless the treatment solution is affordable.

To date, alternative technologies have not been affordable when applied to soil and solid matrices. These matrices are highly variable, and material handling, moisture content, and heat and mass transfer issues limit the application of many potential technologies. In addition, it is noted that where potential treatment solutions have high costs, these high costs are due to the fact that they have high resource demands (in energy, reagents, safety measures, etc). These high resource demands extract an environmental price, often displaced from the point of use (eg. The production of a reagent may produce emissions at the reagent production facility).

BEI has spent years developing its Thermal Oxidizer technology. The technology is now in its Fifth Generation and has been well proven. BEI also has several years of operating experience with this proprietary technology at a BEI owned facility – Récupère Sol Inc. in St. Ambroise, Québec.

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<sup>19</sup> The reference for this quote is [www.epa.gov/epaoswer/hazwaste/combust/general/strat-2.txt](http://www.epa.gov/epaoswer/hazwaste/combust/general/strat-2.txt).

## **5 Appendix A: Fixed Treatment Facility Vs Onsite Treatment**

Stakeholders have additionally requested that BEI provide a rationale for the construction of a Fixed Treatment Facility instead of promoting on site treatment. BEI is of the opinion that many of the impacts will not be significantly different for the on site versus off site technologies.

The owner of a waste is free to select on-site treatment. Onsite treatment is very popular for non-persistent organic compounds that are biodegradable, are broken down at low temperatures, or are amenable to alternative technologies such as chemical destruction. Persistent Organic Pollutants (POPs), however, are not biodegradable and they are resistant to decomposition by low temperature thermal treatment or chemical destruction.

Many POP impacted sites have not been remediated to date. Where POP impacted site cleanups have occurred, the majority of the material from these sites has been shipped to landfills untreated when allowed by regulations. Landfilling of PCB impacted soils at over 50 PPM is not allowed in Canada. The opening of the Récupère Sol facility, which specializes in the treatment of contaminated solids, has provided the site remediation market with an environmentally sound alternative to landfills.

Owners of waste want reliable solutions that will permanently eliminate their liabilities once the project is undertaken. Permitting for on site in-situ or ex-situ solution will raise public awareness on the customer's contamination problem. Once identified, the problem area has to be remediated or the customer faces public criticism as a waste generator/owner.

Onsite treatment options for POP contaminated solids have rarely found favour with site owners for reasons such as:

- absence of effective on-site technologies
- complexities, risks and cost of permitting
- cost of set up and decommissioning
- difficulty in control of fugitive emissions from material preparation
- proximity issues in urban areas
- process emissions impacting residential areas
- noise issues
- space requirements
- supervision and monitoring costs
- availability of utilities
- time required to remediate the site

To be feasible, on site treatment requires a large quantity of waste in a single location. There is limited experience with on site treatment in Ontario.

### **5.1 Centralized Facility vs. Onsite Treatment**

The alternative technologies discussed in the preceding chapters of this report are applicable for on site versus off site remediation.

On site treatment has the advantage of not having to transport contaminated soil to a fixed facility, but has the certain limitations in operation:

- Permitting, mobilization and demobilization for each project is required and involves time, risks and costs.

- Small sites are not economical to remediate due to high soft costs such as permitting, impact assessment and monitoring, community consultation, air and noise monitoring etc.
- The low treatment rate of transportable equipment makes large sites difficult to permit due to the long treatment times.
- Fugitive Emissions Controls required are the same as for a fixed site, but the cost cannot be spread over many projects.
- Sites close to residential and commercial zones would have proximity issues or may not be able to obtain operating permits due to technical issues such as noise, space constraints, fugitive emissions or perception issues.

Table 6 compares the pros and cons for a centralized facility versus onsite treatment. It is assumed that the same technology would be utilized; that is, the comparison is technology neutral.

**Table 6 - Comparison of Centralized Versus On Site Treatment**

<b>Factor</b>	<b>Pros and Cons of Centralized Treatment</b>	<b>Pros and Cons of On Site Treatment</b>
Minimum quantity of waste to be treated.	The centralized plant can handle any size of project.	The total quantity of waste must be considerable to justify permitting, mobilization, and demobilization costs.
Approvals	Only one approval must be obtained lasting a number of years	Every project requires a site specific approval requiring time and costs. Public opposition increases risk of permitting.
Automation and Process Control	Fixed facility can provide a high degree of automation and install expensive advanced process controls justified by improved operation consistency	The mobilization & demobilization costs are significant. Automation and Sophisticated control network increased mob and demob costs.
Transportation	Transportation impacts and costs are higher for centralized.	No transportation costs and impacts.
Fugitive Emissions	Fugitive emissions control can be provided in fixed facility at high capital expenditures. Costs can be amortized over the life of the fixed facility.	Expenditure for fugitive control has to be absorbed by one project.
<b>Factor</b>	<b>Pros and Cons of Centralized Treatment</b>	<b>Pros and Cons of On Site Treatment</b>
Seasonal operation window	Centralized facilities can be equipped with infrastructure allowing for 12 months per year operation.	Weather can reduce the operating window of on site plant. Provision of infrastructure for year round operation must be absorbed by the project.
Proximity issue	Proper zoning	Sites close to residential and commercial zones would have proximity issues or may not be able to obtain operating permits.
Mobilization & Demobilization	Not applicable	Mobilization and demobilization can generate waste such as abandoned foundations, damaged equipment, equipment transportation, etc.
Hours of operation.	Centralized facilities are located where the zoning and various bylaws allow 24 hour a day operation.	May be subject to operation constraints

Experience of Operators	A centralized facility allows operators to be trained continuously. Operators have steady, long term work, improving their effectiveness.	Operators must be retrained for each site due to the varying conditions. Long times between projects require extensive retraining.
Morale of Operators	Operators live at home, and are therefore well rested, and have high morale.	Operators living away from home for long periods of time.

The evaluation of in situ versus centralized treatment has led BEI to conclude that the clean up of Persistent Organic Pollutants (POP) containing sites with in situ technologies is not viable at this time in Canada. BEI also concludes that the advantages of a centralized facility far outweigh any disadvantages.

## 5.2 The Ontario Experience

Significant on site treatment of POP wastes has, to BEI's knowledge, been completed twice in Ontario at:

- An on site incineration facility was utilized to treat PCB liquids at Smithville, Ontario; and
- An on site gas phase technology was used to treat liquids, and attempted on solids at an industrial facility in St. Catharines, Ontario.

### 5.2.1 Smithville

*"In 1985 the province of Ontario took over the management of the PCB waste that was contaminating the community water supply in the town of Smithville, Ontario. A contract was awarded to the U.S. company Enesco Inc. of Little Rock, Arkansas to perform the PCB destruction work using the ENSCO MPW-2000 transportable rotary kiln incinerator. The incinerator underwent compliance testing at Smithville beginning in February 1991, and operated until December 1992. During this period, the incinerator destroyed about 18,000 tonnes of liquid PCBs and shredded PCB-contaminated electrical equipment, concrete and soil."*<sup>20</sup>

At the time the on site incinerator was set up in Smithville, there were no centralized facilities for treating PCB wastes in Canada. The only options were to set up a centralized facility in Ontario, or do the destruction on site.

### 5.2.2 St. Catharines

A St. Catharines Ontario corporation had a quantity of PCB liquids and PCB impacted solids from the closure of a forging facility requiring treatment. The Eco Logic facility was set up in at the corporations site to treat the PCB liquids and solids. Treatment of liquids was technically successful and a small quantity of concrete was treated, but technical and economic difficulties impeded the treatment of the soil, and the project was subsequently abandoned.

Commercially, the treatment of liquids was a failure because treatment cost exceeded the market price of PCB liquid disposal. To the best of BEI's knowledge, no other company besides the St. Catharines company elected to utilize the Eco Logic process in Ontario after the St. Catharines results. BEI was informed by EcoLogic that the equipment was scrapped.

<sup>20</sup> [http://www.chem.unep.ch/pops/POPs\\_Inc/proceedings/cartagena/BUCCINI2.html](http://www.chem.unep.ch/pops/POPs_Inc/proceedings/cartagena/BUCCINI2.html)