CHEMICAL OXIDATION TREATMENT AND/OR DESTRUCTION OF POLYCHLORINATED BIPHENYL- (PCB-) CONTAMINATED SOIL

Prepared For:
WeirFoulds, LLP

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1.0 INTRODUCTION

WeirFoulds LLP (WeirFoulds) retained Conestoga-Rovers & Associates (CRA) to provide an expert opinion regarding the appropriateness and effectiveness of the treatment of polychlorinated biphenyl - (PCB) - contaminated soil using chemical oxidation. Chemical oxidation is a chemical reaction by which molecules are broken apart in a reaction with a chemical reagent called an oxidant, such as sodium persulfate. Chemical oxidation uses these oxidants to convert the PCBs into non-hazardous chemicals. WeirFoulds requested the focus to be on treatment and/or destruction of contaminated soil containing greater than 50 parts per million (ppm) PCBs. Contaminated soil containing concentrations of PCBs greater than 50 ppm is a regulatory threshold in Canada. Soil containing PCBs at concentrations greater than 50 ppm must be treated to remove PCBs. Contaminated soil containing concentrations of PCBs less than 50 ppm can be landfilled. In ascertaining the appropriateness and effectiveness of the treatment of PCB-contaminated soil using chemical oxidation, CRA was asked by WeirFoulds to answer nine questions, which are set out in Section 5.0 of this report. In order to answer these questions CRA has completed a scientific literature search, a permit and licensing review, and a treatment and/or destruction facility search.

CRA operates in Canada, the United States, Mexico, Brasil, Argentina, and Europe. Throughout CRA's 34-year history, CRA has provided services in environmental consulting and has contracted with and inspected facilities that accept, treat and/or destroy contaminants in soil.

This report is organized as follows:

- Section 2.0 presents CRA's scientific literature search
- Section 3.0 presents CRA's permit and licensing review
- Section 4.0 presents CRA's treatment and/or destruction facility search
- Section 5.0 presents the conclusions of this review

This report concludes that chemical oxidation has been shown to be able to treat and/or destroy PCB-contaminated soil in a laboratory setting only. Treatment refers to the partial removal of the PCBs to reduce their concentration from greater than 50 ppm to less than 50 ppm. Destruction refers to the elimination of PCBs to a significant degree, normally greater than 99.999%.

Based on the research performed, CRA has not found evidence of chemical oxidation being used on a commercial or industrial scale to treat and/or destroy PCB-contaminated soil. Based on the research performed, CRA has not found evidence of licenses or permits being granted for this purpose with the exception of Horizon Environnement Inc. Further, CRA has not found evidence of chemical oxidation being an accepted and recognized method for the treatment and/or destruction of PCB-contaminated soil on a commercial or industrial scale.

Effective chemical oxidation treatment and/or destruction on an industrial scale, based on reviewed laboratory studies, is dependant upon the following conditions:

- Sufficient contact between the PCB and the oxidant
- The grain size and organic content of the soil matrix
- Presence of co-contaminants
- Reaction time and number of treatment cycles
- Design of the treatment and/or destruction facility

In addition, due to the complexity of and variability within the soil matrix, it would be difficult to prove that treatment and/or destruction has occurred on an industrial scale.

2.0 LITERATURE SEARCH

CRA completed a literature review to examine papers published relating to chemical oxidation treatment and/or destruction of PCBs in soil. CRA completed a search for papers that address chemical oxidation as a treatment and/or destruction method for PCB-contaminated soil.

CRA completed the literature review using the academic search engine "Scopus". Scopus is a comprehensive database for scientific, technical, and medical information, containing over 14,000 journal titles from 4,000 publishers, and abstracts going back to 1966 from worldwide sources. Other academic databases are available however most relate only to a particular area of study: i.e., chemistry, ecology, engineering, or environmental science. Since PCB treatment and/or destruction technology spans all of these disciplines it was necessary to use a database with the capability of searching the literature on all of these subjects.

Other multidisciplinary databases are available, however most are tied to particular publishing companies (i.e., Scholar's Portal, Springer/Link) and only search the literature published by the company. Therefore they do not search the entire scientific literature. The remaining multidisciplinary databases available are Applied Science and Technology, Scopus and Web of Science. CRA's experience has been that Scopus searches most efficiently. Scopus allows greater control over the parameters searched and allows the researcher to combine searches and exclude parameters from the search. When parallel searches were run using other databases, Scopus returned a greater number of articles and articles with greater relevance than Applied Science and Technology. Scopus is widely used by academics (Laursen 2010, pers comm.)

CRA searched the Scopus database for documents relating to PCB or pesticide (which have treatment and/or destruction requirements similar to PCBs) removal in soil. The search returned 244 articles. Chemical oxidation treatment can be used for treatment of many other contaminants in addition to PCBs. Articles related to chemical oxidation treatment of non-PCB or pesticide contaminants were not included in the search. CRA reviewed the abstracts of these articles for relevance to the topic, which reduced the number to 63 articles. These articles are listed in Table 1. There were seven articles that described treatment of PCB-contaminated soils using chemical oxidation. CRA selected these articles for detailed review. The selected articles are identified in Table 1 by author.

2.1 CHEMICAL OXIDATION LITERATURE

The seven papers reviewed where chemical oxidation was used for the destruction of PCB or similar molecules were:

- Villa et al., 2010
- Quiroga et al., 2009
- Javorska et al., 2009
- Waisner et al., 2008
- Hong et al., 2008
- Pierpoint et al., 2003
- Osgerby et al., 2002

The chemical oxidants described in these articles were Fenton's Reagent, ozone, and catalyzed sodium persulfate. Three papers studied Fenton's Reagent, three studied ozone, and one paper studied catalyzed sodium persulfate. All papers described the results of laboratory scale tests. Laboratory scale means that the quantities used were those easily handled in a laboratory. Typically these quantities involve soil samples between 1 gram (g) and 400 g. The findings of the papers are summarized in the table below.

Reference	*Oxidant*	*Initial PCB Concentration*	*PCB concentration after Treatment and/or destruction (Removal)*	*Reaction Time*	*Comments*	*Process Requirements*
Villa et al., 2010	Photo-Fenton's Reagent	19-38 ppm	0.21-0.51 ppm (98%)	6 hours	Photo-oxidation experiments	-Constant stirring -pH adjustment -Ambient sunlight
Quiroga et al., 2009	Fenton's Reagent	100 ppm	3 ppm (97%)	72 hours	Sandy soil degree of removal dependent on level of chlorination	-Constant stirring -pH adjustment -photo-reactor
Javorska et al., 2009	Ozone	0.7 ppm	0.26-0.53 ppm (24-63%)	6 hours	Removal of PCB dependant on soil organic matter	-Dried sieved soils
Waisner et al., 2008	Catalyzed sodium persulfate	22.6 ppm	6.78-4.21 ppm (70-81%)	72 hours	Lime and heat catalysis tested	-Temperature controlled reactors with constant stirring -Catalysis of sodium persulfate required
Hong et al., 2008	Ozone	20 ppm	2.6-3.9 ppm (81-87%)	25-33 minutes	Used pressure to increase ozone contact with PCB	-Pressure controlled reactors with constant stirring
Pierpoint et al., 2003	Ozone	182 ppm	41.9 ppm (77%)	4-30 minutes	Ozone rich water used to improve solubility of contaminants	-Constant stirring -Addition of ozone rich water
Osgerby et al., 2002	Fenton's Reagent	100 ppm	32-99 ppm (1-68%)	n/a	Variable results obtained	-Constant stirring -pH adjustment
1 ppm is equivalent to 1 mg/kg Typical study soil volume = 1-400 g						

2.2 REVIEW OF CHEMICAL OXIDATION

Fenton's Reagent, ozone, and catalyzed sodium persulfate had the ability to destroy PCBs; however, the results were variable. These papers show that the destruction of PCB in soil by chemical oxidation using Fenton's Reagent, ozone and catalyzed sodium persulfate is technically feasible based on laboratory tests. CRA identified only one paper in the literature that described the destruction of PCBs by catalyzed sodium persulfate (Waisner et al., 2008), while three papers each were found for ozone and Fenton's Reagent. The catalyzed sodium persulfate technology has been studied less than the other oxidants and therefore there is less evidence supporting its use and effectiveness.

All the studies used reactors for constant mixing of soil slurries (soil in water) with the oxidant to treat the soils. The reactors used for the laboratory scale studies described in the literature reviewed were vessels (50 millilitres [mL] to 4 litres [L]) in which soil in water was continuously agitated in order to keep it in a slurry and in constant contact with the aqueous phase. Constant mixing is necessary due to the low solubility of PCB in water. The solubility of PCB in water is typically less than 500 micrograms per litre (μg/L) (Little, 1981). The PCB must be dissolved in water in order to come into contact with the chemical oxidant (Huling and Pivetz, 2006); therefore the poor solubility of PCBs limits the effectiveness of chemical oxidation. Using a reactor to achieve constant mixing of PCB with water permits the contact between the PCB and the oxidant.

Three of the studies CRA reviewed had starting concentrations of PCBs in soil that were greater than 50 ppm (Quiroga et al., 2009; Pierpoint et al., 2003; and Osgerby et al., 2002). Quiroga et al., and Osgerby et al., used Fenton's Reagent oxidation to oxidize PCB in a soil slurry.

The soil used in the Quiroga study was sandy, with a low organic matter content and therefore would have comparatively less sorption of PCB to the soil than would a clay or silty soil or a soil with organic matter in it. Similar reductions in concentration would likely not be obtained in a soil that had a significant amount of organic matter.

Osgerby et al. had variable results; therefore, their study suggests that chemical oxidation using Fenton's Reagent gives inconsistent results.

Pierpoint et al., used ozone and ozone-rich water to achieve a 77 percent reduction in PCB concentrations in their laboratory experiments. Therefore, Pierpoint reduced PCB concentrations from 182 ppm to 41.9 ppm.

For the studies using lower starting concentrations of PCB the percent removals ranged between 25 percent and 98 percent. The smaller starting concentration was 0.7 ppm (Javorska et al. 2009). This study used ozone for the treatment and found that PCB removal was highly dependant on the amount of organic matter present in the soil. Villa et al. (2010), Waisner et al. (2008) and Hong et al. (2008) all used soil with an initial PCB concentration of between 19 ppm and 40 ppm. The studies using starting concentrations less than 50 ppm did not demonstrate that soil containing PCBs greater than 50 ppm could be treated by chemical oxidation. In general, larger oxidant doses were required to treat larger concentrations of PCBs in soil.

The papers studied PCB removal by chemical oxidation at a laboratory-scale only. No studies were found in the scientific literature showing the scale-up of PCB treatment and/or destruction to a commercial or industrial scale process. Therefore, CRA concludes that the commercial or industrial scale application of the technology has not been studied and cannot be verified by the scientific literature as recognized and accepted. Based on CRA's review of the studies performed in a laboratory setting, several factors determine the success of the chemical oxidation reaction taking place and treating and/or destroying PCBs. These factors would apply to a commercial/industrial scale operation. These factors are:

- Sufficient contact between the PCB and the oxidant
- The grain size and organic content of the soil matrix
- Presence of co-contaminants
- Reaction time and number of treatment cycles
- Design of the treatment and/or destruction facility

In addition, due to the complexity of and variability within the soil matrix, it would be difficult to prove that treatment and/or destruction has occurred on an industrial scale.

These factors are discussed further below.

2.2.1 REQUIREMENTS FOR CHEMICAL OXIDATION FOR PCB TREATMENT AND/OR DESTRUCTION AT THE LABORATORY SCALE

Contact Between the PCBs and the Oxidant

Important process requirements and conditions placed on chemical oxidation as a treatment and/or destruction process for PCBs in soil include the requirement that the soil must be made into an aqueous slurry and placed in a reactor with constant mixing to overcome the low solubility of PCBs in water (Hong et al., 2008; Waisner et al., 2008). In order for the PCBs to be available to be oxidized, water or an aqueous phase solution is required to act as a carrier. The carrier is the medium which allows for the interaction between the PCB and oxidant. In the absence of the water slurry, little contact between the PCBs and the reagents is possible. In the absence of continuous mixing, this contact is negligible and treatment and/or destruction will not occur. At the laboratory scale, constant mixing can provide sufficient contact between the oxidant and the PCB, however as soil volumes increase maintaining the contact becomes difficult.

Soil Matrix

All the studies reviewed concluded that the amount of oxidant required and the operating parameters (dose, reaction time, addition of other reagents) for the reactors would be specific to the individual soil matrix. The term "soil matrix" refers to the composition of the soil (e.g., sand, clay, oils). Soil can vary in composition. Sandy soil generally contains very little organic carbon while other soil can contain a large amount of organic carbon. PCBs sorb strongly to soil organic matrices and dissolve in organic solvents such as oils (Hong et al., 2008). The organic matrix must be oxidized before the PCBs are released. The PCBs must be released before the PCBs can be oxidized (Javorska et al., 2009). Therefore, if organic material is present in the PCB-contaminated soil, large amounts of oxidant would be required to oxidize the organic matrix and the PCBs. Multiple treatments with the chemical oxidant would also typically be required.

Co-Contaminants

Another factor affecting the success of chemical oxidation is the presence of co-contaminants such as petroleum hydrocarbons and metals. Petroleum hydrocarbons will consume the oxidant long before it has an opportunity to react with the PCBs (see discussion above).

The metals can be oxidized making them more soluble and able to leach from the treated soil. Waisner et al., (2008) found that the oxidation process caused the leaching of lead. Metals can be solubilized from soil by chemical oxidation since some metals are more soluble in their oxidized forms. For example chromium VI, the oxidized form of chromium is very soluble in water, while chromium III is much less soluble. If chromium III is present in soil that is treated by chemical oxidation, it can be converted to chromium VI which can leach from the soil. Similar processes affect the solubility of metals such as arsenic, copper, lead, vanadium and zinc (Huling and Pivetz, 2006). As a result, the soil may need to be treated for lead (and other metals). In the absence of chemical oxidation treatment, the metals would likely remain in their insoluble form and might not require treatment. The presence of metals may deplete the oxidant and therefore reduce the amount available for PCB treatment. The presence of lead and other metals does not affect the destruction of PCBs, however it does create a potential need for secondary treatment of metals in the waste/treated soil.

Reaction Time and Number of Treatment Cycles

The oxidants studied in the literature have different contact time requirements. The contact time is the amount of time that the oxidant is in contact with the soil. For sodium persulfate and Fenton's Reagent, contact times were between 6 hours and 3 days per oxidant application (see Section 2.1). For ozone, the contact time was 6 hours or less. In several of the papers, the initial PCB concentration was small. Also, the contact times were based on laboratory scale tests and were not determined for industrial scale tests.

In order to ensure complete contact, the PCB in the soil must be dissolved and come into contact with the oxidant for sufficient time to be oxidized, between the oxidants and the PCB-contaminated soil, multiple cycles of the reaction would be needed. The greater the quantity of soil, the longer a treatment cycle to ensure maximal contact. As well, addition of multiple doses of reagent would be required because only a small amount of the PCB would be removed during each treatment cycle. If the starting concentration is high, this process would need to be repeated several times in order to reduce the PCB concentration to less than 50 mg/kg. Depending on the initial concentration of the PCBs in soil and the soil type being treated, the total length of treatment (in the process vessel or reactor) could extend over several months.

Design of the treatment and/or destruction facility

Since treatment and/or destruction of PCB-contaminated soil by chemical oxidation would need to be performed in a reactor, which would provide constant mixing, (Hong et al., 2008; Waisner et al., 2008), the reactor would need to be contained in a closed building equipped with filters for the protection of the equipment and the containment of any PCB dust. Prior to treatment, the storage[1] system for PCB-contaminated soil would need to ensure that the soil is contained and protected from the elements. Storage would not have any significant role in the effectiveness of

[1] Storage refers to the conditions under which the PCB-contaminated soil is held prior to treatment.

chemical oxidation treatment and/or destruction of PCB-contaminated soil. Small losses of volatile compounds and some small portion of the PCBs could occur during storage; however, these losses would be insignificant compared to the contaminant mass in the soil.

Analysis of Samples

A further issue with chemical oxidation treatment and/or destruction of PCB-contaminated soil is the difficulty of analyzing partially oxidized PCB wastes. The most common form of PCBs are Aroclors that are composed of mixtures of PCB with different degrees of chlorination based on a chlorination percentage. There are 209 possible PCB congeners with either different numbers chlorine atoms or chlorine substituted on different carbon atoms in the biphenyl molecule (DeGrandchamp and Barron, 2005). The Aroclors are mixtures of the 209 PCB molecules and the third and fourth number of the Aroclor denotes the percentage chlorination of the biphenyl molecule. Therefore, Aroclor 1248 is 48 percent chlorinated. The Aroclors with a higher percent chlorination will have larger amounts of the more chlorinated congeners. The less highly-chlorinated congeners should be oxidized more readily (Javorska et al; Quiroga et al., 2009) leading to changes in the pattern of PCB congeners in the Aroclor. The resulting PCB mixture would not then be recognizable as a specific Aroclor, and would be difficult to quantitate. Analysis of each individual PCB congeners, which is expensive and more time consuming (2 weeks standard turnaround time versus 4 weeks for commercial laboratory analyses), would then be required to determine if the PCB concentration of all congeners had been reduced to less than 50 ppm. The published analytical laboratory rate for PCB Aroclor analyses is $55 - $75/soil sample and greater than $500 for congener-specific PCB analyses.

Ideal Facility Scenario

If an entity were to construct an industrial scale treatment facility that could use chemical oxidation to treat and/or destroy PCBs at concentrations greater than 50 ppm in soil, it is CRA's opinion, based on the literature, that the following constraints would be needed to be imposed on the design, construction, and operation of the facility:

- A pilot-scale plant[2] would need to be designed, tested, and operated to provide necessary scale-up information for the design of a full-scale plant. The design constraints listed below are equally applicable to the pilot-scale plant.

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2 A pilot-scale plant is a step between the laboratory and commercial operation. The laboratory scale was less than 400 g of soil. (see Section 2.1) The pilot scale operation would be in the 10-100 kg range. A full scale plant would be in the 1,000-10,000 kg range. (Peters, M; and Timmerhaus, K. Plant Design and Economics for Chemical Engineers, Third Edition. McGraw-Hill, 1980)

- Soil would be received and stored prior to treatment in a contained area with a ventilation system designed to collect and treat PCB-contaminated dust.
- The soil would be analyzed upon receipt using accepted and statistically valid methods for characterizing the soil type, soil natural oxidant demand (NOD), the PCB content, and the concentration of co-contaminants.
- Based on the soil data, the operator would determine a reagent dose and load a volume of soil, water, and reagents into the reactor. The reactor would slurry the soil with the water; permitting the oxidation reaction to occur. Constant mixing over a prolonged period would be necessary.
- Based on the pilot scale data, once one treatment cycle was complete, the operator would collect a sample from the batch and analyze it for PCB Aroclors, PCB congeners, co-contaminants, and breakdown products (products produced as a result of the reaction).
- Additional treatment cycles may be needed, depending on the results of the analyses, and would follow the same course.
- Once the batch is treated, the water would be drained, collected, and treated. A wastewater treatment plant would be required.
- Depending on the analytical data, supplemental treatment may be required for co-contaminants and/or breakdown products.
- The soil would have to be dried; its moisture content would be too great to landfill. A soil drying or curing step would be required.
- The oxidation reaction is relatively violent; emissions from the process would have to be controlled. The process would have to be in an enclosed facility with a ventilation system designed to collect and treat PCB-contaminated dust and process emissions.

3.0 PERMIT AND LICENSING REVIEW

CRA completed a government regulatory search to determine if chemical oxidation has been recognized and permitted as a method for the treatment and/or destruction of PCB-contaminated soil through government approvals and permits. CRA completed this search for Canada, the United States, and the United Kingdom (UK).

CRA reviewed the following governmental websites:

- Ontario Ministry of the Environment (MOE)
- Québec Ministère du Développement durable, de l'Environnement et des Parcs (MDDEP)
- Environment Canada (EC)
- Ministry of the Environment (all other provinces)
- United States Environmental Protection Agency (USEPA)
- UK Environment Agency

Within the websites, CRA searched for permits/approval documents for the non-thermal treatment and/or destruction of PCBs. CRA also reviewed each jurisdiction's policies on PCB treatment and/or destruction. References for the sites searched are presented in Table 1.

In addition to specific governmental websites, CRA completed an online search for companies claiming permits or licenses issued in North America and the UK that pertain to the treatment and/or destruction of PCBs in soil. The results of this search for each jurisdiction searched are presented below.

While CRA did not complete a comparison of PCB regulations across jurisdictions, CRA reviewed the regulations of each jurisdiction to assess what constituted treatment and/or destruction, if specific treatment and/or destruction processes were approved or excluded, and what, if any, regulations existed for the operation of treatment and/or destruction facilities.

3.1 CANADA

The Ontario MOE was the only Canadian jurisdiction that provided licence listings to the public. The listings of the non-thermal treatment and/or destruction of PCBs were limited to Sonic Environmental Inc. (Sonic). Sonic's technology was by means of extracting the PCBs from soil and concentrating them in a waste solvent solution. The slurry would then be sent away for treatment and/or destruction by thermal desorption or incineration. Their technology does not destroy PCBs. There were no approvals listed for treatment and/or destruction of PCBs in soils by chemical oxidation.

The MDDEP listed companies and the type of approval received (air, transfer, disposal), but the approval itself was not made public. Approvals did list treatment and/or destruction of PCB-contaminated soils, and treatment and/or destruction of soils by chemical oxidation but none were listed as treatment and/or destruction of PCB-contaminated soils by chemical oxidation, with the exception of Horizon Environnement Inc.

None of the other provincial environment ministry websites contained any information on approvals granted. EC provides regulations and guidelines on the treatment and/or destruction of PCBs, but not permitting. As in most jurisdictions, soil-containing PCBs at concentrations greater than 50 ppm are considered hazardous waste. No specific technologies were mentioned in the regulations.

3.2 UNITED STATES

The USEPA website provided regulations on PCB treatment and/or destruction in the United States and also listed companies that were commercially permitted to treat and/or destroy PCBs. None of the companies listed had permits for chemical oxidation treatment and/or destruction. Individual states do not provide approvals for waste disposal facilities. PCB-contaminated soil at greater than 50 ppm is regulated by the Toxic Substances Control Act (TSCA). Landfills and treatment and/or destruction facilities must comply with TSCA. The act also specifies how the soil must be handled. The methods of PCB management used, according to state websites, are landfill disposal and incineration. The regulations regarding PCB treatment and/or destruction did not list specific treatment and/or destruction methods other than incineration.

3.3 UNITED KINGDOM

The UK Environment Agency does not appear to have regulations or permits for the treatment and/or destruction or management of PCB-contaminated soil other than through incineration and landfill, where incineration is preferred. The following is an excerpt from the Environment Agency website:

> *PCBs are controlled under the UK Pollution Prevention and Control Regulations and they are a UK 'Red list' pollutant, the presence of which in the environment is of particular concern. PCBs are also regulated under European directive 96/59/EC (Restrictions on the marketing and use of certain dangerous substances), which aims to eliminate PCBs completely by the end of 2010. The directive requires member states to produce an inventory of equipment containing PCBs and then to ensure that it is safely disposed of by 2010. Incineration of PCBs is regulated by the Hazardous waste directive (2008/98/EC).*

The Hazardous waste directive refers to PCB-containing equipment and waste oils, but does not specifically discuss the disposal or destruction of PCB-containing soil.

4.0 FACILITY REVIEW

CRA completed a literature search to identify facilities that use chemical oxidation as a method for the treatment and/or destruction on an industrial or commercial scale, for PCB-contaminated soil. CRA also identified technology characteristics (ex-situ technologies, in-situ technologies, thermal, non thermal technologies, etc.). CRA focused the search on technologies and facilities which treat and/or destroy or are reported to treat and/or destroy soil contaminated with PCBs at concentrations greater than 50 ppm. CRA completed this search for Canada, United States, and Europe.

CRA used the following resources:

- Internet Search Keywords: Chemical Oxidation, PCB-contaminated soil, disposal facility, treatment and/or destruction technology
- USEPA Website
- USEPA Superfund Innovative Technology Evaluation (SITE) Program
- USEPA Commercially Permitted PCB Disposal Companies
- USEPA Contaminated Site Clean-Up Information (CLU-IN)
- United Nations Environment Program (UNEP) Website
- Interstate Technology and Regulatory Council
- CRA United Kingdom (UK) office[3]
- CRA Waste Services Group[4]
- Contact with chemical providers
- Contact with Hazardous Waste Management contractors

CRA contacted two chemical manufacturers/distributors: Chemco Inc (Chemco), Saint-Augustin-de-Desmaures, Quebec, Canada and FMC Corporation (FMC). CRA contacted these companies as a means to double check if their company had knowledge of a facility that treats and/or destroys PCB-contaminated soil greater than 50 ppm using chemical oxidation. CRA believes this to be a reasonable check since these two

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3 CRA's UK operations are a full-service environmental consultancy with extensive experience in contaminated land remediation and PCB-contaminated soil treatment and/or destruction.

4 CRA has established a Waste Services Group that manages and controls CRA's clients' waste materials and products on their behalf. This group also consults on soil treatment and disposal facilities and audits their compliance with laws, regulations, and our clients' requirements. This group maintains inventories of and contact with approved waste disposal facilities and contractors.

companies were the most likely to supply such treatment facilities with chemical reagents, if the facilities existed.

CRA contacted hazardous waste management contractors (HAZCO, Clean Harbors, The Environmental Quality Company (EQ) and Quantum Murray). These contractors work on contaminated site remediation and have experience with hazardous waste management including PCBs. CRA contacted these companies to determine if their company had knowledge of a facility that treats and/or destroys PCB-contaminated soil greater than 50 ppm using chemical oxidation.

As a final check, CRA consulted with our approximately 600 internal project managers to determine if they had personal knowledge of such treatment facilities in North America. The vast majority of those project managers work on projects involving the management of contaminated soil and most have personal knowledge of PCB treatment and/or destruction facilities.

Findings from these searches and discussions with the resources identified above are summarized in the subsections below.

4.1 CANADA

The following industrial facilities are operating and accepting PCB-contaminated soil at concentrations greater than 50 ppm in Canada:

Facility	*Location*	*PCB Technology*
Bennett Environmental Inc.	Saint Ambroise, Quebec	Thermal Oxidation Process
Swan Hills Treatment Centre	Swan Hills, Alberta	Incineration
Phase Separation Solutions Inc.	Wolseley, Saskatchewan	Thermal Phase Separation Technology
Horizon Environnement Inc.	Grandes-Piles	Chemical Oxidation

Based on the review of information available, and CRA's experience and knowledge, Horizon Environnement Inc. is the only facility licensed in Canada to treat and/or destroy PCB-contaminated soil at concentrations greater than 50 ppm using ex-situ, non thermal, chemical oxidation.

4.2 UNITED STATES

USEPA's list of Commercially Permitted PCB Disposal Companies is summarized below. Commercially permitted means these companies have obtained a permit from the USEPA to treat/destroy and/or dispose of PCB-contaminated soil.

Facility	*Location*	*Method of Treatment/Destruction and/or Disposal*
Clean Harbors Environmental Services Inc	Deer Park, TX	Incineration
Clean Harbors Aragonite	Salt Lake City, UT	Incineration
Veolia Environmental Services	Port Arthur, TX	Incineration
Repuplic Waste Services of Texas Limited	Avalon, TX	Chemical Waste Landfill
Waste Control Specialists	Andrews, TX	Chemical Waste Landfill
Chemical Waste Management Chemical Services	Model City, NY	Chemical Waste Landfill
Waste Management Inc	Alabama Inc.	Chemical Waste Landfill
Wayne Disposal Inc.	Belleville, MI	Chemical Waste Landfill
Clean Harbors Grassy Mountains	Salt Lake City, UT	Chemical Waste Landfill
Chemical Waste Management	Kettleman City, CA	Chemical Waste Landfill
Chemical Waste Management of the Northwest	Arlington, OR	Chemical Waste Landfill
U.S. Ecology, Inc	Beatty, NV	Chemical Waste Landfill
U.S. Ecology Idaho	Grand View, ID	Chemical Waste Landfill
Terra-Kleen Response Group, Inc.	San Diego, CA	Physical Separation[i]
Maxymillian Technologies, Inc	Pittsfield, MA	Thermal Desorption
TD*X Associates	Salt Lake City, UT	Thermal Desorption
i) Physical Separation - PCBs are removed from soil and transferred to solvent; PCBs are not destroyed		

CRA could not identify a permitted treatment and/or destruction facility located in the US that treats and/or destroys PCB-contaminated soil with concentrations greater than 50 ppm using chemical oxidation.

CRA identified Amstar Envirchem Technologies (Amstar) from the USEPA website where it is identified as a permitted treatment and/or destruction facility. Based on the Amstar website, the company uses a non-thermal nucleophilic substitution reaction to treat and/or destroy PCBs on impacted surfaces. The Amstar PCB treatment and/or destruction process involves the application of a reagent with a pressure washer to surfaces with PCB contamination. Based on CRA's conversations with Amstar, Amstar was never successful at treating soil quantities larger than a beaker (laboratory scale) of PCB-contaminated soil. Amstar could not treat and/or destroy PCB contaminated soil to an acceptable concentration. Amstar was never permitted to treat and/or destroy PCB-contaminated soil (only surfaces). This is a mobile process; soil remains on site and is not transported to a commercial/industrial facility. It is not a constructed industrial facility.

The USEPA SITE program evaluates emerging and demonstrating technologies that could potentially aid in remediation of hazardous waste sites. CRA reviewed the technology profiles eleventh edition created in 2003 to research emerging and demonstrating PCB-contaminated soil technologies. The SITE website indicates that USEPA does not update the SITE program. The following vendors were accepted into the USEPA SITE program for either emerging or demonstrating PCB-contaminated soil technologies in 2003.

Vendor	*Technology Name*	*Demonstration/ Emerging Year*	*Treatment and/or Destruction Technology*
X-19 Biological products	Microbial Degradation of PCBs	2000-2001	Biological Degradation
Gas Technology Institute	Chemical and Biological Treatment	2001-2003	Biological Degradation
Gas Technology Institute	Fluid Extraction- Biological Degradation Process	1990	Biological Degradation
Micro-Bac International Inc.	Bioaugmentation Process	2000-2001	Biological Degradation
Biotherm, LLC	Biotherm Process™	1991	Dehydration and Solvent Extraction[ii]
ELI Eco Logic Inc.	Thermal Gas Phase Reduction Process and Thermal Desorption Unit	1992	Thermal Desorption
New Jersey Institute of Technology	GHEA Associates Soil Washing Process	1990	Soil Washing[iv]
IT Corp[1]	X*TAX™ Thermal Desorption	1992	Thermal Desorption
SoilTech ATP Systems, Inc	Anaerobic Thermal Processors	1991-1992	Thermal Desorption
Terra Therm Inc.	In- Situ Thermal Destruction	2001	In- Situ Thermal Destruction
ART International Inc	Low Energy Extraction Process	1997	Solvent Extraction[ii]
Bergmann, a Division of Linatex Inc	Soil and Sediment Washing	1992	Soil Washing[iv]
BioGenesis Enterprises Inc.	BioGenesis Soil and Sediment Washing Process	1992	Soil Washing[iv]
Concurrent Technologies (Center for Hazardous Materials Research)	Organics Destruction and Metals Stabilization	1995	Reaction with elemental sulfur (Thermal)

Vendor	*Technology Name*	*Demonstration/ Emerging Year*	*Treatment and/or Destruction Technology*
CF Systems Corp.	Liquefied Gas Solvent (LG-SX) Extraction Technology	1988	Solvent Extraction[ii]
Commodore Environmental Services Inc	Solvated Electron Remediation System	1996	Solvated Electron Solution Reaction[iii] (Ammonia + Sodium)
General Atomics	Circulating Bed Combustor	1995	Incineration
Resource Conservation Company	B.E.S.T. Solvent Extraction Technology	1992	Solvent Extraction[ii]
IT Corp[1]	Mixed Waste Treatment Process	1995	Thermal Desorption/Separation/ Chemical Precipitation
IT Corp[1]	Photolytic and Biological Soil Detoxification	1992	In Situ shallow treatment – ultraviolet radiation and surfactants
National Risk Management Research Laboratory	Base-Catalyzed Decomposition Process	1992	Chemical and Thermal Dehalogenation Treatment[v]
Terra-Kleen Response Group Inc.	Solvent Extraction Treatment System	1997	Solvent Extraction[ii]
Trinity Environmental Technology, Inc.	PCB – and Organochlorine – Contaminated Soil Detoxification	1992	Chemical and Thermal Dehalogenation
Gas Technology Institute	Cement-Lock Technology	Not listed	Solidification
Solidtech Inc	Solidification and Stabilization	1988	Solidification
Geo-Con Inc.	In Situ Solidification and Stabilization process	Not Listed	Solidification
BWX technologies, Inc.	Cyclone Furnace	1991	Thermal Destruction
Energy and Environmental Research Corp	Hybrid Fluidized Bed System	1990	Thermal Destruction
Gas Technology Institute	Fluidized-Bed/Cyclonic Agglomerating Combustor	1990	Thermal Destruction
Minergy Corp	Glass Furnace Technology for Dredged Sediments	2001	Thermal Destruction
Vortec Corporation	Vitrification Process	1999	Vitrification[vi]

Vendor	*Technology Name*	*Demonstration/ Emerging Year*	*Treatment and/or Destruction Technology*
Notes: i) Company is Bankrupt ii) Solvent Extraction – PCBs are removed from soil and transferred to solvent; PCBs are not destroyed iii) Chemical Reaction that is not an oxidation process iv) Soil Washing – PCBs are transferred from soil to a solvent; PCBs are not destroyed v) Thermal process vi) Thermal process that creates a monolithic block of soil			

CRA located the SITE technology profiles for PCB-contaminated soil by using the Applicability Index that is provided as an attachment to the eleventh edition. The applicability index provided sorted information, first by matrix then by contaminant of concern. CRA obtained and reviewed the technology profile for each of the vendors that was listed in the in the soil/PCB section of the index. CRA considered a technology to be not applicable if it was not intended to treat and/or destroy PCBs, not intended to treat soil, not a treatment and/or destruction technology, a test kit, a sampler, a sensor, or phytoremediation process.

The majority of the above emerging technologies are thermal technologies that use the addition of heat or the technology is an extraction/PCB separation technology and not a destruction technology.

Gas Technology Institute (GTI) is located in Des Plaines, Illinois. This company has a chemical and biological treatment technology that was included in the SITE emerging technology program in 2001. Chemical oxidation is a pretreatment step in their chemical and biological treatment technology. As reported by GTI SITE technology profile (February 2003), a chemical reagent is added to the contaminated soil resulting in the generation of carbon dioxide, water and "partially oxidized intermediates" and this pretreatment step is followed by biological treatment. This treatment technology does not rely on chemical oxidation as the sole destruction method for PCB-contaminated soil. Based on the information available to CRA, GTI is not marketing this technology.

Commodore Environmental Services Inc (Commodore) has a solvated electron technology (SET) that combines an ammonia sodium solution into a reactor with contaminated soil. This is a mobile process and is not a constructed industrial facility. The USEPA in December 2005 entitled Reference Guide to Non-Combustion Technologies for Remediation of Persistent Organic Pollutants in Stockpiles and Soil reported that the SET technology was not made available to customers due to high costs associated with the technology. From conversations with Commodore, they indicated that their nation-wide permit has expired and they apply for permits on a site-by-site basis. The largest volume of soil Commodore has treated was 180 cubic yards. The initial PCB concentration was 777 ppm and was reduced to less than 1 ppm. Commodore has a mobile process that goes to sites and remediates small quantities of soil, typically stored in drums (+/- 4 cubic metres of soil). Commodore does not operate a commercial facility using this process.

CRA reviewed the technologies provided on the CLU-IN website. The CLU-IN website provided a guide published by the USEPA in December 2005 entitled Reference Guide to Non-Combustion Technologies for Remediation of Persistent Organic Pollutants in Stockpiles and Soil. This publication provides details for full scale technologies and pilot scale technologies to treat and/or destroy persistent organic pollutants (POPs) and is the most up to date version available. The publication also included full scale technologies that treat and/or destroy non-POP and have the potential to apply the technology to treat and/or destroy POPs; however there was no data to assess the technologies viable for PCB treatment and/or destruction. The following technologies were included for PCB-contaminated soil.

Technology Name	***Vendor***	***PCB Technology***
Full Scale Technologies		
Gas Phase Chemical Reduction (GPCR)	Eco Logic/Bennett	Thermal Desorption and Reduction
GeoMelt™	AMEC Earth & Environmental	Thermal Vitrification
Pilot –Scale technologies		
Base Catalyzed Decomposition (BCD)	BCD Group Inc.	Thermal Desorption
CerOx™	CerOx Corporation	Electrochemical Cell Reaction Technology
Phytotechnology	N/A	Plants
Sonic Technology	Sonic Environmental Solutions Inc.	Solvent Extraction[i] (Terra Kleen process)
Notes: N/A – Not Applicable i) This process purports to use a sonic destruction process to treat PCBs in the solvent but it is not a commercial technology		

CerOx™ is a technology owned by Cerox Corporation. CerOx™ is an Electrochemical cell reaction technology that is used to oxidize organic compounds such as PCBs. According to the publication, CerOx™ was only pilot tested for liquids contaminated with PCBs, not soil.

CRA compared this list of treatment and/or destruction technology vendors with internal resources and listings of treatment and/or destruction facilities and technology vendors. CRA has no record of more recent, additional soil treatment and/or destruction facilities or technology vendors of relevance to this assessment.

Gaps and limitations in the information available include:

- Site technology profiles have not been updated since 2003
- Lack of up to-date versions of publications

Expired permits, companies no longer in business, and amalgamated companies posed challenges in establishing the status of PCB treatment/destruction operations in 2010. In order to establish the current status of facilities and technologies providing treatment and/or destruction of PCB-contaminated soil, CRA researched and, where possible, contacted companies listed in profiles or articles of past years to determine if the facilities and/or technologies existed, were permitted, and were successful.

4.3 EUROPE

Based on CRA's experience (confirmed by CRA; UK office) and research (publications reviewed), thermal destruction is the standard treatment and/or destruction method for PCB-contaminated soil in Europe.

UNEP published survey results of PCB destruction facilities entitled Inventory of Worldwide PCB Destruction Capacity, September 2004 and is the most up-to-date version available. The survey was voluntary and the following European facilities were concluded to treat and/destroy PCB-contaminated soil.

Facility	*Location*	*PCB Technology*
BCD Technologies PTY Ltd.	Australia	Thermal Desorption
Ekokem Oy Ab	Finland	Incineration
Tredi Saint Vulbas	France	Incineration
RZR Herten	Germany	Incineration
TRV Thermische Ruckstandsverwertung GmbH & Co. KG	Germany	Incineration
SAVA Sonderabfallverbrennungsanlagen GmbH	Germany	Incineration
Bayer Industry Services GmbH & Co OHG	Germany	Incineration
GSB Sonderabfall - Entsorgung Bayern	Germany	Incineration
AVG Abfall - Verwertungs - Gesellschaft	Germany	Incineration

Facility	*Location*	*PCB Technology*
mbH		
Eco Logic	Slovak Republic	Thermal Desorption +Gas Phase Chemical Reduction (GPCR)
Valorec Services AG, Regionale Sondermuellverbrennungsanlage	Switzerland	Incineration
EMS-Dottikon AG	Switzerland	Incineration
AVR Nutsbedrijf Gevaarlijk Afval B.V.	Netherlands	Incineration

Table 13 of the UNEP document provided a list of facilities that treated PCBs, the facility location, and if the facility accepted soil. The table was based on the results of the surveys that are provided on the UNEP website; CRA read each of the surveys completed by the facilities that were reported to treat and/or destroy PCB-contaminated soil and updated the list as required.

CRA's UK office identified the following facilities in addition to the identified facilities above.

Facility	*Location*	*PCB Technology*
AGR Entsorgung GmbH – RZR Herten	Germany	Incineration
HIM Hazardous Waste Incineration Plant	Germany	Incineration
Tradebe Fawley	United Kingdom	Incineration
Veolia Environmental Services	United Kingdom	Incineration
Sakab	Sweden	Incineration
Kommunekemi a/s	Denmark	Incineration

5.0 CONCLUSIONS

The literature review showed that although PCB destruction in contaminated soil has been demonstrated in the laboratory, scale-up considerations have not been studied in the literature. Based on information available and on CRA's institutional knowledge and experience, this process is highly variable, dependent upon the type of soil being treated, and would have to be done in continuously-mixed reactor on a soil-water slurry over many treatment and/or destruction cycles of extended duration. CRA believes it is unreasonable, impractical, and not economically feasible due to the process requirements.

Based on the review of information from the regulatory websites that is available and CRA's experience and knowledge, CRA did not locate approvals for chemical oxidation as a method for treatment and/or destruction of PCB-contaminated soil; with the exception of Horizon Environnement Inc.

Based on the review of information available and CRA's experience and knowledge, Horizon Environnement Inc is the only facility in the U.S., Canada, and Europe that purports to treats PCB-contaminated soil at concentrations greater than 50 ppm using ex-situ, non thermal, chemical oxidation.

5.1 ANSWERS TO WEIRFOULDS' QUESTIONS

In ascertaining the appropriateness and effectiveness of the treatment of PCB-contaminated soil using chemical oxidation, WeirFoulds asked CRA to answer nine questions. This section reproduces the questions posed by WeirFoulds (in italics) and CRA's responses to those questions.

1. *Is chemical oxidation a recognized and accepted method for the destruction or treatment, on an industrial or commercial scale, of PCBs in soil? By recognized and accepted, we mean recognized and accepted by the scientific community. By treatment, we mean the reduction of the concentrations of PCBs to a level below 50 ppm.*

   Answer: No

2. *If chemical oxidation has been recognized and accepted as a method for the destruction or treatment, on an industrial or commercial scale, of PCBs in soil, what are the particular characteristics, limitations or conditions of the recognized and accepted method?*

   Answer: Not applicable based on the answer to Question 1. If the process were to be scaled up, it would have to be conducted in a continuously mixed reactor, in a water or aqueous solution, and would require numerous treatment and/or destruction cycles to reduce the PCB concentrations of the soil to less than 50ppm.

3. *Has chemical oxidation been used, in any jurisdiction in North America or Europe, on an industrial or commercial scale to destroy or treat PCBs contained in soil? The expression "industrial or commercial scale" refers to multiple instances of the treatment of PCB-contaminated soil in quantities that are moderate to large, over a period of time, as opposed to single instances for treatment of negligible quantities of PCB-contaminated soil (for example, as would be the case in a laboratory setting).*

   Answer: No

4. *If chemical oxidation has been used, in any jurisdiction in North America or Europe, on an industrial or commercial scale to destroy or treat PCBs contained in soil, what are the particular characteristics of the chemical oxidation method used?*

   Answer: Not applicable based on the answer to Question 3.

5. *Has chemical oxidation been recognized, or formally approved, by environmental regulators, in North America and in Europe, as an acceptable treatment methodology for the destruction or treatment of PCBs in soil? We exclude from this question the Certificate of Authorization issued by the MDDEP in Quebec.*

   Answer: No

6. *If so, on what basis, in what circumstances, and subject to what conditions or limitations?*

   Answer: Not applicable based on the answer to Question 5. See response to Question 2.

7. *If chemical oxidation is used as a method to treat PCB-contaminated soil, by what percentage and over what time period are the concentrations of PCBs reduced to a level below 50 ppm.*

   Answer: chemical oxidation is not used as a method to treat PCB-contaminated soil on an industrial scale as per the answer to Question 1

8. *Would your opinion with respect to questions 1 and 2 change if the following parameters are taken into consideration?*

   A) *The treatment by chemical oxidation takes place in a closed building, protected from the weather;*

      Answer: No

   B) *The building is equipped with dust filters and carbon-activated filters;*

      Answer: No

C) *The PCB- contaminated soil is kept in a pile, under a tarp, where a slight negative pressure is maintained;*

Answer: No

D) *The PCB-contaminated soil is stored for a duration of 20-30 months, depending on the presence of volatile organic compounds ("VOC");*

Answer: No

E) *The maximum duration of treatment is 6 months; and*

Answer: No

F) *A maximum of 6,000 TM*[5] *is treated at any given time.*

Answer: No

9. *What role, if any, does the storage of PCB-contaminated soil have on the effectiveness of chemical oxidation as a method for the destruction or treatment of PCB-contaminated soil?*

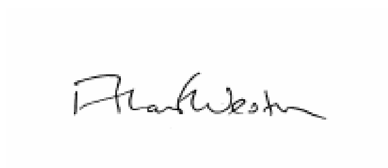
Answer: None

CRA's opinion is that, given the conditions that are required, it has not been demonstrated to be feasible to have a chemical oxidization process to treat and/or destroy PCB-contaminated soil on a commercial/industrial scale.

5 Metric Tonnes

All of Which is Respectfully Submitted,
CONESTOGA-ROVERS & ASSOCIATES

Stephen Quigley, P.Eng, PE [6]



Alan Weston, Ph.D.

[6] Licensed : Ontario, Newfoundland, Arizona, Delaware, Maryland, and New Hampshire

TABLE 1

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TABLE 1

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Authors	*Title*	*Year and Source*
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	Directive 2008/98/EC of the European Parliament and of the Council	*http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:312:0003:0030:EN:PDF*
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	Certificates of Approval	*http://www.environet.ene.gov.on.ca/instruments/1754-6KVQGB-14.pdf*
Ministère du Développement durable, de l'Environnement et des Parcs	Règlement sur les matières dangereuses	http://www2.publicationsduquebec.gouv.qc.ca/dynamicSearch/telecharge.php?type=3&file=/Q_2/Q2R15_2.HTM
	Certificats d'authorisation délivrés	http://www.mddep.gouv.qc.ca/regions/region_06/industriel/Document.asp?tag=206,%3C,DESC_TYPE_DOC_DELIVRE
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