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**Expert Group on Best Available Techniques and  
Best Environmental Practices**

**First meeting**

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Item 3 of the provisional agenda\*

**Further work on the enhancement or strengthening, as appropriate,  
of the guidelines on best available techniques and provisional guidance  
on best environmental practice relevant to the provisions of Article 5  
of the Stockholm Convention on Persistent Organic Pollutants**

**Request from the seventh meeting of the Conference of the Parties  
to the Basel Convention on the Transboundary Movement of  
Hazardous Wastes and their Disposal<sup>1</sup>**

**Note by the Secretariat**

1. At its first meeting, the Conference of the Parties to the Stockholm Convention, in its decision SC-1/19, adopted the terms of reference for the Expert Group on Best Available Techniques and Best Environmental Practices. Section II of the above-mentioned terms of reference states that: “The Expert Group shall consider the request from the Conference of the Parties of the Basel Convention at its seventh meeting and, if practicable, develop information on best available techniques and best environmental practices with respect to unintentionally produced POPs, including recent technologies for destruction and irreversible transformation listed in the Basel Convention’s general technical guidelines, as referred to in decision SC-1/21 of the Conference of the Parties.”
2. At its seventh meeting, the Conference of the Parties to the Basel Convention on Transboundary Movement of Hazardous Wastes and their Disposal, adopted decision VII/13 on Technical guidelines on persistent organic pollutants. Paragraph 6 of this decision “Invites the bodies of the Stockholm Convention to consider best available technologies and best environmental practices with respect to unintentionally produced persistent organic pollutants, including the more recent technologies for destruction and irreversible transformation listed in the technical guidelines”.

\* UNEP/POPS/EGBATBEP.1/1.

<sup>1</sup> This document has not been formally edited.

3. Annex I to the present note contains a copy of Chapter IV, Section G, subsection 2: Destruction and irreversible transformation methods of the General technical guidelines for the environmentally sound management of wastes consisting of, containing or contaminated with persistent organic pollutants (POPs) as contained in annex 2 of document UNEP/POPS/COP.1/INF/12/rev.1.

### **Possible action by the Expert Group**

4. The Expert Group may wish to consider the above note by the Secretariat and, if deemed appropriate, prepare a response to the Conference of the Parties to the Basel Convention, for consideration at the second meeting of the Conference of the Parties to the Stockholm Convention.

## Annex I.

### **Chapter IV, Section G, Subsection 2 of the General technical guidelines for the environmentally sound management of wastes consisting of, containing or contaminated with persistent organic pollutants (POPs)<sup>2</sup>**

#### **2. Destruction and irreversible transformation methods**

122. The following disposal operations, as provided for in Annexes IVA and IVB of the Basel Convention, should be permitted for the purpose of destruction and irreversible transformation of the POP content in wastes when applied in such a way as to ensure that the remaining wastes and releases do not exhibit the characteristics of POPs:

- D9 Physico-chemical treatment,
- D10 Incineration on land, and
- R1 Use as a fuel (other than in direct incineration) or other means to generate energy.

123. POPs that are isolated from the waste during a pre-treatment should subsequently be disposed of according to operation D9 and D10.

124. This subsection describes commercially available operations for the environmentally sound destruction and irreversible transformation of the POP content in wastes.<sup>3</sup> It is noted that pertinent national legislation applies for these operations.

125. While the information provided within these guidelines regarding vendors of technologies for destruction and irreversible transformation is believed to be accurate, UNEP disclaims any responsibility for possible inaccuracies or omissions and consequences, which may flow from them. Neither UNEP nor any individual involved in the preparation of this report shall be liable for any injury, loss, damage or prejudice of any kind that may be caused by any persons who have acted based on their understanding of the information contained within this publication.

126. Information on the economics of the following technologies can be found in appendix IV.

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<sup>2</sup> As contained in document UNEP/POPS/COP.1/INF/12/rev.1

<sup>3</sup> Further information regarding these technologies or others currently in the pilot or test phase can be found in Review of Emerging, Innovative Technologies for the Destruction and Decontamination of POPs and the Identification of Promising Technologies for Use in Developing Countries (UNEP, 2004b in annex V, References).

**(a) Alkali metal reduction<sup>4</sup>**

127. *Process description:* Alkali metal reduction involves the treatment of wastes with dispersed alkali metal. Alkali metals react with chlorine in halogenated waste to produce salt and non-halogenated waste. Typically, the process operates at atmospheric pressure and temperatures between 60 °C and 180 °C.<sup>5</sup> Treatment can take place either in situ (i.e., PCB-contaminated transformers) or ex situ in a reaction vessel. There are several variations of this process.<sup>6</sup> Although potassium or potassium sodium alloy has been used, metallic sodium is the most commonly used reducing agent. The remaining information is based on experiences with the metallic sodium variation.

128. *Efficiency:* Destruction efficiency (DE) values of greater than 99.999 per cent and destruction removal efficiency (DRE) values of 99.9999 per cent have been reported for aldrin, chlordane and PCBs (Ministry of Environment of Japan, 2004). The sodium reduction process has also been demonstrated to meet regulatory criteria in Australia, Canada, Japan, South Africa, United States of America, and the European Union for PCB transformer oil treatment, i.e., less than 2 ppm in solid and liquid residues.<sup>7</sup>

129. *Waste types:* Sodium reduction has been demonstrated with PCB-contaminated oils containing concentrations up to 10,000 ppm.<sup>8</sup> Some vendors have also claimed that this process is capable of treating whole capacitors and transformers.<sup>9</sup>

130. *Pre-treatment:* Ex-situ treatment of PCBs can be performed, however, following solvent extraction of PCBs. Treatment of whole capacitors and transformers could be carried out following size reduction through shearing.<sup>10</sup> Pre-treatment should include de-watering to avoid explosive reactions with metallic sodium.

131. *Emissions and residues:* Air emissions include nitrogen and hydrogen gas. Emissions of organic compounds are expected to be relatively minor.<sup>11</sup> However, it has been noted that PCDDs/PCDFs can be formed from chlorophenols under alkaline conditions at temperature as low as 150 °C (Weber, 2004). Residues produced during the process include sodium chloride, sodium hydroxide, polyphenyls and water.<sup>12</sup> In some variations, a solidified polymer is also formed.<sup>13</sup>

132. *Release control and post-treatment:* After the reaction, the by-products can be separated out from the oil through a combination of filtration and centrifugation. The decontaminated oil can be reused, the sodium chloride can either be reused or disposed of in a landfill, and the solidified polymer can be disposed of in a landfill.<sup>14</sup>

133. *Energy requirements:* Immediate energy requirements are expected to be relatively low owing to low operating temperatures associated with the sodium reduction process.

134. *Material requirements:* Significant amounts of sodium are required to operate this process.<sup>15</sup>

135. *Portability:* This process is available in transportable and fixed configurations.<sup>16</sup>

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<sup>4</sup> Additional information is available from UNEP, 1998b; UNEP, 2000b; and UNEP, 2004b. See annex V, References.

<sup>5</sup> Ariizumi Otsuka, Kamiyama and Hosani, 1997, and Japan Industrial Waste Management Foundation, 1999, see annex 5 references

<sup>6</sup> See Piersol, 1989 in annex V, References.

<sup>7</sup> See Piersol, 1989 and UNEP, 2004b in annex V, References.

<sup>8</sup> See UNEP, 2004b in annex V, References.

<sup>9</sup> Ibid.

<sup>10</sup> Ibid..

<sup>11</sup> See Piersol, 1980 in annex V, References.

<sup>12</sup> See UNEP, 2004b in annex V, References.

<sup>13</sup> See UNEP, 2000b, in annex V, References.

<sup>14</sup> Ibid.

<sup>15</sup> UNEP, 2004b, in annex V, References.

<sup>16</sup> Ibid.

136. *Health and safety:* Dispersed metallic sodium can react violently and explosively with water, presenting a major hazard to operators. Metallic sodium can also react with a variety of other substances to produce hydrogen – a flammable gas that is explosive in admixture with air. Great care must be taken in process design and operation to absolutely exclude water (and certain other substances, e.g. alcohols) from the waste and from any other contact with the sodium. A facility in Delfzijl, The Netherlands, has been severely damaged by a fire.

137. *Capacity:* Mobile facilities are capable of treating 15,000 litres per day of transformer oil.<sup>17</sup>

138. *Other practical issues:* Sodium reduction used for in-situ treatment of PCB contaminated transformer oils may not destroy all the PCBs contained in the porous internals of the transformer. Some authors have noted that there is a lack of information on the characterization of residues.<sup>18</sup>

139. *State of commercialization:* This process has been used commercially for approximately 20 years.

140. Vendors include:

(a) Dr. Bilger [Umweltconsulting GmbH](http://www.bilgergmbh.de) – [www.bilgergmbh.de](http://www.bilgergmbh.de);

(b) Decoman srl, Italy – [www.decoman.it](http://www.decoman.it);

(c) Envio Germany GmbH & Co. KG – [www.envio-group.com](http://www.envio-group.com);

(d) Kinectrics Inc. – [www.kinectrics.com](http://www.kinectrics.com);

(e) Nippon Soda Co. Ltd. – [www.nippon-soda.co.jp](http://www.nippon-soda.co.jp);

(f) Orion BV, Netherlands – [www.orionun2315.nl/en/index.php](http://www.orionun2315.nl/en/index.php).

(g) Powertech Labs Inc. – [www.powertechlabs.com](http://www.powertechlabs.com);

(h) Sanexen Environmental Services Inc. – [www.sanexen.com](http://www.sanexen.com)

**(b) Base catalysed decomposition (BCD)<sup>19</sup>**

141. *Process description:* The BCD process involves treatment of wastes in the presence of a reagent mixture consisting of hydrogen donor oil, alkali metal hydroxide and a proprietary catalyst. When the mixture is heated to above 300°C, the reagent produces highly reactive atomic hydrogen. The atomic hydrogen reacts with the waste to remove constituents that confer the toxicity to compounds.

142. *Efficiency:* DEs of 99.99–99.9999 per cent have been reported for DDT, PCBs, PCDDs and PCDFs.<sup>20</sup> DEs of greater than 99.999 per cent and DREs of greater than 99.9999 per cent have also been reported for chlordane (Ministry of the Environment of Japan, 2004). It has also been reported that reduction of chlorinated organics to less than 2 mg/kg is achievable.<sup>21</sup>

143. *Waste types:* BCD should be applicable to other POPs in addition to the waste types listed above.<sup>22</sup> BCD should be capable of treating wastes with a high POP concentration, with demonstrated applicability to wastes with a PCB content of above 30 per cent.<sup>23</sup> It was believed that in practice, the formation of salt within the treated mixture could limit the concentration of halogenated material able to be treated.<sup>24</sup> However, the vendor has indicated that the build-up of salt within the reactor simply limits the amount of waste that can be fed to the reactor and that this problem does not appear insolvable. Applicable waste matrices include soil, sediment, sludge and liquids. The company BCD Group also claims that the process has been demonstrated to destroy PCBs in wood, paper and metal surfaces of transformers.

144. *Pre-treatment:* Soils may be treated directly. Different types of soil pre-treatment may be necessary:

(a) Larger particles may need to be removed by sifting and crushed to reduce their size; or

(b) pH and moisture content may need to be adjusted.

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<sup>17</sup> Ibid.

<sup>18</sup> See UNEP, 2000b, in annex V, References.

<sup>19</sup> Additional information is available from CMPS&F – Environment Australia, 1997; Costner, Luscombe and Simpson, 1998; Danish Environmental Protection Agency, 2004; Rahuman, Pistone, Trifirò and Miertu, 2000; UNEP, 1998b; UNEP, 2001; UNEP, 2004b and Vijgen, 2002. See annex V, References.

<sup>20</sup> See UNEP, 2004b in annex V, References.

<sup>21</sup> See UNEP, 2001 in annex V, References.

<sup>22</sup> See UNEP, 2004b and Vijgen, 2002 in annex V, References.

<sup>23</sup> See Vijgen, 2002 in annex V, References.

<sup>24</sup> See CMPS&F – Environment Australia, 1997; Rahuman et al., 2000 and UNEP 2001 in annex V, References.

145. *Thermal desorption* has also been used in conjunction with BCD to remove POPs from soils prior to treatment. In these situations, the soil is premixed with sodium bicarbonate prior to being fed into the thermal desorption unit.<sup>25</sup> Water will need to be evaporated from aqueous media, including wet sludge, prior to treatment. Capacitors can be treated following size reduction through shredding.<sup>26</sup> If volatile solvents are present, such as occurs with pesticides, they should be removed by distillation prior to treatment.<sup>27</sup>

146. *Emissions and residues*: Air emissions are expected to be relatively minor. The potential to form PCDDs and PCDFs during the BCD process is relatively low. However, it has been noted that PCDDs can be formed from chlorophenols under alkaline conditions at temperature as low as 150°C (Weber, 2004). Other residues produced during the BCD reaction include sludge containing primarily water, salt, unused hydrogen donor oil and carbon residue. The vendor claims that the carbon residue is inert and non-toxic. For further details, users are referred to the literature produced by BCD Group, Inc.

147. *Release control and post-treatment*: Depending on the type of hydrogen donor oil used, the slurry residue may be treated in different ways. If No. 6 fuel oil has been used, the sludge may be disposed of as a fuel in a cement kiln. If more refined oils are used, these may be removed from the sludge by gravity or centrifuge separation. The oils can then be re-used and the remaining sludge can be further treated for usage as a neutralizing agent or disposed of in a landfill.<sup>28</sup> In addition, BCD plants are equipped with activated carbon traps to minimize releases of volatile organics in gaseous emissions.

148. *Energy requirements*: Energy requirements are expected to be relatively low owing to low operating temperatures associated with the BCD process.

149. *Material requirements*:

- (a) Hydrogen donor oil, such as No. 6 fuel oil or Sun Par oils No. LW -104, LW -106 and LW -110;
- (b) Alkali or alkaline earth metal carbonate, bicarbonate or hydroxide, such as sodium bicarbonate. The amount of alkali required is dependent on the concentration of the halogenated contaminant contained in the medium.<sup>29</sup> Amounts range from 1 per cent to about 20 per cent by weight of the contaminated medium; and
- (c) Proprietary catalyst amounting to 1 per cent by volume of the hydrogen donor oil.

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<sup>25</sup> See CMPS&F – Environment Australia, 1997 in annex V, References.

<sup>26</sup> See CMPS&F – Environment Australia, 1997 and UNEP 2001, in annex V, References.

<sup>27</sup> See CMPS&F – Environment Australia, 1997 in annex V, References.

<sup>28</sup> See UNEP, 2004b, in Annex V, References.

<sup>29</sup> See CMPS&F – Environment Australia, 1997 and UNEP 2001 in annex V, References.

150. The *equipment* associated with this process is thought to be readily available.<sup>30</sup>
151. *Portability*: Modular, transportable and fixed plants have been built.
152. *Health and safety*: In general the health and safety risks associated with operation of this technology are thought to be low,<sup>31</sup> although a BCD plant in Melbourne, Australia, was rendered inoperable following a fire in 1995. The fire is thought to have resulted from the operation of a storage vessel without a nitrogen blanket.<sup>32</sup> Some associated pre-treatments such as alkaline pre-treatment of capacitors and solvent extraction have significant fire and explosion risks, although they can be minimized through the application of appropriate precautions.<sup>33</sup>
153. *Capacity*: BCD can process as much as 2,600 gallons per batch, with a capability of treating two–four batches per day.<sup>34</sup>
154. *Other practical issues*: Since the BCD process involves stripping chlorine from the waste compound, the treatment process may result in an increased concentration of lower chlorinated species. This can be of potential concern in the treatment of PCDDs and PCDFs, where the lower chlorinated congeners are more *toxic* than the higher chlorinated congeners. It is therefore important that the process be appropriately monitored to ensure that the reaction continues to completion. In the past, it has been reported that the BCD process was unable to treat high concentration wastes because of salt build-up.<sup>35</sup> More recently, however, it has been reported that this problem has been overcome.<sup>36</sup>
155. *State of commercialization*: BCD has been used at two commercial operations within Australia, with one still operating. Another commercial system has been operating in Mexico for the past two years. In addition BCD systems have been used for short-term projects in Australia, Spain and the United States of America. A BCD unit for the treatment of both soil and pesticide wastes contaminated with PCDD and PCDF is now under construction within the Czech Republic.
156. *Vendors*: The patent for this technology is held by BCD Group, Inc., USA (www.bcdinternational.com). BCD Group, Inc. sells licences to operate the technology. Currently, licences are held by companies based in Australia, Czech Republic, Japan, Mexico and the United States of America.

**(c) Catalytic hydro-dechlorination (CHD)**

157. *Process description*. CHD involves the treatment of wastes with hydrogen gas and palladium on carbon (Pd/C) catalyst dispersed in the paraffin oil. Hydrogen reacts with chlorine in halogenated waste to produce hydrogen chloride (HCl) and non-halogenated waste. In the case of PCBs, biphenyl is the main product. Process operates at atmospheric pressure and temperatures between 180 °C and 260 °C (Sakai, Peter and Oono, 2001; Noma, Sakai and Oono, 2002; and Noma, Sakai and Oono, 2003a and 2003b).
158. *Efficiency*. DEs of 99.98–99.9999 per cent have been reported for PCBs. It has also been reported that a reduction of the PCB content to less than 0.5 mg/kg is achievable.
159. *Waste types*. CHD has been demonstrated with PCBs removed from used capacitors. PCDDs/PCDFs contained in PCBs as impurities have also been dechlorinated. A vendor has also claimed that chlorinated wastes in liquid state or dissolved in solvents can be treated by CHD.
160. *Pretreatment*. PCBs and PCDDs/PCDFs need to be extracted using solvents or isolated by vaporizing. Substances with low boiling points such as water or alcohols should be removed by distillation prior to treatment.
161. *Emission and residues*. No emissions would occur during the dechlorination reaction because it takes place in the closed hydrogen circulation system. HCl is not discharged from the reaction because it is collected with water as hydrochloric acid within the circulation system. Biphenyl isolated after the reaction by distillation does not contain any toxic materials.

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<sup>30</sup> See Rahuman et al., 2000 in annex V, References.

<sup>31</sup> See CMPS&F – Environment Australia, 1997 and Rahuman et al., 2000 in annex V, References.

<sup>32</sup> See CMPS&F – Environment Australia, 1997 in annex V, References.

<sup>33</sup> Ibid.

<sup>34</sup> See Vijgen, 2002 and UNEP, 2004b in annex V, References.

<sup>35</sup> See CMPS&F – Environment Australia, 1997 in annex V, References.

<sup>36</sup> See Vijgen, 2002 in annex V, References.

162. *Release control and post-treatment.* Biphenyl, the main product, is separated out from the reaction solvent by distillation after the reaction, and the catalyst and reaction solvent are reused for the next reaction.
163. *Energy requirements.* Energy requirements are expected to be relatively low due to low operating temperatures associated with the CHD process.
164. *Material requirements.* The CHD process requires the same amount of molecules of hydrogen as those of chlorine in PCBs, as well as 0.5 per cent by weight of catalyst.
165. *Portability.* CHD is available in fixed and transportable configurations depending on the volume of PCBs to be treated.
166. *Health and safety.* The use of hydrogen gas requires adequate controls and safeguards to ensure that explosive air-hydrogen mixtures are not formed.
167. *Capacity.* In Japan, a plant which is capable of treating 2 Mg PCB per day using the CHD process is currently being designed and will be constructed in two years.
168. *Other practical issues.* There are many reports about PCB dechlorination by using CHD. Generally, Pd/C catalyst shows the largest degradation rate compared to the other supported metal catalyst. Reaction temperature can be increased to 260°C when paraffin oil is used as reaction solvent.
169. *State of commercialization.* A company in Japan started to treat capacitors containing or contaminated with PCBs using a CHD plant in 2004. A commercial-scale CHD plant will be operated in two years in Japan.
170. *Vendor(s).* The patent for this technology is held by Kansai Electric Power Co and Kanden-Engineering Co. ([www.kanden-eng.co.jp](http://www.kanden-eng.co.jp)).
171. *Additional information.* For further information, see the Technical Guideline for Treatment of PCBs in Japan (Japan Industrial Waste Management Foundation, 1999).

**(d) Cement kiln co-incineration<sup>37</sup>**

172. *Process description:* Cement kilns typically consist of a long cylinder of 50–150 metres, inclined slightly from the horizontal (3 per cent to 4 per cent gradient), which is rotated at about 1–4 revolutions per minute. Raw materials, such as limestone, silica, alumina and iron oxides are fed into the upper or so-called “cold” end of the rotary kiln. The slope and rotation cause the materials to move toward the lower or “hot” end of the kiln. The kiln is fired at the lower end of the kiln where temperatures reach 1400°C–1500°C. As the materials move through the kiln, they undergo drying and pyroprocessing reactions to form the clinker.
173. *Efficiency:* DREs of greater than 99.99998 per cent have been reported for PCBs in several countries (Ahling, 1979; Benestad, 1989; Lauber, 1987; Mantus, 1992. US EPA, 1986; Lauber, 1982; von Krogbeumker, 1994; Black, 1983).
174. *Waste types:* As mentioned above cement kilns have been demonstrated with PCBs, but should be applicable to other POPs. Cement kilns are capable of treating both liquid and solid wastes.<sup>38</sup>
175. *Pre-treatment:* Pre-treatment can involve:
- (a) Thermal desorption of solid wastes prior; and
  - (b) Homogenization of solid and liquid wastes through drying, shredding, mixing and grinding.

<sup>37</sup> Additional information is available from CMPS&F – Environment Australia, 1997; Costner et al., 1998; Danish Environmental Protection Agency, 2004; Karstensen, 2001; Rahuman et al., 2000; Stobiecki, Cieszkowski, Siłowiecki and Stobiecki, 2001 and UNEP, 1998b. In addition, information on BAT and BEP with respect to cement kilns firing hazardous waste is available from the European Commission, 2001 and UNEP 2004c. See annex V, References.

<sup>38</sup> See CMPS&F – Environment Australia, 1997; Rahuman et al., 2000 and UNEP, 2004c in annex V, References.

176. *Emissions and residues:* Emissions may include, inter alia, nitrogen oxides, carbon monoxide, sulphur oxides and dioxide, metals and their compounds, hydrogen chloride, hydrogen fluoride, NH<sub>3</sub>, PCDDs, PCDFs, benzene, toluene, xylene, polycyclic aromatic hydrocarbons, chlorobenzenes and PCBs.<sup>39</sup> It should be noted, however, that cement kilns can comply with PCDD and PCDF air emission levels below 0.1 ng TEQ/Nm<sup>3</sup>.<sup>40</sup> Residues include cement kiln dust captured by the air pollution control system.

177. *Release control and post-treatment:* Process gases require treatment to remove cement kiln dust and organic compounds, sulphur dioxide, nitrogen oxide, as well as heat so that formation of PCDDs and PCDFs is minimized. Treatments include use of pre-heaters, electrostatic precipitators, fabric filters and activated carbon filters.<sup>41</sup> It has been reported that PCDD and PCDF concentrations within cement kiln dusts range between 0.4 and 2.6 ppb.<sup>42,43</sup> Accordingly, recovered cement kiln dusts should be put back into kilns to the maximum extent practicable, while the remainder may require disposal in a specially engineered landfill or permanent storage in an underground mine or formation.

178. *Energy requirements:* New kiln systems with 5 cyclone preheater stages and precalciner will require an average of 2,900–3,200 MJ to produce 1 Mg of clinker.<sup>44</sup>

179. *Material requirements:* Cement manufacturing requires large amounts of materials including limestone, silica, alumina, iron oxides and gypsum.<sup>45</sup>

180. *Portability:* Cement kilns are available only in fixed configurations.

181. *Health and safety:* Treatment of wastes within cement kilns can be regarded as relatively safe if properly designed and operated.<sup>46</sup>

182. *Capacity:* Cement kilns co-incinerating wastes as a fuel are normally limited up to a maximum of 40 per cent of the heat requirement for hazardous waste.<sup>47</sup> It has been noted, however, that cement kilns with high throughput can potentially treat significant quantities of waste.<sup>48</sup>

183. *Other practical issues:* Cement kilns treating wastes may require modifications to the rotary kiln.<sup>49</sup> Potential feed points for supplying fuel to the kiln system are:

- (a) The main burner at the rotary kiln outlet end;
- (b) A feed chute at the transition chamber at the rotary kiln inlet end (for lump fuel);
- (c) Secondary burners to the riser duct;
- (d) Precalciner burners to the precalciner;
- (e) A feed chute to the precalciner/preheater (for lump fuel);
- (f) A mid kiln valve in the case of long wet and dry kilns (for lump fuel).(UNEP, 2004c)

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<sup>39</sup> See UNEP, 2004c in annex V, References.

<sup>40</sup> See UNEP, 2004c in annex V, References.

<sup>41</sup> See CMPS&F – Environment Australia, 1997; Karstensen, 2001 and UNEP, 2004c in annex V, References.

<sup>42</sup> TEQ were not indicated.

<sup>43</sup> See UNEP 2004c in annex V, References.

<sup>44</sup> Ibid.

<sup>45</sup> See CMPS&F – Environment Australia, 1997 in annex V, References.

<sup>46</sup> Ibid.

<sup>47</sup> See UNEP, 2004c in annex V, References.

<sup>48</sup> See UNEP, 1998b in annex V, References.

<sup>49</sup> See CMPS&F – Environment Australia, 1997 and UNEP, 2004c in annex V, References.

184. Chlorides have an impact on the quality of the cement and so have to be limited. Chlorine can be found in all the raw materials used in cement manufacture, so the chlorine levels in the hazardous waste can be critical. However, if they are blended down sufficiently, cement kilns can treat highly chlorinated hazardous waste.

185. *State of commercialization:* Cement kilns in the United States of America and some European countries have been used to treat wastes contaminated with POPs. (World business council, 2004: Formation and Release of POPs in the Cement Industry.)

186. *Vendors:* A number of existing cement kiln co-incineration operations are identified in the inventory of worldwide PCB destruction capacity.<sup>50</sup>

(e) **Gas phase chemical reduction (GPCR)**<sup>51</sup>

187. *Process description:* The GPCR process involves the thermo-chemical reduction of organic compounds. At temperatures greater than 850°C and low pressures, hydrogen reacts with chlorinated organic compounds to yield primarily methane and hydrogen chloride.

188. *Efficiency:* DEs of 99.9999 per cent have been reported for DDT, HCB, PCBs, PCDDs and PCDFs.<sup>52</sup>

189. *Waste types:* In addition to the substances listed above, GPCR should also be capable of treating wastes consisting of, containing or contaminated with all other POPs.<sup>53</sup> GPCR is capable of treating wastes with a high POP concentration.<sup>54</sup> This includes aqueous and oily liquids, soils, sediments, transformers and capacitors.<sup>55</sup>

190. *Pre-treatment:* Depending on the waste type, one of the following three pre-treatment units is used to volatilize wastes prior to treatment in the GPCR reactor:

- (a) Thermal reduction batch processor (TRBP) for bulk solids, including those in drums;
- (b) Torbed reactor for contaminated soils and sediments, but also adapted for liquids; and
- (c) Liquid waste pre-heater system (LWPS) for liquids.<sup>56</sup>

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<sup>50</sup> See UNEP, 1998b in annex V, References.

<sup>51</sup> Additional information is available from CMPS&F – Environment Australia, 1997; Costner et al., 1998; Danish Environmental Protection Agency, 2004; Kümmling, Gray, Power and Woodland, 2001; Rahuman et al., 2000; Ray, 2001; UNEP, 2001; UNEP, 2004b; and Vijgen, 2002. See annex V, References.

<sup>52</sup> See CMPS&F – Environment Australia, 1997; Kümmling, 2001; Rahuman et al., 2000; UNEP, 2004b and Vijgen, 2002 in annex V, References.

<sup>53</sup> See CMPS&F – Environment Australia, 1997; UNEP, 2004b and Vijgen, 2002 in annex V, References.

<sup>54</sup> See UNEP, 2004b and Vijgen, 2002 in annex V, References.

<sup>55</sup> See CMPS&F – Environment Australia, 1997; UNEP, 2004b and Vijgen, 2002 in annex V, References.

<sup>56</sup> See CMPS&F – Environment Australia, 1997; Kümmling et al., 2001; UNEP, 2001; UNEP, 2004b and Vijgen, 2004 in annex V, References.

191. In addition, other pre-processing is required for large capacitors and building rubble. Large capacitors are punctured and drained, while rubble and concrete must be reduced in size to less than one square metre.<sup>57</sup>

192. *Emissions and residues:* In addition to hydrogen chloride and methane, low molecular weight hydrocarbons may be emitted. Residues from the GPCR process include used liquor and water. Solid residues will also be generated from solid waste inputs.<sup>58</sup> Since the GPCR process takes place in a reducing atmosphere the possibility of PCDD and PCDF formation is considered limited.<sup>59</sup>

193. *Release control and post-treatment:* Gases leaving the reactor are scrubbed to remove water, heat, acid and carbon dioxide.<sup>60</sup> Scrubber residue and particulate will require disposal off-site.<sup>61</sup> Solid residues generated from solid waste inputs should be suitable for disposal in a landfill.<sup>62</sup>

194. *Energy requirements:* Methane produced during the process can provide much of the fuel needs.<sup>63</sup> It has been reported that electricity requirements range from 96 kWh per ton of soil treated to around 900 kWh per ton of pure organic contaminants treated.<sup>64</sup>

195. *Material requirements:* There is a need for hydrogen supplies, at least during start-up. It has been reported that methane produced during the GPCR process can be used to form enough hydrogen to operate the process thereafter.<sup>65</sup> The hydrogen production unit has been plagued, however, by reliability problems in the past.<sup>66</sup> Other material requirements include caustic for the acid scrubber.<sup>67</sup>

196. *Portability:* GPCR is available in fixed and transportable configurations.<sup>68</sup>

197. *Health and safety:* Use of hydrogen gas under pressure requires suitable controls and safeguards to ensure that explosive air-hydrogen mixtures are not formed.<sup>69</sup> Operating experience gained to date has indicated that the GPCR process can be undertaken safely.<sup>70</sup>

198. *Capacity:* GPCR process capacity is dependent on the capacity of the three pre-treatment units, as specified below:

- (a) TRBP has a capacity of up to 100 tons of solids per month or up to 4 litres per minute of liquids. Two TRBPs can be used in parallel to double capacity;
- (b) TORBED reactor has a capacity of up to 5,000 tons of soils and sediments per month, although this pre-treatment unit is still in the development stage; and
- (c) LWPS has a capacity of three litres per minute.<sup>71</sup>

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<sup>57</sup> See CMPS&F – Environment Australia, 1997 in annex V, References.

<sup>58</sup> See UNEP, 2004b and Vijgen, 2002 in annex V, References.

<sup>59</sup> See CMPS&F – Environment Australia, 1997 and Rahuman et al., 2000 in annex V, References.

<sup>60</sup> See Kümmling et al., 2001; CMPS&F – Environment Australia, 1997 and Rahuman et al., 2000 in annex V, References.

<sup>61</sup> See Rahuman et.al, 2000 and Vijgen, 2002 in annex V, References.

<sup>62</sup> See UNEP, 2004b in annex V, References.

<sup>63</sup> See CMPS&F – Environment Australia, 1997; Rahuman et al., 2000; UNEP, 2001; UNEP, 2004b and Vijgen, 2002 in annex V, References.

<sup>64</sup> CMPS&F – Environment Australia, 1997 in annex V, References.

<sup>65</sup> See CMPS&F – Environment Australia, 1997; Rahuman et al., 2000; UNEP, 2004b and Vijgen, 2002 in annex V, References.

<sup>66</sup> See CMPS&F – Environment Australia, 1997 in annex V, References.

<sup>67</sup> See UNEP, 2004b in annex V, References.

<sup>68</sup> See UNEP, 2001; UNEP, 2004b and Vijgen, 2002 in annex V, References.

<sup>69</sup> See CMPS&F – Environment Australia, 1997 in annex V, References.

<sup>70</sup> See CMPS&F – Environment Australia, 1997 and UNEP, 2004b in annex V, References.

<sup>71</sup> See UNEP, 2004b and Vijgen, 2002 in annex V, References.

199. *Other practical issues:* Contaminants such as sulphur and arsenic were found to inhibit treatment in earlier development stages, although it is unclear whether this problem is still encountered.<sup>72</sup>

200. *State of commercialization:* Commercial scale GPCR plants have operated in Canada and Australia. The GPCR plant in Australia operated for more than five years. In addition, a GPCR plant has recently been authorized in Japan.<sup>73</sup>

201. *Vendors:* The patent for this technology is held by the sole supplier ELI Eco Logic International Inc. (www.ecologic.ca). ELI Eco Logic International Inc. sells licences to operate the technology.

(f) **Hazardous waste incineration**<sup>74</sup>

202. *Process description:* Hazardous waste incineration uses controlled flame combustion to treat organic contaminants mainly in rotary kilns. Typically a process for treatment involves heating to a temperature greater than 850 °C or, if the chlorine content is above 1 per cent, greater than 1,100 °C, with a residence time greater than 2 seconds, under conditions that assure appropriate mixing. Dedicated hazardous waste incinerators are available in a number of configurations including rotary kiln incinerators, static ovens (for liquids only). High-efficiency boilers and lightweight aggregate kilns are also used for the co-incineration of hazardous wastes. (See Brunner, 2004, for additional information regarding the application of these technologies.)

203. *Efficiency:* DREs of greater than 99.9999 per cent have been reported for treatment of wastes consisting of, containing or contaminated with POPs.<sup>75</sup> DEs of greater than 99.999 and DREs of greater than 99.9999 per cent have been reported for aldrin, chlordane and DDT (Ministry of the Environment of Japan, 2004), while DEs between 83.15 and 99.88 per cent have been reported for PCBs (United States Environmental Protection Agency, 1990).

204. *Waste types:* As noted above, hazardous waste incinerators are capable of treating wastes consisting of, containing or contaminated with any POP. Incinerators can be designed to accept wastes in any concentration or any physical form, i.e., gases, liquids, solids, sludges and slurries.<sup>76</sup>

205. *Pre-treatment:* Depending upon the configuration, pre-treatment requirements may include blending, dewatering, and size reduction of wastes.<sup>77</sup>

206. *Emissions and residues:* Emissions include carbon monoxide, carbon dioxide, HCB, hydrogen chloride, particulates, PCDDs, PCDFs and PCBs and water vapour.<sup>78</sup> Incinerators applying BAT, inter alia, designed for high temperature and equipped with prevention of reformation of PCDDs and PCDFs and dedicated PCDD and PCDF removal (e.g., activated carbon filters), have led to very low PCDD and PCDF emissions to air and discharges to water.<sup>79</sup> In the residues, PCDDs and PCDFs are mainly found in fly ash and salt, and to some extent in bottom ash and scrubber water sludge.

<sup>72</sup> See CMPS&F – Environment Australia, 1997 in annex V, References.

<sup>73</sup> See CMPS&F – Environment Australia, 1997; Kümmling et al., 2001; Ray, 2001; UNEP, 2004b and Vijgen, 2002 in annex V, References.

<sup>74</sup> Additional information is available from Danish Environmental Protection Agency, 2004; Federal Remediation Technologies Roundtable (FRTR), 2002; Rahuman et al., 2000; UNEP, 1995c; UNEP, 1998b; UNEP, 2001 and United States Army Corps of Engineers, 2003. In addition, information on BAT and BEP with respect to hazardous waste incinerators is available from the European Commission 2004 and UNEP 2004c. See annex V, References.

<sup>75</sup> See FRTR, 2002; Rahuman et al., 2000; UNEP, 1998b and UNEP, 2001 in annex V, References.

<sup>76</sup> See UNEP, 1995c in annex V, References.

<sup>77</sup> See UNEP, 1995c; UNEP, 1998b and UNEP, 2004c in annex V, References.

<sup>78</sup> See UNEP, 1995c; UNEP, 1998b and UNEP, 2004c in annex V, References.

<sup>79</sup> UNEP, 2001 in annex V, References.

207. *Release control and post-treatment:* Process gases may require treatment to remove hydrogen chloride and particulate matter and to prevent the formation of and remove unintentionally produced POPs. This can be achieved through a combination of types of post-treatments, including cyclones and multi-cyclones, electrostatic filters, static bed filters, scrubbers, selective catalytic reduction, rapid quenching systems and carbon adsorption.<sup>80</sup> Depending upon their characteristics, bottom and fly ashes may require disposal within a specially engineered landfill.<sup>81</sup>

208. *Energy requirements:* The amount of combustion fuel required will depend upon the composition and calorific value of the waste.

209. *Material requirements:* Material requirements include cooling water and lime or another suitable material for removal of acid gases.

210. *Portability:* Hazardous waste incinerators are available in both portable and fixed units.

211. *Health and safety:* Health and safety hazards include those associated with high operating temperatures.<sup>82</sup>

212. *Capacity:* Hazardous waste incinerators can treat between 30,000 and 100,000 tons per year.<sup>83</sup>

213. *Other practical issues:* None to report at this time.

214. *State of commercialization:* There is a long history of experience with hazardous waste incineration.<sup>84</sup>

215. *Vendors:* A number of existing hazardous waste incineration facilities are identified within the inventory of worldwide PCB destruction capacity.<sup>85</sup>

**(g) Photo-chemical dechlorination (PCD) and catalytic dechlorination (CD) reaction**

216. *Process description:* PCD and CD is a technology using the combined methods of both photo-chemical dechlorination (PCD) reaction and catalytic dechlorination (CD) reaction (Watanabe, Ohara and Tajima, 2002 and Watanabe, Ohara, Tarima, Yoneki and Hosya, 2003). In the destruction process, PCBs are mixed with NaOH and isopropyl alcohol (IPA) so that the PCB concentration in IPA should reach several per cent by weight. Subsequently, PCBs are dechlorinated by two independent processes, i.e., PCD and CD processes. Each process is operated at moderate temperature (<75 °C) and atmospheric pressure. After the PCBs are dechlorinated, biphenyl, NaCl, acetone, and water are generated, but no gases such as hydrogen or hydrochloric gas are produced.

217. *Efficiency:* DEs of 99.99-99.9999 per cent have been achieved for PCBs and 99.9999-99.999999 per cent for PCDDs and PCDFs (Tajima et al., 2003; and Watanabe et al., 2003).

218. *Waste types:* PCD and CD has been demonstrated to treat oil from transformers and capacitors containing PCBs with a high concentration and contaminated with PCDDs and PCDFs, and should be applicable to other POPs as well. Soils and sludge are not treatable with this technology. PCB in clothing, packaging, wood and other multi-porous materials should be extracted by solvent.

219. *Pretreatment:* Electrical equipment contaminated with PCBs requires some pretreatment. After removing PCBs from the equipment, the contaminated material such as cases, coils and insulation papers are disassembled and separated. PCBs are extracted from those materials by hydrocarbon washing agent, such as decane. PCBs and the solvent are separated by the distiller. Distilled PCBs and solvent are respectively destroyed by the PCD and CD processes. The solvent is reused for washing. It is not necessary to pretreat soils, sludge and water.

220. *Potential emissions and residues:* Air emissions are expected to be relatively minor. The potential for PCDDs and PCDFs to be formed during the PCD and CD processes is not considered theoretically. Residues include solid NaCl and used catalyst. (Watanabe et al., 2002; Watanabe et al., 2003)

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<sup>80</sup> UNEP, 2004c.

<sup>81</sup> See United States Army Corps of Engineers, 2003 in annex V, References.

<sup>82</sup> Ibid.

<sup>83</sup> See UNEP, 2004c in annex V, References.

<sup>84</sup> See UNEP, 2001 in annex V, References.

<sup>85</sup> See UNEP, 1998 in annex V, References.

221. *Post-treatment:* A distiller separates IPA from the solution, and large parts of IPA can be recycled several times as solvent of PCBs. Wastes generated from the processes include biphenyl, NaCl, acetone, water and residual IPA. NaCl is filtrated from the solution and disposed to landfill. The used catalyst is washed with water in order to remove NaCl, and it can be reused several times for the CD process.

222. *Energy requirements:* The PCD process requires 3 kJ/g PCB for mercury lamp. The energy requirement is expected to be relatively low due to low operating temperatures (75 °C) associated with the PCD and CD process (Watanabe et al., 2002; Watanabe et al., 2003).

223. *Material requirements:*

- (a) Alkali: NaOH (NaOH/Cl = 1.3)
- (b) Catalyst: 2 kg/m<sup>3</sup> by volume of the hydrogen donor
- (c) Hydrogen donor: IPA

224. *Portability*: Modular, transportable plants should be available. A fixed plant has been established in Kawasaki, Japan.
225. *Health and safety*: In general, the health and safety risks associated with operation of this technology are regarded to be low. (Watanabe et al., 2002; Watanabe et al., 2003; Sasaki, Masaaki, Watanabe, Nishida, Fujita, Harano, Nagata and Mimura et al., 2003).
226. *Capacity*: The PCD and CD technology is available with a capacity 50 kg oil per day by one unit. The capacity could be flexible due to the size of facility (e.g. either lower or as high as 2 ton/day)
227. *Other practical issues*: The PCD and CD method is especially suitable for pure PCB. This technology satisfies the stringent release standards in Japan (PCBs in the waste oil < 0.5 mg/kg).
228. *State of commercialization*: The PCD and CD technologies have been operated in Kawasaki, Japan, for the past two years (Watanabe et al., 2002; and Watanabe et al., 2003).
229. *Vendor(s)*: The patent and all rights for this technology are held and reserved by Toshiba corporation ([www.toshiba.co.jp/efort/market/pcb/index\\_j.htm](http://www.toshiba.co.jp/efort/market/pcb/index_j.htm)). Toshiba Corporation sells licensees for operation of the technology.
230. *Additional information*: For further information, see the Technical Guideline for treatment of PCBs in Japan (Japan Industrial Waste Management Foundation, 1999; Watanabe et al., 2002; Watanabe et al., 2003; Sasaki et al., 2003; Noma et al., 2002; Noma et al., 2003).

**(h) Plasma arc<sup>86</sup>**

231. *Process description*: The Plascon™ process uses a plasma arc with temperatures in excess of 3000°C to pyrolyse wastes. Together with argon, wastes are injected directly into the plasma arc. The high temperature causes compounds to dissociate into their elemental ions and atoms. Recombination occurs in a cooler area of the reaction chamber, followed by a quench resulting in the formation of simple molecules.<sup>87</sup>
232. *Efficiency*: Bench scale tests with oils containing 60 per cent PCBs have achieved DREs ranging from 99.9999 to 99.999999 per cent.<sup>88</sup>
233. *Waste types*: In addition to PCB oils, a Plascon™ plant in Australia has recently been configured to treat pesticide wastes.<sup>89</sup> Waste types to be treated must be liquid, gas or solids if in the form of a fine slurry, which can be pumped. Very viscous liquids or sludges thicker than 30 to 40 weight motor oil cannot be processed without pre-treatment. Other solid wastes cannot be treated unless some form of pre-treatment is undertaken.<sup>90</sup>
234. *Pre-treatment*: Pre-treatment is not required for most liquids. Solids such as contaminated soils, capacitors and transformers can be pre-treated using thermal desorption or solvent extraction.<sup>91</sup>
235. *Emissions and residues*: Emissions include gases consisting of argon, carbon dioxide and water vapour. Residues include an aqueous solution of inorganic sodium salts, such as sodium chloride, sodium bicarbonate and sodium fluoride. Bench-scale tests with PCBs showed PCDD levels in scrubber water and stack gases in the part per trillion (ppt) range.<sup>92</sup> At a Plascon™ plant in Australia, used to treat a variety of wastes, the level of PCBs in the effluent discharged complies with a 2 ppb limit.<sup>93</sup> POP concentrations in solid residues are unknown.<sup>94</sup>
236. *Release control and post-treatment*: Currently, there is little information available regarding post-treatment requirements

<sup>86</sup> Additional information is available from CMPS&F – Environment Australia, 1997; Costner et al., 1998; Rahuman et al., 2000; Ray, 2001; UNEP, 1998b; UNEP, 2000b; UNEP, 2001 and UNEP, 2004b. See annex V, References.

<sup>87</sup> See CMPS&F – Environment Australia, 1997 in annex V, References.

<sup>88</sup> See Rahuman et al., 2000 and UNEP, 2004b in annex V, References.

<sup>89</sup> See UNEP, 2004b in annex V, References.

<sup>90</sup> See CMPS&F – Environment Australia, 1997 and UNEP, 2004b in annex V, References.

<sup>91</sup> Ibid.

<sup>92</sup> See CMPS&F – Environment Australia, 1997 and Rahuman et al., 2000 in annex V, References.

<sup>93</sup> See UNEP, 2004b in annex V, References.

<sup>94</sup> Ibid.

237. *Energy requirements:* A 150 kW Plascon unit requires 1,000–3,000 kWh of electricity per tonne of waste.<sup>95</sup>

238. *Material requirements:* Currently, there is little information available regarding material requirements. It has been noted, however, that this process does require argon gas, oxygen gas, caustic and cooling water.<sup>96</sup>

239. *Portability:* Plascon is available in transportable and fixed units.<sup>97</sup>

240. *Health and safety:* Since the Plascon process has a low through-put, there is a low risk associated with release of partially treated wastes following process failure.<sup>98</sup> Currently, there is little additional information available regarding health and safety.

241. *Capacity:* A 150 kW Plascon unit can process 1 to 3 tons per day of waste.<sup>99</sup>

242. *Other practical issues:* None to report at this time.

243. *State of commercialization:* BCD Technologies operates two plasma plants in Australia: one in Brisbane for PCBs and POPs; and another in Melbourne for treating CFCs and Halons. BCD Technologies also operates a BCD plant for low level PCBs and POPs and also has two thermal desorbers for treating contaminated solids. Mitsubishi Chemical Corporation has installed a Plascon plant in Japan to treat wastes consisting of, containing or contaminated with PCBs.

244. *Vendors:* The vendor for the Plascon process is SRL Plasma Pty Ltd Narangba Australia ([www.srlplasma.com.au](http://www.srlplasma.com.au)) and Commonwealth Scientific Industrial Research Organization (CSIRO). The three patents for Plascon are jointly owned by SRL Plasma PTY Ltd and CSIRO.

(i) **Potassium tert-Butoxide (t-BuOK) method**

245. *Process description:* PCBs in insulating oils are dechlorinated by the reaction with potassium tert-butoxide (t-BuOK). t-BuOK reacts with chlorine in PCBs to produce salt and non-chlorinated waste. Typically, the process operates at atmospheric pressure and temperatures between 200°C and 240°C (Oono, Kaneda and Kirata, 1997 and Oono and Kaneda, 1997).

246. *Efficiency:* DEs of 99.98-99.9999 per cent have been reported for PCBs. It has also been reported that a reduction of the PCB content to less than 0.5 mg/kg is achievable.

247. *Waste types:* The t-BuOK method has been demonstrated with low contaminated mineral oils. A vendor has also claimed that the chlorinated wastes in liquid state or dissolved in solvents can be treated by the t-BuOK method.

248. *Pretreatment:* t-BuOK reacts with water to produce potassium hydroxide and tert-butanol. If a high volume of water is contained in the mineral oils contaminated with PCBs, t-BuOK will react easier with the water than with the chlorine in PCBs. Therefore, water in the oils should be removed before the reaction.

249. *Emissions and residues:* No emission would occur during the reaction. There is little potential for PCDDs and PCDFs to be formed as by-products during the reaction due to very fast dechlorination rate, which causes chlorine to be released quickly (Takigami, Sakai and Oono, 2002a and 2002b).

250. *Release control and post-treatment:* By-products can be separated out from the oils by washing with water after the reaction. The decontaminated oils can be reused as fuel.

251. *Energy requirements:* Energy requirements are expected to be relatively low due to low operating temperatures associated with t-BuOK process.

252. *Material requirements:* When the PCB content in the mineral oils is below 200 ppm, the amount of t-BuOK required is about 0.5 per cent by weight of the contaminated oils.

253. *Portability:* This process is available in fixed and transportable configurations depending on the volume of the contaminated oil to be treated.

<sup>95</sup> See CMPS&F – Environment Australia, 1997 in annex V, References.

<sup>96</sup> See CMPS&F – Environment Australia, 1997 and UNEP, 2004b in annex V, References.

<sup>97</sup> See UNEP, 2004b in annex V, References.

<sup>98</sup> See CMPS&F – Environment Australia, 1997 and UNEP, 2004b in annex V, References.

<sup>99</sup> Ibid.

254. *Health and safety*: In general, the health and safety risks associated with the operation of this technology are considered to be low.
255. *Capacity*: It has been reported that 36,000 litres per day of contaminated oil have been treated with this technology in Japan.
256. *Other practical issues*: It is possible to treat a large amount of contaminated oils in a short period of time with this technology, as it can be continuously operated.
257. *State of commercialization*: A company in Japan has been treating contaminated mineral oils with a continuously operated plant since 2004.
258. *Vendor(s)*: The patent for this technology is held by Kansai Electric Power Co and Kanden-Engineering Co. ([www.kanden-eng.co.jp](http://www.kanden-eng.co.jp)).
259. *Additional information*: For further information see the Technical Guideline for treatment of PCBs in Japan (Japan Industrial Waste Management Foundation, 1999).

**(j) Super-critical water oxidation (SCWO) and subcritical water oxidation<sup>100</sup>**

260. *Process description*: SCWO and subcritical water oxidation treat wastes in an enclosed system, using an oxidant (such as oxygen, hydrogen peroxide, nitrite, nitrate, etc.) in water at temperatures and pressures above the critical point of water (374°C and 218 atmospheres) and under subcritical conditions (370 °C and 262 atmospheres). Under these conditions, organic materials become highly soluble in water and are oxidized to produce carbon dioxide, water and inorganic acids or salts.
261. *Efficiency*: DEs of greater than 99.999 per cent and DREs of greater than 99.9999 per cent have been reported for aldrin, chlordane and PCBs for SCWO (Ministry of the Environment of Japan, 2004). DEs of greater than 99.999999 and DREs of greater than 99.9999999 per cent have been reported for subcritical water oxidation (Ministry of the Environment of Japan, 2004). DREs as high as 99.9999 per cent have also been demonstrated for PCDDs in bench-scale tests.<sup>101</sup>
262. *Waste types*: SCWO and subcritical water oxidation are thought to be applicable to all POPs.<sup>102</sup> (Japan Industrial Waste Management Foundation, 1999). Applicable waste types include aqueous wastes, oils, solvents and solids with a diameter less than 200 µm. The organic content of the waste is limited to less than 20 per cent.<sup>103</sup>
263. *Pre-treatment*: Concentrated wastes may have to be diluted prior to treatment in order to reduce the organic content to less than 20 per cent. In the case of subcritical water oxidation, dilution of wastes is not necessary. If solids are present, they will have to be reduced to less than 200 µm in diameter.
264. *Emissions and residues*: During laboratory scale PCB destruction, it was shown that the SCWO technology has the potential to form high concentrations of PCDF (in the per cent range) during PCB degradation even at temperatures of practical operation (Weber, 2004). It has been reported that emissions contain no oxides of nitrogen or acid gases such as hydrogen chloride or sulphur oxide and that process residues consist of water and solids if the waste contains inorganic salts or organic compounds with halogens, sulphur or phosphorus.<sup>104</sup> Limited information has been reported regarding potential concentrations of undestroyed chemicals.<sup>105</sup> The process is designed such that emissions and residues can be captured for reprocessing if needed.<sup>106</sup>
265. *Release control and post-treatment*: Currently, there is no specific information available regarding post-treatment requirements.

<sup>100</sup> Additional information is available from CMPS&F – Environment Australia, 1997; Costner et al., 1998; Rahuman et al., 2000; UNEP, 2001 and UNEP, 2004b. See annex V, References.

<sup>101</sup> See CMPS&F – Environment Australia, 1997; Rahuman et al., 2000 and Vijgen, 2002 in annex V, References.

<sup>102</sup> See UNEP, 2004b in annex V, References.

<sup>103</sup> See CMPS&F – Environment Australia, 1997; Rahuman et al., 2000 and Vijgen, 2002 in annex V, References.

<sup>104</sup> See CMPS&F – Environment Australia, 1997 in annex V, References.

<sup>105</sup> See CMPS&F – Environment Australia, 1997 and UNEP, 2004b in annex V, References.

<sup>106</sup> See UNEP, 2004b in annex V, References.

266. *Energy requirements:* Energy requirements are expected to be relatively high because of the combinations of high temperatures and pressures. It has been claimed, however, that as long as relatively high hydrocarbon content is present in the feed, no energy input is required to heat up the feed to supercritical temperatures.<sup>107</sup>
267. *Material requirements:* The SCWO and subcritical water oxidation reaction vessel must be constructed of materials capable of resisting corrosion caused by halogen ions.<sup>108</sup> Material corrosion can be severe at the temperatures and pressures used in the SCWO and subcritical water oxidation process. In the past, the use of titanium alloys has been proposed to tackle this problem. Current vendors claim to have overcome this problem through the use of advanced materials and engineering designs.<sup>109</sup>
268. *Portability:* The SCWO and subcritical water oxidation units are currently used in a fixed configuration, but are thought to be transportable.<sup>110</sup>
269. *Health and safety:* The high temperatures and pressures used in this process require special safety precautions.<sup>111</sup>
270. *Capacity:* Current SCWO demonstration units are capable of treating 500 kg/hr, while full-scale units will be designed to treat 2,700 kg/hr.<sup>112</sup>
271. *Other practical issues:* Earlier designs were plagued by reliability, corrosion and plugging problems. Current vendors claim to have addressed these problems through the use of special reactor designs and corrosion resistant materials.<sup>113</sup>
272. *State of commercialization:* A full-scale, commercial plant has recently begun to operate in Japan. In addition, the SCWO process has been approved for full-scale development and use in the chemical weapons programme of the United States of America.
273. *Vendors:* Firms providing this service include:
- (a) Foster Wheeler Development Corporation ([www.fosterwheeler.com](http://www.fosterwheeler.com));
  - (b) General Atomics ([www.ga.com](http://www.ga.com));
  - (c) Mitsubishi Heavy Industries, Ltd. ([www.mhi.co.jp](http://www.mhi.co.jp)).

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<sup>107</sup> See Rahuman et al., 2000 in annex V, References.

<sup>108</sup> See Vijgen, 2002 in annex V, References.

<sup>109</sup> Ibid.

<sup>110</sup> See UNEP, 2004b and Vijgen, 2004 in annex V, References.

<sup>111</sup> See CMPS&F – Environment Australia, 1997 in annex V, References.

<sup>112</sup> See UNEP, 2004b and Vijgen, 2002 in annex V, References.

<sup>113</sup> Ibid.

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