PCB Caulk: An Ambiguous Public Health Concern

By

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Abstract

Polychlorinated biphenyls (PCBs) are a group of chlorinated chemicals that were used in a variety of industrial applications from the 1930’s to 1979. The chemical properties of PCBs were found to be useful in industrial and commercial products. Controversy surrounded PCBs as they were identified as wide-spread environmental contaminants and were found to pose health risks to humans and animals. These findings prompted the United States Congress to include PCBs in the Toxic Substances Control Act (TSCA) of 1976. One of the lesser known uses of PCBs was in building materials. Caulking, paints and other sealants that contained PCBs were used in building construction and renovation projects from approximately the 1950’s through the 1970’s. PCB caulking was applied in schools, churches, government buildings, commercial and office buildings, as well as in colleges and universities. The presence of PCBs in caulking has caused soil contamination around buildings and continues to pose a potential indoor contaminant threat, which is a cause of concern for building occupants. The use of PCB caulk was recognized as an emerging problem in the early to mid-2000’s in the United States when PCBs were being discovered in schools, universities and in municipal buildings. In some of the reported cases, concerns from the threat of contamination spread amongst building occupants. This paper examines the current regulatory issue of PCB caulk in the United States. Background information on the history, the chemistry, the impact on the environment and ecosystems, as well as the toxicology effects of PCBs on humans and animals is presented. The issue of PCBs in building materials and their intersection with TSCA, the discovery of PCBs in schools and the EPA’s research and guidance recommendations are discussed. The goals of this paper are to give the reader thorough background knowledge of PCBs and to shed light on an emerging and complicated regulatory issue in the United States.
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1.0 Introduction

Polychlorinated biphenyls (PCBs) are a group of chlorinated chemicals that were used in a variety of industrial applications from the 1930’s to 1979. The chemical properties of PCBs allowed them to find many uses in industrial and commercial products such as electrical transformers, capacitors, light ballasts, caulking, sealants, paints, etc. Controversy surrounded PCBs as they were identified as widespread environmental contaminants and were found to pose health risks to humans and animals. These findings prompted the United States Congress to include PCBs in the Toxic Substances Control Act (TSCA) of 1976 (15 U.S.C. §§ 2601 et seq.). TSCA authorized the U.S. Environmental Protection Agency (EPA) to develop the TSCA regulations (40 C.F.R. § 700 et seq.). In 1979, TSCA banned any future production of PCBs and set forth regulations for managing existing PCB containing equipment and waste streams.

One of the lesser known uses of PCBs was in building materials. Paints, sealants and wood floor finishes are known to have had PCBs as additives. PCBs were used as effective additives in caulking and paints because of their plasticizer properties. Caulking, paints and other sealants that contained PCBs were used in building construction and renovation projects from approximately the 1950’s through the 1970’s. For the purposes of this paper, PCB caulking, paint and sealants will be grouped under the blanket phrase “PCB caulk” unless specified otherwise.

Studies confirmed that PCB caulking was applied in schools, churches, government buildings, commercial and office buildings, as well as in colleges and universities. The breakdown of PCB impacted building materials has been linked to soil contamination around the perimeters of buildings (Herrick 2007a). Furthermore, the presence of PCBs in caulking poses a potential indoor contaminant threat, which is a cause of concern for building occupants (Frederiksen et al. 2012). The use of PCB caulk was recognized as an emerging problem in the early to mid-2000’s in the United States when PCBs were being discovered in schools, universities and municipal buildings. In some of the reported cases, concerns from the threat of contamination spread amongst building occupants. The sequence of events that led to the escalated fear of PCBs in schools was similar to that of the problem of asbestos-containing building materials in schools during the 1980’s.

In his article, "The Public Health Implications of Polychlorinated Biphenyls (PCBs) in the Environment," Gilbert Ross takes the perspective that PCBs are not as harmful as once thought. Although acute and chronic toxicological health effects have been documented in humans and laboratory test animals, it is unknown if all types and mixtures of PCBs pose a significant health risk to humans (Ross 2004). Stakeholders on either side of the debate are split as to whether or not PCBs have serious toxic effects on humans. When PCB caulk projects began to surface, the link between exposure and PCB caulk was not well understood by the EPA. In 2009, the EPA began researching the exposure risk of PCBs in caulk (EPA 2015a). Assessing the risks posed by PCB caulk is a complex matter that has evolved significantly since the time when TSCA went into effect. Most of these complexities are associated with the number of different chemical compounds that are considered PCBs. To date a total of 209 individual PCB compounds have been identified, many of these have not been subject to the rigorous investigations needed to understand their potential health risks.
The management of PCB caulk has become a confusing regulatory issue for the EPA and the regulated public. When PCB caulk is identified inside or on a building and the potentially responsible party reports the findings to the EPA, site characterization and some form of remediation follows. PCB caulking assessment and remediation projects can be tedious and costly undertakings for school districts, universities, municipalities, states, federal government agencies, and private building owners. TSCA regulations had not likely been developed with the idea of PCB impacted building materials in mind. Consequently, the use of these regulations on this relatively new issue has caused confusion and prompted debate within the regulatory community. Figure 1 shows an example of a PCB remediation project.

**Figure 1:** A remediation worker removes PCB caulking from a building expansion joint. Personal protective equipment is worn to protect the worker from PCB exposure. *(Metropolitan Engineering... 2014)*

This paper examines the current regulatory issue of PCB caulk being discovered inside or on schools, universities, colleges and privately owned buildings in the United States. The background sections provide information on the history of PCBs, the chemistry of PCBs, the impacts of PCBs on the environment and ecosystems, and the toxicology effects of PCBs on humans and animals. The issues of PCBs in building materials and their intersection with TSCA, the discovery of PCBs in schools and the EPA’s research and guidance recommendations are addressed. The goals of this paper are to give the reader thorough background knowledge of PCBs and to shed light on an emerging and complicated regulatory issue in the United States.
2.0 Background

It is important to learn the characteristics of chemicals to understand how they behave. Although viewed negatively, PCBs were successfully used for many years in numerous industrial and commercial applications. In order to set the stage for a discussion on the current PCB building material issue, it is important to discuss the background history, environmental impacts and toxicology of PCBs.

2.1 History

PCBs are anthropogenic chemical compounds that were likely first formulated in the late 1880’s. In their article, “Application of Polychlorinated Biphenyls,” Mitchell Erickson and Robert Kaley provided a detailed summary of the early history of PCBs, “PCBs were first described in the German chemical literature in the 1880’s (Schmidt and Schultz 1881). PCBs were first manufactured commercially in 1929 by the Swann Chemical Company in Anniston, AL. Theodore Swann had developed a commercially viable process to manufacture biphenyl from benzene by bubbling benzene through molten lead” (Erickson and Kaley 2010). The prime use period for PCBs were from approximately 1930 through the early 1970’s.

PCBs were introduced commercially in the early 1930’s. “In 1935, the Swann Chemical Company…was purchased by the Monsanto Company...Swann’s line of polychlorinated polyphenyl products, known as Aroclor® products, was among the product lines now manufactured by Monsanto” (Erickson and Kaley 2010). They manufactured PCBs for over 40 years. Andrew Anthony Havics dedicates a chapter of the book Managing Hazardous Materials: A Definitive Text to PCB facts and history relevant for those working in the hazardous materials management community. Monsanto continued to sell PCBs under the trade name “Aroclor” until the company voluntarily halted production in October 1977 (Havics 2007). They were manufactured in the United States, Europe and Japan. Manufacturing of PCBs in the United States was banned by TSCA in 1979.

The positive and effective aspects of PCBs made them easily adaptable to numerous industrial and commercial applications. Colin Baird, in his book Environmental Chemistry, dedicated a chapter to the history and chemistry of PCBs. “Commercially, they were attractive because they are chemically inert liquids and are difficult to burn, have low vapor pressure, are inexpensive to produce and are excellent electrical insulators. As a result of these properties, they were used exclusively as the coolant fluids in power transformers and capacitors. Later, they were also employed as plasticizers, that is, agents used to keep other materials such as PVC products more flexible; in ‘carbonless’ copy paper; as de-inking solvents for recycling newsprint; as heat transfer fluids in machinery; as water proofing agents; and even further uses were found for them” (Baird 2001). Figure 2 is a photograph of PCB electrical transformers likely to contain PCBs. Because PCBs were a reliable product and had numerous uses, they were mass produced for over 40 years. Between the 1930’s and 1970’s, approximately 1.25 billion pounds of PCBs were manufactured; it is estimated that 965 million pounds were used in electrical equipment (Havics 2007). PCBs were a popular product among industrial users, and the quantities manufactured are a testament to the product.
Numerous uses for PCBs were discovered. They were added to enhance many common commercial and industrial products. According to the EPA, “In 1975 it was estimated that industries consumed PCBs as follows: Capacitors, 70%; Transformers, 30% PCBs were formerly used in the USA as hydraulic fluids, plasticizers, adhesives, fire retardants, way extenders, de-dusting agents, pesticide extenders, inks, lubricants, cutting oils, in heat transfer systems, carbonless reproducing paper.” Production of PCBs decreased drastically: from over 86 million lbs. in 1970 to 35 million lbs. in 1977. The EPA banned most uses of PCBs in 1979 (EPA c2013). The versatility of PCBs made them ideal additives to multiple products. Commercial uses of PCBs are summarized in Table 1 below.
### Table 1: Commercial PCB Uses (Erickson and Kaley 2010)

<table>
<thead>
<tr>
<th>Application</th>
<th>Aroclor(s)</th>
<th>Metric Tons (g×10^6)</th>
<th>Reference^a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical equipment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capacitors (large, small, fluorescent light ballasts)</td>
<td>1242, 1016, (1254)^b</td>
<td>286,000</td>
<td>Durfee et al. 1976</td>
</tr>
<tr>
<td>Transformers</td>
<td>1254, 1260 (1242, 1016)</td>
<td>152,000</td>
<td>Durfee et al. 1976</td>
</tr>
<tr>
<td>Transformer equipment</td>
<td></td>
<td></td>
<td>EPRI 1999</td>
</tr>
<tr>
<td>- slip gears</td>
<td></td>
<td></td>
<td>EPRI 1999</td>
</tr>
<tr>
<td>- phase converters</td>
<td></td>
<td></td>
<td>EPRI 1999</td>
</tr>
<tr>
<td>Slip motors</td>
<td></td>
<td></td>
<td>EPRI 1999</td>
</tr>
<tr>
<td>Electromagnets</td>
<td></td>
<td></td>
<td>EPRI 1999</td>
</tr>
<tr>
<td>Hydraulics/Lubricants/Heat Transfer Fluids</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air Compressor/Gas Transmission Turbine Lubricants</td>
<td>Pydraul</td>
<td>G, A</td>
<td>Hammond et al. 1972; USEPA 2004</td>
</tr>
<tr>
<td>Turbol</td>
<td>Santovac</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1221, 1242</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat Transfer</td>
<td>1242, 1248, 1254</td>
<td>9,100</td>
<td>Durfee et al. 1976</td>
</tr>
<tr>
<td>Hydraulic Fluids (and other lubricants)</td>
<td>1232–1260</td>
<td>36,000</td>
<td>Durfee et al. 1976; Hammond et al. 1972 EPRI 1999</td>
</tr>
<tr>
<td>Vacuum Pumps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motor coolants (mining equipment)</td>
<td>French import</td>
<td></td>
<td>Durfee et al. 1976</td>
</tr>
<tr>
<td>Heat transfer systems</td>
<td>1242</td>
<td>9,100</td>
<td>Durfee et al. 1976; Hammond et al. 1972 EDRI 1999</td>
</tr>
<tr>
<td>Vacuum pumps</td>
<td>1248, 1254</td>
<td>A</td>
<td>Hammond et al. 1972</td>
</tr>
<tr>
<td>Vapor diffusion pumps</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Immersion oils for microscopes</td>
<td>1260 &amp; PCT</td>
<td></td>
<td>McCRone 1985</td>
</tr>
<tr>
<td>Optical oils in telescopes</td>
<td></td>
<td></td>
<td>EPRI 1999</td>
</tr>
<tr>
<td>Cutting oils</td>
<td>1254</td>
<td>A</td>
<td>Hammond et al. 1972</td>
</tr>
<tr>
<td>PCBs Incorporated into Products and Materials</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Miscellaneous Industrial</td>
<td></td>
<td>12,000</td>
<td>Durfee et al. 1976</td>
</tr>
<tr>
<td>Plasticizers</td>
<td></td>
<td>52,000</td>
<td>Durfee et al. 1976</td>
</tr>
<tr>
<td>Carbonless Copy Paper (microencapsulation of ink)</td>
<td>1242</td>
<td>20,000</td>
<td>Durfee et al. 1976; Hammond et al. 1972</td>
</tr>
<tr>
<td>Inks</td>
<td>1254</td>
<td>P</td>
<td>Hammond et al. 1972</td>
</tr>
<tr>
<td>Thermographic and xerographic copying</td>
<td></td>
<td>P</td>
<td>ITF 1972</td>
</tr>
<tr>
<td>Paints, varnishes, lacquers, and other surface coatings</td>
<td>Many</td>
<td>No info</td>
<td>ITF 1972</td>
</tr>
<tr>
<td>Flooring and floor wax/sealants</td>
<td></td>
<td>G.A</td>
<td>USEC 1999</td>
</tr>
<tr>
<td>Coal-tar enamal coatings</td>
<td></td>
<td></td>
<td>USEC 1999</td>
</tr>
<tr>
<td>Pipeline Valve Grease</td>
<td>1268</td>
<td>G</td>
<td>USEPA 2004</td>
</tr>
<tr>
<td>Adhesives</td>
<td>1221–1254</td>
<td>P</td>
<td>Hammond et al. 1972; EPRI 1999</td>
</tr>
<tr>
<td>Adhesive Tape</td>
<td></td>
<td></td>
<td>USEC 1999</td>
</tr>
<tr>
<td>Caulk and Joint sealants</td>
<td>1254 &amp; other</td>
<td></td>
<td>Multiple (see text)</td>
</tr>
<tr>
<td>Gasket sealers</td>
<td></td>
<td></td>
<td>Power Res Inst 1999</td>
</tr>
<tr>
<td>Insulation and other building materials</td>
<td>1254, 1268</td>
<td>A</td>
<td>Multiple (see text)</td>
</tr>
<tr>
<td>Rubber products</td>
<td>1232–1254, 1268</td>
<td>A, G</td>
<td>Hammond et al. 1972; EPRI 1999</td>
</tr>
<tr>
<td>Wire and cable coatings</td>
<td>1254, 1260</td>
<td>A, G</td>
<td>Cleghorn et al. 1990; EPRI 1999; USEC 1999</td>
</tr>
<tr>
<td>Die or investment castings</td>
<td>DecaCB (Imported)</td>
<td>13–22/year</td>
<td>Durfee et al. 1976</td>
</tr>
<tr>
<td>Petroleum Additive</td>
<td></td>
<td>450</td>
<td>Durfee et al. 1976</td>
</tr>
</tbody>
</table>

^a In general, we have cited the oldest primary reference for uses, assuming that newer references generally used the first as a source

^b Aroclors in parentheses are known minor uses

^P patent literature, A article in published journal, G US Government Publication, M Monsanto Marketing Literature
Monsanto sold PCBs under the trade name Aroclor, and each mixture had a corresponding product code. There are conflicting understandings as to what the number “12” stood for in the product code. Havics says, “Commercial PCB mixtures are generally designated by a number in which the first two digits are 12 (the number of carbons), while the last two digits are the percentage of chlorine in the mixture. For instance, the Aroclors designated 1242, 1254, 1260, and 1262 represent 42%, 54%, 60%, and 62% chlorination in the PCB mixture product, respectively” (Havics 2007). While Erickson and Kaley’s opposing interpretation is, “…The ‘12’ in the product name refers to the fact that there are 12 carbon atoms in the biphenyl molecule, which is decidedly not true. In fact, for every product in the Aroclor 1200 series (refined PCBs), there was a corresponding product in a less well-known 1100 series, the crude PCBs. As noted elsewhere, the final step in the manufacture of the 1200- series PCBs was the distillation of the corresponding crude 1100-series material. Thus, Aroclor 1142 was distilled to produce Aroclor 1242” (Erickson and Kaley 2010). The EPA accepts the belief that the 12 represents the number of carbon atoms.

As time went on, the harmful effects PCBs had on human and animal health, and their ability to accumulate in the environment, became known. “The combination of the ubiquitous nature of low level PCB presence in the environment and the historical perception that PCBs are associated with adverse health effects has driven both public and regulatory concern” (Ross 2004). The United States government responded to PCBs by enacting TSCA. Baird stated, “When their accumulation and harmful effects became recognized, open uses, that is, those in which their disposal could not be controlled, were terminated” (Baird 2001). Currently, PCBs remain heavily regulated by the EPA.

The issues associated with PCBs have been scrutinized for over 30 years. “Publications number in the tens of thousands and the publication rate shows no sign of slowing. PCBs remain an economic force over 30 years after the last products were made. Issues relating to PCBs provide professional opportunities, funding, and income to numerous regulators, academic, and government research scientists, consultants, remediation firms, and attorneys” (Erickson and Kaley 2010). The trend indicates that research will likely continue until PCBs are no longer present in the environment, biota and the food we eat.

2.2 Chemistry of PCBs

PCBs are anthropogenic organic compounds. Richard Hagen provides background information on the chemistry of hazardous materials in the book *Hazardous Materials Management Desk Reference*. An organic compound is a compound that contains carbon that is covalently bonded to hydrogen and may contain other compounds (Hagen 2005). Molecules that share a pair of electrons are covalently bonded. They are also referred to as chlorinated diphenyls or chlorodiphenyls.

Baird describes the formation process, “The conversion of benzene to formulate PCBs was exploited for commercial applications. Benzene is heated to about 750º Celsius in the present of lead as a catalyst to form biphenyl…The reaction of biphenyl with chlorine produces a mixture of many of the 209 congeners of the PCB family” (Baird 2001). The chemical structure of PCBs is depicted in Figure 3. Congeners are different members of a chemical family that
differ only in number and position of the same substituent. The ratio of chlorine to biphenyl, reaction time and temperature determines the exact proportion of the PCB.

![Chemical Structure of PCBs](image)

**Figure 3:** Chemical Structure of PCBs  
(ATSDR 2014)

PCBs were typically distributed as liquids or semi-solid liquids. “PCB compounds were sold commercially as partially separated mixtures. Typically individual PCB compounds were solids, but the mixtures were usually liquids or low melting point solids. The average chlorine content used in different products ranged from 21% to 68%” (Baird 2001). PCB liquids entered the environment, which prompted the EPA to include spill provisions for PCBs in the TSCA regulations.

### 2.3 Properties of PCBs

Chemicals are often classified in terms of their physical, chemical and biological properties. More importantly, individual properties of chemicals are used to help predict their behaviors. The properties of PCB compounds have caused them to become persistent environmental contaminants and potentially toxic to humans and animals. Hagen, Havics and the EPA provided thorough explanations of general chemical and PCBs properties.

PCBs exist in the liquid to semi-liquid physical states. Havics stated, “Aroclors 1221, 1232, 1242 and 1248 are clear oily liquids; 1254 is a light yellow viscous liquid; and 1260 is a light-yellow sticky resin (Havics 2007). The physical appearance and viscosity vary per mixture. Properties of select Aroclors are summarized in **Table 2** at the end of this section.
PCBs are chemically inert; meaning they are un-reactive (stable) under normal temperature and pressure conditions. “At or near room temperature, they do not oxidize or enter into reactions with other resins or oils. They are unaffected by contact with boiling caustic soda solutions, resist the action of dilute acids, and are stable for long periods at higher temperature of up to 316º Celsius” (Havics 2007). Because of their stability and resistance to degradation, many industrial and commercial applications were found for PCBs. They were particularly successful in heat resistant applications for machines (pumps, compressors, hydraulic lifts, elevators, etc.) and electrical equipment (transformers, capacitors, etc.).

PCBs are insoluble in water. Solubility is the amount of any solid, liquid or gas (the solute) that can dissolve in a unit volume of liquid (the solvent). Solubility of PCBs tends to decrease with increasing molecular weight and chlorine content (Hagen 2005). PCBs are known to bioaccumulate in animals and humans. “All PCBs are practically insoluble in water but are soluble in hydrophobic media, such as fatty or oily substances” (Baird 2001). Octanol/Water Partition Coefficient ($K_{ow}$) is the equilibrium ratio of the concentrations of material partitioned between octanol and water. It is an index of the potential of a chemical to be bioaccumulated (Hagen 2005). Havics offers more detail. Chemicals with high $K_{ow}$ value have a greater potential to bioaccumulate. The logarithm $K_{ow}$ ranges from 4.10 to 9.60, suggesting a high bioaccumulation risk (Havics 2007). Bioaccumulation of PCBs has been proven through decades of animal studies and available human exposure studies.

Boiling point refers to the temperature at which a liquid changes to a gas under standard atmospheric pressure (760mm of mercury). Vapor pressure is the pressure exerted by a vapor in equilibrium with its liquid at a given temperature (Hagen 2005). Vapor pressure is used to measure the volatility of a chemical. Generally, the boiling point of PCBs is greater than 270º Celsius and the vapor pressure will range (8.4 x 10$^{-3}$ to 6.3 x 10$^{-7}$) based on the type of congener (Havics 2007). The EPA describes PCBs as moderately volatile from water to soil (EPA c2013). Therefore, PCBs are not highly volatilized into the atmosphere and they will not degrade easily unless exposed to extremely high temperatures.

PCBs have a low melting point, which is characteristic of organic compounds. Melting point is defined as the temperature at which crystalline solid changes to a liquid (Hagen 2005). The EPA reports the melting point for PCBs to range from 340º to 375º Celsius (EPA c2013). The melting point is important for determining the temperature at which a substance will change physical state (i.e., solid to liquid or liquid to gas).

Specific gravity is the ratio of the density of a liquid as compared with that of water (Hagen 2005). Water has a specific gravity of one (1). PCBs have a specific gravity of 1.44 at 30º Celsius (EPA c2013). Chemicals with specific gravities greater than one sink in water. Therefore, pure PCBs will sink when added to water or when entering a water body.
Table 2: Properties of Selected Aroclor Products  
(Erickson and Kaley 2010)

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>1016</th>
<th>1221</th>
<th>1232</th>
<th>1242</th>
<th>1248</th>
<th>1254</th>
<th>1260</th>
<th>1268</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color (APHA)</td>
<td>40</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>150</td>
<td>1.5(NPA) molten</td>
</tr>
<tr>
<td>Physical state</td>
<td>Mobile oil</td>
<td>Mobile oil</td>
<td>Mobile oil</td>
<td>Mobile oil</td>
<td>Mobile oil</td>
<td>Viscous liquid</td>
<td>Sticky resin</td>
<td>Off-white powder</td>
</tr>
<tr>
<td>Stability</td>
<td>Inert</td>
<td>Inert</td>
<td>Inert</td>
<td>Inert</td>
<td>Inert</td>
<td>Inert</td>
<td>Inert</td>
<td>Inert</td>
</tr>
<tr>
<td>Density (lb/gal 25°C)</td>
<td>11.40</td>
<td>9.85</td>
<td>10.55</td>
<td>11.50</td>
<td>12.04</td>
<td>12.82</td>
<td>13.50</td>
<td>15.09</td>
</tr>
<tr>
<td>Specific gravity at °C</td>
<td>1.36-1.37</td>
<td>1.18-1.19</td>
<td>1.27-1.28</td>
<td>1.30-1.39</td>
<td>1.40-1.41</td>
<td>1.49-1.50</td>
<td>1.55-1.56</td>
<td>1.80-1.81 25°</td>
</tr>
<tr>
<td>Distillation range (°C)</td>
<td>323-356</td>
<td>275-320</td>
<td>290-325</td>
<td>325-366</td>
<td>340-375</td>
<td>365-390</td>
<td>385-420</td>
<td>435-450</td>
</tr>
<tr>
<td>Acidity mg KOH/g, maximum</td>
<td>.010</td>
<td>.014</td>
<td>.014</td>
<td>.015</td>
<td>.010</td>
<td>.010</td>
<td>.014</td>
<td>.05</td>
</tr>
<tr>
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<td>238</td>
<td>None to boiling point</td>
<td>None to boiling point</td>
<td>None to boiling point</td>
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<td>Flash point (°C)</td>
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<td>141-150</td>
<td>152-154</td>
<td>176-180</td>
<td>193-196</td>
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<tr>
<td>Vapor pressure (mm Hg @ 100°F)</td>
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<td>.001</td>
<td>.000037</td>
<td>.000006</td>
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<td>NA</td>
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<tr>
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<td>38-41</td>
<td>44-51</td>
<td>82-92</td>
<td>185-240</td>
<td>1800-2500</td>
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<td>–</td>
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<tr>
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<td>13-16</td>
<td>3.6-4.6</td>
<td>5.5-7.7</td>
<td>16-19</td>
<td>42-52</td>
<td>390-540</td>
<td>–</td>
<td>–</td>
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</tbody>
</table>

N/A not available

2.4 PCBs Contamination

The stability, widespread usage and careless disposal practices of PCBs prior to modern environmental regulations, led to them becoming a widespread environmental contaminant. Prior to TSCA, the disposal of PCBs and PCB containing equipment (transformers, machinery, etc.) was not regulated. As a result, PCB containing equipment reached landfills where the PCB content could leach into the environment over time. PCBs may have also been released to the environment during production, use and storage activities. Erickson and Kaley stated, that as the threat PCBs posed to the environment came to light, Monsanto responded. “By early 1970, Monsanto had undertaken a program to address the presence of PCBs in the environment” (Erickson and Kaley 2010). The following section will discuss the effects of PCBs on ecosystems and the fate and transport of PCBs in the environment.

2.4.1 Effects on Ecosystems

It is well documented that scientific researchers have discovered PCBs accumulated in locations throughout the world’s ecosystems. In the U.S., releases of PCBs to the environment (soil, water or air) can be attributed to their uncontrolled uses prior to TSCA. PCBs that are released to the environment can be absorbed by plant life and ingested by animals. The chemical properties of PCBs allow them to become stored in adipose (fatty) tissues of organisms, where they are not readily excreted or metabolized. As a result, PCBs have bioaccumulated in the tissue of plants and animals. Additionally, the concentrations of PCBs will biomagnify through the food chain.
PCBs enter the food chain at the lowest trophic level, the primary producers. PCBs are sticky substances, and when they become deposited in soil, will remain close to the surface. Over time PCBs will be converted into gases and evaporate out of soil (Faroon and Olson 2000). Plant-life absorbs gaseous PCBs into their structure. Next, herbivores in the food chain consume the plants. When plant matter is digested, PCBs are processed through the organism and ultimately PCBs settle in the adipose tissue. Once in their body systems, plants and animals cannot readily break down PCBs.

PCBs undergo biomagnification in the food chain. Biomagnification is the increase of a chemical concentration along a food chain. It results from a sequence of bioaccumulation steps that occur along a food chain (Baird 2001). Biological monitoring of PCB contamination in fish, birds and cattle has documented the biomagnification process (Faroon and Olson 2000). In the next stage of the food chain, predators feed on herbivores. The cycle continues as low level predators are consumed by larger high level predators. The PCB concentrations increase as they travel up each trophic level. Therefore, the largest predators in the food chain will accumulate the highest levels of PCBs in their bodies.

2.4.2 Fate and Transport

PCBs are recognized as persistent environmental contaminants. Generally, PCB concentrations in the environment have decreased since the ban in 1979; however, they remain present in various environmental media. Due to their chemical structure, they are not readily broken down by other chemicals or bacteria. Therefore, PCBs can exist for years in the air, water and soil.

As a result of their chemical composition, PCBs are practically insoluble in water. PCBs with heavy molecular weights are more likely to settle into sediments. The Agency for Toxic Substances and Disease Registry (ATSDR) is a U.S. federal agency for public health. Obaid Faroon and James Olson of ATSDR, authored a paper, *Toxicological Profile for Polychlorinated Biphenyls (PCBs)*, which focuses on the human health implications of PCB exposure. “In water, PCBs may be transported by currents, attach to bottom sediment or particles in the water, and evaporate into air” (Faroon and Olson 2000). Furthermore, sediments that contain PCBs can also discharge them to surrounding waters.

PCBs are present in the atmosphere. They absorb into solid particles or vapor and are transported by wind or evaporation into the atmosphere. PCBs are eventually redeposited on land when dust settles or during rain and snow fall events. Lighter molecular weight PCBs are more likely to be present in the atmosphere. Baird discusses this process, “Although their solubility in water is very slight – indeed they are more likely to be adsorbed onto suspended particles in the water than dissolved in it – the tiny amount of PCBs in surface water are constantly being volatized and subsequently redeposited on land or in water after traveling in air for a few days. By such mechanisms, PCBs have been transported worldwide; there are measurable background levels of PCBs even in Polar Regions and at the bottom of the oceans. The environmental load of PCBs will continue to be recycled among air, land and water, including the biosphere, for decades to come…” (Baird 2001). The amounts of PCBs released to the environment and the natural processes that transport PCBs has caused them to be ubiquitous.
2.5 Toxicology of PCBs

Toxicology is the study of the adverse effects of chemical, physical and biological agents on living organisms (Cox and Borgias 2005). The negative stigma associated with PCB contamination has caused their toxicological effects on animals and humans to be widely studied. PCBs were distributed as mixtures. The origins of the mixtures are not readily identified when mixed with other media. Because of this finding, researchers and regulatory agencies have found it difficult to determine which congeners may have caused adverse health effects in humans during exposure incidents. Different chlorination concentrations of PCBs congeners will yield different biological effects. The physiological properties of every individual animal and humans are different. In general, correlations between dose (concentration) and exposure time show that chronic exposure or large exposure doses of PCBs could cause adverse health effects.

The most common means of PCB exposure are by dermal absorption, ingestion or inhalation. When PCBs enter the body of a human or animal, they are transported by the bloodstream to the liver and the muscles. They then become deposited and accumulate in the adipose tissue. Toxicological studies have shown that PCBs have a half-life in humans from less than one year to 15 years or greater (Faroon and Olson 2000). “The half-life of PCBs in humans is generally cited as about 2.6 to 4.8 years…” (Havics 2007). The rate at which PCBs will break down in the body is dependent on the congener, the degree of chlorination and the species of organism.

There are identified adverse health effects that result from PCB exposure. The most well known are effects to the skin as a results of dermal exposure and reproductive toxicity. “…Health effects that have been associated with exposure to PCBs in humans and/or animals include liver, thyroid, dermal and ocular changes, immunological alterations, neurodevelopment changes, reduced birth weight, reproductive toxicity, and cancer” (Faroon and Olson 2000). The most frequently reported symptom of dermal exposure was chloracne and pigmentation of the skin. Chloracne is caused by exposure to organochlorine compounds (Baird 2001). Symptoms will vary in species based on dose, exposure time, the type of congener and the degree of chlorination. Other factors that affect the severity of exposure are age, sex, diet, and the general health of a species.

Laboratory studies have shown that PCBs cause tumors in animals. The target organ most affected is the liver. The EPA identifies PCBs as probable human carcinogens. The International Agency for Research on Cancer (IARC) considers PCBs to be associated with cancer, but a conclusive link has not been established by the IARC. The National Institute for Occupational Safety and Health (NIOSH) identifies PCBs as a carcinogen (Havics 2007). Ross explains an important contradiction in regards to animal studies. “Toxicology tests are specifically designed to detect and elicit adverse effects, and for this reason, high dose levels, unrealistic for humans, are employed. These doses invariably exceed the level of realistic human exposures, often by hundreds to thousands of times” (Ross 2004). The likelihood that PCBs cause cancer in humans is still uncertain and debatable.
Many of the documented PCB human exposure cases came from workers in the PCB manufacturing industry as well as from two wide spread ingestion exposure incidents in Japan and Taiwan. “Information on health effects of PCBs is available from studies of people exposed in the workplace, by consumption of contaminated rice oil in Japan (the Yusho incident) and Taiwan (the Yu-Cheng incident), by consumption of contaminated fish, and via general environmental exposures, as well as food products of animal origin” (Faroon and Olson 2000). Workers in the PCB industry were exposed for long periods of time to varying congeners as part of the manufacturing process. Workers were exposed by skin absorption or through ingestion related to hand-to-mouth transfer. PCBs experienced their peak production period during a time before worker occupational health and safety legislation in the U.S. was fully passed. In the U.S., the Occupational Health and Safety Administration (OSHA) was created in 1970. According to Faroon and Olson, the general population becomes exposed to PCBs by consuming contaminated food and inhaling airborne PCBs present in exterior and indoor air. PCBs are transferred from mother to child during breast feeding. The major dietary sources contributing to PCB contamination are fish, meat and dairy products (Faroon and Olson 2000).

Two major human exposure incidents cast PCBs into a negative light. In both the Yusho incident in Japan (1968) and the Yu-Cheng incident in Taiwan (1979) thousands of people ingested PCB contaminated cooking oil and suffered adverse health effects. Baird summarizes the Japanese exposure event. In the Yusho incident, PCBs were used as a heat exchanger in the process to deodorize the oil. They were accidentally mixed with the cooking oil and the product was distributed. Polychlorinated dibenzofurans (PCDFs) is a toxic chemical created when PCBs are exposed to high heat. The conclusions drawn from the incidents indicated that PCDFs and some dioxins were responsible for two-thirds of the exposure and PCBs were responsible for the remaining. In both cases, large numbers of men, women and children who had ingested PCB, PCDF and dioxin tainted cooking oil suffered serious health effects. The health effects experienced were much more severe than those of workers in the PCB industry (Baird 2001). A similar occurrence appended in the Taiwan exposure incident.

Eleven years after the Yusho exposure incident, a similar large scale exposure of PCBs occurred in Taiwan. The Yu-Cheng incident occurred in 1979. Yu-Cheng translates into English as “Oil Disease.” PCBs were used in a heat transfer fluid used in the process to deodorize and decolorize rice oil. Through a processing error, PCB oil was mixed with the food grade rice oil. It is estimated that 2,000 Taiwanese people consumed the oil. Exposure victims suffered from acne, pigmentation of the nails and skin, and hypersecretion of the meibomian glands. The medical side effects were collectively referred to as the “Yu-Cheng Syndrome.” The children born to exposed women during and after the incident were extensively followed for physical and developmental outcomes. The incident gained international attention (Hsu et al. 1994). Incidents such as these cast a dark shadow over PCBs and, in the U.S., fueled the legislation to ban PCBs.

PCB formulations are known to have contained hazardous impurities. Polychlorinated dibenzodioxins (PCDDs), polychlorinated dibenzofurans and polychlorinated quaterphenyls (PCQs) are of particular interest because of their toxicity (Havics 2007). These chemical compounds are a byproduct of heating PCBs. Exposing PCBs to high temperatures in the presence of oxygen causes thermal degradation, which chemically converts PCBs to PCDFs...
(Baird 2001). Some researchers believe that these impurities which are mixed with PCBs, not the PCBs alone, cause adverse biological effects. The evidence that impurities cause adverse health effects has been observed in the high exposure incidents that took place in Japan and Taiwan.

### 2.5.1 PCB Toxicological Debate

The toxicity of PCBs remains under debate by the research and medical communities. “Other epidemiologic studies have failed to demonstrate any consistent significant clinical evidence of chronic health effects from PCB exposure” (Havics 2007). Some groups feel that the dangers of PCB contamination have been widely dramatized by the media and environmental groups. “Much of this litigation has little scientific or clinical support, but because of the years of notoriety, publicity, and perception, many people mistakenly believe that PCBs are tied to an assortment of human maladies” (Ross 2004). Other opposing views are the lack of human fatality information show that PCBs are not harmful.

The stances of human health advocates are that PCBs are probable human carcinogens and they can cause birth deformities. “Although the acute toxicity of PCB mixtures is low, they are expected to increase cancer risks in humans and have neurodevelopmental and hormonal effects” (Priha et al. 2005). These advocates cite the bioaccumulation of PCBs in the environment and adverse health effects on wildlife as sufficient evidence for the dangers.

### 3.0 U.S. Regulatory Synopsis

#### 3.1 Toxic Substances Control Act

The Toxic Substances Control Act (15 U.S.C. §§ 2601 et seq.) is the principal environmental act that addressed PCB issues in the U.S. In 1976, TSCA was enacted by the U.S. Congress. It was passed into law on January 1, 1977. The EPA created the regulations that administer TSCA. The TSCA regulations were published in the Code of Federal Regulations (C.F.R.) in section 40 C.F.R. § 700-799. The EPA manages and enforces TSCA at the regional office level. Each regional TSCA program has a Regional PCB Coordinator. It is up to each Regional PCB Coordinator to understand and interpret the TSCA regulations.

The Toxic Substances Control Act regulates toxic chemicals at the point which they are manufactured and used. The goal of the TSCA is to regulate new or proposed chemicals in the U.S. to ensure that they do not pose unreasonable risks to human health or to the environment. Beyond PCBs, TSCA regulates asbestos-containing material, lead-based paint, dibenzo-p-dioxins and dibenzofurans. Valentino De Rocili provides a history and overview of TSCA in the book, *Hazardous Materials Management Desk Reference*, “…TSCA requires any chemical that reaches the consumer marketplace to be tested for possible toxic effects before commercial
manufacturing begins. TSCA also regulates the mitigation of spills and the proper disposal of hazardous materials and remediation wastes. TSCA requires corrective actions in cases of cleanup of toxic material contamination” (De Rocili 2005). Manufactures and importers must file pre-manufacture notifications with the EPA when they propose to manufacture or import a chemical not previously included as an EPA chemical substance. TSCA specifically regulates the manufacturing, use and disposal of PCBs. These findings led to the phase out rule for the use of PCBs (De Rocili 2005). The PCB sections of TSCA were written to deal with PCBs in dielectric fluid and electrical equipment. At the time TSCA was enacted, it was likely unknown the extent to which PCBs were used in caulk.

TSCA has been amended on numerous occasions since it was first enacted in 1976. On June 29, 1998, the EPA issued the “Disposal of Polychlorinated Biphenyls (PCBs); Final Rule” which were major amendments to TSCA. It is commonly referred to as the “PCB Mega Rule.” Many of the Mega Rule’s changes to TSCA are relevant to the discussion of PCB caulk. The Mega Rule brought significant changes to TSCA including a new waste classification scheme, permitting a broader range of disposal/treatment options for low risk, high-volume wastes such as contaminated soil or natural gas pipelines (Havics 2007). The rule created definitions for, “PCB bulk product waste (any non-liquid waste that had concentrations of PCBs >50 parts per million (ppm))” and “PCB remediation waste (waste containing PCBs at concentrations >50 ppm that originated from spills, release or unauthorized disposal).” In addition, the rule created disposal options for PCB remediation waste and PCB bulk product wastes. Three new disposal options were created for PCB remediation wastes; Self-Implementing, Performance Based and Risk-Based. Four disposal options were set forth for PCB Bulk Product Wastes; Performance Based, Risk Based, disposal in a municipal or non-municipal non-hazardous waste landfill or use as daily landfill cover (Havics 2007). The 1998 TSCA amendments have shaped much of the current PCB regulatory environment.

Due to the fact that toxic chemicals are regulated in manufacturing, TSCA differs from other EPA regulations that prevent contaminants from entering the land, water and air. PCBs are primarily regulated under TSCA; however, there are other environmental laws that incorporate PCBs. The Clean Water Act (CWA) (33 U.S.C. 1251 et seq.) is the primary environmental law for protecting surface and drinking water in the U.S. The CWA has provisions for regulating PCBs in drinking water. The EPA has issued primary drinking water standards for PCBs in the form of both a maximum contaminant level (MCL) and an MCL goal (40 C.F.R. § 141.61 and 141.50). The Resource Conservation and Recovery Act (RCRA) (42 U.S.C. 6901 et seq.) is the primary environmental law that regulates solid and hazardous wastes. RCRA’s Land Disposal Restriction (LDR) (40 C.F.R. § 268) regulate the disposal of hazardous waste in the land. The universal treatment standards under the LDR regulations specify maximum concentrations for wastewater and non-wastewater media (Havics 2007). Additionally, state environmental agencies have the authorization from the EPA to adopt the federal laws pertaining to PCBs or develop state-specific laws that are above and beyond federal laws.
4.0 PCB in Caulking

PCBs were used as additives in caulking, paint and sealants from approximately the 1950’s to 1977. They were utilized because of their effectiveness as a plasticizer. Aroclor 1254 was identified as the PCB congener used in sealant and caulking compounds (Faroon and Olson 2000). The addition of PCBs to a formulation of caulking allowed it to have increased strength and pliability. Also, building materials that contain PCBs held up better to exterior weather conditions due to the addition of the plasticizers. As a result of wide-spread use, PCBs have been identified in paints, caulks and other sealants in public and private buildings.

4.1 PCB Caulking Research Studies

The link to PCBs in caulking was identified in Europe by sampling backwards from contaminated areas in attempts to locate sources of PCBs released to the environment. The first documented studies of PCBs were reported in the 1990’s in Germany, Sweden and Finland (Priha, Hellman, Sorvari 2005). Discoveries of PCBs caulking in the U.S. occurred between the mid 1990’s to mid-2000’s. At that time, PCBs were being identified in municipal water plants, school and university buildings. “The first evidence on schools in the USA comes from a report on a school at Cape Cod, MA, that was found to have elevated PCB levels and closed in 1996...This finding of PCBs and the costs that would have been associated with their removal was a major factor in the decision to demolish the school” (Herrick 2015, Leung 1996). PCBs in caulking were first identified as sources of exterior soil contamination around the perimeter of buildings. Figure 4 depicts how exterior building caulk deteriorates and causes soil contamination. As the EPA and environmental consultants searched for sources of PCBs inside building, they discovered PCBs in other building materials such as caulking, sealants and paint.
Figure 4: Deteriorating PCB caulk leaches out PCBs, contaminating the ground around perimeters of buildings.
(Herrick 2007a)

The largest PCB caulking study in New England was conducted by Dr. Robert F. Herrick of Harvard University’s School of Public Health. He studied PCB impacted buildings in the greater Boston, Massachusetts area. Herrick identified PCB containing caulk in several buildings throughout the greater Boston area. “…Buildings constructed of masonry- including schools, hospitals, water and sewerage treatment plants, power plants, hospitals, and other public buildings constructed or renovated during the 1960s or 1970s may contain these types of caulking and sealing materials” (Herrick 2004). In 2003, Herrick and his team collected samples from 24 buildings throughout the greater Boston area. Eight of the buildings that were sampled had concentrations of PCBs in caulking greater than 50 ppm. Herrick’s sampling results are summarized in his Table 3 included below. The buildings that had concentrations greater than 50 ppm of PCBs were used as government offices, university student housing and dormitories, university classrooms and offices, elementary, middle and high schools and a synagogue. PCB concentrations in the study ranged from below laboratory method detection limits to 36,200 ppm (university student housing building). Herrick’s study suggested that PCBs in exterior caulking of buildings is a source of soil contamination near the perimeter of buildings. He concluded that PCBs were released from exterior building materials by the natural weathering process.
It is noteworthy to discuss the concentrations of PCB found during sampling for the various studies and cases researched for this paper. The PCBs identified in caulking, paints and sealants varied greatly in concentration. Sampling indicated that concentrations varied from undetected above laboratory method detection limits to upwards of thousands of orders of magnitude >50 ppm. It is unclear as to why the concentrations could range so greatly in a building. Perhaps, by the time samples were collected, previous renovation work had removed PCB-impacted building materials or mixtures of PCB caulking were not homogenous at the time they were applied.
4.2 Primary and Secondary Contamination

Buildings that have been constructed or renovated from approximately the 1950’s through 1977 have the potential to be impacted by PCB caulk. Sources of PCB contamination are often two-fold; primary or secondary sources. The EPA defines primary and secondary sources. “Primary sources of PCBs are defined…as those that were manufactured containing PCBs or had PCBs added during construction…Secondary sources of PCBs are defined…as those materials that become contaminated due to absorption from direct contact with primary PCB sources such as caulk, or through absorption of PCBs in the indoor air that have been emitted by primary sources such as caulk and light ballasts. Materials such as paints, dust, masonry, floor and ceiling tiles, and mastics may become secondary sources after years of exposure to PCBs emitted from primary sources” (Thomas et al. 2012). Each source presents a different method for contaminating indoor air, see Figure 5.

Figure 5: Complexity of PCB Contamination Inside Buildings
(Thomas et al. 2012)

Over time, the chemical properties of PCBs caused them to migrate into adjacent porous surfaces such as cement, brick or wood. “PCBs are categorized as Semivolatile Organic Compounds (SVOCs), which are known to redistribute from the originally introduced SVOC containing building material (primary sources) to all indoor surfaces (secondary sources).…PCBs can also migrate from primary sources to adjacent material (secondary sources)…Therefore, remediation of SVOCs is problematic since simple removal of the original source is often insufficient...” (Lyng et al. 2015). 3 The persistent contamination characteristic of PCBs has caused the remediation of PCB caulking in and on buildings to become complicated, time consuming projects.
4.3 Methods of Contamination

PCBs are released from caulk, sealants and paint during construction or renovation activities. The problem being is that often time dust containing PCBs is not controlled and it redeposits throughout the building under construction or renovation. “These removals are performed without testing the caulking to determine its PCB content, and workers generally do not use protective equipment” (Herrick 2004). As caulk breaks down or is physically removed, PCBs are released to the interior of a building. Building construction, renovation and maintenance activities that involve sanding, scraping, grinding, cutting or demolition have the potential to release PCBs. Fugitive PCBs emissions generated during construction activities can sorb to dust particles and linger inside buildings. Construction workers physically completing the removals and building occupants face the highest risks of exposure.

Additionally, the degradation of PCB caulk on the exteriors of buildings has been identified as a source of soil contamination near the perimeter of buildings. In exterior applications, PCB caulk degrades over time by weathering. “Studies have also indicated that significant quantities of PCBs can be released into soil and water runoff during activities associated with the renovation of building caulk, such as concrete grinding and power washing (Astebro et al. 2000; Sundahl et al. 1999). It is also suspected that, without appropriate containment, PCBs may also be released to the environment during the demolition of buildings” (Klosterhaus et al. 2014). As building materials degrade over time, PCBs can be released and will leach into the soil that surrounds a building. PCB contaminated soil poses and exposure risk to children, adults or construction workers who may come in contact with this soil.

4.4 Indoor Air Considerations

Indoor air contamination is of particular interest when considering human health risks because inhalation is the primary route of exposure for humans. PCBs that are released into the indoor air could result in an inhalation exposure risk for building occupants. PCB-impacted dust within buildings is a source of indoor air contamination. Dust particles can absorb fugitive PCBs that are emitted to indoor air from primary sources or if dust comes in direct contact with primary sources (EPA 2015b). Humans are sensitive to contaminants present in indoor air, and inhalation of indoor contaminants could be a health risk to building occupants.

Prior to 1979, fluorescent light ballasts were once manufactured with PCB material. Typically the insulating fluid in the capacitor of ballasts contained PCBs. Figure 6 depicts ballasts that were manufactured with and without PCBs. It is possible to find PCB containing fluorescent light ballast that are still in use if a building has not undergone an interior lighting upgrade project after PCBs were banned. The exposure hazard associated with ballasts occurs when they become heated. When a ballast is heated by electrical current, it could off-gas PCBs into the surrounding indoor air. “When certain types of ballasts reach the end of their useful life, spontaneous leaking and smoking from the capacitors may occur, accompanied by a remarkably objectionable odor that penetrates the area” (Liu et al. 2015). In addition, a ballast may rupture and release its PCB dielectric fluid contents into a building. The end results are PCBs contaminating indoor air.
4.5 PCB Caulk and TSCA

The Toxic Substances Control Act was likely enacted to address PCBs in dielectric fluids and electrical equipment. At the time the TSCA regulations were written, it is suspected that the EPA was not fully aware that PCBs were widely used for other application beyond electrical equipment. TSCA regulations have no requirements that mandate sampling for PCBs in caulks, sealants and paints. The regulations provide criteria for cleaning spills or releases associated with PCB electrical equipment, not caulks, sealants or paint.

Under the TSCA regulations, a sequence of events would be initiated once a sample of contaminated media (such as caulking) exceeded the regulatory concentration threshold of ≥50 ppm PCBs. TSCA defines media containing PCBs concentrations <50 ppm as “Non-PCB.” Items containing ≥50 ppm but ≤500 ppm are “PCB-Contaminated.” If concentrations of PCBs are detected in sampled media at concentrations ≥50 ppm, the EPA requires notification and disclosure of the sampling results. At that time, the property becomes a “PCB Remediation Waste” cleanup site and the owner or the Responsible Party must characterize the extent of contamination. The owner or Responsible Party must then choose one of the disposal options for “PCB Bulk Product Wastes” or “PCB Remediation Wastes” to bring the site into compliance.
An example of the TSCA regulatory process would be using a “Self-Implementing Plan” disposal option to cleanup PCB Remediation Waste. The property owner would prepare a Self-Implementing Plan and submit it to the EPA Regional PCB Coordinator for approval. Once the EPA Regional PCB Coordinator reviews and approves the Plan, it would be implemented. The release area would be delineated by collecting samples in a grid pattern approximately every ten feet (three meters). Confirmatory samples would be required every five feet to verify remediation cleanup. Finally, PCB-Remediation Waste and “Porous Surfaces” require sampling and cleanup to concentrations of ≤1 ppm for “High Occupancy Areas” or ≤25 ppm for “Low Occupancy Areas.” Any media (cement, soil, etc.) would be removed or decontaminated until concentrations of <1 ppm existed. Figure 7 shows a remediation project where PCB impacted masonry was removed. The whole process, from EPA approval to delineation and remediation, can become tedious and time consuming for owners, consultants and field work personnel.

Figure 7: The photograph is of Lake Region School in Maine. Bricks and mortar that had been contaminated by PCB caulk adjacent to it was removed from the exterior of the school building. Removal extent will vary based on the extent PCBs traveled into the porous masonry.

(PCS in Schools... 2016)

Demolition of structures containing PCB caulk, sealants and paints can be handled differently. Because there are no requirements for sampling building materials under TSCA, a building owner can survey a particular area of a building prior to demolition and make assumptions based on knowledge to characterize certain media as PCB Bulk Product Waste. The EPA considers PCB Bulk Product Waste as non-liquid, PCB-Contaminated items such as building demolition debris. The goal for demolition projects would be ≤1 ppm for High Occupancy Areas or ≤25 ppm for Low Occupancy Areas. The cleanup goal is met by removing the source material (caulk, paint, etc.) and managing the waste in accordance with TSCA’s disposal requirements. All remediation wastes must be properly managed and disposed. The most common way to dispose of PCB Bulk Product Wastes are by landfill disposal at either a non-TSCA landfill approved to accept PCB Bulk Product Waste or a TSCA approved landfill.
When PCB caulk contamination is identified by sampling and laboratory analysis, the EPA will require cleanup to standards of ≤1 ppm for High Occupancy Areas. Caulks and sealants are typically used around windows and between masonry materials on buildings, such as expansion joints. Over time the PCBs migrate into the adjacent porous surfaces. In EPA Region 1, this has led to inches of porous masonry material being removed from buildings surfaces to reach the cleanup goal of ≤1 ppm (Herrick 2004). The EPA issued a draft reinterpretation of TSCA’s PCB Bulk Product Waste definition to allow for PCB “coated or serviced” building materials to be disposed of as PCB Bulk Product Waste (Rudzinski 2012). See Figure 8 for further explanation. The EPA’s intentions were to help speed up PCB caulk cleanup projects. Either way, the cleanup projects are tedious, time consuming and are costly undertakings for building owners.

![Figure 8: EPA’s PCB Bulk Product Waste Reinterpretation](EPA 2016)

### 4.6 PCB Building Materials in School Buildings

The discovery of PCBs in building materials began when caulking from building exteriors was found to contain PCBs. Interest in PCB caulk in U.S. schools has been primarily focused in New England and the Northeast. The first PCB caulk remediation projects in the U.S. were at university and municipal school district buildings in Massachusetts (EPA Region 1) during the early to mid-2000’s. Massachusetts schools in Falmouth, Lexington, New Bedford, Princeton, Shrewsbury, Westport, and Worcester as well as the University of Massachusetts in
Amherst and Berkshire Community College in Pittsfield have all dealt with issues and/or remediation projects that resulted in PCB caulk discoveries. Rhode Island and Connecticut, neighboring states of Massachusetts, have documented PCB caulking cases. Since 2009, over 100 Connecticut schools impacted by PCB building materials have been identified (DesRoches 2015). Three contiguous New England states have had PCB caulk incidents. In addition, at least one documented school PCB project has occurred in Maine and numerous have occurred in New York. This poses the question: what is the extent of PCB building material contamination that exists around the U.S.?

PCB caulk has been discovered at the University of Rhode Island (URI). In the Fall 2000, URI employees working in Chafee Hall expressed concern as they attributed many adverse health effects employees had suffered to the building. URI contracted a consultant to collect samples within the building. PCBs were detected in caulking and dust samples. As a result of the contamination, Chafee Hall was closed in December 2000 for more than a year (Chafee Test Results … 2001). EPA Region 1 was notified, and a remedial action plan was developed and approved. While it was closed to the URI population, it was further assessed and remediated. Remediation consisted of removal of PCB impacted caulking, masonry, dust, and light ballasts. An epidemiological study was conducted on URI employees and graduate students who worked in the building. The building reopened in phases after remediation was completed, in September 2001 and Fall 2002, respectively. It cost URI $4 Million to address the contamination (Ray 2011). In 2002, results of the building occupant’s blood serum study indicated that none of the PCB levels detected were higher than the national average. There was inconclusive evidence that PCBs attributed to the abnormally high rate of cancer experienced by the building occupants (Medical Tests Show… 2014). Most recently, in March 2015, samples of window caulking from URI’s Fogarty Hall revealed PCBs in caulk. Fogarty Hall was constructed in 1964 and was undergoing a partial renovation at the time the samples were collected (Humphrey 2015). The Chafee Hall case was the first large scale PCB caulk remediation project to take place in Rhode Island.

In 2008, concerns over PCB contamination in New York City (NYC) schools (EPA Region 2) became a public controversy when several public school buildings were found to contain PCB caulking. “Polychlorinated biphenyls are common in window and door caulking found in 266 New York City schools built or renovated in the 1960s and 1970s, officials concede” (Egbert 2008). Hysteria ensued amongst school children, parents of school children and teachers over fears for their health. The presence of PCB caulking led to anger and frustration by concerned parents of students and teachers. There was public outcry for the NYC Department of Education to remediate the schools. The NYC schools cases were a catalyst for the EPA to address this relatively ambiguous contamination issue. Figure 9 is a photograph illustrating the extent of PCB contamination at a New York School.
In January 2010, EPA Region 2 entered a Consent Agreement with the New York City School Construction Authority (NYC SCA) to assess and remediate NYC public schools. Five schools were chosen for a pilot study. The purpose of the pilot study was to assess the presence of PCB building materials and developed preferred remedial methodologies (NYC School Construction Authority… 2011). The study allowed EPA exposure scientists to sample impacted media and learn real-world PCB information (EPA 2015a). Currently, the NYC SCA is undertaking a long-term monitoring program to assess PCB building materials in the five pilot study schools. The program consists of bulk material sampling, removal of bulk material over established thresholds, encapsulating lower level PCB bulk material with an epoxy coating and air sampling (NYC School Construction Authority… 2015). Remediation projects can be challenging for school districts because they are publically funded and often times operate on tight financial budgets. Also, assessment and remediation work must be done off hours or when schools are on academic breaks. This procedure limits the risk of exposure to school students, teachers and employees.

The most recent case of PCB caulk in schools to gain national media attention occurred in Malibu, California. In 2013, a group of Malibu’s public school teachers raised concerns over colleagues who were diagnosed with thyroid cancer and others that suffered migraines. The teachers attributed their adverse health effects to a PCB soil remediation project that took place at a Malibu school in 2011. PCBs and other contaminants were detected in soil (Carroll 2014). Local parents, including supermodel Cindy Crawford (see Figure 10) and actor Josh Malina, formed the group America Unites for Kids (formerly Malibu Unites) to urge the Santa Monica-Malibu Unified School District to sample its school buildings for PCB caulk. Public Employees for Environmental Responsibly (PEER), a public employee advocacy group, joined the protest to
be a backer for the school teachers. The parents and PEER feared for their children’s safety. In 2013, the school district had caulking sampled and analyzed for PCBs, and PCBs were detected. The district worked with the EPA Region 9 to have it remediated. The district did more assessment and followed the EPA’s guidance for air, soil and surface testing. The sampling results were within EPA guidance levels, and the EPA advised the district that no additional testing was needed (Carroll 2014). The district stuck by the EPA’s recommendations that they were in compliance. America Unites for Kids and PEER felt that the school district has not done enough to address PCBs in their schools, and they are demanding the school district sample all its schools. They are very vocal in their dissatisfaction. America Unites for Kids and PEER filed suit under TSCA citizen’s suit provision against the district for the removal of PCBs ≥50 ppm. The case is set to go to trial in May 2016 (DeNicola 2015). The celebrity involvement and the group’s vocal dissatisfaction cast this latest PCB caulk case into the national media attention.

![Figure 10](image)

**Figure 10:** On August 12, 2014, celebrity Cindy Crawford participated in a media press conference to urge the Santa Monica-Malibu Unified School District to test its schools for PCB caulk

(Bashaw 2014)

### 4.7 EPA’s Research

The attention brought on by the New York City school cases warranted the EPA to respond to protect children and school employees. The EPA had to give immediate attention to the newly identified source of PCB contamination. “In September 2009 the USEPA announced new guidance for school administrators and building managers for managing PCBs in caulk and to help minimize possible exposure. However, there was limited information on PCBs in school buildings in the United States. Neither the PCB sources, nor the routes of exposure have been well-characterized in school buildings. As such, there remained considerable uncertainty regarding the extent to which children and staff members may be exposed to PCBs in school
environments. The USEPA also announced in 2009 that additional research would be performed by the Office of Research and Development’s (ORD) National Exposure Research Laboratory (NERL) and the National Risk Management Research Laboratory (NRMRL) to further study this issue” (Thomas et al. 2012). The events set in motion in NYC expedited research activities to gain knowledge in the relatively unstudied public health issue.

Between 2009 and 2012, teams of EPA scientists and consultants studied PCBs in building materials. The research focused on PCB sources, evaluating potential routes and pathways of exposure, and studying mitigation and remediation methods. Laboratory studies were conducted at the EPA’s Risk Management Research Laboratory. The findings were published in five studies and a literature review of PCBs (EPA 2015c). The studies and findings are summarized as follows:

- **Study 1**: *Laboratory Study of Polychlorinated Biphenyl (PCB) Contamination and Mitigation in Buildings, Part 1. Emissions from Selected Primary Sources* (Guo et al. 2011)
  - **Findings**: Emissions from old caulk caused elevated PCBs in surrounding air. PCB emissions rates from old fluorescent light ballasts increased at simulated operating temperatures. Old light ballast that are still in use have reached their service life and are at risk of rupturing and emitting PCBs.

- **Study 2**: *Laboratory Study of Polychlorinated Biphenyl (PCB) Contamination and Mitigation in Buildings, Part 2. Transport from Primary Sources to Building Materials and Settled Dust* (Guo et al. 2012a)
  - **Findings**: Building materials, such as paint and masonry, and indoor dust can absorb PCBs. Effectively, these materials become secondary sources of contamination. Emissions rates from secondary sources are not as high as primary sources (ex. PCB caulk). Remediation must considered effects of secondary sources.

- **Study 3**: *Laboratory Study of Polychlorinated Biphenyl (PCB) Contamination and Mitigation in Buildings Part 3. Evaluation of the Encapsulation Method* (Guo et al. 2012b)
  - **Findings**: This study was the first attempt to test the encapsulation containment method. PCB sources were painted with commercial coatings to separate the source from the surrounding environment. Encapsulation reduced PCB emissions when the PCB source was at a low concentration. Ten commercial products were tested, and it was concluded that high-performance coatings were most effective at encapsulation. Encapsulation of high-level PCB sources may not reduce indoor emissions to desirable levels. Therefore, it is a temporary measure until PCB building materials can be removed.

- **Study 4**: *Laboratory Study of Polychlorinated Biphenyl (PCB) Contamination and Mitigation in Buildings, Part 4. Evaluation of the Activated Metal Treatment System (AMTS) for On-site Destruction of PCBs* (Xiaoyu et al. 2012)
  - **Findings**: The EPA tested a remediation method called Active Metal Treatment System (AMTS) on paint, caulk and concrete. AMTS was developed by the National Aeronautics and Space Administration (NASA) and researchers at the University of Central Florida. ATMS dechlorinates PCBs. It was effective on
paint, but it was less effective on thicker media such as caulk and concrete because of limited penetrating capabilities. The EPA noted that after their research was completed, NASA had developed an improved method. The EPA recommended further research.

**Study 5:** *Polychlorinated Biphenyls (PCBs) in School Buildings: Sources, Environmental Levels, and Exposures* (Thomas et al. 2012)

- **Findings:** EPA exposure scientists collected air, dust, soil and surface wipe samples from a NYC school that was scheduled for demolition. In addition, caulk, tile and paint were sampled. Furthermore, PCB measurement data from five other NYC schools was used for exposure risk assessment modeling for school children. Data was collected before and after mitigation methods were implemented. Modeling predicted <1% of students had a risk of exposure exceeding the reference dose after mitigation methods were completed. Caulk and light ballasts were identified as the sources of PCBs in all six of the NYC schools included in the study.

### 4.8 EPA Recommendations

In July 2015, the EPA updated its recommended assessment and management strategies for PCB caulking. Their recommendations were presented in their paper, “Practical Actions for Reducing Exposure to PCBs in Schools and Other Buildings” (EPA 2015d). The information presented in this section is from the EPA’s guidance. These revised recommendations were created based on new information learned during the EPA’s PCB caulk studies. The intended audience was school administrators, building owners and building managers. If a building was constructed between 1950 and 1979, the EPA recommends the following:

- Remove all known or suspect PCB-containing fluorescent light ballasts
- Remove any PCB-containing building materials during planned renovation and repair projects
- Consider encapsulation of PCB building materials to reduce exposure by building occupants
- Follow best management practices for PCB building materials

Best management practices for minimizing exposure to PCBs in caulk including frequent cleaning of schools to reduce dust, cleaning with wet methods (mopping, dust with damp cloths, etc.) to control dust, use vacuums with high efficiency particulate air (HEPA) filters, wash children’s hands and toys frequently, and wash hands with soap and water often and particularly before consuming food. Finally, building heating, ventilation and air conditioning (HVAC) systems should be operated and properly maintained in accordance with the mechanical industry standards to reduce PCBs in indoor air.

The EPA offered the encapsulation method of PCBs caulk, sealants and paint as an alternative to removal. Building owners could leave PCB contaminated building materials in place and stop PCBs from becoming a secondary contaminant for indoor air by sealing them with specialized coatings. The EPA claimed that encapsulation has been proven to be effective
in reducing indoor air concentrations of low level PCBs. If PCBs were to be encapsulated, it would become the responsibly of the building owner to create a monitoring plan to ensure PCBs stay encapsulated. Similarly, the EPA allows asbestos-containing building materials (ACM) in schools to remain as long as the building owner inspects and inventory ACM annually and ensures that ACM remains intact and are in good condition.

The EPA recommends testing indoor air if school districts are concerned with the presence of PCBs or if PCBs are to be encapsulated. The recommended goal is to keep PCB indoor air concentrations below the Oral Reference Dose (RfD) of 20 nanograms (ng) PCB/kilogram (kg) body weight per day. “An RfD is an estimate of a daily exposure to the human population, including sensitive subgroups that is likely to be without an appreciable risk of harmful effects during a lifetime” (EPA 2015e). The EPA calculated the “Exposure Level for Evaluation of PCBs in School Indoor Air” for a child at age one (100 ng/meter (m)³) to a teenager at age 19 (500 ng/m³). The goal is to keep PCB exposure as low as reasonably achievable and that total PCB exposure be kept below the RfD. The EPA’s exposure levels for evaluating PCBs in indoor air are presented in the following Table 4.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|c|c|}
\hline
\textbf{Age} & \textbf{1 to <2 yr} & \textbf{2 to <3 yr} & \textbf{3 to <6 yr} & \textbf{6 to <12 yr} & \textbf{12 to <15 yr} & \textbf{15 to <19 yr} & \textbf{19+ yr} \\
\hline
\textbf{Exposure Level} & 100 & 100 & 200 & 300 & 500 & 600 & 500 \\
\hline
\textbf{Note:} These exposure levels were derived to serve as health protective values intended for evaluation purposes. These levels should not be interpreted nor applied as “bright line” or “not-to-exceed” criteria. For further explanation, see Q&A #26 & #27. Exposure levels have been revised to reflect more recent data on dietary exposure and have been rounded to the nearest hundred ng/m³. \\
\end{tabular}
\caption{PCB Exposure Levels for Indoor Air in Schools (EPA 2015f)}
\end{table}

If PCBs are identified in indoor air samples then the EPA recommends conducting further building assessments to determine the source. A problem with indoor air sampling is that there are many “potential” sources of PCBs and contaminants in air are not easily traced back to a source. Analyzing samples for the individual congeners is the method used to link air samples to a specific caulk location.
5.0 Conclusions and Recommendations

PCBs were excellent additives for many commercial and industrial products because of their inert state, plasticizing properties and their ability to withstand high heat environments. However, the potential toxic health effects on humans and animals as well as their affinity to bioaccumulate in the environment led to their demise. The discovery of PCBs in building materials has morphed into an ambiguous regulatory development. TSCA, the guiding PCB legislation, was likely not enacted to address PCB caulk. The EPA has researched the issue and developed guidance for managing PCB exposure risks and they have encouraged researchers to continue studying the problem and advance the knowledge of the topic.

The fact that PCBs have a long history of being a recognized health risk to humans and animals has likely led to the panic it has caused for those occupying schools where PCB caulk was discovered. The events related to PCB caulk in schools are similar to the identification of asbestos in schools during the 1980’s. Asbestos containing building materials were commonly used in the U.S. throughout most of the 20th century because asbestos gave building material added strength as well as high heat and fire proofing capabilities. However, the known human health risks associated with asbestos are fatal lung diseases and cancer. In the late 1980’s the EPA was successful at banning the production and use of most asbestos containing building materials in the U.S. Many old buildings contained, and may still contain, asbestos. In 1986 the EPA was given authorization to developed regulations for the Asbestos Hazard Emergency Response Act (AHERA) (15 U.S.C. §§ 2641 et seq.). AHERA required school districts to inspect, characterize, inventory, develop written management plans and abate asbestos containing building materials in their schools to protect occupants (children, teachers, staff, etc.). The ban went into effect in 1989. Since the development of the AHERA regulations, the management and abatement of asbestos has become routine and predictable for environmental and facilities managers. Today, the concern once caused by ACM in schools has subsided and is well under control. Perhaps, as more research on the subject is conducted and new remediation technologies are developed, the PCB caulk problem will, like asbestos, become routine and manageable.

The toxicology of PCBs has been debated for many years. The scientists are divided on the exposure risks. It is likely that at least some types of PCBs cause adverse health effects or cancer, but exposure is dependent on many other factors such as the congener, dose, time and physiology. However, other studies have shown that there is not enough conclusive scientific evidence to support that PCBs cause adverse health effects. In regards to PCBs in building materials, the population most at risk of exposure is children. In addition, other building occupants (teachers and staff) and construction workers are at risk. Construction workers who are removing, grinding, and sanding PCB contaminated building materials during demolition and renovation activities are at risk of exposure. If PCB containing building materials are suspected to be present on a project, then construction workers handling these materials should be given means to protect themselves (e.g. personal protective equipment, education on the risks and best management practices, and safety procedures). Controlling PCBs from lingering within indoor air is paramount.
It is likely that TSCA was enacted to manage PCB releases associated with electrical equipment, not to address PCB caulk on the exterior of a multi-story, masonry building. Building owners who are sampling for PCBs and are finding levels ≥50 ppm, are subject to TSCA’s PCB regulations and are required to notify the EPA. The EPA’s regional offices TSCA programs are faced with the interpretation of the TSCA regulations and determining how to administer and enforce the regulations for buildings. It is not a clear cut process for the EPA which leads to varied regulatory decision making on each project.

PCB caulk assessment and cleanup under the TSCA regulations can be tedious; including such actions as collecting confirmatory samples using small grid spacing, drilling into porous surface to collect dust samples at depth intervals, removing porous surfaces and investigating potential sources of PCBs which may contain PCBs but are not releasing them. The EPA must approve a Self-Implementing Plan before starting remediation. The cost for entering into a Self-Implementing Plan or taking a Risk-Based approach can be quite expensive (on the order of thousands to millions of dollars). With the discovery of PCBs in caulk, some EPA Regional offices have become inundated with new sites, particularly in Region 1 (Northeast). The EPA will assign a higher priority to a school because the contamination affects children, rather than a private sector project. The approval process, assessment and cleanup could lead to building renovation project delays. Furthermore, the identification of PCBs has led to unforeseen project costs on the order of tens of thousands to millions of dollars. It is possible that if a municipal school district had a large site or multiple PCB sites, the costs to assess and remediate could financially strain or deplete a public school district’s budget.

Building owners are able to follow the Performance Based Disposal option for PCB Bulk Product Waste and remain in compliance with TSCA. The benefits of choosing the Performance Based Disposal approach are that sampling and notification to the EPA are not required. Because the sampling of PCB caulking is not required under TSCA, pre-demolition surveys can be conducted to identify suspect PCB containing building materials. Building owners should choose to hire environmental consultants experienced in TSCA and PCB building materials to conduct surveys. Surveys may result in some form of sample collection if it is deemed appropriate. If no samples are collected, building owners can assume that suspect building materials are contaminated with PCB at concentrations of ≥50 ppm and manage the wastes as PCB Bulk Product Waste. The wastes can be land disposed at either a landfill authorized to accept PCB Bulk Product Waste or a TSCA approved landfill. It is considerably less expensive to dispose of waste at a landfill authorized to accept PCB Bulk Product Waste versus a TSCA landfill. However, a potential problem arises in that the actual concentrations of PCBs in bulk waste are unknown if sampling is not conducted. Therefore, high concentrations of PCBs could be land disposed which could cause future groundwater contamination if the landfill is not equipped with a leachate collection system. Currently, there is no violation of TSCA by following the Performance Based Disposal option.
Assessment and remediation of PCB caulk should be left to the experts. Home-grown remediation efforts could lead to worker exposures, building occupant exposures, further spread of PCB contamination, and improper land disposal of wastes. The best advice is to research and hire a professional environmental consultant or consulting firm experienced in PCB caulk assessment and remediation. An added bonus would be to hire a consultant that has a good working relationship with the EPA’s Regional PCB Coordinator. That relationship should create some efficiency and consistency through the regulatory process. Consultants may subcontract environmental remediation companies to actually remove PCB caulk. Further screenings will ensure that consultants’ subcontractors are professional, health and safety trained, and experienced in PCB caulk remediation. Reputable environmental consultants are often members of local industry groups such as the New England Academy of Certified Hazardous Materials Managers (NEACHMM) or the Rhode Island Society of Environmental Professionals (RISEP). In order to find the appropriate firm, interested parties could contact professional industry organization groups such as those listed above as a starting point to search for a reputable consultant.

Based on this literature review, the following recommendations are offered. First the EPA, other Federal agencies, private research firms and/or academic researchers should continue studying the problem to determine if PCBs in caulk, sealants and paint are truly human health risks. Next, armed with that new scientific information, the EPA should evaluate if revising the TSCA regulations is warranted. Finally, the goals should be to amend TSCA in favor of the protection of human health (e.g. school children, school employees and construction workers) and the environment.
Notes

1. Erickson and Kaley cited:

2. Priha, Hellman, and Sorvari cited:

3. Lyng et al. cited:

4. Klosterhaus et al. cited:

5. Liu et al. cited:
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