Inadvertent PCBs in Pigments:

Market Innovation for a Circular Economy

Final Report

Prepared for:
The Spokane River Regional Toxics Task Force

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Executive Summary

In an effort to decrease polychlorinated biphenyl (PCB) and other toxic chemical contamination in Washington waters, the Spokane River Regional Toxics Task Force (SRRTTF) is working on multifaceted approaches to reduce loading that include both regulatory and voluntary initiatives. This project addresses inadvertently generated PCBs that are released into waterways, with a focus on PCBs in paper and packaging materials. Northwest Green Chemistry was contracted to prepare a white paper that could be used to inform external stakeholders and to suggest next steps for reducing inadvertent PCB contamination using green chemistry, alternatives assessment and voluntary market-based strategies.

The issue of whether inadvertent PCBs in pigments used on individual packages and newsprint present a risk to users of those materials is not the focus of this paper. Rather, the issue is that inadvertent PCBs in pigments are ubiquitous and provide a steady flow of additional PCBs into products and the environment on a global scale. Pigments used on paper and packaging materials contaminate recycling streams that hinder both recycling businesses and our ability to achieve a safe and healthy circular economy. The continued discharge of PCBs into waterways decreases the effectiveness of expensive, ongoing remediation efforts designed to protect human and environmental health. This is occurring at a time when the government in China has announced that it will no longer be accepting international paper and plastic waste for recycling and there is growing awareness of damage from consumer product waste that is mismanaged and found to pollute the ocean and other water bodies. Calls for a circular economy that 1) designs out waste and pollution, 2) keeps products and materials in use, and 3) regenerates natural systems are growing.

This paper and related presentation materials represent the first phase of work intended to inform and engage external stakeholders about inadvertent PCBs in pigments used for paper packaging and newsprint and to motivate them to take strategic action to identify and adopt inherently safer pigments that contain no or ultra-low levels of inadvertent PCBs. It provides some background information on the scope of the problem including sources of inadvertent PCBs and regional inadvertent PCB control initiatives. Information is derived from reviews of media articles, presentations, scientific studies and interviews with stakeholders. The report also includes recommendations for next steps including targeted collaborations, green chemistry and engineering research projects, alternatives assessment, and model procurement activities that can help drive the substitution of pigments containing the highest levels of inadvertent PCBs with alternatives that contain no or ultra low levels of inadvertent PCBs.

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1. Introduction

Polychlorinated Biphenyls (PCBs) are a class of man-made organic chemicals consisting only of carbon, hydrogen and chlorine atoms. PCBs have no known taste or smell and range in consistency from oil to a waxy solid. They have varying numbers (from 1 to 10) of chlorine atoms on a biphenyl backbone (United States Environmental Protection Agency). The number of chlorine atoms and their location in a PCB molecule determine many of the physical and chemical properties. Varying the number and locations of chlorine atoms on the biphenyl backbone results in 209 variations known as PCB congeners. Figure 1 shows a selection of example PCB congeners.

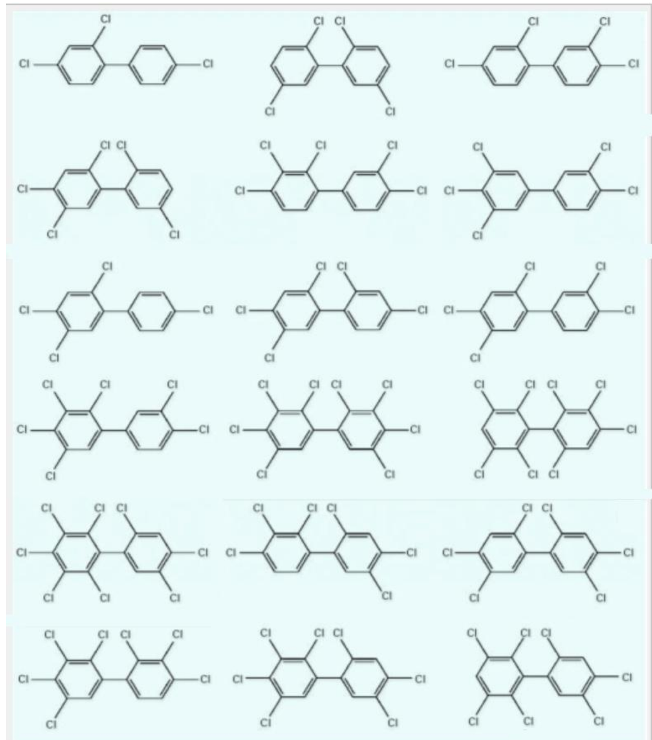

Figure 1: A selection of PCB congeners (*Plísková , Vondrácek*

PCBs can be divided into two broad groups based on their origins: legacy and inadvertent PCBs. Legacy PCBs refer to those that were intentionally manufactured for use in products. Inadvertent PCBs refer to those that are produced as by-products or contaminants from manufacturing other products. Congeners that share a common chemical structure are also likely to share physical and toxicological properties. However those properties may vary depending on the number and location of chlorine atoms on each individual congener. Those congeners of PCBs that have been studied in the greatest depth have come to represent the entire class, and therefore all congeners are treated as probable human carcinogens (United States Environmental Protection Agency 2018) (L. A. Rodenburg, et al. 2010). Likewise, currently in the US, all PCB congeners are essentially regulated as a group (Commonwealth of Massachusetts 2018). This is pragmatic because PCBs typically occur as mixtures rather than as individual congeners and the amount and pattern of different congeners found in the environment and formed inadvertently is variable. Additional research is needed to better understand the variability between congeners (Borlakoglu and Walker 1989). The National Toxicology Program is currently evaluating PCB 11, commonly found in inadvertent PCB mixtures (and not in legacy mixtures), for potential toxicity with emphasis on the similarities and differences between PCB 11 and other PCB congeners including PCB 126 (known ‘dioxin-like’ activity), PCB 153 (persistent but not ‘dioxin-like’), PCB 95 (neurotoxic), and two commercial legacy PCB mixtures (Aroclor 1254 and Aroclor 1016).

The Spokane River Regional Toxics Task Force (SRRTTF) is working on multifaceted approaches to reduce loading that include both regulatory and voluntary initiatives. This report addresses inadvertently generated PCBs that are released into waterways, with a focus on PCBs in paper and packaging materials. The focus of this paper is primarily on inadvertent PCBs found in organic pigments. While pigments are just one source of inadvertent PCBs, inadvertent PCBs in pigments used in newsprint and paper packaging are contaminating recycling streams and interfering with efforts to promote both recycling and to meet water quality standards for the Spokane River. Reducing contamination from PCBs, both legacy and inadvertent, is a global challenge that affects water bodies worldwide. A number of voluntary intervention strategies are recommended to help reduce inadvertent PCBs in paper packaging and newsprint and to address this systemic problem at the source.

2. PCBs and Health Effects

PCBs pose health hazards that can include (Washington State Department of Ecology 2015) (United States Environmental Protection Agency 2018):

- Increased risk of cancer
- Immune deficiencies
- Neurotoxicity
- Reproductive impacts
- Developmental effects
- Skin changes

PCBs are concerning due to their persistence (P) in the environment, ability to bioaccumulate (B) up the food chain, and their toxicity (T), and as such, they are considered persistent, bioaccumulative and toxic substances (PBTs). PBTs have spurred international action because they are found in even the most remote regions of the world due to global transport. As PCBs bioaccumulate through contaminated food and water in humans and other organisms they result increase risk. Figure 2 illustrates how PCBs are transferred throughout the food web with particular emphasis on marine ecosystems.

Humans can be exposed to PCBs via air, water, soil, inhalation and ingestion. Health impacts are exacerbated as PCBs accumulate in the body fat of living organisms faster than they can be broken down, resulting in widespread and long-term human and environmental exposure (Estuary Partnership 2014). Consuming PCB-contaminated food facilitates the buildup of PCBs in body tissues, potentially compromising the healthy development of children. PCBs are able to cross the placental barrier between mother and child (United States Environmental Protection Agency 2018). Another study found that children of mothers with high body burdens of PCBs exhibited short-term memory challenges and behavioral issues (Colborn, von Saal and Soto 1993). These extended exposures, resulting in developmental impacts (among others), create a systemic burden for whole ecosystems and communities. More research on the different PCB congeners will lead to better understanding of their PBT properties.

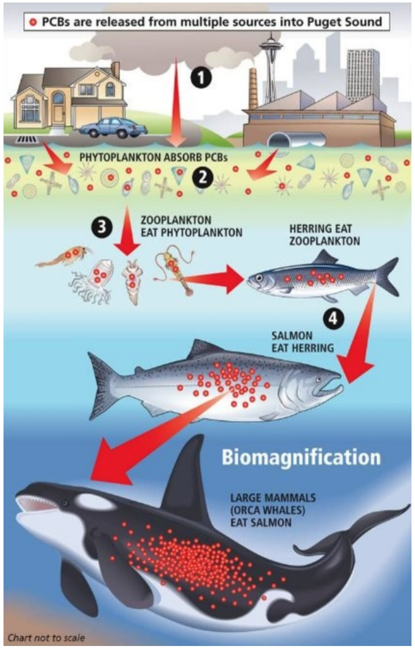

Figure 2: PCBs released into Puget Sound *(W. Litten 2014)*

Exposure to PCBs via consumption of contaminated fish is a worldwide challenge, affecting nations as widespread as the United Kingdom, Pakistan, Brazil, China, and Nigeria, among others (Rose, et al. 2015) (Eqani, et al. 2015) (Miranda and Yogui 2016) (Pan, et al. 2016) (Adeogun, et al. 2016). Local governments continue to advise against consumption of many regional fish populations due to their PCB content, even after decades of discontinued legacy PCB manufacture. Inadvertent PCBs in waterways are delaying safe consumption of fish (San Francisco Bay Regional Water Quality Control Board 2016). The plight of orca (killer) whales is has been in the press recently. Their survival is being challenged by loss of food supply, vessel traffic, and toxics, including PCBs. PCBs are believed to be altering orca behavior, damaging their immune systems, and harming reproduction to the extent that researchers suspect many families of killer whales may not survive the next few decades. Appendix B provides more details on exposure routes of PCBs.

3. Legacy and Inadvertent PCBs

In order to understand the scope of the problem of inadvertent PCBs, it is helpful to understand review a brief history of legacy PCBs and how they differ from inadvertent PCBs.

Legacy PCBs. PCBs have exceptional physical and chemical properties including “fire resistance, low electrical conductivity, high resistance to thermal breakdown, high degree of chemical stability, and resistance to many oxidants and other chemicals” (United Nations Environment Programme (UNEP) Chemicals). They are versatile chemicals, and as a result, millions of pounds of PCBs were once manufactured and used in products such as (United States Environmental Protection Agency):

- Transformers and capacitors
- Electrical equipment including voltage regulators
    - Switches
    - Re-closers
    - Bushings
    - Electromagnets
- Oil used in motors and hydraulic systems
- Fluorescent light ballasts
- Cable insulation
- Oil-based paint
- Caulking
- Plastics
- Carbonless copy paper

From 1929 until 1977, the Monsanto Chemical Company was the sole producer of PCBs in the United States marketed under the “Aroclor” tradename. Thus legacy PCBs in the U.S. are often simply be referred to as “Aroclors” (Kopp). Although Monsanto produced about half of the total volume worldwide, legacy PCBs were also made internationally under other trade names. (Battelle Memorial Institute). In 1979, nations around the world took action to stop the manufacture of legacy PCBs. The US EPA introduced a ban on PCB manufacture, and PCBs were included on the Stockholm Convention list of twelve priority persistent organic pollutants (Daryl J. McGoldrick, McGoldrick and Murphy).

Inadvertent PCBs. Although manufacture of PCBs was banned in 1979, PCBs continue to be formed as inadvertent byproducts in up to 200 manufacturing processes (A. Stone). Seventy of these processes have a high potential to create PCBs. Appendix A provides an extensive list of end products and manufacturing processes known to produce inadvertent PCBs. When chlorine, salts, and hydrocarbons or chlorinated hydrocarbon compounds are mixed and reacted at high temperatures, PCB impurities can result. While just one source, many of today’s pigment production processes require chlorine and heat, which presents an inherent risk of creating inadvertent PCBs in unknown amounts (L. A. Rodenburg, et al. 2010).

4. Sources of Inadvertent PCBs

Inadvertent PCBs come from primary and secondary production sources. Addressing inadvertent PCB production from primary sources should also reduce inputs from secondary sources.

- *Primary production sources*: facilities that directly generate inadvertent PCBs, such as some chemical and pigment manufacturers
- *Secondary production sources*: downstream users of chemicals and products that contain PCBs, such as printers and recyclers

Primary production sources include (Oregon Department of Environmental Quality (DEQ) n.d.):

- Organic and inorganic pigment manufacture
- Production of chlorinated solvents
- Agricultural chemicals
- Detergent bars
- Wood treatment

Secondary production sources of inadvertent PCBs are typically associated with facilities that discharge effluent into rivers, streams, lakes and oceans. Potential sources for these inadvertent PCBs include (NGC interview with Doug Krapas, Environmental Manager at IEP):

- Paper Mills:
    - Newsprint pigments (inks and dyes)
    - Packaging pigments (inks and dyes)
- Wastewater Treatment (City of Spokane Wastewater Management Department 2015):
    - Antibacterial hand soap
    - Antibacterial dish soap

    - Laundry detergent
    - Shampoo
    - Toothpaste
    - Clothing dyes when washed
- Municipal Stormwater Runoff:
    - Road paints
    - Asphalt sealers
    - Pesticides
    - De-icers

It is important to note the difference in scale of release of PCBs from legacy and inadvertent sources. While legacy PCBs are no longer produced, the Washington State Chemical Action Plan (2015) for PCBs estimates ongoing releases from secondary sources of up to 1500 kg per year for light ballasts and 160 kg per year for caulk exposed to the environment in older buildings. Releases of inadvertent PCBs are estimated at 0.2 to 31 kg per year for inadvertent PCBs from dyes and pigments. While the scale of inadvertent PCB release can be orders of magnitude less, continued release of both legacy and inadvertent PCBs into the environment slows successful remediation projects (University of Iowa - IIHR Hydroscience and Engineering 2015). Lengthening these projects adds cost - which is already in the billions of dollars - for businesses, consumers, regional and state governments, and the federal government. For example, General Electric alone reportedly spent $1.7 billion on a nine-year project to remove PCBs from the Hudson River (McKinley 2016) (Wu 2018).

Because researchers have not found any link between Aroclor production and PCB 11, it has become a hallmark indicator of inadvertent PCB creation (Hu, Martinez and Hornbuckle, Discovery of Non-Aroclor PCB (3,3′-Dichlorobiphenyl) in Chicago Air 2008).

In 2002, Litten et. al were among the first researchers to express concern about PCB 11 in the environment (Litten, Fowler and Luszniak 2002). They made the connection between pigment manufacture and inadvertent PCBs after detecting PCB 11 in surface and wastewater near two pigment factories in the New York/New Jersey Harbor area.

Studies have shown that PCB 11 concentrations have remained steady in a number of locations, including the Great Lakes region. For example, researchers at Indiana University found that PCB 11 concentrations have not decreased since 2004 (Hites 2018). In 2007, researchers found PCB 11 in 91% of air samples taken near 40 Chicago elementary schools, with varying concentrations throughout the year. The presence of airborne PCB 11 increases children's risk of exposure via inhalation (Hu, Martinez and Hornbuckle, Discovery of Non-Aroclor PCB (3,3′-Dichlorobiphenyl) in Chicago Air 2008) (Shanahan, et al. 2015).

While there is no evidence suggesting that PCB 11 accumulates in living organisms, its pervasiveness in the environment and in printed products, from packaging to children's pajamas, has raised concern (Guo, et al. 2014). There is emerging evidence that PCB 11 may have health hazards, such as neurotoxicity (Shain, Bush and Seegal 1991). Another study found that PCB 11 accumulation in the body could suppress cell growth, but its toxicological profile is still being developed (Yueming, et al. 2013).

5. Inadvertent PCBs: Current Challenges

Inadvertent PCBs continue to contribute to the accumulation of PCBs in certain waterways. For example, the Department of Environmental Sciences, Rutgers University, found that PCB limits in the Delaware River have been exceeded in part due to inadvertent PCB production (L. A. Rodenburg, J. Guo and S. Du). Additional research clarified that non-legacy PCBs are being generated from production processes, rather than as dechlorination breakdown products from legacy PCBs. The thorough documentation of legacy PCB congeners helps researchers discern which PCBs in the environment are from legacy sources and which continue to be generated inadvertently. This provides insight into where inadvertent PCBs are hindering decades of costly environmental remediation efforts related to legacy PCBs. Table 1 shows specific PCB congeners that have led to violations of Federal water quality standards in various regions.

Table 1: PCBs above Federal Water Quality Standards (L. A. Rodenburg, J. Guo and S. Du)

PCBs detected above Federal Water Quality Standard of 64 pg/L (pico-grams per liter) (ppq - parts per quadrillion)	
PCB 11	**PCB 206+208+209**
Halifax Harbor (40-126 pg/L)	Delaware River (~230 pg/L)
New York/New Jersey Harbor (over 100 pg/L)	Houston Ship Channel (~130 pg/L)
Delaware River (~20 pg/L- above local criterion)	
Houston Ship Channel (~200 pg/L)	
San Francisco Bay (~100 pg/L)	

Sources of legacy PCBs remain from still-in-use transformers, capacitors, caulking, paints, and other materials manufactured in the twentieth century. However, their potential regional impacts and concentration in the environment have been significantly reduced in the decades since the EPA ban (Chang, Pagano and Crimmins) (Estuary Partnership) (Daryl J. McGoldrick, McGoldrick and Murphy).

Our collective understanding of environmental and human health impacts of PCBs as a chemical class is muddied by a number of factors, including:

- The existence of 209 congeners
    - The level of hazard of a specific PCB congener or mixture is related to the structure of the congener.
    - Each congener or mixture may contain more, fewer or equal hazards to those that have been previously identified.

- Industrially discharged PCBs may be documented accurately by facilities when they are first manufactured. But they are transformed in the environment (chemically and by microorganisms) as time passes. This results in PCBs in the environment that are different than the actual substances that were discharged (Beyer and Biziuk).
- Data gaps:
    - Ongoing research is building toxicological profiles for individual congeners and mixtures of inadvertent PCBs, with emphasis on congener-specific impacts.
    - Inadvertent PCBs are formed as mixtures that have variable congener compositions depending on specific manufacturing process conditions and the quality and impurity profiles of the raw materials and intermediates.

6. Products and Pigments that Contain Inadvertent PCBs

The Washington State Department of Ecology (WA DOE) conducted a preliminary study of inadvertent PCB concentrations in consumer products including packaging, paper products, paints and colorants, caulks, and miscellaneous items (e.g. printer inks and food) (A. Stone). The study provided insight into how water becomes contaminated with PCBs from recycled food packaging and paper products. Inadvertent PCBs were detectable at up to 16 ppb in newsprint and paper packaging and up to 45 ppb in other product categories investigated by WA DOE. Their findings point to dyed products - including clothing, cosmetics, soaps, hand sanitizers, and household cleaning products - as probable sources of inadvertent PCBs. These products are likely to find their way into water and subsequently to leach PCBs (Guo, Capozzi and Kraeutler). For details on PCB concentrations measured by WA DOE, see Appendix E.

The production of at least three classes of organic pigments (Azo, Phthalocyanine and Polycyclic pigments) are known to generate inadvertent PCBs. These pigments are used in packaging and newsprint. They cover the spectrum of yellows, oranges, reds, greens, blues and purples. Within the Azo pigment class there are Diarylide Yellow, Hansa Yellow, Quinacridone, Naphthol AS and Isoindolinone subcategories that can potentially contain inadvertent PCBs. Figure 3 illustrates these pigments and the inadvertent PCB congeners correlated to them. There could be more PCB congeners that have not been tested for or reported and more pigments that contain these contaminants (Hu and Hornbuckle, Inadvertent Polychlorinated Biphenyls in Commercial Paint Pigments) (Willy Herbst).

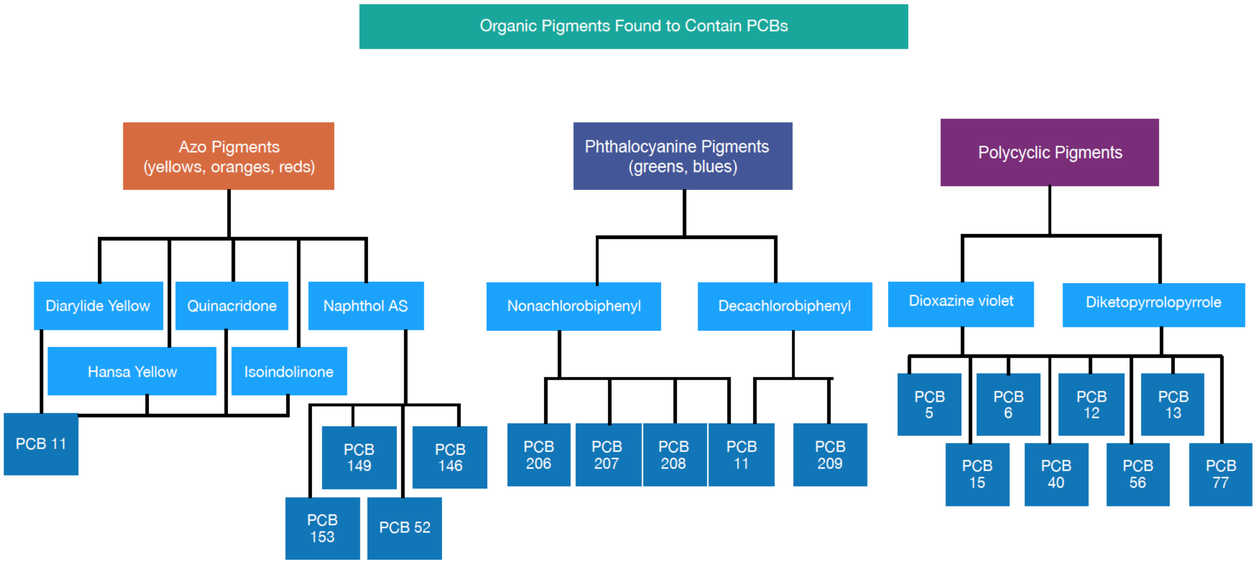

Figure 3: Organic Pigments Found to Contain Inadvertent PCBs

Diarylide Yellow, a commonly used yellow pigment, is a key source of PCB 11. According to one report, a single cereal box can "contaminate nearly seven thousand liters of water at a level of 20 pg/liter, the average PCB 11 concentration in the ambient waters of the Delaware River" (L. A. Rodenburg, J. Guo and S. Du). It's possible that PCB 11 contributes to the Delaware River exceeding PCB water quality limits.

In printed products, like paper, textiles and commercially available paints, inadvertent PCB 11 can be detected with extremely high consistency. It is present in as many as 86% of pigments (Bienkowski). A study evaluating food containers found PCB 11 in 66% of products tested (Muncke). The frequent use of Diarylide Yellow in packaging materials - 65% is used in printing - with resulting detectable levels of PCB 11 means it is a significant source of exposure to consumers and the environment. This makes PCB 11 an excellent candidate for further toxicological studies and mitigation strategies.

Inorganic pigments, such as titanium dioxide, can also contain inadvertent PCBs. Approximately 95% of all titanium mineral production is used to make titanium dioxide (United States Geological Survey). The white pigment adds vibrancy to a vast range of products, including paints, paper, plastic, and rubber. Its distinctive brightness and versatility has made it the leading pigment used globally. More than a million tons are produced each year in the U.S. and millions more are made worldwide. It is widely marketed as a pigment for packaging inks and coatings and is even used directly in food applications (Titanium Dioxide Manufacturers Association).

There are two industrial manufacturing processes for titanium dioxide. One relies on sulfate and the other relies on chlorine (European Commission) (The Essential Chemcial Industry - Online). The chlorinated process can generate inadvertent PCBs while the sulfate process does not. Up to 30% of titanium dioxide in Europe is produced by the chloride process. The inadvertent PCBs produced when manufactured through the chlorinated process varies depending upon process conditions and purity (Ctistis, Schon and Bakker). These inorganic pigments can be found in a wide range of ink and paint products as a base or main component. It has been proposed that inorganic pigments, such as titanium dioxide and iron oxide, could also contain inadvertent PCBs. However, a study by Hu and Hornbuckle (2010) did not find PCBs in their testing of inorganic pigments used in paints, including those which primarily containing titanium dioxide, the most widely used inorganic pigment.

7. Regulatory Approaches

7.1. Inadvertent PCB Regulations

Current national and most international regulations allow inadvertent PCBs to be produced in pigments at maximum concentrations of 50 ppm with an average of 25 ppm. In 1984, non-governmental organizations, including the Environmental Defense Fund, Natural Resources Defense Council and the American Chemistry Council worked together with the US EPA to set national limits on inadvertent PCB generation (Washington State Department of Ecology 2015). US EPA adopted this consensus proposal and promulgated a rule in 1984 for inadvertent generation of PCBs that are not in closed or controlled manufacturing processes (49 FR 28172).

The consensus proposal included the following limits on inadvertent PCBs:

- 50 ppm of inadvertently generated PCBs in products and an annual average of <25 ppm
- Releases to ambient air must be <10 ppm.
- Discharges to water must be <0.1 ppm
- All wastes must be disposed of properly. Process wastes with PCB levels > 50 ppm must be disposed of in accordance with TSCA.
- The concentration of monochlorinated biphenyls is discounted by a factor of 50 and dichlorinated biphenyls are discounted by a factor of 5.
- Certification, reporting and records maintenance.

There are chemical management guidelines for producers of inadvertent PCBs. However, the last reported EPA PCB report comes from 2011 (Washington State Department of Ecology 2015). This lack of data presents difficulties in determining current or precise records of locations, quantities, and frequency of PCB creation.

International inadvertent PCB production has implications for the packaging industry in the U.S. since imported products containing 50 ppm or lower amounts of inadvertent PCBs are not restricted (and likely not tested for PCBs) (United States Environmental Protection Agency 2016). Paper and cardboard are a good example of the challenges imported PCBs present. In 2015, the United States imported 11,563 million metric tons of paper and cardboard (Statista 2017). In the EU, 41% of all packaging waste is made up of paper and cardboard (European Commission), and it could be assumed that packaging waste has a similar composition in the U.S. In an analysis of PCBs in consumer products, WA DOE found inadvertent PCBs were present in all paper products tested. With PCB-containing paper products being created both domestically and entering packaging streams through imports, it is challenging to measure the success of collaborative mitigation efforts conducted by businesses and governments.

7.2. Water Quality Requirements

The US EPA has a national recommended Clean Water Act criterion for PCBs of 64 pg/L. Water quality criteria are set by the States and authorized Tribes, and the US EPA has the authority to approve or disapprove the States' or Tribes' criteria. Once approved, the criteria become effective for Clean Water Act purposes. Under the Clean Water Act, discharges of PCBs are regulated by the State or Tribe's water quality criteria, as implemented through National Pollution Discharge Elimination System (NPDES) permits. The Spokane Tribe has a PCB criterion that applies to a portion of the Spokane River, which is more stringent than the State pf Washington criterion. Table 2 gives examples of PCB limits by region.

Table 2: Examples of Regionally Varying PCB Limits

Region	mg/L (ppm)
National Primary Drinking Water Regulations	5.0x10^-4 (0.0005)
State of Washington	7x10^-9 (0.000000007)
Spokane Native American Tribe	1.3x10^-9 (0.0000000013)
Delaware River	1.6x10^-8 (0.000000016)
San Francisco Bay	1.7x10^-6 (0.0000017)
State of Ohio Lake Erie Drainage Basin	2.6x10^-8 (0.000000026)
State of New Jersey	6.4x10^-5 (0.000064)

Regional efforts are largely based on adaptive learning until best practices are developed. A common thread through regional management practices is significant initial data collection done in collaboration with local facilities to identify sources, types and concentrations of PCBs in water. As localities collect data and identify inadvertent PCB origins, pigment manufacturers and packaging and/or paper recyclers may be held increasingly accountable for PCBs produced.

The National Primary Drinking Water Regulations set the maximum contaminant level for PCBs in drinking water to 0.0005 mg/L (0.5 ppb) (United States Environmental Protection Agency). In contrast, the Spokane Native American Tribe currently has a 1.3 pg/L (ppq) PCB limit for waterways, the strictest water quality standard in Washington (possibly the nation).[1] This low limit was set to prevent additional river and salmon contamination and ultimately to protect those whose lifestyles include regular fish consumption. Similarly, there are stringent limits for other

[1] http://www.spokanetribe.com/upload/FCKeditor/Final%20Revised%20Water%20Quality%20Standards.pdf

areas with high PCB concentrations such as the Delaware River, where no more than 16 pg/L (ppq) are permitted (Delaware River Basin Commission). Ironically, drinking water standards are less restrictive than some river discharge limits for PCBs. This reflects the challenge of reducing levels of persistent, bioaccumulative and toxic substances in the environment. Water with very low levels of PCBs may be deemed safe to drink, but ongoing discharge of PCBs continues to add to the environmental burden and fish contamination due to the nature of PCBs as a chemical class that is persistent, bioaccumulative, and toxic.

Current gas chromatography techniques can detect and differentiate between congeners and Aroclor PCBs at levels as low as 0.054 µg/L in water and 57 µg/kg for soil (Clu-In). This is far below the maximum 50 ppm limit. Businesses at risk of producing inadvertent PCBs could increase the frequency of their testing as a preventative measure. Where PCBs are found, businesses can use benchmark progress on reducing PCB loading into waterways. As even lower limits are required to reduce risk it becomes more challenging to find and/or develop more sensitive measurement techniques. With very low levels of measurement come challenges including issues related to background and blank contamination. Pragmatic tests and thresholds for third-party testing data are needed so that manufacturers can better inform procurement professionals about their products when they request PCB-free choices.

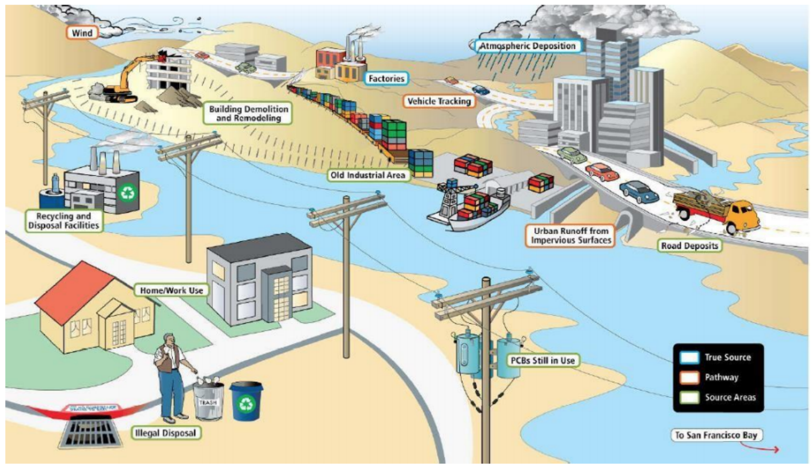

Figure 4: Example conceptual model of PCB sources and pathways (San Francisco Bay Regional Water Quality Control Board)

The case studies below demonstrate how different regions have attempted to address high levels of inadvertent PCBs in local waterways.

7.3. Area Case Studies

7.3.1. Delaware

In the Delaware River estuary, PCBs have been measured at 1,000 times above national water quality limits. In 2005, the Delaware River Basin Commission (DRBC) initiated a pollution minimization plan to identify both point and non-point sources of PCB loadings into the river. By collaborating with facilities that discharge, PCB loadings have dramatically reduced since 2005. This includes working with the top ten PCB dischargers, who collectively reduced their PCB loading by 76% (Delaware River Basin Commission).

7.3.2. San Francisco

The State of California took action on PCBs after exceptionally high contamination was detected in the San Francisco Bay (San Francisco Bay Regional Water Quality Control Board). Much of this contamination is from legacy PCBs. Stormwater runoff, however, is contaminated with inadvertent PCBs. San Francisco has identified several sources of inadvertent PCBs, including manufacturing processes. They also identified construction sites where old building materials leach secondary legacy PCBs into the environment. San Francisco has implemented a new total maximum daily PCB load limit: and bans the introduction of PCBs into waterways at any concentration. While this goal is especially ambitious, it begins like other regional programs; the city must first identify low-concentration sources of PCBs and determine which are from legacy sources and which are inadvertent. From there strategic next steps can be decided.

7.3.3. Spokane

The Washington State Department of Health became concerned about the impacts on the community of consuming PCB-contaminated fish. Spokane County invested in a water treatment plant that includes $20 million worth of state-of-the-art membrane technology designed to remove pollutants to very low levels. The wastewater entering the plant has PCB concentrations in the 10,000 to 20,000 parts per quadrillion (ppq) range, according to Spokane County data. Treated water leaves the plant with PCB concentrations of about 200 ppq (Kramer). Of course, not every locality is able to invest in such a facility.   Other initiatives in Spokane include the Spokane River Regional Toxics Task Force, created to address problems of toxic chemicals such as PCBs. The SRRTTF identified 45 control actions to control PCB loading in their Comprehensive Plan to Reduce PCBs in the Spokane River report (Spokane River Regional Toxics Task Force). See Appendix D.

The impacts of inadvertent PCB production are not limited to these regions in the U.S. There is growing concern about the production of inadvertent PCBs in China, where $2x10^4$ metric tons of organic yellow pigments are made each year, many of which are Diarylide Yellows (Shang, Li and Wang).

The Japanese Ministry Economy, Trade, and Industry (METI) surveyed pigment manufacturers between 2011 and 2012. A total of 588 pigment samples were analyzed and 359 samples contained PCBs at levels below 0.5ppm. There were 17 samples found to contain PCBs above the 50ppm limit. The Ministry ordered the manufacturers of these pigments to suspend all import, export, and production; as well as ordering the collection of all previously made batches. Japan subsequently adopted the international standard of 50 ppm for inadvertent PCBs based on values listed in the Stockholm Convention on persistent organic pollutants (Kawanishi 2016), ((METI) 2013). This example shows how global efforts can help identify sources of inadvertent PCBs and address concerns for human and environmental risk from continued pollution.

8. An Obstacle to a Circular Economy

A circular economy “aims to redefine growth, focusing on positive society-wide benefits. It entails gradually decoupling economic activity from the consumption of finite resources and designing waste out of the system. Underpinned by a transition to renewable energy sources, the circular model builds economic, natural, and social capital. It is based on three principles: (Ellen MaCarthur Foundation 2017):

- Design out waste and pollution
- Keep products and materials in use
- Regenerate natural systems"

The circular economy is also a key component of the UN Sustainable Development Goals (S. Stone 2017). When recycling leads to unwanted contamination in materials and water, then these principles cannot be fulfilled. The toxicity of PCBs can economically devalue products made from recycled materials and limit the potential for a circular economy.

Paper and paper-based packaging is an enormous global industry, with 407.5 million metric tons of paper products consumed globally each year (Statista). In the United States we consume more paper per capita than any other nation. Approximately 52 million short tons of U.S. paper product consumption are recovered for recycling. This means it is crucial that paper products are safe for humans and the environment, especially because of their relatively high rate of recirculation.

Both newsprint and recycled packaging materials contain inadvertent PCBs as a result of PCB-containing inks used on them or on the original (pre-recovery) product (A. Stone) (Profita).

Distinctive product packaging is viewed as an essential brand strategy to market and sell to consumers. The broad spectrum of pigments used for branding poses a challenge when packages enter recycling streams. Before new products can be made from recycled packaging the material must be processed.

Operations at Inland Empire Paper (IEP), a paper recycler in Millwood, Washington, are directly impacted by PCB contamination in recyclable material (NGC interview with Doug Krapas, Environmental Manager at IEP). Inadvertent PCBs in the recycler's effluent correlated with PCBs in pigments used on the paper products they recycle, such as newspapers, magazines, mailing materials and packaging. IEP has taken costly voluntary steps to be an exemplary environmental steward - eliminating chlorine from their papermaking processes, reducing their overall water use, and purifying their wastewater. Yet, the facility still exceeds PCB discharge limits in their region due to inadvertent PCBs that originate from the recycled feedstock and the water quality standards that are currently unachievable, even with state of the art technology. IEP may be forced to eliminate recycling at its facility to ultimately comply with the PCB water quality standards. While eliminating recycling would allow IEP to meet water quality standards for the Spokane River, opportunities to make and sell recycled paper would be lost. And the PCB problem would not be solved. PCBs would simply be moved to different treatment processes and would likely reach the environment through other avenues such as landfill leachate. See Figure 5, the IEP PCB Fact Sheet.

Inland Empire Paper Company
PCB FACT SHEET

- IEP was a PCB free mill prior to 1991 as confirmed by EPA
- It was only after IEP began to recycle in 1991 that PCBs were discovered in its effluent
- These PCBs have been traced to the inks used in the newsprint etc that IEP recycles
- Federal regulations through the Toxic Substances Control Act (TSCA) allow consumer products to contain inadvertent PCBs with concentrations up to 50 parts per million (ppm)
- Inks and pigments used in the publishing of newspapers and magazines contain trace amounts of PCBs as a byproduct of their manufacturing processes
- Many of these same pigments are used in other products such as paints, caulking, and insecticides
- The Federal allowance (50 ppm) is 20,000,000 times higher than the concentration of PCBs in IEP's effluent
- PCBs make up approximately 0.000000000003 percent of IEP's discharge annually, and would fill only about a third of a shot glass if collected in one place
- Federal water quality standards regulate PCBs to 0.000000064 ppm, a full 781,250,000 times more stringent than the 50 ppm allowance
- There are no current technologies available to remove PCBs down to the EPA's water quality standards
- Elimination of paper recycling may be the only viable option for IEP to meet forthcoming stringent water quality standards
- Elimination of paper recycling in the U.S. does not solve the problem, as the PCBs will just be moved to landfills and be dispersed to the environment from the stacks of incinerators
- IEP is part of the solution, as our processes result in significant removal of PCBs from the recycled paper – roughly 90% of PCBs that come into IEP's system are taken out
- There is a more obvious and logical solution that eliminates the creation of new PCBs into the environment: enact regulatory change
- Incentivize manufacturers to find safe alternative chemical processes by changing Federal regulations to ban chemical processes which result in inadvertent PCBs
- Experts – including members of the Washington State Department of Ecology – state that there are viable alternative manufacturing processes which produce inks without creating PCBs
- IEP, in collaboration with the Riverkeepers and the Lands Council, submitted a letter to EPA requesting a change to the TSCA regulations
- IEP is also working with legislators, labor representatives, Native American tribes, government agencies, and others to work towards changing this regulation
- Eliminating the source of PCBs entering the environment provides a common-sense alternative against the elimination of paper recycling

Figure 5: Inland Empire Paper Company PCB Fact Sheet

9. Strategic Solutions and Next Steps

Regulatory approaches play a critical role in reducing inadvertent PCB pollution. However, proposing legal and regulatory actions are beyond the scope of this paper. Rather, we propose a set of voluntary and collaborative approaches to complement regulatory action and to expedite needed solutions. Successful voluntary initiatives can complement regulations, inform regulations and in some cases reduce the need for regulations. Voluntary initiatives could help identify best practices such as best available technologies and feasible lower limits for inadvertent PCBs in pigments. When markets shift voluntarily, regulations can then help to raise the bar and level the playing field for all players.

Northwest Green Chemistry proposes a set of activities that are inter-related and that fall under the four categories. They are discussed in the next section.

- Targeted cross-sectoral and multi stakeholder collaborations
- Green chemistry and engineering research
- Alternatives assessment
- Procurement to drive substitution of safer alternatives

9.1. Targeted Collaborations

Cross-sectoral and multi-stakeholder collaborations can be effective approaches to shifting industry practices and creating buy-in from participants. Benefits from targeted collaborations include shared education, awareness and motivation and access to information and insights that can only come through conversations with people at different points in the supply chain. Participants can provide advice and guidance and work together to generate practical solutions. Active engagement by participants typically leads to greater commitment to solutions that are developed. Targeted collaborations can be designed to address the entire supply chain and to include stakeholders who represent human health and environmental interests such as representatives from governments and environmental or health advocacy NGOs.

There are various models of targeted collaborations. For some industry sectors, company representatives have formed roundtables where pre-competitive, sustainable innovations are discussed. For example, the American Chemical Society's Green Chemistry Institute facilitates several industrial roundtables: Pharmaceutical, Formulator, Chemical Manufacturer, Biochemical Technology and Hydraulic Fracturing (American Chemical Society). These collaborations result in educational resources, tools for implementing greener alternatives, grants to support research into sustainable, safer products and processes and industry adoption of these safer alternative products and processes.

Another example is the Green America Center for Sustainability Solutions that convenes brands, NGOs, government agencies and scientists and engineers (Green America Center for Sustainability Solutions). These stakeholders collaborate (bound to a non-disclosure agreement) to understand supply chain hazards, identify safer processes and select alternatives substances. Other industry collaborations such as Zero Discharge of Hazardous Chemicals (ZDHC), a coalition of signatory textile, leather and footwear brands, work to conform to a standardized list of restricted substances for companies in the sector (Zero Discharge of Hazardous Chemicals (ZDHC)). Any of these models could inform a targeted industry collaboration to address inadvertent PCBs in packaging or newsprint.

Business-focused chemical management initiatives are, in fact, already common in the colorants sector but they are not always multi-sectoral or inclusive of diverse stakeholders. Several industry associations have created guidelines for their member companies around best practices for inadvertent PCBs and would be valuable partners for creating more progressive internal industry standards on inadvertent PCB production. These organizations include:

- The Ecological and Toxicological Association of Dyes and Organic Pigments Manufacturers (ETAD). ETAD has produced a series of guidelines for pigments (Ecological and Toxicological Association of Dyes and Organic Pigments Manufacturers (ETAD) 2018). ETAD works to harmonize regulations, making compliance easier for both member companies and regulatory bodies. They also conduct research and testing for pigment hazards. Note that some of the ETAD PCB activities appear to fall under the scope of work of the Color Pigments Manufacturers association through collaboration.
- Color Pigments Manufacturers Association (CPMA). CPMA provides similar benefits to members as ETAD, though some companies are members of both organizations. CPMA is heavily focused on public policy related to pigment manufacturers in the U.S. (Color Pigments Manufacturers Association 2018)
- American Coatings Association (ACA). The ACA participated in discussions and assisted in identifying non-Diarylide Yellow- containing road paints to meet updated Washington State Department of Transportation (WSDOT) procurement requirements. The ACA also provided comments describing several traffic marking alternatives and believes that all road paint products need to be evaluated for application and local requirements including performance and safety attributes such as durability, color fastness, and optical properties.

Greater multi-stakeholder and cross-sectoral collaboration is necessary to increase awareness around and drive demand for safer, lower PCB-containing products. NGC has begun identifying and engaging some key stakeholders in initial scoping discussions. A list is found in Appendices C and F. Some highlights are discussed below.

Northwest Green Chemistry has engaged in discussions with the NGO Green Blue Institute (GreenBlue) that hosts the Sustainable Packaging Coalition (SPC). The SPC is a member-based organization of approximately 240 national and global organizations across the packaging supply chain committed to taking meaningful actions toward packaging sustainability. GreenBlue leaders have expressed willingness for NGC and potentially other members of SRRTTF to present to GreenBlue and SPC leadership on inadvertent PCBs. They want to better understand the issue and to consider potential next steps. GreenBlue is willing to help guide the interactions to help SPC members understand that the issue of inadvertent PCBs is a global issue and that it is important enough for them to commit member time to consider. The SPC hosts annual meetings in the US and internationally. If successfully adopted, the issue would be brought to their members via webinars and possibly via live presentations at annual meetings. They are committed to the idea of a circular economy and to the extent that inadvertent PCBs hinder a circular economy, this project could be a model for how to positively intervene to reduce the systemic challenges of toxics in packaging and paper material streams.

Other potential activities with GreenBlue and SPC leadership that were discussed include 1) assistance with research of available safer alternatives, 2) creation of educational and training materials as part of the SPC training curriculum and 3) creation of a packaging design guide for members to address the challenge of inadvertent PCBs. The SRRTTF could benefit from this collaboration by gaining access to individuals from brands, packaging manufacturers and others in the supply chain who can provide insight into how pigments are selected for use in paper packaging. Engagement should also provide insight into how aware these companies are of the issues of inadvertent PCBs and if there are best practices already being used.

NGC has been in communication with individuals at Clariant, a Swiss manufacturer of pigments, paints, inks and coatings amongst other products, including their leading global color scientist, Dr. Romesh Kumar. Dr. Kumar has agreed to assist NGC and SRRTTF with answering technical questions about inadvertent PCBs and feasible alternatives. Discussions with another pigment and paint manufacturer have already revealed that the company sees inadvertent PCBs as a nascent issue and they are looking for guidance on what specifications, i.e. allowable levels of inadvertent PCBs, they should set for their suppliers. NGC views further interaction with GreenBlue, SPC, and the other stakeholders identified in Appendix F as a critical first step in gathering information and identifying creative solutions to expedite solutions to inadvertent PCBs. NGC has limited connections in the newsprint industry. However, Doug Krapas of the SRRTTF has generously agreed to provide suggested contacts as needed.

9.2. Green Chemistry and Engineering Research

Green chemistry and engineering are approaches to science and engineering that drive innovation by creating products and processes that reduce or eliminate the use and generation of hazardous substance. Hazard in green chemistry and engineering is considered broadly to include, not only toxicity, but also toxic by-products, emissions, energy consumption, and risk from processes that generate heat and other physical hazards. Green chemistry and engineering solutions typically take time to research, develop and come to market. But they are an investment in innovation.

Northwest Green Chemistry has engaged with the director of the University of California's Berkeley Center for Green Chemistry (BCGC) and the Greener Solutions course. They have expressed interest in having graduate students in the Greener Solutions program explore both chemistry and engineering solutions to the challenges of inadvertent PCBs. The Greener Solutions program matches graduate students and advanced undergraduates with organizations to take on interdisciplinary projects that leverage student knowledge to address real-world problems. While most of the solutions the students identify will take more that one semester to fully realize in the marketplace, the student teams produce an opportunity map for manufacturers as a deliverable. The students have completed projects such as "Establishing a proactive approach to address emerging contaminants in the informal e-waste sector with HP (2012) and "Identifying a range of safer alternatives to address the use of free isocyanates in spray foam insulation (2014).

To engage with the Greener Solutions course, a project would need to be approved by an internal team and a scope of work would need to be developed that offers an appropriate challenge to the students. There is interest in exploring alternative green chemistry approaches such as alternative synthetic pathways for making pigments that do not generate inadvertent PCBs. These processes could include new synthetic pathways or biomimetic approaches. There is also interest in exploring innovative green engineering approaches that could improve existing processes and existing pigments by reducing the generation of inadvertent PCBs. NGC recommends that the SRRTTF move forward with discussions to develop a Greener Solutions project that could benefit the goals of the SRRTTF.

9.3. Alternatives Assessment

Alternatives assessment (AA) is a process for identifying and comparing potential chemical and non-chemical alternatives that can be used as substitutes to replace chemicals or technologies of concern. Alternatives assessment is designed to reduce the likelihood of restricting or banning a chemical or product and replacing it with a ‘regrettable substitution’. The AA process provide a robust framework for comparing the chemical or technology of concern to alternatives by considering, at a minimum, hazard, exposure, performance, and cost and availability. Interstate Chemicals Clearinghouse Alternatives Assessment Guide also includes optional modules for comparing products based life cycle assessment, social impact assessment and materials management. In the case of inadvertent PCBs, alternatives could include existing or emerging pigments that are 1) manufactured using chemicals that do not produce inadvertent PCBs, or 2) manufactured with process steps that keep inadvertent PCBs to ultra low levels. Alternatives could also include different ways of providing color to packaging materials or even alternative forms of packaging.

Alternatives assessment is designed to answer the following questions

1. Do commercially available alternatives exist and/or are there alternatives emerging?
2. Are they safer?
3. Do they meet performance requirements?
4. Are they affordable/economical?
5. Can they be purchased in sufficient quantities?
6. Will they support circularity?

Alternatives assessment is a flexible process that can be a streamlined or extremely comprehensive. First of all, it is necessary to identify the chemical of concern and how it is used. In the case of inadvertent PCBs, it will likely be necessary to narrow the scope of pigments for which alternatives are evaluated, and the product types in which they are used. The next step is to determine if the chemical or pigment of concern can simply be avoided or eliminated. If not, then it is necessary to identify and engage relevant stakeholders and to establish a decision framework that will help identify the requirements for what would be considered a viable alternative. From there, the assessment modules (hazard, exposure, performance, etc.) outlined in the AA guidance are selected. The next step is to search broadly for alternatives. And then finally, the alternatives are evaluated and compared. Throughout the AA process, diverse stakeholder engagement is needed to ensure balanced perspectives and access to the best available information.

Finding viable chemical or product choices is valuable to industry and consumers. It can reduce risks to human health and the environment while driving both incremental product improvements and disruptive innovation. NGC has conducted and/or is currently conducting alternatives assessment projects, at different levels of comprehensiveness, to identify safer, more sustainable products or materials that are suitable replacements for copper-based recreational boat paints, for certain phthalates, for bridge coatings and for food packaging materials containing per- or poly-fluorinated additives. Each AA has involved a different approach and scope. But they are all best achieved with active stakeholder engagement.

At this time, the availability of viable alternatives to pigments containing inadvertent PCBs used for paper packaging and newsprint is unknown. Understanding the performance, cost and availability requirements of those who purchase pigments is a key step. Currently, products containing up to 50 ppm PCBs are considered within regulatory limits (National Pollution Prevention Roundtable). Our initial web-based searches did not identify inks and dyes for packaging materials that are verifiably 'PCB-free'. With ongoing demand for packaging, there is growing need for packaging inks that are safe and sustainable (Smyth and Smithers).

There are non-Diarylide Yellow pigments on the market, but it is not known if they are comparable or preferable for packaging and newsprint. For example Dominion Colour Corporation produces DCC Yellow 7391 (Dominion Colour Corporation). It would be valuable to evaluate its performance properties, cost and availability and inherent potential for hazard and exposure across the product life cycle to determine if it is indeed a preferred alternative.

As an example of a potentially disruptive chemical innovation Lumen BioScience is creating a 'natural' pigment made from algae (Lumen Bioscience). While it is not yet applicable for inks and dyes, it is a step toward innovative pigment manufacturing solutions. Lumen Bioscience advanced their spirulina pigment research only after a $13 million investment, demonstrating the need for champions and investors to bring disruptive innovations to fruition.

Products that are potential alternatives to PCB-containing products must also be evaluated for environmental and human health hazards. A product that avoids one hazard only to introduce another is probably not a more sustainable product choice. The whole life cycle of a potential alternative must also be considered. For more information on evaluating sustainability throughout the product design process, tools such as the Product Innovation and Social Mapping framework created by Northwest Green Chemistry can support a holistic approach to product design. Likewise, the Sustainable Packaging Coalition has developed principles and tools to support sustainable packaging design and assessment. But these SPC tools do not currently address impurity issues such as those associated with inadvertent PCBs.

NGC recommends working with SRRTTF to scope and launch an alternatives assessment to identify alternatives for specific pigments for specific applications. Work could be done sequentially or concurrently to identify alternatives for pigments used in packaging paper or newsprint. The availability of alternative pigments, processes or products is essential to the success of the fourth strategy, Implementing procurement policies to drive substitution.

9.4. Implementing Procurement Policies to Drive Substitution

Alternatives assessment and substitution are related but separate activities. The identification of viable, inherently safer alternatives is essential for procurement and substitution. However, the existence of inherently safer alternatives does not guarantee that they will be adopted in the marketplace and that they will be used as substitutes for the chemicals of concern.

Procurement policies can also drive the purchase of inherently safer alternatives. Public procurement policies can also foster innovation, especially for emerging sustainable technologies (Baron). The promise of a market for innovative products can be a big incentive for their development as long as the promise is fulfilled.

Environmentally-focused policies can be significant market drivers; the public procurement expenditure in OECD countries is, on average, 13% of their GDP. Agencies or organizations that specify no or ultra-low PCB pigments in their procurement requirements for packaging products could drive substitution and encourage design of new products.

The State of Washington and the City of Spokane have taken steps to address inadvertent PCBs through the power of procurement specifications. In addition to the promising development of procurement language around PCB-containing products, Washington developed a PCB risk calculator. This tool is designed to help purchasers identify products that might contain PCBs and ultimately to help them make more informed selections. The calculator is free and publicly accessible on a dedicated website (Washington State Department of Enterprise Services). In addition to implementing procurement requirements with environmental considerations, the State of Washington provides regular employee trainings on updated specifications. Developing model procurement language, test methods and specifications and/or a labeling scheme for identifying pigments and materials that contain no or ultralow levels of PCBs could help procurement professionals. Greater adoption of similar policies requires incentivizing procurement professionals. Identifying and nurturing relationships with sustainability champions in purchasing departments is also essential. The City of San Francisco, for example, has a robust sustainable procurement program. It is often up to individuals in procurement departments to initiate discussions on and establish environmentally preferable purchasing policies. These programs allow competitive 'greener' products to be purchased even if they are priced slightly higher than less sustainable products. We recommend making training and outreach opportunities on inadvertent PCBs available to procurement departments.

Procurement policies do not need to come only from government. Voluntary procurement specifications developed by industry can help to shift the market. Both Apple and Hewlett Packard have implemented procurement policies limiting PCBs in all of their products to 0.1ppm. This is 500 times more rigorous than the US EPA legal limit. The purchasing power of large corporations and member groups such as the Sustainable Packaging Coalition is enormous. If SPC members agreed to set voluntarily lower limits, similar to Apple and HP, for inadvertent PCBs as a prerequisite for products purchased from their suppliers, there could potentially be a shift in the market place.

A current example with road paint can illustrate how some of the elements outlined in the four strategies described above can work together. Yellow road paints are often specified with diarylide yellow pigments that are known to contain inadvertent PCBs. In discussion with the American Coatings Association (ACA), it was determined that non-Diarylide Yellow formulations for yellow road paint are available and that they are expected to contain reduced inadvertent PCBs. Importantly, the Washington State Department of Transportation (WSDOT) already has approved the use of non-Diarylide Yellow formulations for yellow road paint as part of their color box for road paints based on other specifications such as performance. As a result, WSDOT was able to update their procurement specifications to exclude the purchase of Diarylide Yellow road paint (Spokane River Regional Toxics Task Force). The procurement specification language was subsequently shared with the City of San Francisco procurement department where individuals are considering how best to implement it. While it is recommended that the non-Diarylide Yellow paints undergo evaluation and monitoring for 1) performance (i.e. durability and technical characteristics) relevant to its use in other parts of the country and 2) hazard and exposure to ensure that it does indeed contain low or ultra low levels of inadvertent PCBs or other toxic chemicals, this case study is an example of how engaging key individuals in the supply chain can lead to systemic solutions. While this case study is still in its early stages, it illustrates the effectiveness of using targeted collaborations to identify viable alternatives developed with greener chemistry or engineering processes, that can be specified for use using procurement policies. It is unknown if alternatives are available for thermoplastic road paints or other coatings in general (ACA).

10. Conclusion

Inadvertent PCBs are a continuing concern because they add to the overall loading and hinder efforts to reduce total PCB levels in the environment. Lower levels of PCBs are necessary for many reasons, including protection of aquatic life and human populations that regularly consume fish. PCBs also present a growing concern and a threat to the ability of regions and nations to realize the United Nations Sustainable Development Goals because their presence in pigments contaminates recycling streams and diminishes the potential for economically sustainable recycling of materials in a circular economy.

In this report we provide background information on the issue of inadvertent PCBs and propose a set of four strategies to help shift the marketplace toward the use of pigments that contain no or ultra-low levels of PCBS. These strategies include:

- Targeted cross-sectoral and multi stakeholder collaborations
- Green chemistry and engineering research
- Alternatives assessment
- Procurement to drive substitution of safer alternatives

A number of key stakeholders from different sectors have already been identified and have expressed their willingness to engage in this project. The challenge of inadvertent PCBs is a complex challenge that crosses the global supply chain. Therefore, participants from across the supply chain and stakeholders from governments and NGOs need to be engaged to understand the constraints and the opportunities, and to develop creative solutions that will lead to systemic solutions. It is hoped that the proposed strategies presented in this white paper will help the SRRTTF refine the next steps needed to most effectively achieve their mission and goals.

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12. Appendix A: Manufacturing Processes

Figure B1 is the U.S. EPA's list of 70 manufacturing processes have high potential of generating inadvertent PCBs (Washington State Department of Ecology).

Table A1: US EPA list of manufacturing processes likely to generate inadvertent PCBs

The following was transcribed from EPA rulemaking records from "Polychlorinated Biphenyls (PCBs); Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions: Exclusions, Exemptions and Use Authorizations" Doc No. OPTS-62032. This was transcribed for Panero *et al.* (2005).

Chlorinated Compounds Produced Using Direct Chlorination	Chlorinated Compounds Produced Using Chlorinated Feedstocks	Non-chlorinated Compounds Produced Using Chlorinated Feedstocks	IPPPE U No.
Petroleum Feedstock: BENZENE			
Chlorinated benzenes	Chloronitrobenzenes	Phenol	8
Chlorinated phenols	Dichloronitrobenzenes	Aniline	9
Hexachlorocyclohexane	Dichloroanilines	o-Phenylenediamine	28
Chloranilines	Chlorinated methyl phenols	o-,p-Nitroanilines	29
Trichloroanilines	Chlorophenyl phenylethers	Diphenylamine	34
	Chlorinated benzidines	Acetanilide	17
Petroleum Feedstock: ETHYLENE			
Mono, di-chloroacetic acid	Ethyl chloroacetate	Glycine	108
Sodium chloroacetate	Vinyl chloride	Cyanoacetic acid	111
Chlorinated ethanes	Vinylidene chloride	Sodium, carboxymethyl cellulose	112
Chlorinated ethylenes	Bis (2-chloroethyl) ether	Ethyl cellulose	118
Ethylene chlorohydrin	Chlorinated acetophenones	Ethylene diamine	134
Chlorinated, fluorinated ethanes	Choline chloride	Aminoethylethanolamine	135
Chlorinated, brominated ethylenes	Hexachlorobutadiene	Mono-, di-, and triethylene glycol ethers	150
Chlorinated, fluorinated ethylenes		Tetramethylethylene diamine	(3341)
Chlorinated acetaldehyde			
Chlorinated acetyl chloride			
Hexachlorobenzene			
Petroleum Feedstock: METHANE			
Chlorinated methanes	Chlorinated, fluorinated methanes	Carbon tetrabromide	162
Phosgene	Chlorinated, brominated methanes	Carbon tetrafluoride	(812)
Tetrachloroethane	Bis (chloromethyl) ether		
Chlorodifluoroethane (?)	Cyanuric chloride		
Perchloromethyl mercaptan (?)	Trichloroethylene		
Cyanogen chloride			

Chlorinated Compounds Produced Using Direct Chlorination	Chlorinated Compounds Produced Using Chlorinated Feedstocks	Non-chlorinated Compounds Produced Using Chlorinated Feedstocks	IPPPE U No.
Petroleum Feedstock: NAPHTHALENE			
Chloronaphthalenes			
Tetrachlorophthalic anhydride			
Petroleum Feedstock: PARAFFINS			
n-Propyl chloride		n-Propylamine	231
Carbon tetrachloride		Butyronitrile	232
Perchloroethylene		Amyl amines	243
Hexachloroethane		Amyl alcohols	244
Amyl chlorides		Amyl Mercaptans	245
Chloroprene		Benzophenone	249
Hexachlorocyclopentadiene		Linear alkylbenzenes	(2417)
Methallyl Chloride			
Petroleum Feedstock: PROPYLENE			
Dichlorohydrin	Epichlorohydrin	Isopropylphenols	272
Chloranil	Bis (2-chloroisopropyl) ether	Propylene oxide	280
Propylene chlorohydrin		Anisols	302
Chlorinated propanes		Allyl alcohol	317
Chlorinated propylenes		Glycerol	318/319
		Propyl amines	(1446)
Petroleum Feedstock: TOLUENE			
Benzyl chloride	Benzoyl chloride	Benzyl alcohol	334
Benzyl dichloride		Benzyl amine	335
Benzyl trichloride		Benzamide	337
Chlorotoluenes		Toluenesulfonamide	358
Chlorobenzaldehyde		Benzoyl peroxide	(495)
Chlorobenzoic acids & esters			
Chlorobenzoyl chlorides			
Toluenesulfonyl chloride			
Chlorobenzotrichlorides			

*The IPPEU No. refers to the process description in the 1977 EPA summary (EPA, 1977). Those numbers bracketed by parentheses refer to the OCPDB numbers in the 1980 EPA summary (EPA, 1980)

Table A2: End products of manufacturing processes in which PCBs are incidentally generated (Moll)

End-Products of Manufacturing Processes in Which PCBs are Incidentally Generated
<u>Dyes</u> diarylide yellow dyes/pigments made with halogenated solvents halogenated dyes/pigments halogenated solvents, unspecified phthalocyanine <u>Organic Chemicals</u> alkyl benzene alkyl chlorophosphine derivatives benzene chlorination (process) benzene phosphorus dichloride biphenyl derivatives carbon tetrachloride chlorinated aryl phosphines chlorinated naphthalene derivatives chlorobutane derivatives chlorosilane derivatives chloroxylene derivatives diphenyl oxide and derivatives ethyl benzene halogenated solvents, unspecified monochlorinated butylated diphenyl monochlorinated terphenyls organo phosphorus trichloride derivative pentachloronitrobenzene phenyl chlorosilanes phenyl siloxanes polychlorinated terphenyls tetrachloroethylene aluminum chloride

13. Appendix B: Exposure to PCBs

An in-depth discussion of routes of exposure to PCBs is outside the scope of the main report. However, the following supplementary details may be of interest.

Air/Atmosphere

Lighter-weight PCB congeners are widely distributed around the world through the air. They accumulate in remote regions, far from urban development. About 90% of the PCBs entering Lake Superior, for instance, come from the atmosphere (Colborn, von Saal and Soto). This is an important route of exposure to consider when discussing the ubiquity of PCBs. Not all chemicals are mobile in air, which makes PCBs especially challenging to control once dispersed. Therefore, controlling their manufacture, inadvertent or intentional - can aid in decreasing global environmental PCB contamination.

Water

According to the US EPA, PCBs enter waterways primarily through runoff from landfills and building materials and discharge of waste chemicals (A. Stone). Fish are particularly vulnerable to this class of chemicals, which contributed to the implementation of nationwide water concentration limits for PCBs (Carey, Lanksbury and Niewolny). Marine species - like pacific salmon and killer whales (which eat pacific salmon) - are especially prone to the consequences of PCB pollution. Salmon readily accumulate the lipid (fat) loving PCBs due to their high fat content; while killer whales accumulate relatively high levels of PCBs through their diets since they are at the top of the food chain. Research presented in a 2016 National Oceanic and Atmospheric Administration report revealed that pacific salmon have average PCB levels between 7.7 and 14.4ng/g ww (Mongillo, Ylitalo and Rhodes). This results in higher occurrences of developmental impacts and overall mortality for these species (Lerner, Björnsson and McCormick) (Desforges, Sonne and Levin). Additionally, aquatic species have the potential to transport PCBs from highly contaminated to less contaminated areas (McGill, Gerig and Chaloner).

Drinking water can also be a source of exposure, suggesting why the Clean Water Act has such a low concentration limit compared to TSCA.

Food

In Japan, the primary trade name for PCBs was Kanechlor 400. Kanechlor resulted in widespread PCB poisoning in 1968.The number of people reportedly harmed from the contamination in Kanemi Rice Oil varies, with some estimates as high as 15,000 (Umeda). The impacts of this exposure were still detectable in the body tissues of those affected even nine years after the incident (Yoshihara, Kawano and Yoshimura).

Although legacy PCBs are no longer manufactured in the U.S., PCBs may still enter the environment and create a risk of exposure through:

- Illegal importation of products containing PCBs
- Illegal disposal of legacy PCB-containing products
- Inadvertent manufacture of PCBs
- Insufficient worker training on hazards and PCB contamination risks leading to:
    - Improper use of or insufficient personal protective equipment
    - Improper handling techniques
    - Improper disposal of PCB-contaminated equipment

(United States Evironmental Protection Agency)

14. Appendix C: Ink Manufacturers

(National Association of Printing Ink Manufacturers)

Printing Sector	Company Name	Location
Flexo Gravure	Actega North America, Inc	Lincolnton, NC
Flexo Heatset Letter Press Offset Publication	Alden & Ott Printing Inks LP	Arlington Heights, IL
Flexo Heatset Letter Press Offset	Braden Sutphin Ink Co.	Cleveland, OH
Heatset Offset	Central Ink Corp.	West Chicago, IL
Flexo Offset	Chromatic Technologies, Inc.	Colorado Springs, CO
Flexo Gravure Heatset Letter Press Offset	Colorcon, No-Tox Products	Chalfont, PA
Flexo	Graphix Essentials	St. Louis, MO
Flexo	Grand Rapids Printing Ink	Grand Rapids, MI
Flexo Gravure Heatset Letter Press Offset Publication	Flint Group	Plymouth, MI
Letter Press Offset	Gans Ink and Supply Co., Inc.	Los Angeles, CA
Gravure	Gotham Ink & Color	Stoney Point, NY
Offset	Grand Rapids Printing Ink	Grand Rapids, MI
Flexo Gravure	Hi-Tech Color, Inc.	Odenton, MD

Flexo Heatset Letter Press Offset Publication	hubergroup North America	Kankakee, IL
Letter Press	Hongtu Industry	CongQing City, China
Heatset Offset	Ink Systems, Inc.	Commerce, CA
Flexo Gravure Heatset Letter Press Offset Publication	INX International Ink Co.	Schaumburg, IL
Flexo	Joules Angstrom U.V. Printing Inks Corp.	Pataskala, OH
Flexo Heatset Letter Press Offset Publication	R.A.Kerley Ink Engineers, Inc.	Broadview, IL
Gravure	LioChem	Conyers, GA
Flexo Gravure	Magnum Inks & Coating	Middletown, OH
Flexo Heatset Letter Press Offset Publication	Mallard Ink Co., Inc.	St. Anthony, MN
Flexo Offset	Megami Ink Mfg. Co., Ltd - U.S. Branch	Schaumburg, IL
Flexo	Optihue® Inks	Kenton, OH
Flexo Letter Press Offset	Press Color, Ink..	Glendale, WI
Flexo Gravure	Siegwerk USA Co.	Des Moines, IA

Letter Press Offset	Spinks Ink Company	Tampa, FL
Flexo Gravure Heatset Letter Press Offset Publication	Sun Chemical Corporation North American Inks	Northlake, IL
Flexo Gravure Heatset Letter Press Offset	Superior Printing Ink Co., Inc.	Teterboro, NJ
Flexo Heatset Letter Press Offset	Toyo Ink America, LLC.	Wood Dale, IL
Letter Press Offset	US Ink	Carlstadt, NJ
Flexo Gravure	Wikoff Color Corporation	Fort Mill, SC

15. Appendix D: PCB Control Actions

Control actions identified as potentially applicable for reducing PCB loads to the Spokane River and Lake Spokane (Spokane River Regional Toxics Task Force)

Group	Sub-Group	Control Action
Stormwater Treatment	**Pipe Entrance and Pipe System**	Infiltration control actions
		Retention and reuse control actions
		Bioretention control actions
		Isolation of contaminated source areas from the MS4
		Filters
		Screens
		Wet vault
		Hydrodynamic separator
	End of Pipe	Constructed wetlands
		Sedimentation basin
		Discharge to ground/dry well
		Diversion to treatment plant
		Fungi (mycoremedation) or biochar incorporated into stormwater treatment
Wastewater Treatment		Development of a Toxics Management Action Plan
		Implementation of a source tracking program
		Chemical fingerprinting or pattern analysis
		Remediation and/or mitigation of individual sources
		Elimination of PCB-containing equipment
		Public outreach and communications
		Review of procurement ordinances
		Pretreatment regulations
Site Remediation		Identification of contaminated sites
		Clean up of contaminated sites

Group	Sub-Group	Control Action
Institutional	Governmental Practices (Regulatory Actions and/or Incentivized Voluntary Programs)	Waste disposal assistance
		Low Impact Development (LID) Ordinance
		Leaf removal
		Street sweeping
		Catch basin/pipe cleanout
		Purchasing standards
		Survey of local electrical equipment
		Regulation of waste disposal
		Removal of carp from Lake Spokane
		Building demolition and renovation control actions
		PCB product labeling law
		Leak prevention/detection in electrical equipment
		Accelerated sewer construction
		PCB identification during inspections
		Regulatory rulemaking
		Compliance with PCB regulations
		Support of green chemistry alternatives
	Educational	Survey schools/public buildings
		Education/outreach about PCB sources
		Education on septic systems disposal
		Education on filtering post-consumer paper
		PCB product testing

16. Appendix E: PCB 11 Concentrations in Printed Materials

Table E1: PCB 11 Concentrations in printed materials worldwide (Washington State Department of Ecology)

Printed Material (Country)	PCB 11 concentration (ng/g or ppb)
Black and white printed newspaper (Georgia)	1.6
Black and white printed newspaper (Moldova)	9.7
Black and white printed newspaper (China)	15
Color newspaper (Georgia)	6.5
Color newspaper (Moldova)	16
Food packaging box (Czech Republic)	6.8
Food packaging box (Ukraine)	5.0

Table E2: PCB 11 concentrations in consumer goods (collected in 2008) (L. A. Rodenburg, J. Guo and S. Du)

material	PCB 11 concentration ($ng\ g^{-1} = ppb$)
black and white printed newspaper (A)	0.85
black and white printed newspaper (B)	0.45
brown (unprinted) cardboard (A)	3.0
brown (unprinted) cardboard (B)	2.8
color glossy magazine (A)	4.5
color glossy magazine (B)	3.3
color newspaper (A)	6.6
color newspaper (B)	5.7
plain white copy paper (A)	ND
plain white copy paper (B)	ND
manila envelope (A)	ND
manila envelope (B)	0.11
yellow cereal box (A)	3.0
yellow cereal box (B)	2.9
yellow plastic bag (A)	3.4
yellow plastic bag (B)	38
yellow sticky note (A)	0.82
yellow sticky note (B)	0.11
lab blank (GFF) (A)	ND
lab blank (GFF) (B)	ND

[a] ND = not detected.

17. Appendix F: Initial Recommended Collaborators

The next steps for reducing inadvertent PCB pollution involve partnering with a wide variety of stakeholders. Although the general approach to solutions is the same for both packaging and newsprint, some of the partners will differ.

Using US EPA reporting data from the 1990's to 2011 we identified several companies that produce pigments correlated to the production of inadvertent PCBs (Washington State Department of Ecology). Collaboration with these businesses, enumerated in the table below, will be an essential part of mitigating inadvertent PCB production and identifying safer alternatives. Additional leading ink manufacturers that could be involved, but that were not mentioned in the WA DOE report, are listed in Appendix D.

Partner	**Stakeholder Type**	**Packaging/Newsprint**
Spokane River Regional Toxics Task Force	NGO	Working group committed to collaborative solutions
GreenBlue	NGO	Packaging
Sustainable Packaging Coalition	NGO-based Association	Packaging
Color Pigment Manufacturers Association (CPMA)	Industry Association	Packaging/Newsprint
American Coatings Association (ACA)	Industry Association	Packaging/Newsprint
Washington Department of Ecology (WA DOE)	Regulatory	Packaging/Newsprint
City of San Francisco Procurement	Procurement	Packaging/Newsprint
Interstate Chemicals Clearinghouse	Policy/Regulatory/Procureme nt	Packaging/Newsprint
Environmental Protection Agency (EPA) Region 10	Regulatory	Packaging/Newsprint
University of California Berkeley Greener Solutions;	University	Alternative processes for

Berkeley Center for Green Chemistry		manufacturing pigments
Companies: ● BASF ● Cappelle ● CDR Pigments and Dispersions ● Clariant ● Ciba-Geigy (Pigments Division, as well as other divisions) ● DIC Trading ● Dominion Colour ● Englehard ● Fabricolor ● Hewlett Packard ● Lansco Colors ● Magruder Color Co ● Mil International ● PCL Group ● Sun Chemical Corporation ● Uhlich Color Co ● UMC (United Mineral and Chem) ● Zeneca	Manufacturers	Packaging/Newsprint
Inland Empire Paper	Recycler	Newsprint