Children's Health and Chemical Exposure:

Beginning Risks

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"If our American way of life fails the child, it fails us all."

This quote, attributed to American author and Nobel Laureate Pearl S. Buck, is often associated with comments about family values, education, and socioeconomic conditions of children in the US. But it also applies to the use of industrial chemicals, in so much as the chemicals found in everyday products and building materials can have an impact on children's health and development. In fact, results of recent research point to a trend that babies are sufficiently exposed in utero that at birth they have detectable body burdens of these chemicals, as measured from cord blood samples. This paper reviews children's health and the concerns of chemical exposure. It supports the need for further development and study of the issue with a call for advancing solutions. For without healthy children, there is little chance of a future with a healthy, vibrant society.

Industrial Chemicals: The Modern Way of Life

The discovery and use of petroleum-based and synthetic industrial chemicals during the past 100 years has revolutionized modern life, particularly during the last half of the 20th century. As a whole, these chemicals are for all practical purposes ubiquitous, as they are found in many types of products, including pesticides, flame retardants, synthetic rubber, adhesives and sealants, consumer products, electronics, cleaning products, plastics, flavorings and food additives, pharmaceuticals, medical equipment, decorative paints, wall coverings, furniture, furnishings, and flooring. The US industrial chemical manufacturing industry generates about $200 billion in annual revenue, with the global industry creating annual revenues of about $1.5 trillion. Global chemical production is expected to double every 25 years for the foreseeable future (Wilson et al 2006, First Research 2011, Hoovers 2011), underscoring developed countries' dependence on these chemicals to sustain and advance modern life.

According to the US Environmental Protection Agency (US EPA), which regulates hazardous waste disposal in the US, more than 20,000 companies, referred to as "hazardous waste generators" produce over 40 million tons of hazardous waste each year. These companies include chemical manufacturers, electroplating companies, petroleum refineries, dry cleaners, auto repair shops, hospitals, exterminators, and photo processing centers. Some hazardous wastes generated in homes, such as paint, mineral spirits, batteries, and used oil, are not regulated by the federal government.

Chemicals also enter the environment as a result of direct discharges from industrial processes, "leaching" from waste and landfill sites, or from use, such as emissions into indoor air from the materials and products that contain them. Pollutants released into the indoor air result in about 100 to 1,000 times greater human inhalation exposure than pollutants released into outdoor air. These pollutants also can settle on to dust. As a result, these sources have a much larger effect on public health if their pollutants are emitted indoors rather than outdoors (WWF 2006, Institute of Medicine 2011).

In addition, many persistent, bio-accumulative, and endocrine disrupting chemicals substances can persist in the environment for long periods and transport long distances via the air and waterways, including migrating from the soil into underground aquifers. They also can get into the food chain, another primary source of exposure, and thus accumulate in living organisms and eventually in people (WWF 2006).

Exposure to industrial chemicals, as noted, can have a profound effect on children's health.

Although this will be explored more fully later in this paper (see *Health Effects From Exposure to Industrial Chemicals* below), the key take away points that make this a critical public health and societal issue include the following, as summarized in a landmark 10-year study of the nature and extent of chemical contamination of food, conducted by the WWF in the United Kingdom:

- "Recent scientific findings show that many chemicals can act together in an additive way. This is crucial as people are exposed to a wide range of chemicals. Individually they may be below safe levels, but together they may exceed a threshold level for adverse effects."
- With incomplete information about exposure routes, whether from food or indoor air or other pathway, setting safe levels to prevent possible health effects is very difficult.
- The developing fetus, infants, and young children are particularly sensitive to chemicals. Exposure to chemicals during pregnancy can interfere with normal development. It is the timing of exposure and not just the level of exposure that determines the possible negative effects. This is particularly true of chemicals classified as endocrine disrupters.
- Long-term low-level exposure during early life may result in unexpected health effects, which may only become apparent many years later.
- For some chemicals, there may be no safe levels, particularly in sensitive populations, such as the developing fetuses, babies, young children, and children with chronic health issues.
- Many of the chemicals have bio-accumulative properties. As a result, their levels can continue to increase if their use is not phased-out. (WWF 2006)

The United Nations has classified 21 of the most damaging chemicals to the environment and human health as persistent organic pollutants (POP) (see Table 1) (UNIDO POPs Portal 2011). In the US, there are more than 80,000 chemical compounds registered for use, with 62,000 compounds grandfathered under the Toxic Substances Control Act (TSCA) without mandatory testing. According to California Policy Research Center, about 2,000 new compounds that may pose hazard to human health are introduced into commercial use each year (Wilson et al 2006). Scientific evidence is mounting that exposure to industrial chemicals and many common consumer products that contain them may be behind a noticeable and disturbing uptick in the incidence of chronic childhood illnesses (Bornehag and Nanberg 2010).

Among those chemicals of most concern as those identified as endocrine disruptors, including dioxins, polychlorinated biphenyls (PCBs), alkylphenols, bisphenol A (BPA), phthalate esters, and various pesticides (Schletter et al 1999, Schletter et al 2000). Flame retardants (BPDEs) also are suspected of being an endocrine disruptor. Schettler et al and others also have identified a wide range of chemicals that cause adverse reproductive, developmental, and neurotoxic effects. These include metals (lead, mercury, manganese, arsenic, and cadmium); organic solvents (methylene chloride, glycol ethers, and trichloroethylene); pesticides (DDT, atrazine, chlorpyrifos, parathion, and lindane); environmental tobacco smoke (ETS) and nicotine; and PCBs.

Table 1. Chemicals Classified as POPs and Their Primary Use(s) (UNIDO POPs Portal 2011)

Chemical Name	Primary Use(s)	Chemical Name	Primary Use(s)
Aldrin	Pesticide, termiticide	Hexachlorobenzene	Fungicide, raw material for synthetic rubber and also had been used in production of fireworks and ammunition
Chlordane	Pesticide, termiticide	Mirex	Insecticide, fire retardant in plastic, rubber, paint, paper, electronics
p,p'-Dichlorodiphenyl-trichloroethane (DDT)	Pesticide	Polychlorinated biphenyls (PCBs)	Dielectrics in transformers and large capacitors, heat exchange fluids, paint additives, carbonless copy paper, plastics, caulking materials, elastic sealants, heat insulation
Dieldrin	Insecticide	Polychlorinated dibenzo-p-dioxins (dioxins)	By-product from chlorine bleaching processes in paper and pulp mills, by-product from manufacturing some industrial chemicals
Endrin	Foliar insecticide, rodenticide, avicide	Polychlorinated dibenzofurans (furans)	No known uses
Heptachlor	Insecticide, termiticide	Toxaphene	Pesticide, By-product from chlorine bleaching processes in paper and pulp mills
Pentabromodiphenyl ether	Flame retardant	Octabromodiphenyl ether	
Chlordecone	Insecticide	Lindane	Insecticide, also used to treat head lice, scabies
Alpha-hexachlorocyclohexane	By-product of producing lindane	Beta-hexachlorocyclohexane	By-product of producing lindane
PFOS (restricted not banned)	Stain resistant products, number of industrial processes	Hexabromobiphenyl	Flame retardant
Pentachlorobenzene	Insecticide, flame retardants		

In recognition of the growing evidence linking industrial chemicals to health risks, the US EPA, using its authority under the TCSA, took an unusually strong step in 2010 by establishing a Chemicals of Concern list and action plans. These plans are being used to prompt restrictions on four types of synthetic chemicals used widely in manufacturing and consumer products, including phthalates, polybrominated diphenyl ethers (PBDEs), long chain perfluorinated chemicals (PFCs), and short-chain chlorinated paraffins (SCCPs). Phthalates and PBDEs will be listed as chemicals of concern. The PFCs and SCCPs may be restricted under other TSCA provisions (Grossman 2010).

For more information about the TSCA, see the AQS white paper *Chemicals in COMMON Products:* Risky *Business for Children's Health*. Also see the AQS white paper *PBDE Flame Retardants and Indoor Environments: Where There's Smoke, There's Fire?* Both white papers are available free from the Aerias AQS IAQ Resource Center (aerias.org), under the Premium Content tab.

Before taking a closer look at the industrial chemicals that put children at risk for health problems, the following section defines the size of the problem, highlights some of the more common childhood health problems that may be associated with exposure to industrial chemicals, and explains why this is a critical public health and societal issue.

Children at Risk: The Numbers

Even though in 2010, most US children had excellent or very good health (82 percent), 13 million (18 percent) had only good or poor health (Sondik et al 2011). In 2009, parents reported that 9 percent of children ages 5 to 17 have activity limitation due to chronic conditions (America's Children in Brief 2011). These figures are significant, because children with chronic and/or high-risk illnesses may be at more risk as their respiratory and immune systems are weaker, and as a result they may be more sensitive to industrial chemicals and their by-products than healthy children. They also spend more time indoors. For people confined indoors due to illness, the consequences can be more severe than for the general population (Cohen 2006).

The Centers for Disease Control and Prevention's (CDC) lists the following as high-risk medical conditions in children: cystic fibrosis, sickle cell anemia, diabetes, congenital heart disease, other heat disease, asthma, cerebral palsy, muscular dystrophy, down syndrome, birth defects, other developmental disorders, mental retardation, transplants, cancer, HIV/AIDS, end stage renal disease, and seizures (Lu et al). Table 1 provides some useful statistics that quantify how many children may be at risk from exposure to industrial chemicals and their by-products.

Table 1. Children At Risk Exposure to Industrial Chemicals

Children in the US	Estimate
Under the age of 18	74.6 million*
Living under the poverty level	15.5 million**
With chronic and/or high risk medical conditions	2.5 million+
With asthma (having asthma at some point during their lifetime)	7 million (10 million)*
With respiratory allergies	8.5 million*
With attention deficit hyperactivity disorder	5 million*
With a learning disability	5 million*
With obesity (over the age of 6 years) / diabetes (adults and children)	9 million++ / 25.8 million+++

* Sondik et al 2011

**America's Children in Brief: Key National Indicators of Well-Being, 2011

+Lu et al ++Harvie 2006 +++ADA 2011

Asthma and Allergies. From 1980 to 1994, the proportion of Americans with asthma increased by 75 percent. In children under the age of five, the proportion grew by 160 percent. Although the increase in asthma prevalence has slowed since the mid-1990s, asthma prevalence remains at historically high levels, as noted in Table 2 (Akinbami et al 2011, Sondik et al 2011).

Asthma remains the leading cause of school absenteeism and hospitalizations in children under the age of 15. In 2008, for example, children aged 5 to 17 years with at least one asthma attack in the previous year missed 10.5 million school days in the past year. Nearly 60 percent had at least one asthma absence day in the past year, and 5.5 percent were limited in their activity due to asthma. Asthma also tends to be seasonal, especially among children, with a noticeable spike in asthma-related emergency room visits and hospitalizations in September (Akinbami et al 2011, Johnston et al 2006, Neidell 2004, AAFA 2005, AAAAI 2005).

Current asthma prevalence differs between demographic groups, with higher rates among females, children, non-Hispanic blacks, and Puerto Ricans, those with family income below the poverty level, and those residing in the Northeast and Midwest regions (Akinbami et al 2011). Researchers have clear evidence that the quality of indoor air is a factor. For example, children exposed to high levels of volatile organic compounds (VOCs) were four times more likely to develop asthma than adults (Rumchev et al 2004). Other studies also have found an association between VOCs and asthma in children (CARB 2005).

Mendell (2007) reviewed 21 studies from the "epidemiologic literature on associations between indoor residential chemical emissions, or emission-related materials or activities, and respiratory health or allergy in infants or children." He found that the most frequently identified risk factors included "formaldehyde or particleboard, phthalates or plastic materials, and recent painting."

Autism Spectrum Disorder. Educators, parents, physicians, and public health officials also are concerned about an apparent increase in the number of children diagnosed with autism spectrum disorders (ASD). And, as with asthma, they wonder if there is a connection with exposure to industrial chemicals. Estimates suggest that around 6 in 1,000 people in the world have ASD, with more boys affected than girls. The increase in prevalence is partially due to changes in diagnostic criteria, terminology, and increased reporting. Although there are no known links between autism and chemical exposure, a recent review of scientific literature on the causes of neurodevelopmental disorders implicated a number of industrial chemicals, including lead, methylmercury, PCBs, arsenic, and toluene (Grandjean and Landrigan 2006).

Cancer. In the US, cancer is the second most common cause of death among children between the ages of 1 and 14 years, surpassed only by accidents. Overall, childhood cancer incidence rates have increased slightly by 0.6 percent per year since 1975. An estimated 11,210 new cases are expected to occur among children 0 to 14 years of age in 2011, with an estimated 1,320 deaths expected, about one third of these from leukemia. The most common cancers in children were leukemia (34 percent of all childhood cancers) and brain and central nervous system cancers (27 percent). Mortality rates for childhood cancer have declined by 53 percent since 1975. The substantial progress in childhood cancer is largely attributable to improvements in treatment and the high proportion of pediatric patients participating in clinical trials (CDC 2011, ACS 2011).

Childhood Obesity and Diabetes. The prevalence of obesity among children ages 6 to 11 has more than doubled in the past 20 years, rising from 6.5 percent in 1980 to 17 percent in 2006. The rate among adolescents ages 12 to 19 has more than tripled, increasing from 5 percent to 17.6 percent. Obesity is a risk factor for developing cardiovascular disease, diabetes, and cancer. In the US, for example, 25.8 million children and adults have diabetes, which equates to 8.3 percent of the population. Among children and teenagers under the age of 20, 215,000 have diabetes, and about one in every 400 children and adolescents has type one diabetes. Even more striking, one in three US children born in 2000 could develop diabetes during their lifetime. There are another 79 million people classified as being pre-diabetic. In 2007 total direct costs of diagnosed diabetes in the US totaled a staggering $174 billion (ADA 2011, BC/BS 2011).

Researchers are investigating the role of “obesogens”, industrial chemicals that may promote obesity. Two chemicals of particular interest are bisphenol A (BPA) and tributyltin. Tributyltin is a biocide used in wood preservation, as an antifouling pesticide in marine paints, and for antifungal action in textiles, and industrial water systems. Prenatal exposure to certain obseogens may predispose children to store more fat from the beginning of their lives. Obesogens have the potential to disrupt multiple metabolic signaling pathways in the developing fetus, leading to permanent alterations in adult physiology. The most prominent studies on the prenatal programming of obesity have shown that maternal malnutrition or excess estrogen or cortisol exposure in the womb causes an increased susceptibility to obesity and metabolic syndrome later in life (Janesick and Blumberg 2011). Also of concern, obese children are less active, which means they likely will spend more time indoors. See *Children’s Activity Patterns* below for more information.

Learning Disabilities and Attention Deficit Hyperactivity Disorder. In 2007, the CDC estimated that 4.6 million (8 percent) of children ages 3 to 17 years had a learning disability (10 percent of boys; 5 percent of girls). About 4.5 million children, ages 3 to 17 years, had Attention Deficit Hyperactivity Disorder (ADHD). Those figures have increased in 2011 to 5 million each, as noted in Table 2 (Bloom et al 2009, Sondik et al 2011).

As with learning disabilities, boys are more than twice as likely as girls (10 percent and 4 percent, respectively) to have ADHD. And, as with asthma, prevalence differs among demographic groups, with white and black children twice as likely to have a learning disability as Asian children. Of particular note, in families with income of less than $35,000, the percentage of children with a learning disability was twice that of children with a family income of $100,000 or more. Also, children in fair or poor health were almost five times more likely to have a learning disability than children in excellent health, and more than twice as likely to have ADHD (Bloom et al 2009, Sondik et al 2011). See *Socioeconomic Diffe*rences below for more about how socioeconomic status may affect a child's risk from exposure to industrial chemicals and indoor air pollution

Children At Risk: Why A Higher Risk

When determining the risk of exposure to industrial chemicals, researchers emphasize: "Children are not little adults" (Tickner and Hoppin 2000). Physical differences, socioeconomic status, and activity patterns are among the key reasons why children are more vulnerable to exposure and face greater health risks from industrial chemicals than adults. In addition, how a child may react varies a great deal depending on the child's overall health, exposure to industrial chemicals and indoor air contaminants, and whether the child is more or less sensitive to a particular chemical or contaminant. The following is an overview of the primary factors that contribute to these risks.

Rapid periods of growth. Human cells, tissues, organs, and body systems grow at different rates, with the most rapid periods of growth occurring in utero, infancy, and puberty. Many organ systems also undergo differentiation during the first years of life. During these rapid periods of growth, developmental processes can be easily disrupted, at which time minute exposures can create irreversible, lifelong effects (Tickner and Hoppin 2000).

Age-related differences. In children, biochemical and physiologic functions are immature; for example, the nervous system does not completely develop until the age of 18. The reproductive system also is particularly vulnerable, especially in school-age children and adolescents. Children have different proportions of fat, water, protein, and mineral content in their bone, blood, and tissues than adults, which results in children having less ability to detoxify and excrete certain substances. In addition, children may absorb toxic substances from the gastrointestinal tract differently and to a greater degree than adults (Tickner and Hoppin 2000).

Another major organ that can be significantly impacted is the developing brain, which is much more vulnerable to chemical exposures than the mature brain. Compared with other organs, the human brain forms over a long period of time, beginning in the first weeks after conception. Brain weight at birth is about one-third that of adult weight. There is a brain growth spurt from the third trimester of pregnancy until about the age of two years. Most of the basic brain structure is laid down before birth, with considerable postnatal activity in the development of connections, brain transmitter systems, and the production of myelin. Also of significance is the blood-brain barrier is not complete until about six months after birth, which has major implications for chemicals that are transported to the fetus through the placenta and babies' exposures in the first few months of life (McElgunn 1999a).

Physical differences. Because of their lower body weight, children breathe in a relatively greater volume of air than adults. Newborns breathe through their mouths, as do many older infants and children—more so than do adults. Also, children's breathing zones are much closer to the ground, and as a result, heavier airborne chemicals pose more of risk to children than to adults. Another significant difference is children have a higher heart rate than adults, which allows substances that are absorbed into the blood to permeate tissues faster (Flynn et al 2000, Tickner and Hoppin 2000).

By and large, children consume more food and water than adults per kilogram of body weight. The 1993 US National Academy of Sciences report, *Pesticides in the Diets of Infants and Children*, found that infants consume up to seven times the amount of water on a milligram per kilogram of body weight than is consumed by adults. Children also consume fewer types of foods, which may result in receiving a higher exposure to a chemical contained on or in a favorite food (McElgunn 1999b, National Research Council 1993). Consequently, children may have significantly greater exposure to chemicals in water, food, and air than adults.

Socioeconomic Differences. In the US, more children live in poverty than any other age group. As a result, these children are more likely to live in public housing or in close proximity to industry, which is a primary source of outdoor air pollution that can be brought indoors via heating, ventilating and air-conditioning systems. As a part of the Minnesota Children's Pesticide Exposure Study, researchers confirmed that higher outdoor VOC concentrations in urban areas contributed to higher VOC concentrations in urban homes (Adgate 2004).

In another Minnesota study researchers demonstrated that low-income children may be a risk for higher exposures to other types of industrial chemicals as well. In this study, the researchers measured more than 75 individual biomarkers, spanning seven chemical / pollutant classes in blood and urine from over 100 children living in a socioeconomically disadvantaged and ethnically diverse area of south Minneapolis. The results showed that a significant proportion of the children were at the high end of the exposure distribution compared with national reference ranges for a variety of environmental chemicals and/or their metabolites, including phthalates, organochlorine pesticides, organophosphate pesticides, metals, PCBs, and VOCs. In addition, levels of cotinine in urine indicated that more than 50 percent of the children were regularly exposed to ETS (Sexton et al 2011).

In addition, children in poor families were more likely to have asthma (12 percent) or had been diagnosed with asthma at some point in their lifetimes (17 percent) than children in families that were not poor (8 percent and 12 percent, respectively) (Sondik 2011). Children living in poverty also may not take advantage of health care services as often as other socioeconomic groups, so underlying chronic illnesses may not be diagnosed (Flynn et al 2000). For example, a study of Detroit, Michigan school children in the third to fifth grades found that 14.3 percent might be under diagnosed for asthma (Joseph et al 1996).

Children's Activity Patterns. A comprehensive review of the literature on the effect of climate change on indoor air quality, concluded, "The literature on indoor environmental quality and health is rich and unequivocal: indoor environmental conditions have a great influence on human health, and adverse conditions harm occupant well-being. Introduction of new materials and weatherization techniques may lead to unexpected exposures and health risks" (IOM 2011).

This review also examined the research on the amount of time children spend indoors and noted the following findings, which are summarized in Table 3:

- Children, particularly young children, spend a large fraction of their time indoors (Cohen-Hubal et al 2000, EPA 2009).
- Children under two years old tend to spend the most time inside, just under 94 percent (Cohen-Hubal et al 2000, EPA 2009).
- Throughout their childhood years, children consistently spent 83 percent to 94 percent of their time indoors, including 19 percent of their time in school (EPA 1996, EPA 2009).
- Younger children tended to spend more of their time at home than older children but only during the traditional school year, with older children spending more time in school. Conversely, during the summer, younger children were more likely not to spend time at home, and older children more likely to spend time at home (Silvers, 1994).
- Children 5 to 12 years old increased their time spent indoors only in summer (Silvers et al 1994). These results did not vary from one region to another (Klepeis et al 2001, Silvers et al 1994).
- Students are spending less time in school and participating less in sports and other outdoor activities than 30 years ago. In 1981, children spent about 75 minutes per day outdoors compared with only 50 minutes in 2003 (Juster et al 2004).
- In adults, however, time spent indoors has remained constant over the past several decades (Klepeis 2001).

Results of a California Air Resources Board (CARB) study on children's activity patterns in that state found that overall children spend on average 85 percent of their time indoors; 70 percent of that time is spent at home. In this study, 1,200 English speaking children 11 years of age or younger were interviewed from spring 1989 to winter 1990. The participants were asked if they used or were near sources of pollution, such as ETS, solvents, pesticides, paint, and gas appliances. The results from the CARB study agree with estimates from other studies in the US and other industrialized nations (Wiley et al 1994). For more information about this study, see the AQS research report *Indoor Air Quality & Sensitive Populations Groups*, which may be accessed free of charge from the AQS Aerias IAQ Resource Center (aerias.org) under the Premium Content tab.

Table 3. Percent of Time Spent Indoors as a Function of Age*

Age	Percent of Time Spent at Home	Percent of Total Time Spent Indoors
Birth to 1 year	76	94
1 to 2 years	73	94
2 to 3 years	67	91
3 to 6 years	66	89
6 to 11 years	61	83
11 to 16 years	61	88
16 to 21 years	57	87

* Adapted from Table 2-1 in IOM 2011.

All of these factors combine to create a higher body burden of chemical pollutants for the same amount of exposure. Researchers note that the combination of disproportionately heavy exposure plus biologic vulnerability makes children very susceptible to adverse health effects (Landrigan et al 1999). Also of note, exposures early in life can lead to a greater risk of chronic health effects that become apparent years later (Tickner and Hoppin 2000).

Health Effects from Exposure to Industrial Chemicals

Biomonitoring: Measuring Exposure. As with adults, children can be exposed to air pollutants via inhalation, ingestion, and external contact. Unlike adults, developing fetuses can be exposed through the placenta and babies through breastfeeding. In other words, a mother's exposure can have a significant impact her baby's developing organs and systems. During prenatal and early postnatal life, for example, chemical exposures can effect gene expression, which may predispose children to disease during adolescence and adult life. Some of these changes can result in lasting functional changes in specific organs and tissues and increased susceptibility to disease that may even affect successive generations (Grandjean et al 2007, Perera and Herbstman 2011).

Increasingly, researchers are using biomarkers to measure body burdens of environmental chemicals or byproducts, particularly in prenatal life and infancy. In the month leading up to a baby's birth, the umbilical cord exchanges the equivalent of 300 quarts of blood each day. Results of tests on cord blood reveal that industrial chemicals, pollutants, and pesticides can cross the placenta as easily as residues from cigarettes and alcohol. In one study, researchers found a total of 287 chemicals (average of 200) industrial chemicals and pollutants in umbilical cord blood from 10 babies born in US hospitals between August and September 2004. The chemicals include mercury, PAHs, perfluorochemicals, pesticides, PCBs, furans, and PBDEs and their by-products (Houlihan et al 2005).

Results of a follow-on two-year study involving five independent research laboratories in the United States, Canada, and the Netherlands showed up to 232 toxic chemicals in the umbilical cord blood of 10 babies from racial and ethnic minority groups (African American, Hispanic and Asian). The laboratory analyses identified 21 contaminants not previously found in American newborns, including bisphenol A; the fire retardant tetrabromobisphenol A; galaxolide and tonalide, polycyclic musks used as synthetic fragrances; perfluorobutanoic acid, a member of the PFC chemical family used to make non-stick, grease-, stain-, and water-resistant coatings for consumer products; and eight PCBs (EWG 2009). Another biomonitoring study showed children's levels are two to five times higher than those of their parents (Fischer et al 2006).

A CDC study, the first to use human subjects, showed that 92.6 percent of more than 2,500 Americans had bisphenol A in their urine. Measured urine concentrations were significantly higher in children and adolescents compared with adults. Bisphenol A has also been measured in the milk of lactating mothers. These data indicate that the developing human fetus and neonate are readily exposed to this chemical (Calafat et al 2008).

In its Fourth National Report on Human Exposure to Environmental Chemicals, the CDC presented exposure data for 212 environmental chemicals, including 75 chemicals measured for the first time in the US population. These chemicals included the following chemical groups: acrylamide and glycidamide; arsenic and metabolites; environmental phenols, including bisphenol A and triclosan; perchlorate; PFCs; PDBEs, and VOCs. The study's findings showed widespread exposure to industrial chemicals, in particular PBDEs, bisphenol A, and perfluorooctanoic acid (PFOA). In addition, the Fourth Report shows that all the participants (ages 6 to 20 years) had detectable perchlorate in their urine. Perchlorate is both naturally occurring and manmade and is used to manufacture fireworks, explosives, flares, and rocket propellant (CDC 2009).

Exposure Pathways in the Body. What happens when chemicals enter the bloodstream and are deposited into major organs is very worrisome. In some cases, health effects associated with these chemical exposures do not become apparent for many years. In a discussion of how best to monitor exposure to environmental chemicals for the National Children's Study, Barr et al explained that once the chemical has been absorbed, it is distributed to primary deposition sites where its concentration is in equilibrium in the blood. To maintain equilibrium, the chemical is slowly released from the deposition or storage site. It is then metabolized, usually in the liver, and eliminated from the blood in urine or feces. Some chemicals, such as VOCs, may be excreted through the alveoli or in exhalation. Other chemicals can be excreted as tears, saliva, sweat or milk in lactating mothers. During the metabolism and removal process low concentrations may reach target organs (Barr et al 2005).

The immature blood brain barrier may allow greater chemical exposures to the developing brain. A diminished ability to excrete and detoxify many chemicals can produce higher levels of chemicals circulating in the blood of the child than the mother. The occurrence of complex processes of cell growth and differentiation may provide the opportunity for irreversible effects to occur during critical windows of development. And the longer life span of the child compared with an adult allows more time for adverse effects to arise (Houlihan et al 2005).

In a 2006 review study, researchers from the Harvard School of Public Health and the Mount Sinai School of Medicine systematically examined publicly available data on industrial chemicals with the goal of identifying which chemicals are the most likely to damage developing brains. The researchers found that 202 commonly used industrial chemicals have the capacity to damage the human brain, and they concluded that chemical pollution might have harmed the brains of millions of children worldwide. About one-half of them are considered high-volume production chemicals. The authors also concluded that the toxic effects of industrial chemicals on children have generally been overlooked (Grandjean and Landrigan 2006, Grandjean and Perez).

An especially noticeable finding is some chemicals may have health impacts at extremely low levels, which are not seen at higher levels. Minute levels of phthalates, for example, which are used to make toys, building materials, drug capsules, cosmetics and perfumes, have been linked to sperm damage in men and genital changes, asthma and allergies in children (Waldman 2005, Bornehag et al 2004). Researchers at the University of London suspected that small amounts of some industrial chemicals might have a dramatic effect on hormone levels. They tested the hormonal strength of 11 common chemicals, known to mimic estrogen. Alone, each chemical was very weak, but when low doses were mixed with natural estrogen, the strength of estrogen doubled (Waldman 2005, Rajapakse et al 2002). High levels of estrogen are associated with some forms of cancer and developmental problems during puberty (Cohen 2006).

Specific Chemicals of Concern

The discussion above provided an overview of health risks associated with industrial chemicals used in everyday products and how children can be exposed to them. This next section goes into more detail about the primary chemicals of concern. For more information about the products in which they are found, see the AQS white paper *Chemicals in COMMON Products: Risky Business for Children's Health*, which is available free from the Aerias AQS IAQ Resource Center at aerias.org, under the Premium Content tab.

Bisphenol A. This chemical is a primary ingredient in polycarbonate plastic, which is used to make a variety of common products, including baby and water bottles, sports equipment, medical and dental devices, dental fillings and sealants, eyeglass lenses, CDs and DVDs, and household electronics. Some epoxy resins containing bisphenol A are used as coatings on the inside of food and beverage cans. Bisphenol A also has been used as flame retardant and fungicide (NTP CERHR 2008). Widespread and continuous exposure to low levels of bisphenol A is primarily through food, but also through drinking water, dental sealants, dermal exposure and inhalation of household dusts (CDC 2009).

As noted above, the CDC published results of its analysis of urine samples from 2,517 people, aged 6 years and older who took part in the National Health and Nutrition Examination Survey (NHANES) from 2003 and 2004. The results showed that bisphenol A is present in nearly 93 percent of the people tested. The results also demonstrated that females have a significantly higher level in their urine than males. Children had the highest levels, followed by teens and adults (CDC 2009).

Results from a number of studies have implicated bisphenol A as having significant health effects in experimental animals, including endocrine disruption, impaired immune system function, brain damage, developmental toxicity, learning disabilities, diabetes, behavioral changes, early puberty, reduced sperm count, cancer, obesity, neurotoxicity (Environmental California 2004), liver damage, disrupted pancreatic β-cell function, and thyroid hormone disruption (Lang et al 2008). The evidence from these studies prompted the National Toxicology Program Center for the Evaluation of Risks to Human Reproduction (NTP CERHR) to initiate a two-year analysis. The researchers reviewed a very limited number of available human studies along with nearly 1,000 studies of experimental animals on the health effects from exposure to bisphenol A. In September 2008, the NTP CERHR released its findings that the evidence from experimental animal studies raised "some concern" that current levels of exposure to human fetuses, infants, and children may result in developmental changes in the prostate gland and brain and diminish sexually dimorphic behaviors. The NTP CERHR report also raised a "minimal concern" for possible changes in the mammary gland and earlier age of attaining puberty in females (Bucher 2009, NTP CERHR 2008).

Since then, other studies of human exposure to bisphenol A have been published that continue to raise concern. For example, in a cross-sectional study of almost 1,500 adults, Lang et al found high bisphenol A levels in urine were significantly associated with heart disease, diabetes, and abnormally high levels of certain liver enzymes (Lang et al 2008). There still is a great deal of uncertainty about the health effects of exposure to bisphenol A in humans. The NTP is working with the CDC and academic investigators to evaluate exposures to bisphenol A in infants in neonatal care settings and in children less than six years of age.

Consumer groups recommend that people wishing to lower their exposure to bisphenol A stay away from canned food and polycarbonate plastic containers, which share resin identification code 7 with many other plastics, unless the packaging indicates the plastic is bisphenol A-free. The National Toxicology Panel recommends avoiding microwaving food in plastic containers, putting plastics in the dishwasher or using harsh detergents to avoid leaching. There also are efforts to ban bisphenol A, including legislation being proposed in the US Congress and in state legislatures. Major manufacturers of baby bottles have voluntary stopped using bisphenol A in their product formulations, as have manufactures of pacifiers and sippy cups.

Environmental Tobacco Smoke. Although ETS is not classified as comprised of industrial chemicals per se, exposure to the mixture of chemicals in ETS, however, can have a significant impact on children's health. Although smoking in public places in the US has become uncommon, smoking in private residences continues. Singh et al (2010) estimated that 7.6 percent of children in the US are exposed to ETS in their own homes. In multifamily buildings, children can be exposed to ETS from neighboring units (Bohac et al 2011).

Some segments of the US population have a relatively high prevalence of indoor smoking. For example, a study of 100 children with asthma living in inner-city Baltimore revealed an indoor smoking prevalence of 46 percent and found that average indoor $PM_{2.5}$ and PM_{10} levels were 33 $\mu g/m^3$ to 54 $\mu g/m^3$ higher in smoking than in nonsmoking households (Breysse et al 2005). In another study, fine particle concentrations were sampled over two-week periods in 294 inner-city homes in which children with asthma resided. In these homes, the average particle mass concentration (27.7 $\mu g/m^3$) was considerably higher than the average concurrently measured outdoor concentration (13.6 $\mu g/m^3$). Smoking occurred in 101 of the homes (34 percent) and caused an average increase of 37 $\mu g/m^3$ for indoor fine particle levels (Wallace et al 2003).

Flame Retardants. Polybrominated diphenyl ethers (PBDEs) are a class of widely used brominated flame retardants (BFRs) that are added to the plastics used in televisions, computers and other electronic products; building materials; furniture; foams; textiles and clothing. Electronics and electrical equipment make up more than 50 percent of BFR applications. Brominated fire retardants are one of five "families" of flame retardants, including brominated, chlorinated, phosphorous containing, nitrogen containing (melamine) and inorganic (antimony, aluminum and tin compounds).

The primary reason for the concern over PBDE safety is that a variety of chemicals have been found to disrupt the endocrine systems in experimental animals. These endocrine disruptions also may damage nerve cells during brain development, which in humans continues up to two years after birth (EPA 2004). For example, children who have higher concentrations of PBDEs in their umbilical-cord blood at birth scored lower on neurodevelopment tests at the ages of one and six years (Herbstman et al 2010).

Also fueling the debate is the PBDE chemical structure closely resembles PCBs, which have well-established toxic effects, including birth defects, cancer, thyroid imbalances, and neurologic damage. Rather than containing chlorine, PBDEs contain bromine. Since PCBs were banned in 1979, BFRs have become more widely used. As of 2000, BFRs accounted for 38 percent of the global demand share of bromine, a significant rise from just 8 percent in 1975 (Birnbaum and Staskal 2004).

According to the CDC, studies of health effects to date have focused solely on animals; for example, rats and mice that ingested food with moderate amounts of PBDEs for a few days had effects on the thyroid gland. Those that ate smaller amounts for weeks or months also had effects on the thyroid and the liver. Preliminary evidence suggests that PBDEs also may cause neurobehavioral changes and affect the immune system in animals (ATSDR 2004).

Because PBDEs dissolve readily in fat, they can accumulate in breast milk and can be transferred to infants and young children. They also can cross the placenta and reach the fetus. Exposure to PBDEs in the womb and through nursing has caused thyroid effects and neurobehavioral alterations in newborn animals, but no birth defects. In addition to breast milk, researchers worry that infants and toddlers may ingest dust particles containing PBDEs.

For more information, see the AQS white paper *PBDE Flame Retardants and Indoor Environments: Where There's Smoke There's Fire*, which is available free of charge from the Premium Content section of the Aerias-AQS Indoor Air Quality Resource Center (www.aerias.org).

Formaldehyde. Formaldehyde is widely used to manufacture building materials and numerous household products, and also is a by-product of combustion and certain other natural processes. Primary sources include pressed wood products such as particleboard, plywood, and medium density fiberboard; finished furniture, shelving, and cabinetry made with composite boards and certain coatings; decorative fabrics and textiles; and paper products. It also may be used as a biocide in certain paints and coatings, adhesives and personal care products.

Based on more than 300 measurements collected in residences and schools, Air Quality Sciences (AQS) studies have found typical concentrations range from 0.05 ppm to 0.08 ppm in homes. An average level of 0.04 ppm has been found in schools, with new or recently renovated or refurbished school environments reaching 0.14 ppm. To avoid acute respiratory symptoms, the levels found in schools are higher than the 0.027 ppm (27 ppb) limit recommended by the state of California's Environmental Protection Agency for residential exposures.

Available clinical and epidemiological data indicate that individual responses to formaldehyde may vary substantially. Irritation may occur at levels of 0.08 ppm or less, and odor detection has been measured as low as 0.03 ppm. When formaldehyde is present in the air at levels exceeding 0.1 ppm, some people may experience watery eyes; burning sensations of the eyes, nose, and throat; coughing; wheezing; nausea; and skin irritation. Some people are very sensitive to formaldehyde, while others have no reaction to the same level of exposure. Other health effects include coughing, fatigue and severe allergic reactions. High concentrations may also trigger asthma attacks.

As noted above, Mendell reviewed a number of studies that investigated associations between health effects to allergies and asthma in infants and children (up to age 16) and indoor environments or activities considered to be risk factors for chemical exposures. His summary included studies that found associations of formaldehyde with asthma, adverse changes in lung function, lung inflammation, and chronic bronchitis. Formaldehyde emissions from particleboard, plasticizers, or plastic materials and recent painting were among the most frequently identified risk factors for residential exposures to industrial chemicals (Mendell 2007). McGwin et al study reviewed 18 studies and also concluded that there was sufficient evidence to implicate formaldehyde with asthma (McGwin et al 2010).

Another study of note found that children exposed to formaldehyde at levels as low as 16 ppb in indoor air were more likely to show allergic sensitization and respiratory symptoms. In addition, 16 percent of children in homes with formaldehyde less than 16 ppb had asthma as compared 44 percent of children with asthma living in homes with formaldehyde concentrations greater than 40 ppb (Garrett et al 1999).

Phthalates. Also called "plasticizers," phthalates are a group of industrial chemicals used to make plastics like polyvinyl chloride (PVC) more flexible or resilient and also as solvents. They are used in hundreds of products, including vinyl flooring, adhesives, detergents, lubricating oils, automotive plastics, plastic clothing such as raincoats, and personal care products, such as soap, shampoo, hair spray, and nail polish. Before 1999, phthalates were used in pacifiers, soft rattles and teethers (CDC 2005).

Phthalates are classified as an endocrine disruptor. Several phthalate compounds have been associated with reduced sperm counts, testicular atrophy, and structural abnormalities in the reproductive systems of male test animals. Results of other studies have linked phthalates to liver cancer (CDC 2005). Some phthalates also have been associated with increases in persistent symptoms of allergies and diagnoses of rhinitis, eczema, and asthma (Mendell 2007). Although the CDC contends the health hazards of phthalates to humans have not been definitively established, the US EPA regulates phthalates as water and air pollutants.

Their use is so widespread that researchers have found phthalates in almost all of the US population, with the highest levels in children ages 6 to 11 years and in women. Using products that contain phthalates, breathing contaminated dust or having a medical treatment, such as a blood transfusion or dialysis that uses equipment made of plastics, are possible exposure pathways (CDC 2005).

Volatile Organic Compounds. Among the most prevalent of all indoor air constituents are VOCs, with as many as 100 to 1,000 different VOCs in the air where children can easily inhale them. Some VOCs can cause eye, nose and throat irritation; cough; headache; general flu-like symptoms, skin irritation and some may cause cancer. Others produce odors that may be objectionable. Complicating matters is the potential for interactions of VOCs with other chemical compounds to form additional compounds that may also be a threat. As a result, even though the concentrations of individual VOCs may be well below odor thresholds or known toxic levels, their occurrence in complex mixtures may lead to perceived poor IAQ, irritation among those exposed or effects not yet known or defined.

Some VOCs, such as toluene, benzene, and dichlorobenzene, have been reported with increases in asthma diagnoses, obstructive bronchitis, pulmonary infections associated with asthma attacks, sensitivity to some foods and eczema. Other VOCs, such as hexane and decane were associated with increased sensitization to foods. In addition, total VOC concentration has been associated with increases in the number of asthma diagnoses, but not with persistent wheezing (Mendell 2007).

House dust is an important repository for semi-volatile organic compounds (SVOCs) and other contaminants in particles (Butte and Heinzow 2002). Results of studies of house dust, for example, have demonstrated the presence of PCBs, PAHs, plasticizers (phthalates and phenols), flame retardants, other organic xenobiotics, and inorganic constituents (Weschler and Nazaroff 2010). Dust ingestion also can be an exposure pathway of concern for SVOCs (Roosens et al 2009). Infants are generally affected more by dust ingestion than adults because of their contact with floors and their high level of hand-to-mouth activity (IOM 2011).

Air Quality Sciences has measured VOC levels in more than 200 US schools and found 345 typical VOCs in the indoor air. Table 4 lists the 14 most common VOCs found in these schools. Other frequently found VOCs of concern in schools include perchloroethylene and methylene chloride, potential carcinogens related to spot cleaners, degreasers, and art supplies. By extension, these VOCs also may be present in daycare facilities where very young children may be exposed.

Table 4. Common VOCs found in schools

VOC	Source(s)	VOC	Source(s)
Toluene	Cleaners, construction materials	Hexanal	Cleaners, adhesives, deodorizers, cabinetry
Xylenes	Cleaners, construction materials	2-Butoxyethanol	Wood cabinetry, cleaners, paints
Siloxanes	Waxes, polishes, deodorants	Ethanol	Cleaners, disinfectants
Formaldehyde	Furniture, ceiling tile, wood shelving, cabinetry	TXIB	Plastics, paints
Hexane	Markers, cleaners	Acetaldehyde	Plastics, paints, foam insulations
Acetone	Markers, art supplies	Longifolene	Cleaners, wood products, flooring
1,4 Dichlorobenzene	Cleaners, deodorizers	Naphthalene	Adhesives, art supplies, rubber flooring

In homes, primary VOC sources include furniture, furnishings, carpets and flooring, beds and bedding, plastics, paints, wood cabinets, cleaning, and personal care products. The state of knowledge about VOCs and SVOCs in indoor environments and public health is far from complete. The chemicals are diverse in their characteristics and complex in their dynamic behavior. Conditions vary with time in any given building and can also vary markedly among buildings. Concentrations are influenced by a variety of factors, some of which reflect properties of the chemicals, some of which depend on properties of the buildings into which they are emitted, and some of which depend on actions of building occupants (IOM 2011).

The Wake-Up Call to Action

The wake-up call to action has been presented. Researchers are actively investigating health effects associated with industrial chemicals and industry groups are speaking up about risks to children. Both the US House of Representative and the US Senate have introduced legislation to overhaul the Toxic Substances Control Act (TCSA) and empower the US EPA to control and manage the risk associated with industrial chemical use in the US. These bills recommend that industry take on the responsibility of demonstrating the safety of industrial chemicals used in everyday products. Another important bill recently announced, called the Endocrine Disrupting Chemicals Exposure Elimination Act of 2011, would empower the National Institute of Environmental Health Sciences (NIEHS) and a panel of experts to ban up to 10 chemicals from commerce per year, categorizing them as of high concern.

In addition to government mandates and legislation, market pressures from foreign competitors, and a growing awareness of the connection between industrial chemicals and adverse health impacts means that product manufacturers will increasingly need to demonstrate their technology leadership and product stewardship toward healthy products. Overall, chemicals should be safe for their intended use, and the potential risks presented to infants and children should be considered in safe use evaluations.

Visit us at aqs.com to learn more about how we can help you, or call us at (770) 933-0638 and ask for Product Evaluations. We can assist with product emissions studies; chemical data review; risk assessments; hazard lists review and other services. Also visit the AQS Aerias IAQ Resource Center to learn more about industrial chemicals and other indoor contaminants. You can access Aerias from the AQS website or at www.aerias.org. For a listing of low-emitting products, visit the GREENGUARD Environmental Institute site at www.greenguard.org.

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