TECHNICAL BRIEFING

Phthalates and Their Alternatives: Health and Environmental Concerns



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Lowell Center for Sustainable Production
UNIVERSITY OF MASSACHUSETTS LOWELL

The Lowell Center for Sustainable Production at the University of Massachusetts Lowell helps to build healthy work environments, thriving communities, and viable businesses that support a more sustainable world.

The Lowell Center for Sustainable Production at the University of Massachusetts Lowell developed this technical briefing to provide an overview of alternatives to phthalates used as plasticizers in a wide range of polyvinyl chloride (PVC) plastic products, with particular emphasis on children's products. The document describes uses of and products containing phthalates (Table 1) and outlines some of the health and environmental concerns raised regarding these substances.

Drop-in substitutes are an attractive solution for manufacturers as they do not require a major production process change, but they may also pose health and environmental concerns, which are summarized in Table 2. Another solution for manufacturers is to choose a type of plastic that does not require a plasticizer. This document identifies petroleum-based and biobased plastics that do not require the use of phthalates and describes the known human health and environmental concerns of these alternative plastics (Tables 3 and 4).

We gratefully acknowledge the support of the New York Community Trust for our continued work on sustainable products.

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Why There Is Concern about Phthalates

Phthalates are a class of synthetic chemicals that are widely used in a variety of consumer products including medical devices, food wrap, building materials, packaging, automotive parts, children's toys, and childcare articles made of polyvinyl chloride (PVC). The annual global production of phthalates is estimated to be 11 billion pounds. The addition of phthalates to PVC makes this brittle plastic more flexible and durable. PVC products may contain up to 50 percent by weight of plasticizers, most commonly phthalates. Phthalates are also used as solvents in many applications and in cosmetics to hold fragrance, reduce cracking of nail polish, reduce stiffness of hair spray, and make products more effectively penetrate and moisturize the skin. Six of the commonly used phthalates in consumer products are di-(2-ethylhexyl) phthalate (DEHP), diisononyl phthalate (DINP), dibutyl phthalate (DBP), diisodecyl phthalate (DIDP), di-n-octyl phthalate (DnOP), and benzyl butyl phthalate (BBP or BzBP).

Phthalates have been identified as reproductive and developmental toxicants, though their toxicity varies somewhat depending on the specific phthalate structure. In addition, the US EPA classifies DEHP and BBP as probable and possible human carcinogens respectively. Further, phthalates are not chemically bound to the PVC polymer. Thus, over time they leach out of products and diffuse into the air, water, food, house dust, soil, living organisms, and other media, particularly under conditions involving heat. Because of health concerns, as of February 2009 the Consumer Product Safety Improvement Act restricted DEHP, DBP, and BBP in children's toys and childcare articles in concentrations exceeding 0.1 percent. DINP, DIDP and DnOP are prohibited pending additional study and review.[a]

Although six phthalates are now restricted from children's products in the US and European Union (EU), they are unregulated and continue to be used in toy making in many other parts of the world, such as China and India. In addition, children continue to be exposed to phthalates in cosmetics and personal care products such as nail polish, lotion, shampoo, soap, and hair spray. School supplies made of PVC such as notebooks and binders, art supplies, backpacks, lunchboxes, paperclips, and umbrellas may contain phthalates. Raincoats, boots, handbags, and soft plastic shoes such as flip-flops may also contain phthalates.

Other consumer products may also be direct or indirect sources of phthalate exposure. These include medical devices such as plastic tubing and intravenous storage bags, floor tiles, automotive parts, food wrap, paints, home furnishings, pharmaceutical coatings, and electrical cords. Table 1 identifies six common phthalates, their primary function, and the products in which they are used.

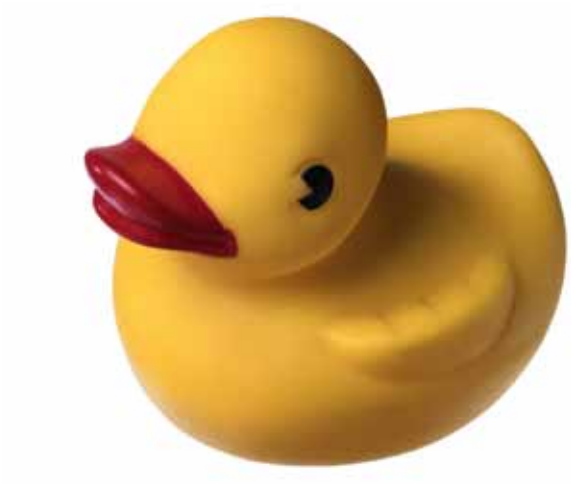
a According to the Consumer Product Safety Commission (CPSC), a children's toy is a product intended for use by a child 12 years or younger for playing and a childcare article is a product that a child 3 years of age or younger uses for sleeping, feeding, sucking or teething.

TABLE 1 **Six Common Phthalates, Their Primary Functions and Products in Which They Are Used**

Phthalate	Function(s)	Product(s)
DEHP	Primarily used as a plasticizer for PVC [1].	Dolls, shoes, raincoats, clothing, medical devices (plastic tubing and intravenous storage bags), furniture, automobile upholstery, and floor tiles [1,7].
DINP	Primarily used as a plasticizer for PVC [1].	Teethers, rattles, balls, spoons, toys, gloves, drinking straws, rubber, adhesives, ink, sealant, paints and lacquers, food and food related uses, clothes, shoes, car and public transport interior [1,3,13].
DBP	Used as a plasticizer for PVC, poly vinyl alcohol (PVA) and rubber. Also used as solvent and fixative in paint and cosmetics [1,9].	Latex adhesives, sealants, car care products, cosmetics, some inks and dyes, insecticides, food wrapping materials, home furnishing, paint, clothing and pharmaceutical coating. (may sometimes be present in toys as impurity or by-product in trace amounts) [1,9].
DIDP	Primarily used as a plasticizer for PVC [1].	Electrical cords, leather for car interiors and PVC flooring [1].
DnOP	Primarily used as a plasticizer for PVC [1].	Floorings, tarps, pool liners, bottle cap liners, conveyor belts and garden hoses [1].
BBP	Used as a plasticizer for PVC, polyurethane, polysulfide and acrylic-based polymers [12].	Vinyl flooring, sealants, adhesives, car care products, automotive trim, food conveyor belts, food wrapping material, and artificial leather. (low concentrations have been detected in baby equipment and children's toys as by-products and impurities; not intentionally added to those products) [1,12].

Sources of Exposure to Phthalates

Since phthalates are not chemically bound to the PVC polymer, they can be released from products or dissolve upon contact with liquids or fats. Phthalates have low volatility and are slowly released from PVC products during use, diffusing into the air. They are also released into the environment during their production, processing and waste disposal. Once in the environment, phthalates bind to particles—primarily dust particles in the home—and can be carried in the air over long distances [2]. Human exposure to phthalates occurs through inhalation and ingestion of contaminated air and food as well as from skin contact. Food may become contaminated when it comes in contact with packaging that contains phthalates. For the general population, this may be a major source of exposure. Children may be exposed to higher concentrations of phthalates from food consumption because they tend to consume more food than adults relative to their body weight [1, 4]. Studies of skin exposure to phthalates are limited, but this route is thought to be insignificant [2].



An additional exposure route for young children is through mouthing toys, childcare articles, and other products containing phthalates. Through mouthing of these products, phthalates can dissolve in saliva and become absorbed into the body [2]. According to the CPSC, the duration of mouthing activity for toys and childcare articles varies by age [3]. A study by the US Center for Disease Control and Prevention (CDC) found that younger children's higher concentration of phthalates may be partly due to mouthing of toys and childcare articles as well as coming into closer contact with PVC flooring products [4]. The extent of oral absorption through mouthing of phthalate-containing products at amounts to which children are expected to be exposed is not well studied. In addition to the length of time of mouthing activity, oral absorption depends on the migration rate of the phthalate in the product that is being mouthed. Studies suggest 100 % oral absorption of phthalates such as DEHP and DINP at daily exposure levels [3, 8, 13].

Fetal exposure to phthalates has been shown to be correlated with maternal exposure. Neonates and developing fetuses at critical points in their development may be exposed through maternal use of PVC products. For example, major medical uses of PVC are in blood and plasma bags, as well as intravenous bags and tubing which may contain as much as 80 percent DEHP, the most frequently used plasticizer in medical devices. Other uses include intestinal feeding and dialysis equipment, catheters, and gloves. Phthalates may leach when the medical device is heated or when the PVC comes into contact with blood, drugs, or intravenous fluids. Newborns and children in pediatric settings may receive the highest doses from blood transfusions, extracorporeal oxygenation, and respiratory therapy [4, 11, 40].

Human Health and Environmental Concerns

Most of the early studies on the health effects of phthalates experimented with doses administered to laboratory animals above human exposure levels. In recent years however, researchers have noted health effects such as reproductive abnormalities and developmental effects in animals given doses of phthalates similar to those to which humans are exposed. Epidemiologic studies have also evaluated the human health impacts of phthalate exposure. These studies have identified a possible association between exposure to phthalates and male reproductive malformation, sperm damage, fertility impairment, female reproductive tract diseases, early puberty in girls, asthma, and thyroid effects. Adverse effects on the lungs, liver and kidneys have been observed in animals and in some limited human studies.

Phthalates may also pose risks for aquatic and terrestrial ecosystems particularly in the vicinity of phthalate processing industries. Some phthalates are bioaccumulative and have been detected in aquatic organisms. For example, BBP has been shown to be toxic to aquatic organisms and may cause long-term adverse effects in aquatic environments. Studies suggest BBP may have endocrine disrupting effects in fish. Birds and mammals may suffer impacts from food chain exposures. However, other phthalates such as DEHP have the potential to biodegrade under aerobic conditions. [See 2, 4, 8, 11, 13, 24, 28, 29, 30, 31, 42, 50.]

Chemical Alternatives to Phthalates

A number of substances have been identified as alternative plasticizers. These alternatives include citrates, sebacates, adipates, and phosphates. They are being substituted in products that traditionally use phthalates, such as toys, childcare articles and medical devices. In addition to their application as alternative PVC plasticizers, these substances are also being used as solvents and fixatives in cosmetic products, inks, adhesives, and other consumer products.

Most of these alternative plasticizers are not well studied with regard to their potential effects on human health and the environment. Although many of these alternatives show promising application potential, significant exposure may lead to adverse health effects. Like phthalates, these alternative plasticizers are not chemically bound to the polymer and can leach out of products. Some documented effects from exposure to the alternative plasticizers that are currently being used in children's products and other consumer products include eye, skin, and respiratory irritations. There is also evidence of effects on the kidney, liver, spleen, testes, and uterus. Most evidence on human health effects is derived from laboratory studies as few epidemiologic studies have been conducted on these materials. In addition, some alternative plasticizers may be toxic to aquatic organisms and may not biodegrade in the environment. Table 2 identifies some alternative plasticizers currently used in children's and other consumer products, and their potential health and environmental effects.

TABLE 2 **Alternative Plasticizers**

Alternative	Function/Product	Human Health Concerns	Environmental Concerns
ATBC: Acetyl tributyl citrate	• Primarily used as a plasticizer in cosmetic products, toys, vinyl, adhesives, medical devices, pharmaceutical tablet coatings, food packaging, flavoring substance in foods, printing inks and plastics in concrete. • Also used as a surface lubricant in the manufacture of metallic articles that contact food [14, 15, 17, 19, 21].	• Intravenous exposure affects the central nervous system and blood in laboratory animals. May have moderate irritation effects on eyes and increase liver weights [21]. • Studies show that it inhibits the proliferation of Lymph node T cells [16]. • Exhibits fire and explosive hazard in the presence of strong oxidizers and nitrates [14].	• Can bioaccumulate and is inherently biodegradable (in an inherent biodegradation test, 80 percent was degraded). However, in a non-standard test aerobic degradation was slow and no data is available on anaerobic degradation [21].
DINCH: Di-isononyl-cyclohexane-1, 2-dicarboxylate	• Primarily used as a plasticizer in PVC medical devices (blood tubes or packaging for nutrient solutions), toys, food packaging, cosmetics products, shoes, exercise mats and cushions, textile coatings, printing inks [17].	• Acute toxicity effect is low. However, an increase in testes weight, liver weight, thyroid weight, serum gamma-glutamyl transferase and thyroid-stimulating hormone was observed in laboratory animals after repeated exposure. Blood and transitional epithelium cells in urine was also observed [22, 40].	• No data found regarding effects of environmental exposures.

Alternative	Function/Product	Human Health Concerns	Environmental Concerns
DOTP: Dioctyl terephthalate	• Primarily used as a plasticizer for PVC toys, childcare articles, consumer products, beverage closures and other polymer materials including cellulose acetate-butyrate, cellulose nitrate, and chloroprene rubbers [32,40].	• Slightly irritating to eyes but will not damage eyes. • Prolonged exposure may cause dermatitis. Studies involving rodents showed inflammatory damage to the kidneys [23].	• Potential for bioconcentration in aquatic organisms is low. Likely to be biodegradable under aerobic and anaerobic conditions [32].
ESBO: Epoxidized soybean oil	• Primarily used as a plasticizer in closure gaskets used to seal glass jars, and as a stabilizer to minimize the ultraviolet degradation of PVC resins baby food jars, fillers, paint and lacquers, adhesives, printing inks, and packaging [18,21].	• A worker developed asthma from exposure to vapors from heated PVC film. Vapor may also produce asthmatic symptoms in as little as 5 minutes [21]. • Studies involving rats have reported skin and eye irritations, secondary agent in bronchospastic reaction. • Suspected to cause some effects on the kidney, liver, testis and uterus by repeated oral administration [18].	• Toxic to the crustacean Daphnia magna. Estimated to be bioaccumulative. Two standard tests administered by OECD concluded it is biodegradable in aerobic environments [21].
Mesamoll II: alkylsulphonic phenyl ester (ASE)	• Used as a plasticizer in PVC, polyurethanes, natural rubber, styrene-butadiene rubber, blends of styrene-butadiene rubber and butadiene rubber, isobutylene-isoprene rubber, acrylonitrile-butadiene rubber, and chloroprene rubber [24].	• Has not been comprehensively studied for toxic effects.	• No data found regarding effects of environmental exposures.
TETM: Tri-2-ethylhexyl trimellitate	• Primarily used for heat-resistant PVC articles, PVC-products used in the hospital sector (blood platelet bags), packing, cables, profiles, and floor/wall coverings [21]	• May cause irritation, nausea and vomiting in humans from exposure to mists and fumes. • Toxic to laboratory animals through inhalation. • Shown to irritate the skin of guinea pigs, rabbits and mice and the eyes of rabbits. • Studies in dogs showed an increase in weight of liver and spleen. • In rats, exposure through diet resulted in slightly increased liver weights and peroxisome proliferation [21].	• Very limited data on environmental effects is available. • Potential for environmental effects is associated with the accumulation of the compound in biota, in aquatic sediments and in soils treated with sewage sludge. • Available data indicate that it does not biodegrade readily [21].
COMGHA: Acetylated monoglycerides of fully hydrogenated castor oil	• Used in PVC-containing films, tubes, bottles, food packaging materials and other polymers such as polyolefin, styrene, and PET [40].	• No data found describing human exposure. • Slightly lower migration rate was found when compared to DEHP [40].	• No data found regarding potential environmental effects.

Alternative	Function/Product	Human Health Concerns	Environmental Concerns
Eastman 168: bis(2-ethylhjexyl)-1, 4-benzenedicarboxylate	• Used as a plasticizer in PVC toys, bottle caps and closures, coatings for cloth, electric connectors, flexible film, pavement, striping compounds, walk-off mats, sheet vinyl flooring, other vinyl products, and PVC/VA copolymer resins. [39].	• No data found.	• No data found regarding potential environmental effects.
DEHA: Di(2-ethyl hexyl) adipate	• Used as a plasticizer in toys, vinyl flooring, wire and cable, stationery, wood veneer, coated fabrics, gloves, tubing, artificial leather, shoes, sealants, and carpet backing. • Also used in films employed in food packaging materials, fillers, paint and lacquers, adhesives, plastic in concrete, and rubber products. • Expected to be widely used in the near future in products for the hospital sector, printing inks and other PVC products [21, 40].	• Slightly toxic when administered intravenously in animal studies. • May produce dose-dependent changes in the body. • Reported to cause liver tumors, reduced bodyweight and increased liver weight (may be a result of hepatic peroxisome proliferation) in mice and rats [21, 40].	• Toxic to algae, crustaceans and fish. • Chronic data on crustaceans show adverse effects on reproduction of Daphnia magna. • Not a bioaccumulative substance. • Available data indicate evidence of biodegradability [21].
DBA: Di-butyl adipate	• Primarily used as a plasticizer for resins. Also used in floor wax [53].	• Combustible. Mildly irritating to skin and causes coughing when inhaled [54]. • No data found on long-term exposure effects.	• Moderately toxic to fish, daphnids and algae. • Readily biodegradable. • No data found on bioaccumulation [53].
BHT: Butylated hydroxytoluene	• Used in childcare articles intended to be mouthed such as teething products and as an antioxidant in EVA and polyethylene plastics. Also used as a food additive [19].	• May cause impaired blood clotting, hemorrhage, cytotoxicity, hepatocellular injury and carcinogenesis [19].	• No data found regarding potential environmental effects.
HPCL: Hyperbranched poly (Є-caprolactone)	• Intended primary use is in PVC applications including coating resins, polymer additive, adhesive agents, and processing aids [41].	• No data found. • According to one study, it does not migrate when used in PVC even under harsh conditions such as high temperature [41].	• No data found regarding potential environmental effects.

Alternative	Function/Product	Human Health Concerns	Environmental Concerns
DEHPA: Di(2-ethylhexyl) phosphate	• Primarily used as a flame retardant in products with specific fire resistant demands. Also used as a plasticizer in PVC products used in the hospital sector, packaging, cables, floor and wall coverings [21].	• In humans, inhalation caused weakness, irritability and headache. • Causes irritation of the eyes, and first and second degree skin burns. Reported to be corrosive to the skin and eyes in rabbits [21].	• Ecosystem toxicity data indicate it is harmful to algae, crustaceans and fish. In a test involving the microorganism thiobacillus ferrooxidans, respiration was inhibited. • Has low bioaccumulation potential and is inherently biodegradable [21].
TEHPA: Tri(2-ethylhexyl) phosphate	• Used in fillers, paint and lacquers, adhesives, plastic in concrete and similar DEHPA applications [21].	• May produce moderate erythema and slight irritation to eyes. • Observed effects in rats include hematological changes and reduced body weight gain. • A slight evidence of carcinogenicity has been observed in female mice [21].	• Data show it is toxic to algae. Not readily biodegradable according to the available aerobic biodegradation data. • Slowly biodegrades under anaerobic conditions when present in weak solutions [21].
OTSA: O-toluene sulfonamide	• Information on use is limited. Anticipated to be used in the future mainly in PVC cables [21].	• Reported to be teratogenic in rats, but only exhibiting a weak mutagenic effect (this is however based on studies without detailed descriptions of the study design) [21]. • Sulfonamides may cause hyperbilirubinemia in infants. In addition, sulfonamides may cause hemolytic anemia in glucose-6-phosphate dehydrogenase-deficient neonates [37].	• Does not readily biodegrade [21].
TXIB: 2,2,4-trimethyl 1,3-pentanediol diisobutyrate	• Primarily used as a plasticizer in PVC toys, flooring, products used in the hospital sector. Also used in fillers, wallpaper, paint and lacquers, printing inks, plastic in concrete, artificial leather, packaging, as well as vinyl and urethanes [21, 47, 48].	• May be associated with eye irritation and nasal allergies [47]. • Has been observed to be slightly irritating in guinea pigs. • Reversible liver weight changes have also been observed in rats from chronic exposure [21].	• Has some potential for bioaccumulation [21].
DOS: Dioctyl sebacate	• Primarily used as a plasticizer for PVC products and elastomers. • Compatible with nitrocellulose and polyvinylidene chloride. • Anticipated to be used in printing ink and adhesives [21, 38].	• Exhibits moderate acute toxicity when administered orally to rats. Oral administration to rats also showed increased liver weight, peroxisome proliferation and increased levels of peroxisome enzymes [21].	• Has a high bioaccumulation potential and has been shown to degrade slowly [21, 38].

Alternative	Function/Product	Human Health Concerns	Environmental Concerns
DBS: Di-butyl sebacate	• Used as a plasticizer, flavoring agent, and cosmetic and perfume additive [56].	• Combustible. • Chronic skin contact may cause skin sensitization [55]. • Mildly toxic when ingested [56].	• Biodegradable. • Low and moderate potential for bio-accumulation and bioconcentration in aquatic organisms respectively [56].
Grindsted soft-n-safe: Made from fully hydrogenated castor oil and acetic acid	• Primarily used as a plasticizer in food contact materials (approved for use in the EU, US, South America and most of Asia), medical devices, vinyl flooring, wallpaper, shrink wrap film, textile dyes, ink applications, adhesives and sealants [26,27].	• According to the manufacturer (Danisco), it shows no indication of dermal absorption/irritation or eye irritation. • No hormone-disrupting or mutagenic effects may result [27].	• According to the manufacturer, there is no indication of aquatic toxicity [27]. • Biodegradable [26].

Alternative Plastics that Do Not Require Phthalates

Petroleum-Based Plastics

Choosing a plastic that does not require the addition of phthalates is another substitution approach. Although all plastics require the use of additives in processing to improve material properties, many types of plastic require fewer and less harmful additives than those required by PVC. These plastics have a wide range of applications in toys, children's products, and other consumer products. Substituting alternative plastics for PVC may also alleviate some of the health and environmental concerns that have been identified in the PVC manufacturing and disposal stages of the life cycle.

Petroleum-based plastics are produced from non-renewable fossil fuel resources. The production of these plastics poses a variety of health and environmental concerns. Extraction of raw materials, manufacturing, and disposal of petroleum-derived plastics generate greenhouse gases and pollutants including hydrogen chloride, hydrogen sulfide, sulfuric acid, heavy metals, chlorofluorocarbons, polycyclic aromatic compounds, volatile organic compounds, and nitrogen and sulfur dioxides. Table 3 describes nine common petroleum-based plastics that can serve as substitutes for PVC plastic in consumer products and their associated human health and environmental concerns.

TABLE 3 **Petroleum-Based Plastics**[b]

Plastic	Application/Product	Human Health Concerns	Environmental Concerns
PU: Polyurethane	• Extensively used for applications where PVC or rubber are used [6]. Used in foam toys, fabrics (in furniture garments and upholstery), wheels, insulators in kitchen appliances, decoration moldings (door frames, windows, columns, medallions), and in construction as sealants. • Also used as adhesive for woods and in varnishes [49].	• Combustible. Produces highly toxic hydrogen cyanide in fires. • Can cause mechanical irritation to the eyes and lungs in dust form. • Exposure to high levels of methylene diphenyl isocyanate and toluene diisocyanate (substances used to produce PU) causes severe lung and eye damage, severe irritation to mucous membranes, euphoria, ataxia, mental aberrations, asthmatic attacks, chest tightness, coughing, breathlessness, inflammation of the bronchi, and noncardiogenic pulmonary edema [49]. • Toluene diisocyanate is classified as a possible human carcinogen by IARC [52].	• Methylene diphenyl isocyanate and toluene diisocyanate degrade rapidly in the environment. • No effects have been observed in landfill disposal or after incineration [49].

b Information in Table 3 is from: Alvarez-Chavez, C. (2009). Sustainability of Bio-Polymers: Comparative Analysis of Corn and Potato Based Bio-Polymers. Doctoral Dissertation. University of Massachusetts, Lowell.

Plastic	Application/Product	Human Health Concerns	Environmental Concerns
EVA: Ethylene vinyl acetate	• Used for toys, teethers, doll parts, footwear items (shoes insoles and slippers), exercise mats, stationery, household, educational and handcraft items, flexible sheeting, film, packaging and coating applications [6, 49]. • Ethylene vinyl acetate has been shown to contain phthalates, which could be intentionally added to the material or present as a result of contamination during processing [6].	• Produces toxic chemicals in fires. • Uses carbon monoxide in production. • Risk of fire due to pellets or powder plastic. • Chloride catalyst is used in some vinyl acetate production. • Risk of children choking from small parts due to product breakage [49].	• Byproducts of ethylene production. Chloride catalyst used in some vinyl acetate production. • Ideal disposal method is in landfill. • Incomplete combustion produces carbon monoxide and low molecular weight aldehydes [49].
PET: Polyethylene terephthalate	• Used for fibers, bottles, electrical components, graphics, film base, and recording tapes [49].	• Antimony trioxide is a catalyst in production. It remains in the material and can leach [49]. • Workers exposed to antimony trioxide developed gastritis, abdominal pain, diarrhea, neuritis, vomiting, dizziness and headaches. • Exposure to antimony trioxide dust and fumes can irritate the respiratory tract and mucous membranes, and cause antimony pneumoconiosis [51].	• Recyclable but not biodegradable or compostable [49].
HDPE: High density polyethylene	• Used for toys and childcare articles, water tanks, tubes, fittings, foil and plastic bags, insulation material and other soft PVC applications [49].	• Flammable compounds (organometallic compounds and peroxides) are used in its production [49].	• Recyclable but not biodegradable or compostable [49].
PP: Polypropylene	• Used for tubes, fittings, packing material, hinges, automobile parts, and other PVC applications; except rotocasting [49].	• Raw materials are flammable and explosive. • Formaldehyde and acetaldehyde are released during fires [49]. • International Agency for Research on Cancer (IARC) classifies formaldehyde as a known human carcinogen) and acetaldehyde as a possible human carcinogen [52]	• Recyclable but not compostable [49].

Plastic	Application/Product	Human Health Concerns	Environmental Concerns
PS: Polystyrene	• Suitable for a wide range of applications in children's products, disposable articles, signs, cabinets, machine parts and picture frames [49].	• Produces toxic chemicals in fire. • Styrene can leach from PS and is toxic to the brain and nervous system, red blood cells, liver, kidneys and stomach in animals [49]. Styrene is classified as a possible carcinogen by IARC [52].	• Consumes higher energy during production than PVC. • Does not degrade easily in the environment. • Difficult to recycle and not compostable. • Styrene can be found in the air, water and soil after release from manufacture, use and disposal of products. [49].
ABS: Acrylonitrile butadiene styrene	• Used for toys, automobile body parts, suitcases, tubes and bolts. Can be used for polyvinyl chloride, polypropylene, polycarbonate and polystyrene applications [49].	• Produces toxic chemicals in fire. • Styrene is toxic to the brain and nervous system, red blood cells, liver, kidneys and stomach in animals [49]. • IARC classifies acrylonitrile and styrene as possible human carcinogens and butadiene is a known human carcinogen [52].	• Extremely difficult to recycle. • Acrylonitrile is volatile and significant quantities escape into air during use. • Styrene can be found in the air, water and soil after release from manufacture, use and disposal of products [49].
SBS: Styrene butadiene styrene	• Used for toys and childcare articles [49].	• Styrene produces toxic chemicals in fire. • Styrene can leach from polystyrene and is toxic to the brain and nervous system, red blood cells, liver, kidneys and stomach in animals [49]. • IARC classifies styrene as a possible human carcinogen and butadiene as carcinogenic to humans [52].	• Difficult to recycle. • Styrene can be found in the air, water and soil after release from the manufacture, use and disposal of products [49].
ABS/Polyurethane Alloy	• Used for shoe soles, sports boots, automotive parts, solid tires, industrial rollers and a variety of mechanical goods [49].	• Polyurethane produces toxic chemicals in fires. • Styrene can leach from polystyrene and is toxic to the brain and nervous system, red blood cells, liver, kidneys and stomach in animals [49]. • IARC classifies acrylonitrile and styrene as possible human carcinogens and butadiene as carcinogenic to humans [52].	• Extremely difficult to recycle. Acrylonitrile is volatile and significant quantities escape into air during use. • Styrene can be found in the air, water and soil after release from the manufacture, use and disposal of products. • Methylene diphenyl isocyanate and toluene diisocyanate degrade rapidly in the environment. • No effects have been observed in landfill disposal or after incineration [49].

Alternative Plastics that Do Not Require Phthalates

Bio-Based Plastics

Biobased plastics are alternatives to petroleum-based plastics. They may be completely made from plant materials or may be a blend of plant-based and petroleum-based plastics. Plants such as corn, soy, rice, wheat and linseed can be converted to plastics. Many of these plastics are currently under development for a wide range of commercial applications. The production of biobased plastics is not without hazards. The use of large quantities of pesticides in industrial agricultural production and hazardous chemicals/additives such as sodium hydroxide, carbon disulfide, and chlorine in processing are of concern to human health and the environment. Genetically modified organisms (GMOs) used in development of biobased plastics are also a concern because their effects in the environment are not well understood. Furthermore, not all biobased plastics are biodegradable or compostable. The biodegradability or effective composting of bio-based plastics is dependent on the material's chemical structure and composition. Table 4 lists biobased plastics under commercial development and their potential health and environmental concerns.

TABLE 4 **Biobased Plastics**[c]

Plastic/Source	Application/Product	Human Health Concerns	Environmental Concerns
Polylactic Acid (PLA)/corn, sugar beets, sugar cane, wheat, sweet potatoes or rice	• Used for hard resin for food containers, film and fibers (apparel and carpeting applications, clothing). May replace thermoplastics in many applications. Properties are similar to polyethylene terephthalate, polypropylene and polystyrene [57].	• Purification of lactic acid requires sulfuric acid. • Uses tin octanoate as a catalyst in processing. Tin octanoate can cause neurotoxic and cytotoxic effects in animals. Organic tin compounds can cause irritation of the skin and lungs, and also masculinization of female or infertility in male aquatic animals. • Emerging health concerns about tin residues in PLA used in medical applications. • 1-octanol used as a polymerization initiator is volatile and combustible and can cause irritation to tissues. • E-coprolactone used to improve properties causes skin irritation and may cause respiratory tract irritation [57].	• Concerns about environmental impacts from use of bioengineered microorganisms in crop production. • Can be completely recycled to lactic acid (but required infrastructure for recycling does not exist). • Will compost at temperatures above 60 °C (must hydrolyze first and needs commercial composting infrastructure which it is not widely available) and can be safely incinerated [57]. • 1-octanol used as a polymerization initiator is toxic to aquatic organisms

c Information in Table 4 is from: Alvarez-Chavez, C. (2009). Sustainability of Bio-Polymers: Comparative Analysis of Corn and Potato Based Bio-Polymers. Doctoral Dissertation. University of Massachusetts, Lowell.

Plastic/Source	Application/Product	Human Health Concerns	Environmental Concerns
Starch derived plastics Thermoplastic starch (TPS)/corn, potato, rice, wheat and tapioca	• Used for packaging, toys, films, shopping bags, planters and planting pots, strings, straws, tableware, tapes, cups, cutlery, edge protectors, golf tees, trays, and mantling for candles and nets. Properties are similar to polyethylene and polystyrene [57].	• Finely pulverized starch can suspend in the atmosphere and cause powerful explosions. • Titanium dioxide used as additive is a potential occupational carcinogen. • Calcium carbonate used as additive may cause irritation in eyes, skin, and respiratory system and cough [57].	• Concerns about ecosystem impacts from bioengineered microorganisms used in crops. • Can biodegrade depending on the type and amount of additive and copolymer used [57].
PHA: Polyhydroxyalkanoate/ Sugar cane, beets, corn steep liquor, palm kernel, soy oils, cellulosic biomass	• Used for toys, films, fibers, adhesives, inks, packaging, coatings, molded goods, and a variety of other applications. Performs better than traditional plastics and comparable to acrylic polymers. Can behave both as a traditional thermoplastic polymer and an elastomer [57].	• PHA is non-toxic and non-allergenic to consumers. • In processing, may use physical, chemical or enzymatic extraction method. Enzymatic method is safer for workers. • Solvents such as chloroform, methylene chloride, and 1, 2-dichloroethane used in physical extraction method are considered possible human carcinogens by IARC. • Another solvent, pyridine, is flammable and causes irritation in eyes and skin, liver and kidney damage. • Methanol, hexane and diethyl ether are used in purification. Methanol is flammable and causes irritation in eyes, skin, upper respiratory system, visual disturbance, and optic nerve damage (blindness). Hexane is flammable, causes irritation in eyes, nose and is neurotoxic. Diethyl ether is flammable, can produce explosive peroxides in contact with oxygen, causes narcosis, nausea, vomiting, irritation of the eyes, skin, and upper respiratory system. • Sodium hypochlorite used in processing can burn eyes and skin, and produce toxic chlorine [57].	• Concerns about impacts on the environment from use of bioengineered microorganisms in crops and during PHA synthesis. • Highly biodegradable by numerous aquatic and terrestrial microorganisms [57].

Plastic/Source	Application/Product	Human Health Concerns	Environmental Concerns
Urethanes Polyol/soy oil/ soybean, castor oil, rapeseed, sunflower and linseed	• Used for adhesives, coatings, flexible and rigid foams, and elastomers [57].	• Combined with isocyanates (toluene diisocyanate or methylene diphenyl isocyanate) to make foam products. • Toluene diisocyanate is volatile, and exposure to it can cause severe irritation to mucous membranes, euphoria, ataxia, mental aberrations, asthmatic attacks, chest tightness, coughing, breathlessness, inflammation of the bronchitis, and noncardiogenic pulmonary edema [57]. • Toluene diisocyanate is classified by IARC as a possible human carcinogenic [52]. • Methylene diphenyl isocyanate can irritate the skin, eyes and respiratory tract. Chronic exposure to methylene diphenyl isocyanate can sensitize the skin or respiratory tract, which may lead to asthma [57].	• No data found regarding potential environmental effects.
Cellulose Cellulose acetate (CA), cellulose acetate propionate (CAP) and cellulose acetate butyrate (CAB)/ cotton fibers and wood	• Used for toys, flexible film substrates for photography, toothbrush handles, selective filtration, adhesive tapes, cellophane, semi-permeable and sealable films and automotive coatings, appliance cases, steering, pens, containers, eyeglass, frames and sheeting [57].	• Poor fire resistant properties. • Corrosive, flammable and toxic chemicals including dichlorine, hydrogen peroxide, carbon disulfide and caustic soda are used in production and can result in worker exposure. • Cellulose acetate is made by reacting cellulose fibers with a corrosive mixture of acetic compounds and sulfuric. • N-methylmorpholine n-oxide is used in processing cellulose and is classified by the Canadian Workplace Hazardous Materials Information System as a sensitizer, skin and eye irritant, and may cause chronic toxic effects. • N-methylmorpholine n-oxide produces explosive peroxides in contact with oxygen. • Triphenyl phosphate, which is used to reduce flammability, is an irritant of the skin and eyes [57].	• Production process has relatively high energy and water requirements. • The potential for biodegradation of cellulose acetate may be affected by the number of ether linkages in cellulose backbone. • One study showed evidence of compostability of cellulose acetate [57].

Plastic/Source	Application/Product	Human Health Concerns	Environmental Concerns
Poly(trimethylene terephthalate) (PTT)/sugar from corn with terephthalic acid (PTA) or dimethyl terephthalate (DMT) derived from petroleum	• Used in fibers for textiles, carpets and apparel. Can be used in packaging and as a substitute product for nylon [57].	• Made by reacting genetically modified sugar from corn with terephthalic acid or dimethyl terephtalate derived from petroleum. • Methanol, which could be used in esterification of dimethyl terephtalate, is flammable, and may cause skin to become dry and crack. Inhalation and skin absorption of methanol can irritate the mucous membrane and affect the nervous system, particularly the optic nerve. • Terephthalic acid is a suspected neurotoxicant. Accidental dermal contact with dimethyl terephtalate is of concern due to the possibility of burns from molten liquid. • Acrolein and allyl alcohol fumes might be produced in small amounts during processing. • Breathing large amounts of acrolein may damage the lungs and could cause death. Breathing small amounts of acrolein may cause eye watering and burning of the nose and throat and a decreased breathing rate (these acute effects usually disappear after exposure stops) [57].	• Biodegradable [57].
Lignin/Plants and Wood	• Used as filler in thermoplastics, thermosets and rubbers. Can be converted into carbon fibers [57].	• Produced as a byproduct of the Kraft process and requires harsh chemical treatment. • Workers can be exposed to corrosive, flammable and toxic chemicals including dichlorine, hydrogen peroxide, carbon disulfide and caustic soda that are used in production. • Kraft lignin is non toxic and approved for food and food packaging applications according to FDA regulations [57].	• Production process has relatively high energy and water requirements. • Biodegradation is lower than cellulose. • Compostable [57].
Natural fiber-reinforced composites (kenaf, hemp, ramie, flax, sisal henequen, jute, pineapple leaf)	• Can be used for reinforcing starch and protein based composites [57].	• Potential for toxic exposures to workers from corrosive and toxic chemicals including dichlorine, hydrogen peroxide, carbon disulfide and caustic soda used in production. • Can also be obtained by biological methods by using enzymes, bacteria and water [57].	• Production has high energy and water requirements. • Biodegradable and compostable [57].

Plastic/Source	Application/Product	Human Health Concerns	Environmental Concerns
Cellulose nano-composites (obtained by chemical treatments and steam explosion of cellulose starting materials)		• Concern about unknown human health impacts of nanoparticles. • Potential for toxic exposures to workers from corrosive, flammable and toxic chemicals including dichlorine, hydrogen peroxide, carbon disulfide and caustic soda used in production [57].	• Concern about unknown environmental effects of nanoparticles. • Production process has relatively high energy and water requirements [57].
Polysaccharide nanocomposites		• Concern about unknown human health impacts of nanoparticles [57].	• Air, water and soil emissions need to be addressed [57].
Soy protein	• Can be used to make foams. • Application limited due to low strength and hydrophilicity. • Soyplus™ has been used for toys, garden supplies, food service items, industrial packaging, mulch, golf tees and building materials [57].	• Production involves the use of alcohol or volatile solvent, alkaline and acid substances, and formaldehyde or glutaraldehyde [57]. • Formaldehyde is a known human carcinogen according to IARC [52]. • Chronic exposure to glutaraldehyde causes skin sensitivity resulting in dermatitis, and irritation of the eyes and nose and occupational asthma [57].	• Biodegradable and compostable [57].
Corn zein	• Used for films, lacquers, varnishes, adhesives, textile fibers and molded plastic objects. • Hot press molding mechanical properties of corn gluten-based materials are similar to PVC [57].	• Production involves the use of alcohol or volatile solvents, alkaline and acid substances, and formaldehyde or glutaraldehyde as crosslinker [57]. • Formaldehyde is a known human carcinogen [52]. • Chronic exposure to glutaraldehyde may cause dermatitis, and irritation of the eyes and nose as well as occupational asthma [57].	• Biodegradable and compostable [57].

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