Contractor's Report to the Board

Health Concerns and Environmental Issues with PVC-Containing Building Materials in Green Buildings

Review of Current Practices and Trends in the Use, Recycling, and Disposal of PVC-Containing Building Materials

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Executive Summary

Many building materials contain polyvinyl chloride (PVC). Examples include roofing, siding, window casings, floorings, fabrics (vinyl), wall coverings, water and sewer pipes, furniture, hard surfaces, flexible wire coatings and electronics. There is growing concern regarding the potential human health and environmental impacts of producing, using and disposing of PVC-containing materials. This concern has given rise to debate over whether or not to specify the use of recycled PVC-containing building products in green buildings. The Office of Environmental Health Hazard Assessment (OEHHA) has performed an extensive literature search to qualitatively investigate the potential human health and environmental issues surrounding the production, use, recycling and disposal of products containing polyvinyl chloride.

More specifically, this effort focused on qualitatively understanding the potential human health and environmental impacts of using recycled PVC in buildings given the presumed continued use of PVC in our society. In addressing this question, OEHHA staff did not conduct a quantitative risk assessment of the health and environmental effects of PVC or recycled PVC. The larger question of whether to use or not use PVC in general is not the subject of this research and, therefore, the use of alternative building materials was not evaluated.

In carrying out this research, OEHHA staff have assumed that PVC will continue to be produced and used in building materials in highly significant amounts. We have assumed that once it has reached its useful life, the PVC material will continue to present a significant solid waste challenge. We have also assumed that once the PVC has reached its useful lifespan, it will most likely be handled in one of three ways: (1) landfilling, (2) waste incineration, or (3) recycling. The above list of assumptions places this report in the proper context.

The main elements of this report are: (1) Description of chemical properties and uses of PVC; (2) Discussion of the lifecycle of PVC products including recycling and unintended fate of PVC products (*e.g.*, accidental fires); (3) Review of selected emissions and exposure scenarios that could occur at each stage of the lifecycle; (4) Identification of selected chemicals of concern associated with PVC products; (5) Discussion of some possible routes of human exposure to selected chemicals of concern; and (6) Discussion of the use of recycled PVC products in the context of the presumed continued extensive use of PVC in our society. This report will assist California Integrated Waste Management Board staff in making recommendations to the Integrated Waste Management Board (IWMB) regarding its future position on the use of PVC-containing recycled content building materials in its green building program.

Overall, our research of the topic and the information presented in this report supports the conclusion that the risk of adverse impacts to humans or the environment from using PVC-containing recycled-content building materials is no greater than the risk associated with using virgin PVC. However, potential risk of adverse impacts can vary with respect to virgin and recycled PVC during other stages of the PVC lifecycle. A qualitative summary of the potential human health and environmental concerns for both virgin and recycled content PVC materials can be found in Table 2 of this document. OEHHA suggests that recycled PVC for use in buildings should not contain lead or other hazardous additives that are not necessary for the integrity of building grade PVC.

Introduction

Many building materials, including flooring, wall coverings, conduit, moldings, window casings, furnishings and pipes, contain polyvinyl chloride (PVC). There is growing global concern regarding the potential human health and environmental impacts of producing, using and disposing of PVC-containing materials. The benefits of using recycled PVC-containing materials versus other building products that could be more environmentally friendly is central to the debate over whether or not to specify the use of recycled PVC-containing building products in green buildings. However, examination of building materials that could be better alternatives to PVC is beyond the scope of the current document. The focus of the current research is to examine whether the use of recycled PVC products poses human health or environmental concerns that are greater than those posed by virgin PVC.

Purpose of This Work

OEHHA has performed an extensive literature search to qualitatively investigate the potential human health and environmental issues surrounding the production, use, recycling and disposal of products containing polyvinyl chloride. More specifically, this effort focused on qualitatively understanding the potential human health and environmental impacts of using recycled PVC in buildings given the presumed continued use of PVC in our society. In addressing this question, OEHHA staff did not conduct a quantitative risk assessment of the health and environmental effects of PVC or recycled PVC.

The larger question of whether to use or not use PVC in general is not the subject of this research and, therefore, the use of alternative building materials was not evaluated. In carrying out this research, OEHHA staff have assumed that PVC will continue to be produced and used in building materials in highly significant amounts. We have assumed that once it has reached its useful life, the PVC material will continue to present a significant solid waste challenge. We have also assumed that once the PVC has reached its useful lifespan, it will most likely be handled in one of three ways: (1) landfilling, (2) waste incineration, or (3) recycling.

The main elements of this report are: (1) Description of chemical properties and uses of PVC; (2) Discussion of the lifecycle of PVC products including recycling and unintended fate of PVC products (*e.g.*, accidental fires); (3) Review of selected emissions and exposure scenarios that could occur at each stage of the lifecycle; (4) Identification of selected chemicals of concern associated with PVC products; (5) Discussion of some possible routes of human exposure to selected chemicals of concern; and (6) Discussion of the use of recycled PVC products in the context of the presumed continued extensive use of PVC in our society. This report will assist California Integrated Waste Management Board staff in making recommendations to the Board Members regarding the Board's future position on the use of PVC-containing recycled content building materials in its green building program.

Research Strategy and Results

In addition to pursuing a more traditional literature search of the subject through the standard library services, OEHHA conducted an extensive search of the World Wide Web using the following keywords: *PVC, polyvinyl chloride, human health, environmental impacts, landfills and incineration.* A number of specific as well as general search engines were employed in this effort. These included but were not necessarily limited to MSN search, Google, Lycos, Altavista, Yahoo, Ask Jeeves, Excite, Mamma, Medline, Dogpile, Webcrawler, and Scirus (see Section XI: Web Based Search Tools below).

The web search employed identified tens of thousands of documents and web pages on the subject. A significant number of these items, upon closer review, were found to be "opinion" papers. These "opinion" articles and web pages appeared to largely reflect personal or professional opinions on the subject and did not appear to be peer reviewed for scientific merit. Although many articles of this nature were reviewed and their content taken into consideration, they were given less weight in the assessment process than articles which represented fully referenced sources of information such as those found in peer reviewed scientific journals or documents produced by state, local, United States federal or international public agencies.

Documents and web pages found using the World Wide Web search tools were cross-referenced against cornerstone references previously identified for this effort. These references include PVC related summary documents obtained from the U.S. Environmental Protection Agency (EPA), Agency for Toxic Substances and Disease Registry (ATSDR), and California Environmental Protection Agency (Cal/EPA).

Other cornerstone references used in this effort include an article entitled "Environmental Impacts of Polyvinyl Chloride Building Materials" authored by Joe Thornton, Ph.D. and published by the Healthy Building Network (Thornton 2002) and two reports by the European Commission (EC 2000a & EC 2000b, Brussels, Germany) entitled "Mechanical Recycling of PVC Wastes" and "Green Paper: Environmental Issues of PVC," respectively.

In addition, over 400 peer-reviewed journal articles, reports and government publications were identified. Upon closer review, not all of these documents were found to be directly applicable to this project. Many addressed exposure scenarios and PVC related products and information that were not relevant to PVC-containing building materials question. The documents most relevant to the IWMB question of whether to support the use of PVC-containing recycled-content building materials in the green building program are referenced in the report and can be found in the References section (Section X) below.

While researching this topic, we also came across a number of individual experts in the field of PVC-based plastics manufacturing, use, recycling, impacts and disposal. Contact information for these individuals is provided in Section XII below. Investigators also identified a number of industry organizations dealing with the plastics trade, plastics research and construction. Contact information for several of these organizations can be found below in Section XIII. Environmental and health organizations concerned about the manufacturing and use of PVC were also identified. Contact information for a number of these organizations can be found below in Section XIV.

Of necessity, given the magnitude of the subject under discussion, and given the understood charter of the IWMB, OEHHA staff focused the review on those articles, reports and publications that dealt specifically with the use, reuse, recycling and disposal life cycle aspects of this subject. Extensive review of precursor chemicals, their life cycles, the vinyl chloride monomer feed-stock production, the manufacturing of PVC itself, materials and products distribution and storage, as well as a number of other "upstream" components of the PVC lifecycle and the economics of production, disposal and recycling, were considered to be outside the scope of this effort. Although a number or articles addressing these topics were referenced in this effort, overall articles addressing these topics were not extensively reviewed.

While not directly referenced in the development of this document, articles and publications on the subject, which address aspects of the entire life cycle of PVC or which may prove useful in addressing the use of PVC-based products in general were also identified. These may prove helpful to the IWMB in making further decisions regarding the PVC use issue in California so we have included a number of these references in a Bibliography, Section XV, provided at the end of this report.

What is Vinyl Chloride (VC)?

Vinyl chloride (VC) is a gas under normal atmospheric temperature and pressure conditions. It is colorless but has a mild, sweet odor (ATSDR 1997). Vinyl chloride gas is toxic and is listed as a Hazardous Air Pollutant by both the EPA (EPA 2000a, EPA 2000b and EPA 2000c) and the Cal/EPA (CARB 2004a). It is listed as known to the state to cause cancer under Proposition 65. VC is defined as a haloalkene, with a molecular structure consisting of 2 carbons, 3 hydrogens and a single chlorine atom (C_2H_3Cl). It is structurally related to vinylidene, trichloroethylene and terachloroethylene. Vinyl chloride is also known as chloroethene, chloroethylene, 1-chloroethylene, ethylene monochloride, monovinyl chloride, MVC, monochloroethene, monochloroethylene, vinyl chloride monomer, VCM, or Trovidur.

If put under pressure or kept at very cold temperatures (less than -13.4°C), vinyl chloride exists as a liquid. Although VC is poorly soluble in water (EPA 2000a), VC can contaminate water at levels that are considered harmful. The occupational permissible exposure limit is 1 part vinyl chloride per million parts air (ppm) in air (8-hour average). The EPA reference exposure concentration (RfC) is 0.04 ppm and the OEHHA air concentration for one in a million lifetime cancer risk is $5x10^{-6}$ ppm. Most people begin to smell vinyl chloride at 3000 ppm in air.

Therefore, odor detection is not sufficient to prevent excess exposure. Vinyl chloride gas is flammable and unstable at high temperatures. When burned or heated to very high temperatures, vinyl chloride decomposes chemically into hydrogen chloride (HCl), carbon monoxide, carbon dioxide and trace amounts of other products of incomplete combustion, including dioxin (ATSDR 1997).

Vinyl chloride is either manufactured specifically for commercial purposes, such as the production of polyvinyl chloride (PVC), or results from the breakdown of other manufactured substances, such as trichloroethylene, trichloroethane, and tetrachloroethylene. The greatest risk of exposure to VC is for workers in VC monomer production facilities (Peneva et al. 1985). Because of this, strict emission control measures are used to provide for safe working environments and for proper permitting operation compliance at VC production facilities. This minimizes the risk of release to both indoor working and outdoor public environments.

According to the Agency for Toxic Substances and Disease Registry, vinyl chloride was first produced commercially in the 1930s by reacting hydrogen chloride with acetylene (ATSDR 1997). Current commercial VC production involves chlorination or oxychlorination of ethylene (see Table 1 below). In direct chlorination, ethylene is reacted with chlorine to produce 1,2-dichloroethane, also called ethylene dichloride (EDC). Oxychlorination also produces 1,2-dichloroethane, but this is accomplished by reacting ethylene with dry hydrogen chloride (HCl) and oxygen (O_2).

The 1,2-dichloroethane from both processes is then subjected to high pressures (2.5-3.0 megapascals, 360-435 pounds per square inch) and temperatures (550-800°C). This causes the 1,2-dichloroethane to undergo pyrolysis, or thermal cracking, which forms the vinyl chloride monomer (VCM) and HCl as a byproduct. The vinyl chloride monomer is isolated (Cowfer and Magistro 1985). The technical-grade VCM product is available in 99.9 percent purity (HSDB 2005).

Table 1: Steps in the Production of Vinyl Chloride from Ethylene and Chlorine[1]	
1a) Direct Chlorination:	$\text{ethylene} + \text{chlorine} \rightarrow \text{EDC}(\text{ethylene dichloride})$ $C_2H_4 + Cl_2 = C_2H_4Cl_2$
-or-	
1b) Oxychlorination:	$\text{ethylene} + \text{hydrochloric acid} + \text{oxygen} \rightarrow \text{EDC} + \text{water}$ $C_2H_4 + 2HCl + 1/2\,O_2 = C_2H_4Cl_2 + H_2O$
2) EDC converted to VCM:	$\text{EDC} = \text{vinyl chloride monomer}(\text{VCM}) + \text{hydrochloric acid}(\text{HCl})$ $C_2H_4Cl_2 \rightarrow C_2H_3Cl + HCl$
3) HCl is reused to repeat Step 1b above.	

[1]Chemical reactions reproduced from buildinggreen.com, http:www.buildinggreen.com/features/pvc/pvc.cfm.

According to the ATSDR, production of vinyl chloride in the United States has grown at an average rate of 7 percent from the early 1980s to the early 1990s with an additional increase of approximately 22 percent between the years 1992 and 1993. Despite increases in production, since 1986 the total number of VC production plants has been reduced. Between 1986 and 1996 reported VC or VCM air emissions also steadily declined by a total of 400 tons per year (EPA 2000e). According to the EPA and others, this is due to improved plant operations encouraged by its vinyl chloride rule (BG 1994). At one time, vinyl chloride was also used as a coolant, as a propellant in spray cans, and in some cosmetics. Since the mid-1970s it has not been used for these purposes (ATSDR 1997). Most of the vinyl chloride produced in the United States today is used to make PVC.

What is Polyvinyl Chloride (PVC)?

Polyvinyl chloride is a synthetic solid resin material, i.e. a plastic. It is also commonly known as *vinyl*. PVC has a complex molecular polymer structure that imparts its many useful characteristics. Many common plastics are made from hydrocarbon monomers by linking multiple monomers together into long chains with a carbon backbone (ECMSIG 2004). Polyethylene, polypropylene and polystyrene are the most common examples of these. The common molecular makeup of plastics is carbon and hydrogen, but particular characteristics can be developed if oxygen, chlorine, fluorine and/or nitrogen are added to the mix. Polyvinyl chloride contains chlorine, nylon contains nitrogen, Teflon contains fluorine, and polyester and polycarbonates contain oxygen.

PVC is formed from vinyl chloride in a special heat driven plastics manufacturing process that polymerizes toxic short gaseous vinyl chloride monomers [C_2H_3Cl] into non-toxic solid PVC [$(C_2H_3Cl)_n$] long polymer chains (Figure 1).

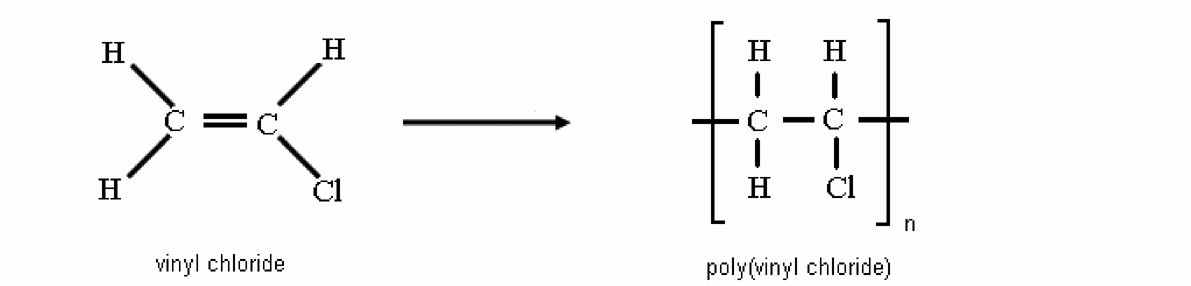

Figure 1: Structure of vinyl chloride monomer and polymer of polyvinyl chloride.

Pure PVC is a bright white, fine-grained, powder or brittle solid. It is non-toxic and inert (EPA 2000b). Because it is non-toxic, there is general agreement among a number of industry and environmental groups that pure solid PVC itself is not a significant threat to humans or the environment. However, to capitalize on its many functional characteristics as a plastic, chemicals may be added to pure PVC during the manufacturing process to impart any or all of the following properties in the finished product:

- Increase product flexibility.
- Increase heat and fire resistance.
- Prevent degradation and increase functional lifespan.
- Provide impact resistance.
- Produce a desired color or texture.

Although these additives do not chemically modify the structure of PVC itself, they change the physical properties of the plastic by physically integrating into its polymer structure. The presence of these additives, mixed in greatly varying proportions with the PVC polymer, allows for tremendous versatility in how PVC-based materials can be manufactured and used. It is the presence of additives in PVC products that is one source of concern with respect to public health and environmental issues.

Typical additives include *plasticizers*. Plasticizers impart flexibility to the PVC and allow it to be used in the manufacturing of products that need to remain flexible, like flooring, fabrics, and coatings for electrical wires. The single largest group of plasticizers used in manufacturing PVC products and materials is a class of compounds called *phthalates* (EC 2000b).

Other chemicals added to pure PVC include *stabilizers*. Pure PVC is mechanically tough, fairly weather resistant, water and chemicals resistant (EC 2000a). It is electrically insulating, but it is also relatively unstable to heat and light. Heat and ultraviolet (UV) light exposure lead to degradation of the PVC and a loss of chlorine in the form of HCl. This can be avoided through the addition of stabilizers, which prolong the life of PVC materials and the resulting PVC-based products' useful life by reducing degradation from UV light and heat. Stabilizers are most often found as *metal-based* compounds containing lead, cadmium and organotins, although the use of lead has largely been phased out. In general, because of the addition of stabilizers, PVC and PVC-containing materials have a very long material life—on the order of 10 to 50 years (EC 2000b).

Historically other additives have included *polychlorinated biphenyls (PCBs)*. PCBs were added to flexible PVC materials to enhance resistance to heat and fire, such as in coating applications for electrical wiring and electronic components. Although some older flexible products still in use today may contain PCBs, the active use of PCBs in the United States has been phased out (EPA 1979).

Where Is PVC Found and How Is It Used?

Polyvinyl chloride was first manufactured in the early 1930s, although mass production and use of PVC took off in the 1950s and 1960s (EC 2000a). In the last 40 years its use has grown substantially in the United States and throughout the world. World production of PVC today approximates more than 23 million tons per year - up from 3 million tons in 1965 (EC 2000b and VI 2004). This corresponds to about one fifth of the total plastic production.

Pure PVC is a bright white, brittle solid but, through the addition of other chemicals, it can be formulated and manufactured in a variety of colors, forms and flexibilities depending on the proposed product use and desired end product specifications (MSDS 2001). Because of this tremendous market flexibility, PVC is used to manufacture a huge number and variety of commercial and consumer products. These products are found in homes and businesses, in automobiles, on ships and planes, in mobile homes and recreational vehicles, in hospitals, schools and in day care centers.

PVC is one of the most important synthetic resin materials (i.e. plastic) in use today (EC 2000b). It is a thermoplastic, which means as a plastic it can withstand heat and temperatures without significant degradation in integrity or structure. Thermoplastics melt with heat and then resolidify without chemical change. With 19 percent and 18 percent share of the total thermoplastics production and consumption, respectively, PVC is the single largest volume thermoplastic in North America (CVSG 1999).

PVC production is mainly located in the United States, Western Europe and Asia. Production in Western Europe in 1998 was 5.5 million tons (about 26 percent of the world production). PVC production has grown by 2-10 percent annually in recent years. Production has recently declined in Europe and increased in Asia (Johnson, 2004). Rates per application have also changed. Production of rigid products has increased while production of flexible materials has decreased (EC 2000a). The fact that PVC is relatively inexpensive to manufacture and is highly adaptable to many applications accounts for why the majority of PVC produced today is used in the construction industry and why growth in this area and other consumer products is expected to continue (CVSG 1999 and VI 2004).

The main distinction among the wide variety of PVC products and their resulting applications is the absence or presence of certain types of additives (EC 2000b). All functional PVC products require the addition of heat stabilizers and lubricants to the PVC material during manufacturing (VI 2004).

However, products made from PVC materials to which plasticizers have been added are called *flexible* products. Examples include wire and cable coatings, packaging materials, plastics wraps, fabrics, containers and bottles. Other flexible materials and products include roofing materials, furniture and upholstery, wall coverings, house wares, exterior siding, children's toys, medical devices, medical storage and delivery products, automotive parts and accessories, as well as vinyl chloride-vinyl acetate copolymer products, such as films and resins otherwise known as household plastic wrap (VI 2004, Cowfer and Magistro 1985 and

Eveleth et al. 1990). Flexible PVC materials contain from 10 to 60 percent additives by weight (EC 2000a and Thornton 2002). The presence of plasticizers in flexible PVC products continues to be a source of concern with respect to potential public health and environmental exposures.

PVC products and materials that contain little or no plasticizers are called *rigid*. Rigid PVC products and materials are, stiff or rigid in nature and are typically brittle. Sprinkler and plumbing pipes and vinyl window casings, are examples of rigid highly pure PVC products. Because rigid PVC materials and products contain little or no plasticizer additives, there are typically less environmental and human health concerns associated with the use of these types of PVC materials.

PVC in Building Materials

PVC is a very important material in the building and construction industry today (EC 2000b). In the United States, building and construction applications account for an estimated 75 percent of all PVC consumption (VI 2004). Of these construction materials, pipes and ducting, conduit, flooring, linings, cladding, roof membranes, window casings and wall coverings comprise more than 65 percent. In the European Union, 60 percent of vinyl is used in building and construction applications.

An additional 25 percent is used in appliances, electronics, and furniture (EC 2000b and VI 2004). Although according to the American Plastics Council, between 1997 and 2001, the area of largest growth for the plastics industry overall has been in the plastics packaging market (compound annual growth of 4.2 percent), PVC's popularity and use as a building material continues to grow in Europe and the United States (3.8 percent per year)(APC 2004).

Organizations that support the production and use of PVC materials and products provide a number of arguments in favor of the use of PVC in building and construction materials. According to the Vinyl Institute, from an engineering perspective, PVC fares very well in construction (VI 2004). It is lightweight and has excellent mechanical strength. It is easy to work with, store, transport and install. It is fire resistant and inherently difficult to ignite. Once ignited it is apparently easily extinguishable once the heat source is removed.

PVC is a good insulator and does not conduct electricity. It is very durable. It is weather and abrasion resistant. PVC resists rotting, chemical corrosion, insect attacks, and shock. According to a number of manufacturing and industry groups, these properties make PVC ideal for long-lived applications, which are highly desired and ideally suited for the building and construction sectors.

For example, the Vinyl Institute estimates that more than 75 percent of all PVC pipes will have a functional lifetime of 40 years with potential in-service lives of up to 100 years or more (VI 2004). Window profiles and cable insulations are expected to have useful lives of more than 40 years. Its chemical resistance properties make PVC ideal for above or belowground applications, especially in the storage and transport of a wide variety of substances including oil, gas, potable water and wastewater. The fact that PVC water pipes have good insulating properties and are less likely to freeze than traditional alternatives, the fact that they do not build up scale deposits, and that they poorly conduct noise, makes PVC pipes highly useful for domestic plumbing applications.

Economically and from a consumer's use and maintenance perspective, PVC also appears to fare very well. Relative to other building materials, PVC building materials are inexpensive to purchase and install (BG 2004). PVC is almost maintenance free, unlike wood or metal products that must be protected by coating applications on a regular basis. Its durability and low maintenance means frequent replacement is unnecessary. From a consumer's perspective, this appears to make PVC products highly desirable and cost effective for both interior and exterior surface applications. Emissions to the environment from painting and staining are also reduced since these treatments are not used to maintain exterior vinyl surfaces (BG 2004).

From an energy and resource efficiency perspective, PVC has been reported to be one of the more efficient construction materials available when analyzed on an energy-equivalent basis (Cowfer and Magistro 1985). Investigators have determined that PVC has a comparatively low energy and resource use during initial production (BG 1994). Once PVC is produced, its initial conversion to finished products is also highly energy efficient as is its re-conversion to newly recycled products, if it is mechanically recycled by simple melting and re-molding or extrusion (Menke et al. 2003).

Its insulatory properties also add to the overall energy efficiency of finished buildings, such as is the case with EPA Energy Star certified highly efficient vinyl windows and exterior cladding. And, although the subject of great controversy PVC waste can be used as fuel in energy producing incinerators and has a heat value similar to that of wood or paper (VI 2004).

Although PVC appears to be highly useful in building applications, there are a number of alternatives to the use of PVC in building materials applications. Each has significant advantages and disadvantages depending on the application. While a comprehensive review and discussion of available alternatives is beyond the scope of this effort, it is important to note that alternatives to some types of PVC building materials are available. According to the Building Green.com organization, alternatives to vinyl flooring include ceramic tile, slab floors, carpeting, wood flooring, cork and linoleum.

Alternatives to PVC pipe also exist, including ABS (acrylonitrile-butadiene-styrene), polyethylene, cast iron and vitrified clay, however, they often have specialized uses and are not universally interchangeable. Alternatives to PVC window profiles are also available. These include aluminum and wood. PVC use in window profiles is, however, expected to continue to grow substantially because of its considerable energy efficiency compared to aluminum and the decreased availability of wood, which has historically been the material of choice for window profiles (BG 2004).

A number of potentially negative human health and environmental aspects of producing, using, and disposing of *PVC-based plastic products in general* have been clearly identified (MASSPIRG 2004 and Thornton 2002). Organizations that oppose the production, use and disposal of PVC materials and products argue, among other things, that:

1. PVC production is highly hazardous to workers.

2. Chemicals released during PVC production, use and disposal, are highly persistent, bioaccumulative, and contribute to global pollution.

3. PVC is an environmentally persistent organochlorine chemical that does not readily biodegrade.

4. PVC products used in indoor environments harm indoor air quality.

5. Products made out of PVC are difficult to recycle.

6. PVC disposal by incineration produces dioxins causing global pollution.
7. Accidental fires in buildings or at landfills containing PVC-based materials are a significant source of environmental pollution.

A number of significant potential impacts associated with the use and disposal of vinyl flooring products have also been raised. These include the inherent composite nature of many finished products, their apparently low recyclability, the concern about chemical "off-gassing," and the need for adhesives during installation (BG 2004).

Concerned environmental organizations have argued that these and other negative aspects apply equally well and should therefore be extended to the use of all PVC in building materials and products (BG 1994, GP 2000, HFN 2004, and Thornton 2002). However, it is worth noting that many of the potentially negative impacts listed above are not unique to the use of PVC in building materials, but apply to the the production and use of plastics in general. For example, toluene diisocyanate, used to make polyurethane, is acutely toxic and listed as known to the state to cause cancer under Proposition 65, therefore, potentially hazardous to human health and an environmental hazard.

However, the use of a chemical, even a hazardous or toxic chemical, in an industrial manufacturing process or the mere presence of a hazardous or toxic chemical within a finished product, does not mean the finished product should necessarily be considered a concern to human health or the environment. There are a number of common resin production monomers that are toxic initially but once polymerized, are considered non-toxic.

In addition, many of the negative aspects noted previously are not directly applicable to answering the fundamental question of whether it would be advisable to specify the use of recycled PVC-containing building products in green buildings because these same issues apply to the use of virgin PVC. Nonetheless, these issues and concerns do warrant additional attention. In light of this, a more extensive discussion of these concerns and others on the subject of human health and environmental impacts of recycled PVC use in green buildings can be found in Sections VII and VIII below.

In the following chapters we identify chemicals and chemical classes of potential concern, we discuss the environmental fate and transport of chemicals of concern, we identify potential human exposure pathways and potential health concerns, we discuss issues of worker safety and we also identify overall concerns and issues regarding more global impacts.

Lifecycle Assessment of PVC-Containing Building Materials

Lifecycle assessments can be very helpful in making decisions about the use of products and materials in our environment. Industrial processes use energy and consume resources. Many use hazardous or toxic raw materials. Most produce by-products and/or wastes, some of which are simply undesirable while others are hazardous and/or toxic. Plastics, including PVC, are used in a wide range of applications because they apparently offer consumer benefits similar to or better than those found with other materials. Awareness about the need to account for impacts throughout the life cycle of plastics and other materials when assessing the environmental benefits and undesirable aspects of their use as building materials is growing in the design and construction communities (Lent 2004).

However, full-scale life cycle assessments are a sizeable challenge even today. A lifecycle assessment is a comprehensive exercise that should ideally address the entire lifecycle of a given product or process, including an examination of the energy, resource, economic, social, health, and environmental impacts associated with a particular material or product. Such an assessment would typically start with the extraction of raw materials, continue with the production of feed-stock, extend thorough the manufacturing of products, the distribution, use, reuse, maintenance, and ultimately end with an examination of the disposal of these same tangible products (DEFRA 2001). Modeling and predictive tools to carry out comprehensive life cycle assessments, although growing in number and functionality, are still not available nor are they applicable for all settings (DEFRA 2001 and NIST 2002).

Given the scope of the work proposed, the researchable questions under consideration, and the level of resources available, in order to focus our efforts in addressing the question of potential human health and environmental impacts from using PVC-containing building materials and products, OEHHA staff limited this portion of our research to the following aspects of the lifecycle of PVC-containing building materials:

- A general discussion of the four main stages in the life cycle of PVC building materials, which include the production, manufacturing, use and disposal.
- The identification of the chemicals of potential concern used or produced during the four main stages of the PVC lifecycle and a discussion of the conditions, if any, under which they would be released.
- The identification of potential pathways by which humans may be exposed to chemicals of concern that may be released throughout the four main steps in the PVC life cycle.
- A discussion of the potential human health impacts that may result from exposure to the identified chemicals of concern.
- A discussion of the potential environmental fate and transport of chemicals of concern that may, if emitted, contaminate air, soil and/or water.
- A discussion of the potential environmental impacts that may result from the release of identified chemicals of concern.
- A discussion of the arguments surrounding the use of PVC in building materials within the context of this research effort.

In assessing advantages and disadvantages of a given material or product over its life cycle, decision makers must balance obvious and desirable benefits against perhaps less obvious disadvantages of producing, using and disposing of the material or product. Results and discussion of the lifecycle components reviewed are found in the following chapters. By outlining and addressing these highly focused lifecycle components, it is expected that the results of this research effort will help readers understand the risks and concerns about using materials containing recycled PVC in green buildings.

Lifecycle of PVC Products

The lifecycle of PVC and PVC-based products is comprised of four major stages—Stage 1: VC Feed Stock Production, Stage 2: PVC Manufacture (which includes polymerization, formulation and molding), Stage 3: PVC Products Use, and Stage 4: Disposal of PVC Products and Materials (adapted from Thornton 2002 and Cowfer and Magistro 1985).

VC Feed Stock Production (Stage 1)

The production of vinyl chloride "feed stock" refers to the conversion of raw chemical materials into VCM. Simple VC monomers function as "feed stock" in the production of the more complex PVC polymer. In the first steps of the VC monomer production process, ethylene and chlorine gas are produced. Ethylene gas is typically purified from petroleum or natural gas. Chlorine gas is usually synthesized directly from sea salt by high-energy electrolysis. According to the ATSDR, the next step is the production of vinyl chloride by the chlorination of ethylene through either of the following two processes described earlier (Section I.C).

Hydrogen chloride is a by-product of this reaction. HCl can be readily combined with more ethylene gas in the oxychlorination reaction to produce additional 1,2-dichloroethane (Thornton 2002). Excess HCl produced can be largely recovered and recycled for industrial use. The vinyl chloride monomer is then isolated for PVC production (Cowfer and Magistro 1985). The technical-grade VC monomer product is available in 99.9 percent purity (HSDB 2005).

Potential Emissions & Exposure Scenarios (Stage 1)

Releases of chlorine, ethylene, ethylene dichloride, hydrogen chloride, vinyl chloride monomer and chlorinated by-products including dioxins—from overheating situations—could occur to both the indoor working and outdoor environments during VC monomer feed stock production. VC monomer is both hazardous and toxic. Most of these other chemicals are hazardous or toxic as well. The greatest risk of exposure to these chemicals is to workers in VC monomer production facilities (Peneva et al. 1985).

Because of this, strict emission control measures are now used to provide for safe working environments and for proper permitting operation compliance at VC production facilities. This minimizes the risk of release to both indoor working and outdoor public environments. However, larger releases may accompany infrequent accidental releases either on-site or during transportation. Emissions under these conditions would have the potential to impact air, soil and water, depending on the physical and chemical properties of the chemicals released.

Regulatory Controls (Stage 1)

Facilities that produce vinyl chloride monomer are regulated by federal and state public health and environmental protection entities (EPA 2000b, EPA 2000c and CARB 2004a). There are on the order of 500 plastics resin producers in the United States, although not all produce PVC. Of these producers, about 70 percent are small producers employing 100 or fewer employees (ECMSIG 2004). As permitted facilities they are subject to health-based rules and regulations that address the release of toxic air contaminants. These facilities must also comply with regulations addressing transport, wastewater treatment and disposal, as well as solid waste management, transport, and delivery to landfills.

VC production facilities may or may not go on to manufacture PVC products onsite as well. More typically VC will be sent as a pressurized liquid via rail car or truck, as a "feed stock," to other commercial facilities for polymerization and subsequent manufacturing into useful PVC-containing products and materials.

The greatest risk to human health or the environment at this stage of the PVC lifecycle is to workers in VC monomer production facilities. These risks were not quantified in the current report. At present no VC feed stock production facilities are located in California (Johnson 2004).

Manufacture of PVC Products (Stage 2)

The manufacturing portion of the PVC lifecycle is carried out in manufacturing plants that are most often independent of facilities that originally produce the VC monomer feedstock. In California, VC is shipped via railroad from neighboring states to a handful of southern California PVC manufacturing facilities (Johnson 2004). At this stage in the lifecycle, vinyl chloride monomer is *polymerized* from gaseous or liquid VC into solid PVC (Cohen 1975). The PVC resin material is then *formulated* to meet end use specifications. It is finally *molded* or *extruded* into the size and shape desired for final products.

Polymerization

In this phase of the manufacturing process, gaseous VC monomers are linked together to produce complex long chain solid PVC polymers. This phase occurs in a well-controlled polymerization reaction that involves either active catalysts and other production aids or industrial solvents (ECMSIG 2004). Pure PVC polymer is typically found as a white solid powder that is inert and non-toxic (EPA 2000b).

Formulation

Once pure PVC has been formed, it can be mixed with other chemicals, according to specialized formulas, to yield a wide variety of plastic products. It is here in the formulation portion of the PVC lifecycle where additives, sometimes in excess of 50 percent by weight (EC 2000a), are blended with the PVC polymer to yield any number of desirable end-product plastic characteristics.

These additives include chemical stabilizers, plasticizers, colorants, etc. These additives do not chemically alter or bind to the PVC polymers. Instead, under the elevated temperature and highly controlled reaction conditions, these small additive molecules simply intercalate into the physical matrix of the PVC polymer to affect the desired physical properties and impart characteristics—like flexibility, heat stability, and color—in the final plastic products. Formulated PVC stock is routinely found as solid colored beads or pellets, which can be stored, sold, shipped and used as needed.

Molding

Once PVC has been formulated to meet certain end-use specification, the solid beads or pellets are heated at temperatures ranging from 140 to 250º C so that they melt together in a molten form (Zitting 1998). Once heated and melted, the formulated PVC plastic can be forced through various molds and dies to produce a myriad of shapes and forms. The molded forms are then cooled to produce the desired solid end-use products. Processing PVC plastic for end-use applications includes *extruding* into long hollow lengths (pipe, cables, window casings), *injection molding* into three-dimensional structures (like valves, bottles, plastic parts and toys), *calendaring* into thin sheets (plastics films and sheet goods), and *dispersion molding* into larger surface areas (such as coatings for carpet backing and floor tiles).

Potential Emissions & Exposure Scenarios (Stage 2)

Vinyl chloride monomer and solvents have the potential to be released into the air during the PVC manufacturing polymerization step. The amount released depends largely on how well controlled the PVC manufacturing process is. The release of these chemicals would be expected to be of greatest potential concern to workers (Peneva et al. 1985). Some studies of occupational settings do not show an increased risk of cancer from occupational exposure to PVC plastics (Hardell et al. 2004). Other studies suggest an increase in health effects, including mortality, seen with occupational exposure to vinyl chloride during production (Gennaro et al. 2003). However, the amount of VC monomer released from formulated PVC during the manufacturing formulation and molding stages is in general considered minimal (DEPA 1995). OEHHA did not attempt to quantify the level of exposure to chemicals of concern.

Plasticizers, stabilizers, and their breakdown products, as well as pure PVC solids might be released in solid (particulate), liquid, or gaseous form during the formulation portion of the lifecycle. Exposure of workers could occur under these conditions. However, formulation typically occurs in closed containers so worker exposure would most likely be limited to times when chemicals were being added to the closed mixers.

Large releases of additive chemicals to the outside environment, although rare, might occur under catastrophic spill or fire scenarios or poor manufacturing management conditions. Pure PVC is a non-volatile, non-flammable solid, which poses negligible safety or environmental concern. The minimum ignition energy for explosion of PVC resin dust is much higher than that found for cornstarch, flour, and many other plastics (MSDS 2001).

However, PVC will burn if ignited. If burned, PVC can impact the health of firefighters and individuals in the vicinity of the burn (Dyer & Esch 1976, Markowitz 1989, Markowitz et. al. 1989, and Upshur et al. 2001). The major gaseous components of burning PVC resin include carbon monoxide, carbon dioxide, hydrogen chloride, and water. Depending on burn conditions, they also include trace amounts of other products of incomplete combustion, including dioxins, but they do not include vinyl chloride monomer.

If PVC is superheated but not burned during the manufacturing molding or extrusion processes, a number of PVC degradation products may be released. The predominant degradation product is HCl gas. Quantities of HCl released during the molding process are on the order of 0.07 to 0.3 mg/m^3. These levels are well below occupational limits and typically of little concern from a broader environmental standpoint (Zitting 1998).

However, these levels exceed the chronic REL of 9 $\mu g/m^3$ for hydrogen chloride developed by OEHHA. Furthermore, if the process is not well controlled, HCl may be released during manufacturing in quantities large enough to impact workers (EC 2000a, Froneberg et al. 1982 and Pearson & Trissel 1993), and possibly other individuals in the immediate vicinity.

Regulatory Controls (Stage 2)

Environmental regulations that address PVC do so primarily in the context of its production and manufacturing from the VC monomer. The generic respirable dust or particles occupational exposure standard for workers set by the United States Occupational Safety and Health Administration (OSHA) would apply to the PVC product-manufacturing environment. The limit for respirable dust of any composition is set at an average value of 5 mg/m^3 over a typical 10-hour work-day (NIOSH 1997).

The greatest risk of exposure to chemicals released during the PVC manufacturing stage of the PVC lifecycle appears to be for workers in the manufacturing plants. However, to operate legally, these facilities must be permitted and comply with State and federal environmental and health and safety regulations that protect workers and the environment. As permitted facilities they are subject to all rules and regulations that address the release of criteria air pollutants and toxic air contaminants. In California, PVC manufacturing facilities must be permitted as stationary industrial sources by the California Environmental Protection Agency, Air Resources Board (CARB) and local air pollution control districts. These facilities must also comply with other state and federal regulations that address wastewater treatment and disposal, as well as solid waste transport and delivery to landfills.

PVC Product Use (Stage 3)

The third major stage in the PVC lifecycle is the use of PVC-based products. For this review it is important to distinguish between the concepts of a PVC-based product's *useful life*, which refers to the life of the finished product still in use, and that of the products' PVC resin *material life*.

A PVC product's *material life* is determined by the composition of the PVC resin itself and the environmental conditions it is subjected to. It is defined by how long the plastic resin can retain its physical and chemical characteristics without significant loss in structure or functionality. In some cases it is defined by how long the PVC remains in its plastic resin form before it is broken down by natural forces.

Many PVC-based products are very durable and have extended material lives, on the order of 10-100 years. As a consequence, once PVC products are introduced into the environment through illegal littering and waste dumping or into the municipal waste stream and disposed of legally as solid waste in a land fill, the PVC material they are composed of remains intact for many years. PVC does degrade naturally over time, but not very quickly.

A PVC-based product's *useful life* is determined in part by its *material life* but also by how it is used. Useful lives may be as short as a few days or weeks, as is the case with PVC packaging and films, depending on how they were designed and what they were used for. A useful life of a year would be considered long for packaging and films. Other PVC products such as flooring, carpet, or roofing materials have an intermediate life, averaging 9 to 10 years (Thornton 2002) before they are typically replaced because of normal wear and tear, aesthetics, or loss of function due to heat and UV light exposure. Products such as pipes, window casings, household materials, appliances, furniture and hard surfaces may have extended useful lives, on the order of 10-50 years (EC 2000b).

Potential Emissions & Exposure Scenarios (Stage 3)

Potential human health and environmental hazards during this stage could include the release of toxic substances from the PVC product into the indoor or outdoor environment during its useful life. Potential emissions at this stage in the lifecycle are a critical issue in determining whether or not to include PVC-containing recycled-content in green buildings.

Trace amounts of VC monomer have been found on newly finished PVC products, but are not expected to of concern for recycled-content products. VC is highly volatile and if present would be expected to rapidly escape into the air from finished virgin PVC-based products and materials. Because of this, VC associated with finished materials or products would likely evaporate during the staging and holding steps in the manufacturing process (Johnson 2004).

Furthermore, little VC can readily escape from the solid PVC matrix even when heated. Scientists exploring the release of volatile organic compounds from flooring materials have found that no VC was emitted from floor coverings (Wiglusz et al. 1998). Scientists conducting studies of working environments where PVC materials were being manufactured into PVC products at temperatures ranging from 165 to 200º C found that little or no VC was released (Zitting 1998 and Forrest et al. 1995). Investigators concluded this was likely due to very low residual concentration of VC in the finished product resins (Forrest et al. 1995). Data such as these suggests that it is not likely that finished recycled-content materials and products in normal use settings would be a significant source of exposure to VC for consumers or members of the public.

Mechanical or chemical treatment, dissolution and leaching by liquids, superheating, and burning are processes that can lead to significant releases of chemical additives, including plasticizers and metal-based stabilizers, from PVC products. Photodegradation and other aging processes of PVC can also lead to release of chemical contaminants. According to the European Commission, “lead and cadmium stabilizers in PVC will most probably remain bound in PVC during the use phase and thus will not contribute significantly to exposure. A potential contamination of the environment by the use of lead or cadmium stabilizers in PVC can take place during the production and waste phase” (EC 2000b).

Documented situations where physical or chemical treatment of PVC products during use has led to human exposures to phthalate plasticizers and metal stabilizers include: 1) chewing of PVC products and salivary dissolution of additives in plastic toys by small children (CPSC 1998), 2) leaching of additives from PVC-based medical devices and packages during normal use in hospital settings (US FDA 2003), 3) leaching by water and subsequent low level detection of organotin stabilizers in municipal water delivered to homes via new PVC water pipes in Canada (Sadiki et al. 1996), and 4) mouthing and chewing behaviors resulting in oral ingestion of dust containing lead from deteriorated imported household mini-blinds by children in home environments (CPSC 1997).

In the first three of the four cases noted above, the risk of health impacts was found to be insignificant, small and/or decreased significantly and rapidly over time (CPSC 1997, CPSC 1998, Sadiki & Williams 1999, and US FDA 2003).

Only the fourth scenario has potential direct relevance with respect to the use of recycled PVC-containing materials in green buildings. In this case the risk of exposure to lead was found to be elevated for children under the age of six who were engaged in mouthing or hand to mouth activity while in the presence of lead dust from imported mini blinds made of PVC that contained lead-based stabilizers.

However, in this case it was found that the imported mini blinds were old and significantly deteriorated due to UV exposure (CPSC 1996). Following this study, the Consumer Products Safety Commission approached the Window Covering Safety Council, which represents the industry, to immediately change the way it produces vinyl mini blinds by removing the lead added to stabilize the plastic in these blinds.

Manufacturers apparently made the change and new mini blinds without added lead were expected to be made available beginning in late 1996 (CPSC 1996). To address the potential for exposure of children to lead from existing imported mini blinds, the CPSC recommends that consumers with young children remove old vinyl mini blinds from their homes and replace them with new mini blinds made without added lead or with alternative window coverings (CPSC 1996).

A number of studies have reported associations between increased respiratory effects, including asthma and bronchial constriction, and the use of flexible PVC composite flooring and other materials in homes and buildings suggesting that exposures to chemical contaminants in PVC were occurring in these settings. However, investigators were not able to discount effects of non-specific volatile organic compounds that may have come from adhesives, other materials present in the products studied, or the effects from additive chemical degradation resulting from unusually wet and alkaline conditions and poor building design (Jaakkola et al. 1999, Jaakkola et al. 2000, Norback et al. 2000, Tuomainen et al. 2003, and Wieslander et al. 1999).

Phthalates such as diethyl phthalate, di-n-butyl phthalate, DEHP, and butyl benzyl phthalate, which are used as plasticizers and stabilizers in PVC, are some of the most common compounds found indoors (Rudell et al. 2003). Polybrominated diphenyl ethers, or PBDEs, flame retardants found in PVC, are also now commonly found in indoor air samples. Studies directly comparing the volatile organic chemical (VOC) emissions from both virgin and recycled PVC-containing vinyl composite floor tile and vinyl-based backed carpets, which were installed using a variety of adhesives, found that both product applications resulted in the release of similar amounts of one or more of the following hazardous volatile chemicals: naphthalene, formaldehyde, acetaldehyde, phenol, 1-methyl-2-pyrrolindinone or 2-ethyl hexanoic acid (IWMB 2003), regardless of whether the product was made from recycled or virgin PVC.

Although it appears that the emissions to indoor environments under these use scenarios are largely due to the chemically heterogeneous nature of the flexible PVC-based composite flooring materials, as well as the use of VOC rich adhesives during installation, potential exposures to hazardous chemicals released when these products are used in indoor environments continues to warrant our attention. Other scientists have looked at the release of volatile organic compounds to indoor air from PVC-based flooring at elevated temperatures and found that these materials are unlikely to be a source of indoor air contamination after about 10 days time (Wiglusz et al. 1998).

Issues of indoor air quality that arise from excessive moisture and subsequent mold growth in buildings containing PVC-based materials have also been raised. However, the mold issue is not limited to the presence of PVC-based building materials. It has been associated with the presence of excess moisture in any number of indoor settings and with a number of plastic or moisture barrier conditions where moisture may be trapped and mold can grow.

Thermal breakdown of the PVC polymer and active release of gaseous hydrogen chloride from superheating or burning of PVC in accidental fires has resulted in firefighter exposures (Dyer and Esch 1976). This exposure scenario is equally likely for virgin or recycled PVC.

Regulatory Controls (Stage 3)

We were unable to find any environmental regulations that address PVC-containing materials and products once they have been manufactured, distributed and put into use. From an environmental perspective, rules and regulations that appear to apply to finished PVC-containing materials and products do so primarily in the context of their initial production and manufacturing from the VC monomer. Depending on the application, once manufactured, products would be expected to fall under either the Consumer Products Safety Commission or U.S. Food and Drug Administration purview. Rules and regulations do also apply later in the PVC lifecycle once PVC-containing materials and products are placed into the waste stream or as they are considered for recycling and reuse.

The vast majority of recent limitations or restrictions on the production, use or disposal of PVC-containing materials and products appear to have resulted from increased awareness and concern about the potential environmental and human health impacts of using PVC-containing products and materials. This has resulted in a growing movement on the part of designers, builders and product manufactures to voluntarily reduce the amount of PVC-containing materials used in their products (EC 2000b and CCC 2004).

Disposal of PVC Products (Stage 4)

At this stage in the lifecycle, PVC products can be treated in any of the four following ways: 1) *dumped* illegally as litter in the environment or burned in trash piles and burn barrels, 2) *recycled*, either chemically or mechanically, into other PVC-containing products and materials, 3) *disposed of as solid waste* and deposited in landfills, or 4) *burned* in either energy producing or non-energy producing permitted waste incinerators.

When and how PVC-based products are disposed of depends greatly on the formulation of the PVC material they are made of and how the final manufactured products are treated and used in our society. Otherwise-useful PVC-containing products and materials, such as flooring and wall coverings, are often routinely "redecorated" out of use and disposed of many years before the expiration of their useful product life.

These products also typically end up in local municipal landfills or in permitted incinerators. Since illegal dumping and burning of PVC and other wastes is uncontrollable and otherwise outside the scope of this effort, in the following paragraphs we discuss potential concerns associated with the remaining three main ways PVC products and materials are disposed of.

Members of the plastics industry have stated that an integrated approach addressing all aspects and stages of plastics usage and disposal is the most desirable approach to the solid waste challenge presented (ECVM 2004a). Such an approach would include the following: (1) prevention of waste in the production phases, (2) re-use of PVC materials, (3) extending the life for certain products,(4) recycling, (5) energy recovery to harness the high-energy value of spent plastics, and as a last resort only, and (6) landfill disposal of residual wastes (ECVM 2004b). However, in reality in most cases, at the end of a PVC-based product's useful life, PVC ends up as solid waste in landfills, is illegally disposed of or is burned legally under controlled conditions in a permitted incinerator.

Potential Emissions & Exposure Scenarios (Stage 4)

A. Disposal in Landfills

Landfilling PVC materials appears to be the least desirable method of disposing of PVC-based materials, from a materials resource recovery perspective. And, since formulated PVC—as a plastic resin—does not readily degrade, especially under anaerobic conditions, when PVC-based products are placed in landfills, they are expected to remain intact for many years, creating a solid waste challenge, (ARGUS 2000, Hjertberg and Gevert 1995, Mersiowsky et al. 1999, Mersiowsky 2002a, and Mersiowsky 2002b). The safety of PVC in landfills has been questioned (Thornton 2002).

When PVC is disposed of in landfills, there is a concern about the potential for chemical additives, including plasticizers and metal-based stabilizers, as well as resin break-down products, to leach out of PVC materials and be released into environmental media, including air, soil and water. This might also occur when PVC products are disposed of inappropriately as litter or waste from illegal dumping.

This potential is greatest for flexible PVC products, which contain the largest amount of added chemicals by weight (Mersiowsky 2002a and Mersiowsky 2002b). Human exposure in these cases could occur via chemical contamination in air or contact with contaminated soil or ground water resulting from poorly managed landfills and related activities. As a consequence, the long-term behavior of PVC in landfills has been investigated by Mersiowsky and others, in both field studies and laboratory-scale simulation studies.

OEHHA's staff review of this issue resulted in the following comments regarding chemicals of potential concern in landfill settings.

(1) PVC & Vinyl Chloride

In landfill settings, PVC materials do not release gaseous vinyl chloride (ARGUS 2000, Hjertberg and Gevert 1995, Mersiowsky et al. 1999, Mersiowsky 2002a, and Mersiowsky 2002b). Vinyl chloride found in landfill settings was attributed to the breakdown of volatile chlorinated organic compounds such as tetrachloroethylene.

(2) Phthalate Plasticizers

By comparing the plasticizer content of aged PVC materials with that of original products, scientists determined that plasticizers were lost from PVC products under landfill conditions in widely varying amounts depending on the phthalate species measured and the finished product being studied. Flexible cables and wires lost more phthalates in general than did flexible flooring materials (Mersiowsky 2000). The phthalate plasticizer di-isodecyl phthalate (DIDP) showed no detectable loss. Di(2-ethylhexyl) phthalate (DEHP) showed no loss in some cases and a minimal loss of less than 10 percent in others. Losses of butylbenzyl phthalate (BBP) varied, up to 30 percent.

However, loss of phthalates from PVC products did not correspond with proportional increases in phthalate concentrations in landfill leachates. The chemicals in the leachates, when detected, were many orders of magnitude lower (Bauer and Herrmann 1998). By measuring corresponding bio-degradation products investigators were able to attribute the loss in plasticizers to bio-degradation by microbes (Ejlertsson 1997, Mersiowsky et al. 1999, Mersiowsky et al. 1999a, and Eljertsson et al. 2000). Although phthalates and their degradation products may occur transiently at low concentrations, complete microbial removal appears to be possible (Ejlertsson 1997 and Jonsson 2003).

Lastly, losses of plasticizers are not expected to continue indefinitely from any source of PVC materials since once the residual content of plasticizers is lost, or ambient temperatures decrease below a critical value, the PVC compound undergoes "glassification." Glassification renders the PVC material stiff and brittle with little or no potential for diffusion of chemicals through the matrix. This appears to occur long before all the plasticizers are gone (Mersiowsky et al. 2000b) so that over time, even plasticized flexible PVC becomes like rigid PVC in its behavior in the environment.

(3) Metal Stabilizers

Scientists have found that rigid PVC products are much less likely to release stabilizers than their flexible, i.e. plasticized counter-parts (Mersiowsky et al. 1999). The greatest concentrations of organotin compounds detected in leachates from laboratory in-field scale studies were associated with plasticized PVC floorings.

The highest leaching occurred during the early acidogenic stages of landfill development where the pH was lowest (Mersiowsky et al. 1999). The overall contribution of the heavy metals lead and zinc to the landfill leachate was generally minor and for the most part indistinguishable from background concentrations in the solid waste.

Organotin stabilizer species were hardly detectable (Ejlertsson et al. 2000a and Mersiowsky et al. 2001) at regular landfill conditions, however, findings increased at elevated temperature (Ejlertsson et al. 2000). Experimental results indicated that these metal stabilizers were adsorbed tightly to the solid waste matrix and did not migrate (ARGUS 2000, Ejlertsson et al.

2000, and Mersiowsky et al. 1999). In the case of organotins, bio-degradation also occurred under typical anaerobic conditions.

Disposal of PVC products in sanitary landfills is generally considered an acceptable method of disposal (Mersiowsky et al. 1999 and SEPA 1996). In many cases the products used to line landfills and protect against leaching are made of PVC (BG 1994). Scientific studies by multidisciplinary university-based research groups have shown that leaching of chemicals of concern in landfill settings does occur but in most cases is minimal. In those cases where releases of chemicals of potential concern were increased, elevated temperatures and acidic conditions were required.

Although, from a resource standpoint, the deposition of PVC-containing materials in landfills may not be particularly desirable, potential human health and environmental impacts resulting from exposure to chemicals from landfill disposal appear to be minimal. Properly managed landfills should be able to mitigate any potential impacts of these chemicals to humans and the environment.

Since the potential for plasticizers and stabilizers to be released from PVC materials in landfill settings does exist, arguments can be made for the continued maintenance and diligent surveillance of sanitary landfills where PVC materials, including those from sources other than just building materials, have been disposed.

The most significant and obvious environmental impact identified for disposal stage of the PVC lifecycle appears to be the sheer solid waste volume of vinyl products in land disposal facilities. For a number of product-specific reasons as well as the typical recycling program challenges of effective collection and sorting, less than 5 percent of PVC found in manufactured products is actually recycled, (EC 2000a). Since most PVC-based waste is expected to reside largely un-degraded in landfills for many years, it is likely that this concern will continue to grow, and may even support increased efforts to sort, collect and recycle PVC products and materials in the future.

B. Open Burning & Incineration

OEHHA also examined, to a lesser degree, the question of health and environmental impacts from burning PVC-containing building materials. Although incineration allows for the recovery of energy from the PVC material, it presents its own set of environmental challenges and concerns. Combustion processes, no matter how well controlled, have the potential to release emissions, and especially those that are due to incomplete combustion, under a variety of burn conditions.

As a result there is the potential for hazardous substances and toxic air contaminants, including dioxins and other products of incomplete combustion, to be released when PVC products and materials, as well as other chlorine-containing materials, are burned either during accidental open fires, in illegal backyard burning, or in permitted incinerators (Jay et al. 1995, Lemiuex 1997, EPA 1987a, EPA 1987b, EPA 1989, and EPA 1998).

The potential for release of dioxin, a highly toxic environmentally persistent chemical, is a concern and continues to warrant our attention at the local, state, national and international levels. Because of this, incinerators of any kind in use in California and throughout the United States as well as parts of the world are heavily regulated (EPA 1990). In light of this, it is reasonable to continue to support the tight regulation of municipal waste incinerators. It is also reasonable to continue to support programs that discourage the burning of plastic wastes in trash piles and burn barrels. And, it is reasonable to encourage the development and support of programs that find alternatives to the legal incineration of waste PVC products and materials.

C. PVC Recycling

Recycling of PVC waste products and materials is a valid method of handling the waste and disposal issue, however, there are a number of challenges in doing so. When PVC is recycled, there is a concern that VC or hazardous additives could be dispersed into the environment.

However, the most widely used recycling method is mechanical recycling (EC 2000a). In mechanical recycling, similar content waste PVC materials and products are simply melted and re-extruded or molded into new recycled products. In the scientific community, investigators have established that emissions from stage two in the PVC lifecycle, that is the initial manufacturing and production of virgin products, produces little or no emissions of VC or additive chemicals (Forrest et al. 1995 and Zitting 1998).

By extension, the re-melting and re-molding or extrusion of recycled products, which occurs under the same production and manufacturing conditions, should produce few emissions into the environment as well. Since recycled PVC feed stock must meet the same or very similar manufacturing specifications as virgin PVC, without significant additional chemical or mechanical treatment, the release of chemicals of potential concern from recycled PVC products is expected to be minimal.

Chemicals found in PVC or resulting from PVC degradation or breakdown could be released during accidental superheating or combustion during recycling. However, scientists conducting studies of working environments where PVC materials were being manufactured into PVC products (at temperatures ranging from 165 to 200º C) found that little or no degradation products, including that of phthalate plasticizers—phthalic anhydride—was released (Zitting 1998 and Forrest et al. 1995). The primary breakdown product of PVC resin even under these conditions remains hydrogen chloride in typically insignificant quantities.

Although presently undocumented, it could be possible for hazardous additives from existing PVC products to be inadvertently distributed over a greater range of consumer products through the recycling process. This could apply in the case of metal stabilizers and PCBs found in some PVC products, especially older electrical wiring and consumer electronics. If these older PVC-based materials were to be recycled, these chemicals of concern could become redistributed into the newly manufactured recycled-content products. However, the likelihood of this will continue to abate since the use of PCBs and lead in the United States has been aggressively reduced since the late 1970’s.

Concern regarding exposure to PCBs or lead from recycled-content PVC materials may be further mitigated by requiring that the PVC reclaim stock destined for recycling be tested for PCBs and lead. The concern for human health and environmental impacts resulting from this scenario may have particular application in food contact and medical/pharmaceutical applications but is much less of a concern for flexible PVC products in construction and building applications and is expected to be little or no concern for rigid PVC products in the same applications (CVSG 1999).

Regulatory Controls (Stage 4)

Environmental regulations that address PVC at this stage in its lifecycle do so primarily in the context of its presence in the waste stream, as it is collected and recycled, as it is transported and disposed of as solid waste in landfills or when it is burned in permitted incinerators.

Recycling and PVC-Containing Materials

Since the recycling of PVC materials is critical to the question under review, OEHHA also examined this issue closely as it pertained to PVC and building applications. We offer the following comments on the subject:

Pure PVC, like other plastic resins, is in principal, completely recyclable (Hydro 1995, PACIA 1996, and VI 1993). As a thermoplastic resin, i.e. one that can withstand heat and temperatures without significant degradation in integrity or structure, PVC can effectively be recycled if it is efficiently collected and sorted from the waste stream. Recycled PVC feed stock retains its original properties and can be readily used again in newly manufactured products.

PVC appears to be routinely recycled from PVC manufacturing residues and scrap materials, pre-consumer wastes as well as some post consumer wastes (AGPU 2004 and CVSG 1999). In many of today's applications, such as window casings and sewer pipes, recycled PVC commonly makes up 60-75 percent of the PVC materials content on a mass basis (VI 2004 and EC 2000a), although the PVC stock is largely comprised of pre-consumer industrial waste.

According to the European Plastics Recycling Workgroup, PVC plastics recycling programs can and do work if all players along the PVC lifecycle chain work together to make it happen (RT 2004). The recycling of *pre-consumer* manufacturing waste is highly efficient and well established yielding only about 1 percent *waste* on an annual basis (CVSG 1999). However, despite the fact that *post-consumer* PVC products are equally amenable to recycling, the same recycling success has not been achieved with post-consumer PVC products. In practice, according to the American Plastics Council, very little end use *post-consumer* PVC products or materials are actually recycled (APC 2001).

Greenpeace has asserted that the level of PVC recycling is woefully inadequate (GP 2004a, GP2004b, and GP 2004c). EC (2000a) reported that PVC recycling is limited, on the order of 1-3 percent (EC 2000a). According to the Environmentally Conscious Manufacturing Strategic Initiatives Group, "Typical plastics (post-consumer) packaging, seldom recycled and very long lived as waste in the environment, is solid waste in the making" (ECMSIG 2004).

Presently post-consumer reclaimed vinyl available for recycling simply does not compete with other resins, including virgin PVC, for established uses (CVSG 1999). This is especially true for flexible applications, which are largely driven by the traditional forces of supply, demand and economic feasibility. Rigid PVC recycling is largely handled through pre-consumer manufacturing and production mechanisms, which appear to be fairly well identified.

The limited level of PVC recycling occurs for a number of reasons. A few are specific to the nature of PVC itself, but a number of the reasons why PVC is not recycled are the same reasons that plague all recycling programs in general. These reasons include, but are not necessarily limited to: 1) the well-known challenges of consumer awareness and recycling program participation, 2) cost-effective collection, 3) cost-effective and practical sorting, 3) storage, and 4) distribution of recyclables to recyclers. According to the American Plastics Council, the availability of post-consumer plastics as cost effective "raw material" for the plastics recycling industry continues to be a limiting factor in how much plastic is actually recycled (APC 2001). These reasons apply especially to PVC comprised largely of post-consumer flexible products and materials, which make up the majority of the PVC waste stream today (APC 2001).

When it comes to recycling post-consumer PVC-based products and materials, there are three additional challenges associated with PVC as a plastic. The first is that the majority of PVC-based products produced today, as in the past, are durable rigid long-lived items like piping, widows, roofing, flooring and siding. The long life of these products limits the amount of newly produced PVC material that enters the waste stream each year, e.g. less than 10 percent on a volume basis per year (CVSG 1999 and EC 2000a).

While this makes for a PVC reclaim material "supply shortage" today, it is also essentially creating a solid waste crisis as the useful life of these PVC-based products is spent and the materials make their way into the waste stream some 20 to 50 years in the future. Since a number of PVC products were put into use in the late 1970s, a fair amount of these would be expected to make their way into the waste stream as early as the late 1990s and early 2000s, based on original production dates (EC 2000a).

The second, more immediate, challenge is the presence of chemical additives in flexible PVC products. These additives contribute greatly to the heterogeneous nature of the PVC material contained in finished consumer products (CVSG 1999). The heterogeneity in flexible PVC products results in heterogeneity in the post-consumer PVC stock that is available for recycling. Once plasticizers have been added to PVC they are not removed during the mechanical recycling process.

Thus, reclaimed PVC will have essentially the collective composition of the PVC materials found in the original waste PVC products. If the reclaimed PVC stock is comprised largely of the same type of PVC material, with similar amounts and kinds of additives, one can more readily guarantee a similar recycled PVC material that will lend its self to similar finished products and uses. If it is not , the resulting reclaimed PVC stock will have varying composition with varying potential uses that may or may not readily substitute for virgin products in the same production and use category.

This is where the current lack of cost-effective collection, sorting, and distribution appears to play a significant role in limiting the functional practice of post-consumer PVC recycling (CVSG 1999). Because of this, post-consumer PVC materials quite often end up as mixed plastics waste, which has limited recycle potential. And, even if mixed materials are recycled, they may not directly substitute for virgin PVC.

The third recycling challenge applicable to PVC is the use of PVC materials in composite products where a large portion of the product is something other than PVC (CVSG 1999). Examples of this include PVC composite vinyl flooring materials, which contain materials other than pure PVC and PVC-based flooring carpets, where the carpet backing may be made of PVC but the fibers are made of nylon, wool or other materials. The practice of composite product use contributes greatly to the "heterogeneity" of PVC post-consumer waste, although not in the same way as is found with the presence of varying PVC additives. The heterogeneity associated with composite PVC waste and its handling in the waste recycling stream also leads to the practice of *"down-cycling."*

In *down-cycling*, lower quality PVC-based recyclates are produced. These recyclates contain non-PVC materials and therefore no longer pure PVC. PVC material that is increasingly less pure will at some point no longer be suitable for use as “stock reclaim” in recycling programs. In these cases it is used in other applications that are not exclusive to PVC. Examples of these applications include the use of down-cycled PVC as a substitute for wood, concrete or general plastics.

These types of products have limited applications and do not lend themselves readily to further effective materials reclamation or recycling (EC 2000a). They also do not substitute directly for virgin PVC. Down-cycling, however, is not unique to PVC, although it is often characterized as such. Down-cycling occurs with other plastics recycling as well, especially in those situations where the collection and separation of pure fractions, as the major bottleneck in the recycling process, contributes greatly to increased heterogeneity in plastic waste fractions (EC 2000a).

Once collected, PVC products, even those flexible forms of a mixed PVC or composite nature, can be recycled. Some of today’s success stories include carpet backing that is recovered and provided to recyclers by commercial carpet installers and carpet producers. Windows and vinyl siding are also recovered and provided to recyclers by builders and distributors (CVSG 1999).

Recycling in these cases is then accomplished through either simple mechanical melting and re-molding of similar materials or through more complex heat-driven or solvent chemical recycling where mixed PVC wastes are degraded into their chemical components and used again as raw material in the production of virgin PVC (CVSG 1999, EC 2000a, ECVM 2004b, RT 2002, and TNO 1999).

These examples along with a number of other applications for recycled-content PVC are in current use (CVSG 1999). The potential for PVC recycling appears to exist (EC 2000a). It is therefore possible that PVC recycling could be increased greatly as markets for these applications grow and recycling becomes more cost effective. However, in the interim, as these materials approach their useful life and make their way into the waste stream, a solid waste challenge will be present in the not so distant future (APC 2004 and EC 2000a).

Accidental Fires and PVC Impacts

Although infrequent, spontaneous and/or accidental fires at landfills and in structures containing PVC-based building materials do occur. From an environmental and human health regulatory standpoint, emissions from unplanned structural fires and accidental fires at landfills are by their very nature essentially uncontrollable. A number of groups advocating a reduction in the production and use of PVC-containing materials consistently argue that these unfortunate events are significant sources of pollution in the PVC lifecycle (Thornton 2002).

There is no question that a number of toxic air contaminants and otherwise undesirable chemicals, including dioxins, can be released during the burning of any plastic materials, including PVC. However, emissions from these events appear to be unquantified to date so a comprehensive comparative analysis of the risk associated with exposure to these emissions is not possible at this time.

From a qualitative perspective it could reasonably be argued that by recycling PVC-containing materials instead of placing them in landfills, one could significantly reduce the risk of impacts from burning PVC in unplanned landfill fires. On the other hand, it could be argued that by recycling PVC materials into useful building products one could be increasing the risk of impacts from burning PVC in accidental structure fires.

OEHHA staff do not have data to compare the relative risk from or frequency of each of these types of fires. Because of this, it is not possible to even qualitatively assess which, if either, is more likely to occur or which method of disposal would have more impacts. But, if it is assumed that the recycled PVC would replace virgin PVC use in building applications, it is logical to assume that the risk from structural fires would not be increased since the risk of impacts from burning PVC in accidental structural fires would be expected to remain the same whether the PVC-containing building materials were comprised of virgin or recycled PVC.

If the risk of impacts from structural fires remains the same for both virgin and recycled PVC-containing building materials, but the risk of impacts from PVC burning in landfill fires or in municipal waste incinerators could be significantly reduced by recycling PVC-containing products and materials instead, it seems to make sense to recycle the PVC into useful products. In fact, the documented release of toxic emissions from burning PVC in accidental landfill fires, appears to support the argument that we as a society should continue to prevent, to the greatest extent possible, the disposal of PVC products and materials as solid waste in municipal landfills where it may accidentally burn.

This argument further supports the concept that, if PVC materials will continue to be produced in large quantities for many building and construction applications, and if once they are produced they are expected to have material life spans of many decades. PVC products and materials, including PVC-containing building materials, should be more aggressively reused or recycled and not allowed to accumulate in municipal landfills where accidental fires might occur.

PVC Building Materials: Human Health and Environmental Concerns

Concerns about potential human health and environmental impacts of PVC-containing building materials exist based on the chemistry that is involved in the production of PVC resin as well as the presence of additive chemicals found in finished PVC products. Issues surrounding these concerns extend not only to PVC as it is manufactured and produced, but to finished PVC products as they are used, the disposal of PVC as solid waste in landfills or as fuel in waste incinerators, accidental or deliberate uncontrolled burning of PVC, as well as the recycling and use of PVC-containing building materials (GP 2000, HFN 2004, and Thornton 2002). Such concerns raise the question of whether it is acceptable to specify the use of PVC-containing recycled-content building materials in green buildings.

To assist the IWMB in addressing these concerns, OEHHA staff conducted a qualitative human health and environmental impacts review. For the purposes of this review, OEHHA staff initially included those chemicals of potential concern that were identified as being present and possibly released during the four main stages in the PVC lifecycle. Where feasible, we also included in our health and environmental review, chemicals of potential concern associated with PVC in general that have been consistently identified by concerned environmental organizations and public health groups. The results of our analysis are presented here.

Chemicals of Potential Concern

When conducting any health or environmental assessment it is important to distinguish between chemicals of concern and chemicals that represent an identified risk to human health or the environment. The mere presence of hazardous or toxic chemicals in a material or product, or associated with a product or material, does not by itself necessarily constitute a threat or "risk" to humans or the environment.

In order to be addressed as chemicals of actual concern by OEHHA staff in this report, potential chemicals of concern must be present, and also: 1) be identified as toxic or hazardous to humans or the environment, 2) be released in some fashion from the PVC-containing building materials and, 3) make their way into the environment into some medium that humans, plants or animals may come in contact with in concentrations that are large enough to present an identified risk. All of these criteria must be met in order for a chemical of concern to become a chemical with an identified risk in answering the question of whether it is acceptable to use PVC-containing recycled-content building materials in green buildings.

Chlorine

Chlorine, a ubiquitous chemical found in many forms throughout the planet, is fundamental to PVC resin manufacturing. Chlorine can make up as much as 57 percent of the weight of the pure PVC polymer resin. Up to 35 percent of chlorine from the chloralkali electrolysis eventually ends up in PVC, which constitutes the largest single use of chlorine in the world (Thornton 2002). As Thornton (2002) and others have stated, chlorine is an ingredient essential for dioxin and PCB formation during waste incineration.

While OEHHA acknowledges the potential for adverse environmental consequences from burning of chlorine-containing plastics, there is no evidence that PVC is more likely to burn and contribute to the formation of products of incomplete combustion if it is recycled than if it is landfilled. Furthermore, since recycled PVC would ideally replace an equivalent amount of virgin PVC, the potential for worker exposure to chlorine during feedstock production would be reduced by recycling, an essentially physical process which does not involve elemental chlorine.

Vinyl Chloride (VC)

The vinyl chloride monomer used to make PVC is toxic to humans and animals. Exposure to vinyl chloride can result in liver, kidney or lung damage. VC is also a known human carcinogen (ATSDR 1997 and OME 1998). It is listed as a known carcinogen by the State of California under Proposition 65. Human and animal data indicate that VC is absorbed rapidly and efficiently via the inhalation and oral routes. However, it is also rapidly converted to water-soluble metabolites, and is rapidly excreted. At low concentrations, VC metabolites are excreted primarily in urine. At high exposure concentrations, VC is eliminated in exhaled air essentially unchanged. Overall, the data indicate that neither VC nor its metabolites are likely to accumulate in the body (EPA 2000a). VC, is not persistent in the environment, and it does not accumulate in plants or animals (ATSDR 1997).

It is important to note that VC is not a breakdown product of PVC degradation in landfills, during superheating or active PVC combustion. However, VC can escape into the air during the manufacturing of VC feedstock or PVC materials polymerization. This potential for exposure is expected to be of greater concern to workers in occupational settings. To the extent that recycled PVC would replace an equivalent amount of virgin PVC, it seems reasonable that the potential for worker exposure during feedstock production would be reduced by recycling since recycling would not involve VC monomer production.

VC monomer has occasionally been found on newly finished virgin PVC products, but only in trace amounts (EPA 2000b). Being highly volatile, VC rapidly escapes from the surface of finished PVC-based products and materials during the staging and holding steps in the manufacturing process, prior to consumer purchase and use. Because of this, the risk of exposure to VC for consumers of PVC-containing recycled-content building materials and building occupants is low. OEHHA does not dismiss the toxicity of vinyl chloride, nor the potential for adverse consequences if humans are exposed to vinyl chloride. However, recycling of PVC as practiced in the United States is essentially a physical process, which does not involve the release of VC monomer.

Hydrogen Chloride

Hydrogen chloride is released from PVC-containing materials as a breakdown product during combustion or superheating (Froneberg et al. 1982). HCl is highly irritating and when inhaled can damage the lungs and upper respiratory tract. Thermal breakdown of the PVC polymer and release of gaseous hydrogen chloride from superheating or burning of PVC in accidental fires has also resulted in firefighter exposures. Superheating during production or recycling may result in HCl and release and exposure of workers.

However, these exposure scenarios are not expected to occur under normal PVC-containing recycled-content building materials use scenarios. Furthermore, HCl is no more likely to be released during the burning of recycled PVC-than during the burning of virgin PVC. Because of this, the risk of exposure to HCl for consumers of PVC-containing recycled-content building materials and building occupants is expected to be low.

Polychlorinated Bi-phenyls (PCBs)

PCBs were historically added to some flexible PVC wiring and electrical coating products. PCBs are a group of synthetic organic chemicals that can cause harmful effects in humans and the environment (ATSDR 2000). Historical PCB exposures have resulted in liver, kidney and skin damage and have been associated with a number of types of cancer. Once in the environment, PCBs do not readily break down. They persist in air, soil and water. PCBs also accumulate in human, plant and animal tissue. They have been found all over the world in all media. However, because there was evidence that PCBs accumulate in the environment and cause harmful effects, the manufacture and use of PCBs was stopped in the United States in August 1977 (ATSDR 2000).

Because PCBs have been effectively phased out of products manufactured since 1977, there is no risk from exposure to PCBs in modern PVC-containing building materials. However, there may be a potential risk of exposure to PCBs in recycled-content PVC products that may contain PCBs as contaminants from old PVC coated wires or electrical components used as recycling feedstock. However, this occurrence has not been documented or quantified. This theoretical risk can be essentially eliminated by sampling and testing for PCBs in recycled PVC feed stock. Testing for PCBs in recycling efforts, especially those dealing with electrical wiring, is in some cases routine.

Dioxin

The release of dioxin, a highly toxic environmentally persistent class of chemicals, is a serious human health and environmental concern that continues to warrant our attention at the local, state, national and international levels (EPA 1985, EPA 1987a, EPA 1987b, EPA 2000d, and Reijnders 1986).

Dioxin is formed when materials, including PVC products, are burned illegally in dumps and waste piles, accidentally in structure or landfill fires, or legally in permitted waste incinerators (Blankenship et al. 1994 and Kramlich et al. 1989). While there is no question that dioxin formation from combustion of PVC materials should be avoided, in terms of this research effort, no information was found to determine that PVC is more likely to burn and contribute to the formation of products of incomplete combustion, including dioxins, if it is recycled than if it is landfilled.

The risk associated with PVC burning, in any type of combustion process, was essentially established as soon as the PVC was manufactured. If PVC, when it is recycled, presumably replaces an equivalent amount of virgin PVC in buildings, then the potential for dioxin formation during combustion of recycled PVC is no greater than during the combustion of virgin PVC found in buildings. It should be remembered that this effort is focused primarily on the issue of whether recycled-content PVC might impact human health or the environment if used in building materials in green buildings.

In addition, dioxin emissions from combustion activities are not unique to PVC-containing building materials. They also result from the burning of other waste fuels, regardless of chlorine content, since there are many sources of chlorine in our environment (Carroll 2001). In light of this, it is reasonable to encourage the development and support of programs that find alternatives to the incineration of PVC products and other waste materials that may contribute to the release of dioxin into our environment.

By extension it seems reasonable to support programs, like recycling, that have the potential to lessen the likelihood that PVC will be burned accidentally in landfill settings, or purposefully and legally in municipal waste incinerators, or purposefully and illegally as waste in burn barrels and trash piles. OEHHA staff offer no comments or opinions about the more global issues regarding the initial production and use of virgin PVC or its relationship to the release of dioxin in our environment.

Metal Based Stabilizers

Metal-based stabilizers are not volatile, although some are water-soluble (Sadiki et al. 1996, Sadiki & Williams 1999, and Bancon-Montigny et al. 2004). For significant amounts of these chemicals to be lost or otherwise released from the intercalated PVC polymer matrix—while products are in use or disposed of in landfill settings—the PVC-containing products and materials must be aggressively mechanically or chemically treated, subjected to dissolution and leaching by liquids, actively superheated, subjected to UV light, or burned (Al-Malack 2001). Scientists have found that rigid PVC products are much less likely to release stabilizers than their flexible (i.e., plasticized), counterparts (Mersiowsky et al. 1999).

Metal-based stabilizers are not readily absorbed through the skin so casual dermal contact with building material surfaces is not expected to be a significant route of exposure. Metal-based stabilizers can, however, be absorbed once ingested, primarily by mouth or secondarily through hand-to-mouth contact, or when inhaled as particles. Circumstances where children have been exposed to lead-based stabilizers from contact with aged, higher lead content, imported mini-blinds have been documented.

Exposure occurrences like this would be expected to be limited for the most part to younger children when mouthing and chewing behaviors are most prominent. It is not likely that mouthing and chewing behavior associated with young children will occur in most green building settings, especially those designed primarily for adult related activities (ATSDR 2002).

Exceptions to this might include private home, day care or pre-school settings where children may be in a position to chew or aggressively mouth flexible PVC building materials. While this exposure scenario is unlikely, it may warrant additional consideration and review when determining the use of specific PVC-containing building materials in some settings. There is also the possibility that older children and adults could be exposed via inadvertent hand to mouth activity and possibly via inhalation exposure if they come into contact with aged and degraded PVC materials. Potential risk could be mitigated by specifying "heavy metal-free" vinyl products in these applications where environmental conditions would lead to significant PVC degradation.

There appears to be little risk to humans and the environment from landfill disposal of PVC-containing building materials. In landfill settings the greatest amount of stabilizer leaching occurred during the early acidogenic stages of landfill development, conditions where the pH was lowest (Mersiowsky et al. 1999) and temperatures were elevated (Ejlertsson et al. 2000).

The overall contribution of the heavy metals lead and zinc to landfill leachates has been found to be generally minor and for the most part indistinguishable from background concentrations of lead and zinc in general solid waste**.** Metal-based stabilizers are expected to adsorb to solid matrix and not migrate from landfill settings (ARGUS 2000, Ejlertsson et al. 2000, and Mersiowsky et al. 1999).

In the case of organotins, bio-degradation also occurred under typical anaerobic conditions. However, this already-low level of risk from leaching of stabilizers from PVC in landfills would in theory be reduced by recycling, since comparable processes would not be expected to occur during the life of the recycled products while in use.

Phthalate Plasticizers

Considerable attention has been focused on potential human health and environmental impacts of phthalate plasticizers that may be released from flexible PVC-containing materials and products. Phthalate plasticizers are a group of chemicals used to impart flexibility in many different plastic resins. But, they are also used extensively in a wide variety of other consumer products. Examples of these include paints, inks, rubber products, adhesives and some cosmetics (VI 2004).

As such, phthalate plasticizers are routinely found in many environmental settings. To make flexible vinyl products, plasticizers are often added to PVC in large quantities – up to 60 percent of the final product by weight (Thornton 2002)—although lower levels are also common (ATSDR 2002). In pure form they occur as colorless, odorless and largely biodegradable liquids.

The phthalate plasticizer most widely used in the manufacture and production of flexible PVC building products is di(2-ethylhexyl) phthalate (DEHP). Because of this, and given the scope of this effort, OEHHA staff have confined this portion of the review to DEHP alone. Other names for this compound are bis(2-ethylhexyl) phthalate (BEHP) and dioctyl phthalate (DOP). Di-n-octyl phthalate, however, is the name for a different chemical that is also used as a plasticizer in other plastics production and manufacturing settings, such as children's toys (ATSDR 1997a). Plasticizers are not added to rigid PVC-containing virgin or recycled building materials.

If released to soil, DEHP typically attaches strongly to soil particles and does not move very far away from where it was released. DEHP does not dissolve readily in water but will dissolve to some degree in solvents such as gasoline, paint removers, and oils. When DEHP is released to water, it may dissolve very slowly into underground water or surface waters. In the presence of oxygen, DEHP in water and soil is broken down readily by microorganisms to carbon dioxide and other simple chemicals (ATSDR 2002). DEHP does not break down as easily under anerobic conditions deep in the soil or at the bottom of lakes or rivers. It can be found in small amounts in fish and other animals, and some uptake by plants has been reported.

Although phthalates and their degradation products may occur transiently at low concentrations in landfills, complete microbial removal appears to be possible (Ejlertsson 1997). DEHP does not evaporate readily. For significant amounts of DEHP to be released from the intercalated PVC polymer matrix—while PVC products are in use or disposed of in landfills—the PVC-containing products and materials must be aggressively mechanically or chemically treated, subjected to dissolution and leaching by liquids, subjected to UV light, or superheated. Little DEHP is present in the air even near sources of production (ATSDR 2002 and Rudell 2000).

Low-level releases of DEHP to indoor air from plastic materials, coatings, and flooring in home and work environments have been documented under high temperature, air flow and moisture conditions and can lead to higher indoor levels than are found in the outdoor air (ATSDR 2002). However, other studies examining the release of DEHP from flooring materials found no emissions of DEHP to air (Afshari et al. 2004). DEHP chemical breakdown products have been detected in a number of PVC-based flooring use settings (IWMB 2003 and HFN 2004) but not in other studies that examined other types of PVC building materials.

DEHP is not readily absorbed through skin. Using radioactive tracers, Wester et al. (1998) estimated that only approximately 1.8 percent of a 24-hour applied dose of DEHP was absorbed through the skin during experiments in human volunteers. During these experiments they noted that 1.1 percent of the radioactivity from a 24-hour dermal application of ^{14}C-labeled DEHP to the forearm of volunteers was excreted in the urine within seven days post application. They used this finding and the observation that approximately 60.8 percent of an intravenously-injected dose of DEHP was excreted in the urine of Rhesus monkeys over the same post treatment time period as the basis for their estimate of dermal absorption.

In this study DEHP was dissolved in ethanol, a solvent that should maximize absorption. Because DEHP is not readily released from PVC-containing virgin or recycled-content building products and it is not readily absorbed through skin, the risk of significant exposure to DEHP contained in PVC by simply touching most building products or materials, especially rigid products that do not contain plasticizers, is very low. DEHP can be absorbed through the lungs in humans and rodents, although the degree to which it is absorbed has not been quantified (Merkle et al. 1988, Roth et al. 1988).

Absorption of ingested DEHP in humans has been calculated at about 20-25 percent (Schmid and Schlatter 1985). Rodents appear to absorb ingested DEHP much better than humans or other primates (Astill 1989 and Rhodes et al. 1986). Rats have been estimated to absorb about 55 percent of the administered oral dose. Differences in absorption should be taken into account when comparing health effects seen in rodents to those observed in humans.

DEHP is produced in high volumes and used in many types of products that have resulted in extensive though poorly defined human exposures and some unique childhood exposures (Shea 2003). A number of case studies where children and some adults have been directly exposed to lower levels of plasticizers found in products made of flexible PVC have served to heighten public awareness and ultimate concern about the use of plastics, most specifically vinyl plastics, in our environment.

One notable exposure scenario includes those circumstances where children less than three years of age were orally exposed to plasticizers found in PVC-products that appear to have leached directly from vinyl toys when chewed or mouthed by the children (Babich 1998). Other documented phthalate exposure scenarios include those where acutely ill infants and some adults have been exposed to plasticizers that have been linked to the use of inhalation or intravenous use medical devices, bags and tubing made out of flexible PVC-based plastics (Hill et al. 2003, Koop et al. 1999, Pearson & Trissel 1993, and Plonait et al. 1993).

Medical device exposure scenarios are regulated by the U.S. Food and Drug Administration and children's toys safety are addressed by the Consumer Products Safety Commission. These potential exposures are not relevant to PVC recycling or building materials. However, in situations where younger children may be present, such as private homes, day care centers or pre-schools, and exposure to either virgin or recycled flexible PVC-containing building materials—especially those largely comprised of composite materials—is possible, and suggested that these materials be used with caution, especially in exposed locations where they could be reached by children.

It has been shown that children may be more highly exposed to DEHP in certain situations, e.g. during clinical procedures or when mouthing vinyl toys (Koch et al. 2004). It is possible that children might be more susceptible than adults to the effects of DEHP depending on the stage of physiological development they are in when they are exposed. However, the Agency for Toxic Substances & Disease Registry has concluded there is no evidence that children are more susceptible or predisposed to toxicity from DEHP exposure, based on inherent biological differences, than adults, but they may be more likely to be exposed based on age-specific behaviors (ATSDR 2002).

DEHP is neither a dermal irritant, nor an allergic sensitizer in humans or rabbits at dermal doses in excess of 19,800 mg/kg (Shaffer et al. 1945 and ATSDR 2002). Phthalates are animal carcinogens and can cause fetal death, malformations, and reproductive toxicity in laboratory animals. Toxicity profiles and potency vary by specific phthalate type. The extent of these toxicities and their applicability to humans remains incompletely characterized and controversial (Shea 2003).

DEHP has received considerable attention recently because of specific concerns about pediatric exposures. Scientific panels, advocacy groups, and industry groups have analyzed the literature on DEHP and have come to different conclusions about its safety (NTP 2000). The controversy exists because risk to humans must be extrapolated from animal data that demonstrate differences in toxicity by species, route of exposure, and age at exposure and because of persistent uncertainties in human exposure data (Shea 2003 and NTP 2000).

DEHP exposure in rodents has been linked to tumor development. Some experts have come to the conclusion that the biological mechanism by which increased tumor incidence in rats and mice occurs, is a non-mutagenic, non-DNA-reactive mechanism involving a cellular receptor and is not relevant to humans (IARC 2000, ATSDR 2002, Cattley and Roberts 2000; Cattley et al. 1998; Huber et al. 1996, Gray et al. 1982; and Kurata et al. 1998). However, there is considerable scientific debate surrounding the issue and OEHHA contends available information is not sufficient to make this conclusion. OEHHA (2002) has listed DEHP as known to the State to cause cancer under the requirements of Proposition 65.

DEHP is on the California Proposition 65 list as a developmental and reproductive toxicant (OEHHA 2003 and NTP 2000). In recent years, concerns have been raised that many industrial chemicals, including DEHP, may be endocrine-active compounds capable of having widespread effects on humans and wildlife by interfering with the action of hormones (Crisp et al. 1998; Daston et al. 1997; Giam et al. 1978, Jobling et al. 1995, NRC 2000, and Safe et al. 1997). Special attention has been paid to the possibility of these compounds mimicking or antagonizing the action of estrogen, and more recently, their potential antiandrogenic properties in males.

However, according to the Agency for Toxic Substances and Disease Registry, there is no evidence at this time that DEHP is an endocrine disruptor in humans at the levels found in the environment (ATSDR 2002). DEHP has been shown to be a developmental and reproductive toxicant in rodents, although studies have not yet identified a mechanism of action (ATSDR 2002). OEHHA remains concerned that DEHP may be acting as a developmental toxicant through endocrine disruption mechanisms although these mechanisms have yet to be clearly identified (OEHHA 2002).

Given the apparently low potential for human exposure to DEHP found in PVC-containing virgin or recycled-content building materials under normal use settings, OEHHA staff conclude that the risk of adverse impacts to older children and adults from exposure to DEHP from this source is minimal.

The risk of adverse impacts from exposure to DEHP in PVC-containing recycled or virgin content building materials in green buildings for younger children—when mouthing and chewing behaviors are greatest—may be greater in private home, day care or pre-school settings where children may be in a position to chew or aggressively mouth aged flexible PVC building materials, or where hand-to-mouth activity may lead to exposures to contaminated dust. Because of this, these situations may warrant additional consideration and review when determining the use of specific PVC-containing building materials in some settings.

Summary of Qualitative Health Review

Overall, based on OEHHA's interpretation of this qualitative review of exposure scenarios and chemicals of concern, it appears that the risk of adverse impacts to humans or the environment from using PVC-containing recycled-content building materials in green building is likely to be comparable to the risk associated with use of virgin PVC. The release of, or exposure to, chemicals of concern from PVC-containing building products, under normal use scenarios, appears to be small. However, potential risk of adverse impacts do vary between virgin and recycled PVC during other stages of the PVC lifecycle. A qualitative summary of the potential human health and environmental concerns for both virgin and recycled content PVC materials can be found in Table 2 below.

Table 2 -- Legend

⊖	Concern, Not Supported	The scientific literature was reviewed. The data does not support the concern raised.
○	Concern, Suspected but not Documented	The scientific literature was reviewed. Either the data reviewed does not address the suspected concern or the data found in the literature was insufficient to support the suspected concern and more research may be needed.

◍	Concern, Documented but Minimal	The scientific literature was reviewed. The data found supports that the suspected concern is minimal either because the chemical of concern is not a significant health or environmental risk, it is not released at all, if it is released it is released only in insignificant quantities, or exposure has been determined to be minimal and does not pose a significant health or environmental concern.
●	Concern, Documented and Elevated	The scientific literature was reviewed. The data found support that the suspected concern is adequately documented and concern is elevated either because the chemical of concern is highly toxic, it is highly persistent in the environment, or potential human or environmental exposure is significant.
(W)	Primary Concern, Worker Exposure	The greatest exposure concern is for workers in VC facilities.

Table 2

Life Cycle Stage		Potential Concern	Virgin PVC	Recycled PVC	Comments
VC Feed Stock Production	Stage 1	Chlorine	◍ *(W)*		The greatest exposure concern is for workers in VC facilities.
		Vinyl Chloride (VC)	◍ *(W)*		The greatest exposure concern is for workers in VC facilities. VC facilities are regulated by Federal and State agencies. There are no VC feed stock production facilities in CA.
		Hydrogen Chloride (HCl)	◍ *(W)*		The greatest exposure concern is for workers in VC facilities.
		Polychlorinated Bi-phenyls (PCBs)			
		Dioxin			
		Metal-Based Stabilizers			
		Phthalate Plasticizers (DEHP)			
Manufacture of PVC Products	Stage 2: Polymerization	Chlorine			
		Vinyl Chloride (VC)	◍ *(W)*		The greatest exposure concern is for workers in PVC manufacturing facilities. These facilities are regulated by Federal and State agencies. There is some risk of public exposure from accidental spills during transport or storage of VC. Once it is manufactured, PVC is a non-toxic & inert plastic.
		Hydrogen Chloride			
		Polychlorinated Bi-phenyls (PCBs)			
		Dioxin			
		Metal-Based Stabilizers			
		Phthalate Plasticizers (DEHP)			
	Formulation	Chlorine			
		Vinyl Chloride (VC)			
		Hydrogen Chloride (HCl)			
		Polychlorinated Bi-phenyls (PCBs)			
		Dioxin			
		Metal-Based Stabilizers	◍ *(W)*		Risk of exposure is minimized by formulating in closed containers.
		Phthalate Plasticizers (DEHP)	◍ *(W)*		Risk of exposure is minimized by formulating in closed containers.

⊖ Concern, Not Supported

○ Concern, Suspected but Not Documented

◍ Concern, Documented but Minimal

● Concern, Documented & Elevated

(W) Primary Concern, Worker Exposure

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Table 2

Life Cycle Stage		Potential Concern	Virgin PVC	Recycled PVC	Comments
Manufacture of PVC Products, Cont'd	Stage 2: Molding	Chlorine			
		Vinyl Chloride (VC)	◍ *(W)*		Trace amounts of VC have been detected on newly finished PVC products. VC is highly volatile. Any trace VC present would likely evaporate during the holding and storage phases of manufacturing. Studies have shown that no VC is emitted from PVC once it is manufactured, even when heated.
		Hydrogen Chloride (HCl)	◍ *(W)*	◍ *(W)*	Under normal molding conditions, HCl emissions are negligible. However, hydrogen chloride is the primary breakdown product of PVC when super heated or burned.
		Polychlorinated Bi-phenyls (PCBs)			
		Dioxin	◍ *(W)*	◍ *(W)*	Under normal process conditions, Dioxin emissions are not detected. Under experimental conditions, if PVC is superheated or burned, Dioxins may be released.
		Metal-Based Stabilizers			
		Phthalate Plasticizers (DEHP)			

⊖ Concern, Not Supported

○ Concern, Suspected but Not Documented

◍ Concern, Documented but Minimal

● Concern, Documented & Elevated

(W) Primary Concern, Worker Exposure

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Table 2

Life Cycle Stage		Potential Concern	Virgin PVC	Recycled PVC	Comments
Product Use: In Building Materials	Stage 3	Chlorine	⊖	⊖	Chlorine is not released from finished PVC.
		Vinyl Chloride (VC)	○		Trace amounts of VC have been detected on newly finished virgin PVC products in manufacturing facilities. However, VC is highly volatile. If any trace VC is present it would likely evaporate during the holding and storage phases of manufacturing. It is unlikely that even trace amounts of VC under normal product use conditions would be a significant source of exposure for consumers or members of the public. Studies have shown that no VC is emitted from PVC once it is manufactured, even when heated.
		Hydrogen Chloride (HCl)	◍	◍	HCl is not released from PVC unless PVC is burned or superheated.
		Polychlorinated Bi-phenyls (PCBs)		○	PCBs were added historically to some flexible PVC products, especially electronic wire and components, to increase fire and heat resistance. The use of PCBs in PVC has been phased out since the 1970s. There is some concern about inadvertently "recycling" older PCB containing PVC into newly recycled PVC products that did not previously contain PCBs. This concern could be mitigated by testing for PCBs.
		Dioxin	◍	◍	Dioxin is not released unless PVC is actively burned.
		Metal-Based Stabilizers	◍	◍	Stabilizers and plasticizers are not typically volatile. For significant amounts of these chemicals to be released from finished PVC products, either virgin or recycled, the products must be mechanically or chemically treated, subjected to dissolution and leaching by liquids, actively superheated or burned or significantly deteriorated by exposure to UV light. A case where children were exposed to lead-based stabilizers released from UV aged and mechanically treated miniblinds has been reported.
		Phthalate Plasticizers (DEHP)	○	○	Flexible PVC contains plasticizers, but rigid PVC does not. Releases to indoor air are suspected. Some documentation exists but more research is needed to better characterize the degree, extent and circumstances under which these releases occur.
		Water Quality Concerns	◍		Small concentrations of organotin stabilizers were detected in water leachates from newly manufactured water delivery pipes in Canada. Concentrations disappeared completely upon flushing.

⊖ Concern, Not Supported

○ Concern, Suspected but Not Documented

◍ Concern, Documented but Minimal

● Concern, Documented & Elevated

(W) Primary Concern, Worker Exposure

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Table 2

Life Cycle Stage	Potential Concern	Virgin PVC	Recycled PVC	Comments
Disposal / Stage 4: Landfills	Chlorine			
	Vinyl Chloride (VC)	⊖	⊖	VC is not released from PVC. VC detected in landfill settings has been attributed to other sources, such as chlorinated solvents.
	Hydrogen Chloride (HCl)			
	Polychlorinated Bi-phenyls (PCBs)			
	Dioxin			
	Metal-Based Stabilizers	◍	◍	Rigid PVC products are much less likely to release stabilizers than are flexible products. Contributions of metals released from PVC in landfill settings are minor and essentially indistinguishable from background levels in solid waste.
	Phthalate Plasticizers (DEHP)	◍	◍	Rigid PVC materials & products do not contain plasticizers. Plasticizers leached from flexible materials have been detected in landfill leachates. However, investigators have shown that complete removal via microbial degredation does occur.
	Solid Waste Production	●		Millions of tons of PVC are produced every year. PVC does not readily degrade in landfill settings. If recycled PVC replaces the use of virgin PVC in products then recycling PVC will likely help reduce the production of solid waste in landfills. If new uses for recycled PVC are found or if PVC is down cycled, solid waste reductions may not be realized.

⊖ Concern, Not Supported

○ Concern, Suspected but Not Documented

◍ Concern, Documented but Minimal

● Concern, Documented & Elevated

(W) Primary Concern, Worker Exposure

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Table 2

Life Cycle Stage		Potential Concern	Virgin PVC	Recycled PVC	Comments
Disposal, Cont'd.	Incineration	Chlorine			
		Vinyl Chloride (VC)	⊖	⊖	VC is not a combustion product of burning PVC.
		Hydrogen Chloride (HCl)	●	●	HCL is the primary breakdown product of PVC when burned. All incineration facilities in CA must be permitted and must control emissions.
		Polychlorinated Bi-phenyls (PCBs)			
		Dioxin	●	●	Dioxin is released when PVC is incinerated/burned. All incineration facilities in CA must be permitted and must control emissions.
		Metal-Based Stabilizers			
		Phthalate Plasticizers (DEHP)			
	Recycling/Mechanical	Chlorine		⊖	Chlorine is not released from finished PVC.
		Vinyl Chloride (VC)		⊖	VC is not released from finished PVC.
		Hydrogen Chloride (HCl)		⦶ *(W)*	HCl may be released from PVC during the recycling process if out of specification superheating or burning of PVC occurs. The primary concern for exposure would be to workers.
		Polychlorinated Bi-phenyls (PCBs)		⦶	To increase fire and heat resistance, PCBs were added historically to some flexible PVC products, especially electronic components and wiring. The use of PCBs in PVC has been phased out since the 1970s. There is some concern about inadvertently "recycling" older PCB containing PVC into newly recycled PVC products that did not previously and would not otherwise contain PCBs.
		Dioxin			
		Metal-Based Stabilizers			
		Phthalate Plasticizers (DEHP)			

⊖ Concern, Not Supported

○ Concern, Suspected but Not Documented

⦶ Concern, Documented but Minimal

● Concern, Documented & Elevated

(W) Primary Concern, Worker Exposure

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Table 2

Life Cycle Stage	Potential Concern	Virgin PVC	Recycled PVC	Comments
Accidental Fires	Chlorine			
	Vinyl Chloride (VC)	⊖	⊖	VC is not a combustion product of burning PVC.
	Hydrogen Chloride (HCl)	●	●	HCl is the primary breakdown product of PVC when burned. However, the risk for community or firefighter exposure to HCl is expected to be the same whether the PVC burned is virgin or recycled.
	Polychlorinated Bi-phenyls (PCBs)			
	Dioxin	●	●	Dioxin can be released when PVC is burned. However, the risk for community or firefighter exposure to dioxin is expected to be the same whether the PVC burned is virgin or recycled.
	Metal-Based Stabilizers			
	Phthalate Plasticizers (DEHP)			
	Structure Fires	●	●	The risk for community or firefighter exposure to dioxin, HCl and other combustion emissions from PVC burning in structure fires is expected to be the same for both virgin and recycled PVC.
	Landfill Fires	●		To the extent that recycling PVC prevents solid waste production and subsequent accidental burning of PVC in landfill fires, recycling PVC may prove beneficial in reducing the risk of community exposure from combustion products released during landfill fires.

⊖ Concern, Not Supported

○ Concern, Suspected but Not Documented

◍ Concern, Documented but Minimal

● Concern, Documented & Elevated

(W) Primary Concern, Worker Exposure

PVC Recycled-Content and "Green" Building Materials

The global issue of using chlorine-based plastics in our society, has for decades been an environmental concern. The issue of using PVC, even recycled-content PVC, in green buildings is by extension highly controversial, emotional, and no less hotly debated. Moreover, vocal opponents to the use of PVC in building materials have said "PVC is the antithesis of a green building material" (Thornton 2002).

As part of this project we examined the questions: 1) what is a *"green building,"* and 2) what does it mean to be a *"green building material."* We found in general that "*A green building is a structure that is designed, built, renovated, operated, or reused in an ecological and resource-efficient manner. Green buildings are ideally designed to meet certain objectives, such as protecting occupant health, improving employee productivity, using energy, water and other resources more efficiently, and reducing the overall impact to the environment* (IWMB 2004). We also found that to be a "*green building material*" a material would ideally meet, at a minimum, one of the following criteria during its design, production, construction, use or operation phases (IWMB 2004 and BG 2004):

1. Resource Efficient. By definition this criterion includes the use of recycled-content, the use of natural, plentiful or renewable materials, production or manufacturing by a resource-efficient process, it should be locally available to reduce impacts of shipping and transport, it might be comprised of salvaged, refurbished, or remanufactured materials from disposal, renovation and improvement activities so as to reduce solid waste, it would ideally be made out of materials that are reusable or recyclable, and lastly, green materials would be durable so that maintenance and repair efforts and long term costs are minimized**.**

2. Good for Indoor Air Quality (IAQ). For this criterion to apply, the material or product should have low toxicity or be non-toxic, release minimal or no chemicals into the air, be assembled using low-VOC materials and/or a low-VOC emitting process, and, be moisture resistant and healthfully maintained through the use of simple, non-toxic or low-VOC methods of cleaning.

3. Energy Efficient. This criterion can be met by utilizing materials and systems that help reduce energy consumption in buildings and facilities and require low energy to produce, use, and dispose of.

4. Conserve Water. This criterion could apply to either inside or outside environments.

Since recycled PVC products retain the same physical and chemical properties as virgin content products, it is likely that most recycled products would also be resource efficient (see Section II for a more in-depth discussion of these criteria as they pertain to PVC and building materials). This assumption is particularly valid for rigid PVC building materials, which readily lend themselves to recycling, and where many of the products currently available already contain a high degree of recycled-content that can directly substitute for virgin PVC. Examples include roofing materials, window profiles, pipes, and siding.

PVC itself is non-toxic, vinyl chloride and additives are not reported to be released in any appreciable quantity from finished products under normal use conditions, and as plastic resins PVC products are moisture resistant and can be healthfully maintained through the use of simple, non-toxic or low-VOC methods of cleaning.

Whether building materials are defined as only structural components, such as roofing materials, windows, pipes and wire cabling, or include finishing components such as decorations and furnishing, flooring, wall coverings and furniture, it is likely that all but the most specialized or progressive of today's modern buildings, "green" or not, contain many PVC-based materials.

More than 20 billion pounds of PVC products are consumed in the United States and Canada each year, and most of these billions of pounds of PVC become rigid durable construction and building materials. Public sector and private sector demands and expectations for cost effectiveness, durability, energy efficiency and recyclability in its building designs and construction make it highly unlikely that PVC use in buildings will significantly decrease in the near future.

The present national trend toward increased use of durable rigid PVC building products clearly points to a significant potential solid waste crisis for PVC materials disposal. Flexible PVC materials pose the greatest practical and technical challenges, when it comes to landfill issues and recycling, but rigid PVC materials have the potential to contribute the most to both challenges on a sheer volume basis.

There are also health and environmental issues related to recycled or virgin PVC. One concern is related to environmental contamination from the additives used in PVC once it is disposed of in a landfill. Acute and chronic health effects from exposure to combustion byproducts due to uncontrolled building fires or landfill fires are also a concern. Low levels of contaminants may be released from PVC in the indoor environment in some cases, depending on the type and condition of the material.

Another significant issue is the production of dioxin and related compounds during uncontrolled burning of PVC in building fires, trash barrel fires and landfill fires and the controlled combustion of PVC materials in regulated incinerators and trash to energy combustion units. OEHHA did not find evidence that these concerns would be exacerbated by using recycled PVC versus virgin PVC.

OEHHA concludes that human health and environmental concerns associated with recycling PVC are not likely to be greater than those associated with use of virgin PVC. Given the resource energy, and disposal issues, recycling and reuse of PVC-containing recycled-content building materials in green building applications appears to be reasonable. With continued production and no recycling it would seem that the PVC material in question will end up as solid waste in landfills or as waste fuel in incinerators.

OEHHA staff recognize that there are potential human health and environmental issues associated with PVC use in our society. Our evaluation has concluded that direct exposure to PVC building materials should present a low risk to individuals under normal use conditions, although only a qualitative assessment was done.

Young children may be at some risk from oral or inhalation exposure to some PVC additives in some settings. We recognize that these issues are not unique to recycled PVC and that risk of human health or environmental harm is likely to be comparable to that associated with use of virgin PVC in similar settings. Health and environmental harm can occur when PVC is burned in an uncontrolled manner by the emission of combustion byproducts, including dioxin. With respect to recycling and the use of PVC in green buildings, we conclude that as long as PVC is being made, recycling should be encouraged, since to do otherwise all but guarantees the PVC material will end up as solid waste in landfills or as fuel for waste incinerators.

Conclusions and Findings

At the end of its useful life, PVC may be landfilled, incinerated, or recycled. Each of these three possible fates has some risk, but quantification of the comparative risks of these options is beyond the scope of this report. PVC in buildings, virgin or recycled, does present a potential hazard since dioxins would be formed if there is a structure fire.

Recycling appears to reduce overall human health and environmental risk of adverse impacts at least to the extent that recycling PVC replaces the production of virgin PVC, it reduces landfill solid waste pressures, and it reduces impacts from PVC burning in landfill fires or from incineration.

OEHHA did not identify additional risks with the recycling process itself, particularly as practiced in the United States, where it is largely a physical process. Based on our review of the subject under discussion and the information presented elsewhere in this report, OEHHA staff conclude the following:

- Use of recycled PVC as a building material in green buildings should present a low risk to individuals under normal use conditions, although only a qualitative assessment was done. The use of recycled PVC in green buildings is not likely to be a more significant health or environmental hazard compared to the use of virgin PVC. However, use of PVC in general should be reviewed carefully under certain circumstances. For example, the risk of adverse health impacts from exposure to additives found in PVC-containing recycled- or virgin-content building materials may be significant for younger children who are most likely to exhibit mouthing, chewing and hand-to-mouth behaviors. Thus, use of PVC materials in private home, day care centers or pre-school settings where children may be in a position to chew or mouth flexible PVC building materials and surfaces should be carefully considered;

- The use of PVC-containing recycled-content building materials in green buildings is likely to have environmental benefits since, if it is not recycled, PVC waste ends up in landfills where it degrades very slowly and could be burned in a landfill fire, or is burned in trash barrels or in municipal waste incinerators where it produces toxic air pollutants that can contribute to unhealthy air and may subsequently enter the food chain.

In light of these conclusions and other information presented in this report, OEHHA staff respectfully suggests the Integrated Waste Management Board consider the following findings:

- From a public health perspective, the recycling and reuse of lead and cadmium free PVC-containing building materials, even in green building applications, is preferred to landfill disposal or used as waste fuel in incinerators.

- Recycled PVC in highly durable, long-lived, rigid goods that are readily recyclable, have advantages in construction and building applications;

- The use of short-lived, disposable, difficult-to-collect and not-readily recyclable flexible PVC products such as those found in consumer goods packaging applications and some building applications, such as shipping films, contribute to solid waste management challenges.

- There are public health and environmental reasons to encourage and support the development and growth of post consumer plastics recycling efforts.

Finally, OEHHA recognizes the production and use of PVC in building materials, including those containing recycled-content, is highly variable and still evolving as an industry. The answer to the question of whether to use PVC-containing building materials in green buildings may vary greatly depending on whether an entire class of products or materials is being evaluated or whether a specific example within the class of interest is being assessed.

In this effort OEHHA staff looked only at the concept of using PVC-containing recycled-content building materials in green buildings, *in general*. We did not assess how a particular brand, model or style of a given PVC-containing recycled-content building product, such as carpeting or other flooring materials, might compare to others.

It is possible that some recycled-content PVC building materials, especially those produced from *down-cycling* or as composite products, may contain chemicals of potential concern that were not addressed in this research. In specific cases where this may occur, or if IWMB staff have additional questions or concerns, OEHHA staff recommend that case-by-case assessments be carried out to determine if any human health or environmental quality issues may result from using those particular products in green building environments.

OEHHA further recommends that the IWMB continue to require manufactures of green building materials to submit to the IWMB, information on the content and composition of those materials, as well as emissions test data, as appropriate. This information may be necessary for assessing whether certain types of building materials or products in certain settings could or should be considered less acceptable for use in green buildings than others.

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Web-Based Research Tools

MSN Search	www.msn.com
Google	www.google.com
Lycos	www.lycos.com
Altavista	www.altavista.com
Yahoo	www.yahoo.com
Ask Jeeves	www.ask.com
Excite	www.excite.com
Mamma	www.momma.com
Medline	www.ncbi.nlm.nih.gov/pubmed/
Dogpile	www.dogpile.com
Webcrawler	www.webcrawler.com
Scirus	www.scirus.com/srsapp/

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6. Agency for Toxic Substance and Disease Registry, Division of Toxicology, 1600 Clifton Road NE, Mailstop E-29, Atlanta, GA 30333, Ph: 404-639-6000

Plastics Trade, Research and Construction Organizations

- American Plastics Council (APC). APC is comprised [sic] of 23 of the leading resin manufacturers, plus one affiliated trade association representing the vinyl industry. APC's membership represents more than 80 percent of the U.S. monomer and polymer production and distribution capacity." http://www.americanplasticscouncil.org.

- Association of Post Consumer Plastic Recyclers. Focuses on recycling plastics and related issues. http://plasticsrecycling.org.

- Building Green.Com. Providers of building products not made from PVC. www.buildinggreen.com

- Enviromart.   Providing recycled and virgin materials. www.enviromart.org.nz

- National Center for Manufacturing Sciences. A cross industry collaborative research and development group representing virtually every sector of the manufacturing community in North America. www.ncms.org.

- Recycling Markets.net. Providers of recycled-content plastics based building materials. www.recyclingmarkets.net

- Society of Plastics Engineers (SPE). Professional society, focusing more on downstream applications than resin production. http://www.4spe.org.

- Society of the Plastics Industry (SPI). Founded in 1937, the Society of the Plastics Industry, Inc. is the trade association representing the fourth-largest manufacturing industry in the United States. SPI's 1,500 members represent the entire plastics industry supply chain, including processors, machinery and equipment manufacturers and raw material suppliers. The U.S. plastics industry employs 1.5 million workers and provides more than $330 billion in annual shipments. http://www.plasticsindustry.org.

- Texas Department of Transportation. Offering information on recycled-content construction materials. www.dot.state.tx.us

- Vinyl Institute. Representing manufactures of vinyl (PVC) based products and providing scientific and technical expertise. www.vinylinfo.org

- Vinyl Council Australia. Representing manufactures of vinyl (PVC) based products and providing scientific and technical assistance in developing recycling technologies. www.vinyl.org.au.

Environmental and Health Organizations Concerned About PVC

- Healthy Building Network. An organization that is guided by an advisory panel of grassroots activists, health professionals, and leaders in the Green Building Movement. www.healthybuilding.net.

- Greenpeace. A non-profit organization with a presence in 40 countries that focuses on a number of environmental issues. www.greenpeace.org

- Massachusetts Public Interest Research Group (MASSPIRG). A statewide Massachusetts group comprised of 25 college campuses that works on a variety of environmental and public health issues. www.masspirg.org.

- Recycling Advocates. Advocates and a resource for recycling plastics including PVC-based materials. www.recyclingadvocates.org

- Vermont Public Interest Group. Vermont's largest environmental and consumer watchdog organization with 20,000 members providing research, advocacy and organizational services. www.vpirg.org.

Related Articles and Publications

Addink, R., F. Espourteille, and E.R. Altwicker. 1998. “Role of inorganic chlorine in the formation of polychlorinated dibenzo-p-dioxins/dibenzofurans from residual carbon on incinerator fly ash.” *Environmental Science and Technology* #32:3356–3359.

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