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Abbreviations

CD	Compact Disc
CO_2	Carbon Dioxide
CONEG	Council of Northeast Governors Coalition
EDC	Entertainment Distribution Company
EIO-LCA	Environmental Input Output Life Cycle Assessment
EPA	(U.S.) Environmental Protection Agency
FSC	Forest Stewardship Council
GHG	Greenhouse Gas
LCA	Life Cycle Assessment
MSDS	Material Safety Data Sheet
NARM	National Association of Recording Merchandisers
NO_x	Nitrogen Oxides
NRDC	Natural Resources Defense Council
PAH	Polyaromatic Hydrocarbon
PCW	Post-Consumer Waste
PLA	Polylactic Acid
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinylchloride
RIAA	Recording Industry Association of America
SO_x	Sulfur Oxides
SBS	Solid Bleached Sulfate
SFI	Sustainable Forestry Initiative
SPWG	Sustainable Packaging Working Group
UV	Ultraviolet
VCM	Vinyl Chloride Monomer
VOC	Volatile Organic Compound

Executive Summary

In recent years, awareness of the environmental impacts of compact disc (CD) packaging has grown within the music merchandising industry, as well as the general public. This report was written for the Sustainable Packaging Working Group (SPWG) and reviews the environmental and potential toxicological impacts of several CD packaging options from the existing scientific literature. These options include:

- Conventional polystyrene jewel case
- Alternative polypropylene jewel case
- Conventional 6-panel paperboard package (a “soft pack” or “folded sleeve”), evaluated for both virgin and 100% recycled content feedstock

A number of alternative packaging materials are be considered qualitatively, including polyvinyl chloride jewel cases, polylactic acid (a bio-based material), and 4-panel digipaks (a hybrid paper-plastic package), primarily through a review of existing studies.

Environmental impacts have been evaluated over several categories, including primary energy use (or cumulative energy demand), greenhouse gas emissions, water use, ecotoxicity, and human health impacts. This has been done following life cycle assessment standards and using U.S. and generic life cycle inventory data.

Energy use and greenhouse gas emissions are cited by SPWG members as the most pressing environmental concern for their companies. Table ES1 shows the life cycle assessment results for greenhouse gas emissions for each packaging option under two waste scenarios (U.S. average disposal methods, with recycling and without (base case)).

Table ES1 Summary table of greenhouse gas emissions associated with CD packaging

Option	Production (kg CO_2 eq)	Waste Mgmt (kg CO_2 eq)	Total (kg CO_2 eq)
PS, base case	31,300	6,400	37,700
PS, U.S. average recycling scenario	31,300	2,500	33,800
PP, base case	18,500	1,400	19,900
PP, U.S. average recycling scenario	18,500	-2,000	16,500
6-panel virgin paperboard, base case	49,700	-1,200	48,500
6-panel virgin paperboard, U.S. average recycling scenario	49,700	-24,000	25,700
6-panel recycled paperboard, base case	27,800	-1,200	26,600
6-panel recycled paperboard, U.S. average recycling scenario	27,800	-12,100	15,700

Ecotoxicity, or the degree to which chemicals released over the life cycle of CD packaging affect living organisms, was also evaluated quantitatively. For all CD packaging options, the largest contributors to ecotoxicity were fossil fuels, through processing as feedstock material, combustion for energy electricity and heat, and the eventual incineration of the fuel embodied in plastic. Recycling was only significant in decreasing ecotoxicity impacts for paper products, reflecting the much higher recycling rates for paper over plastic in the U.S.

For each final product and its monomers/precursors, major additives, and byproducts, a toxicological hazard matrix has been created, covering the major endpoints of cancer, non-cancer human health, aquatic toxicity, and persistence and bioaccumulation, as summarized in table ES2. These human health hazards are only potential and depend crucially on actual exposure.

Table ES1 Summary table of toxicological hazards associated with CD packaging

Material / Substance	Cancer	Non-cancer Human Health	Aquatic Toxicity	Persistence and Bioaccumulation
General				
Polyaromatic hydrocarbons (PAHs)	confirmed in animals	respiratory, reproductive	various	slight persistence, bioaccumulation
Volatile Organic Compounds (VOCs)	some are carcinogens	neurotoxic effects	n/a	depends on compound
Carbon Monoxide	n/a	acutely toxic	n/a	unlikely
Polystyrene				
Styrene monomer	possible carcinogen	neurotoxic effects	n/a	unlikely
Polypropylene	not mutagenic	no evidence	n/a	not persistent
Propene monomer	little evidence in animals	respiratory, possible liver	moderate	unlikely
Titanium tetrachloride	n/a	inhalation and respiratory	n/a	n/a
Polyvinylchloride	n/a	n/a	n/a	persistent, not bioaccumulative
Vinyl chloride monomer (VCM)	known carcinogen	various	confirmed	unlikely
Phthalates	n/a	developmental, reproductive	slight	moderate persistence
Dioxins and furans	positive evidence	various	confirmed	persistent and bioaccumulative
Pulp and Paper				
Tannins	n/a	weak toxicity	confirmed	not persistent, not bioaccumulative
Methanol	n/a	neurotoxic effects	low	not persistent, not bioaccumulative
Dioxins and furans	positive evidence	various	confirmed	persistent and bioaccumulative

Note: See report for full tables and references

Of the substances considered, vinyl chloride monomer has the most research showing a positive association with hazard endpoints, including cancer, neurotoxicity and liver effects in humans. Dioxins and furans, combustion products of chlorinated materials such as PVC or bleached paper, also have very serious documented health effects.

There are many organizations that exist in the space of sustainable materials and packaging. These include environmental and consumer groups, consultancies, product suppliers, and retailers. A review of the measures these groups are taking to address the environmental issues associated with packaging is presented here, including detailed criteria for paper, inks, adhesives, and other materials.

Based on these quantitative results and our qualitative assessment of the design problem facing the CD packaging industry, we present a number of recommendations:

- Minimize the weight of all packaging components to the extent possible.
- Consider the advantages of PP vs PS, such as lighter weight and low energy costs.
- Weigh the environmental pros and cons of moving from polymers to paperboard packaging. Maximize the recycled content of paperboard orders, as this has a much lower impact across all categories than paperboard from virgin sources. Use FSC- or SFI-certified wood as much as is economically feasible.
- Recognize the higher degree of environmental hazards associated with PVC as opposed to other recommended materials in manufacturing jewel cases or plastic film.
- Consider the use of PLA, particularly for CD trays in digipak-style packages.
- Ask suppliers for paperboard packaging designs that are stiff enough to be processed in an over-wrapping machine, as opposed to being shrink wrapped.
- All inks used by suppliers and printers in the industry should adhere to CONEG or similar regulations certifying a minimal level of cadmium, hexavalent chromium, mercury and lead. Depending on brightness and color requirements, vegetable- or soy-based inks should be considered where possible.
- Moving from plastic to paperboard CD packaging will necessitate increases in the use of adhesives, to fasten paperboard front-to-back, affix liner notes, and/or affix plastic CD hubs in the base of digipak-style packages. Low- or no-VOC adhesives that do not contain any known carcinogens should be used in all cases.
- Investigate the required strength of bonds for paperboard packaging and stickers, and avoid the use of unnecessarily strong adhesives, as these tend to have proportionally higher environmental impacts.
- Much of the pulp and paper industry has moved away from elemental-chlorine bleaching and the use of highly toxic materials in pulp digesters, but SPWG members should ensure that upstream suppliers do not use these practices.
- For all packaging options, and especially the plastic jewel cases, materials should be clearly identified and labeled as recyclable or not. Current CD packages have almost no information related to the packaging itself. To facilitate recycling, each manufacturer should use only one type of plastic for jewel cases. The type of plastic used is a matter for each company to determine on an individual basis.
- Consider offering carbon offsets to those customers who would like to address the greenhouse gas impacts of their music and its packaging.
- For whatever measures are taken by SPWG members to address the environmental impacts of CD packaging, these should be advertised prominently. Consumers appreciate transparency, especially those that want to evaluate environmental performance.

SPWG members must decide individually which recommendations they choose to follow; if acted upon, these recommendations can help SPWG members to reduce the environmental impacts of CD packaging considerably and to build up brand image as companies that are acting proactively to address our common environmental problems.

With the advent of digital music and the internet, the music industry has been changing dramatically. Economic pressures on the major companies are complex and intense. CDs made up more than 80% of the global market in 2006, but the sales volume of physical media fell by 21% in 2007 compared with the previous year, and downloads of digital music have not been able to substitute for these losses (The Economist, 2008). Declining revenues will make it difficult for many companies to adapt their practices for producing physical media, such as purchasing new automated packaging equipment that can deal with alternative packaging types. A carbon tax would put further pressure on music merchandisers, as the prices of raw materials and energy would increase. (It is unclear how a carbon tax would affect pricing of digital music.) In general, the music merchandising industry faces difficult choices in balancing packaging innovations and economic viability.

1. Goal and Scope Definition

In November, 2008, the Recording Industry Association of America (RIAA) and the National Association of Recording Merchandisers (NARM) contracted with Sustainability A to Z, LLC to conduct a sustainability evaluation of various packaging options for compact discs (CDs). The client's members include many of the largest companies within the music recording and merchandizing industry. Packaging is the major component of retail CDs and the large volume of discs manufactured and purchased in the United States and globally means that the environmental implications of packaging choices are significant. The goal is to understand the environmental and human health impacts for each packaging option across a suite of impact categories, over the entire life cycle of the packaging. This assessment is intended as a review of current best practices and a streamlined life cycle assessment (LCA), in order to highlight the materials and processes that have the largest impacts. The results will guide the client in making environmentally responsible choices for CD packaging in the future.

There has been a call for green or sustainable CD packaging from artists and consumers alike. Artists want to represent their music and brand as environmentally responsible, and many have insisted on packaging that has certain perceived green characteristics, such as recycled content or zero plastic. The past several years has also seen a sea change in awareness of the environmental performance of various products and materials, with many consumers making purchasing decisions based on environmental criteria. The industry therefore understands the business case for a move towards more sustainable packaging, beyond the obvious savings opportunities from energy and material efficiency measures. To this end, they have formed the Sustainable Packaging Working Group (SPWG) to organize their efforts.

The music industry in general is witnessing a push towards digital media and sales, as more and more tracks are downloaded through online sites. Digital downloads obviate the need for any packaging or printing of CDs themselves, and are probably the environmentally preferable choice in the long term. The system of digital downloading certainly has environmental impacts, however; in particular, the energy consumption from the manufacture and use of IT infrastructure, server farms, and other computing equipment necessary to enable large-scale downloading of musical tracks should not be disregarded. In the short term, internal industry estimates show that conventional CDs will outnumber digital downloads for the next several years, and so this assessment of CD packaging options is still timely.

There are three main packaging options that will be considered here, as specified by the SPWG:

1. Conventional polystyrene jewel case
2. Alternative polypropylene jewel case
3. Conventional 6-panel paperboard package (a "soft pack" or "folded sleeve")

A number of alternative packaging materials will also be considered qualitatively, including polyvinyl chloride, polylactic acid (a bio-based material), and 4-panel digipaks (a hybrid paper-plastic package).

The functional unit of this assessment will be the packaging associated with a print run of 100,000 compact discs, a standard size run for the industry. Different manufacturers of packaging components use varying weights and types of materials for each type of package; these are detailed in Section 3, below. Clearly, the two major types of packaging considered here are polymer- and paper-based. Among the polymer options, all packages have the same design and components. Among the paper options, the report considers virgin material and that produced from 100% post-consumer waste (PCW) content. There are, however, a number of important differences in the chemical and toxicological properties of each feedstock material, the way they are produced, and the processes used to form them into commercial products.

The study is meant as a “cradle-to-grave” assessment. This means that it principally covers all relevant process steps from raw material sourcing to the final waste treatment or recycling of the used packaging. However, those life cycle steps and material components which are the same across the packaging systems examined have been excluded, as detailed below.

The scope of the study explicitly includes the following steps:

- Production of monomers and paper fibers (starting from crude oil / natural gas extraction and logging)
- Production of additives, inks, dyes, adhesives, and other material inputs
- Polymerization and molding of jewel cases
- Production and folding of paperboard (both virgin and recycled content)
- Printing and coating of paperboard and inserts
- Shipping of packaging components to assembly location (average)
- Assembly, automated or hand-assembled, as applicable, including stuffing of books and inserts, application of top-spine sticker, and exterior cigarette or shrink wrap packaging
- Commuting of workers needed for hand-assembly versus automation
- Any wastage that arises during assembly
- End-of-life waste management, including incineration and/or landfilling

Not included within the system boundaries are:

- Production of books or liner notes*
- Production of the CDs themselves*
- Production and application of stickers, security tags, and other material that is affixed to the external packaging*
- Boxing and shipping*
- Retail of the CDs
- Environmental effects directly related to the activities of the consumer
- Impacts associated with the storage of CD packaging materials in homes prior to discard

- The analysis will be limited to direct material inputs. For example, the energy and materials required to build and maintain the factory where production takes place will not be included in the assessment
- Recycling of polystyrene and polypropylene jewel cases
- Composting of PLA jewel cases
- Environmental effects from accidents
- Land use change (this is a very contentious area of environmental product assessment)
- Any assessment of carbon storage while the packaging is in use, as it is not assumed to last long enough as a product to represent a significant carbon stock
- The CD packaging industry, while large, is not significant compared to the general paper or plastics sectors; therefore, assessment of any large-scale changes to economic structure within the industry will not be considered

* These represent items that should have equivalent impacts across all packaging options. In the case of boxing and shipping, it is assumed that there is roughly the same number of units per skid (or other shipping container) for each type of packaging and that the fuel efficiency of transport is independent of the type of packaging.

The following environmental impact categories will be considered: energy use, water use, global warming potential, eco-toxicity, and human health impacts. Other impact categories such as acidification, eutrophication, and photochemical smog formation will not be included.

All data will be provided from members of the SPWG and collected from their suppliers on an as-needed basis. In the absence of specific data, typical weights and materials will be assumed for packaging components, such as front panels, back panels, inks, coatings, top spine stickers, etc. It will be assumed that all types of packaging have the same dimensions (as required by current packaging infrastructure).

Details of specific assumptions are as follows:

- Average data for North American logging, transport, pulping, and papermaking practices will be assumed
- Where the physical constituents of glues, inks, and other input materials cannot be assessed, industry average data will be used
- The analysis of production will include information on the use of energy, water, and materials not incorporated into the product, as well as those that are. This information will ideally be provided by the packaging manufacturers; otherwise, industry average production data will be used
- Average US practices for final disposal will be assumed (incineration vs. landfill, average transport distances and costs). It is assumed that this is a U.S.-focused study, so that other scenarios, such as production and disposal outside of the U.S., are not considered here.
- Various end-of-life scenarios can be modeled, including aggressive recycling or product take-back, depending on the interests and future capabilities of the industry

- Unless otherwise noted, data will be taken from the U.S. LCI database (published by the National Renewable Energy Laboratory) and the Ecoinvent 2.0 LCI database. These data are specific to relatively recent time periods (generally within the last decade) and predominant operating practices in the United States and Europe, respectively.
- Some of the potential environmental effects associated with agriculture as well as crude oil extraction and processing have not been taken into consideration. For agriculture examples are biodiversity, human toxicity, ecotoxicity and soil fertility being affected by pesticides, heavy metals contained in fertilizers and the use of genetically modified crop plants. For petrochemical activities examples are the marine, soil and air environment affected by crude oil and gas losses during production and transportation (by ship and pipeline) or air quality affected by fugitive emissions at refineries with unknown chemical composition and emission pathways. These effects are difficult to examine in LCAs due to the lack of data or appropriate methods.
- The additional labor required to hand-assemble paperboard packages contributes to the increased environmental burden of these packages primarily through the impacts of commuting to and from the assembly plant. The system boundary used here allocates these commuting impacts to paperboard packaging assembly.

Every effort was made to include all materials of concern; however, in order to maintain the study within a feasible scope a limitation of detail in system modeling was necessary. Therefore, so-called cut-off criteria were used. Materials with an input of less than 1% of the total output of the packaging step were excluded if process data for these materials were not available.

Two waste management scenarios will be explored in this report. The base case describes the U.S. average disposal with no recycling. Waste is either incinerated (31%) or landfilled (69%). The recycling scenario describes the average recycling rates for each material: paper (54%), PS (4%), and PP (7%). The remainder is then either incinerated or landfilled, again following the U.S. averages listed above.

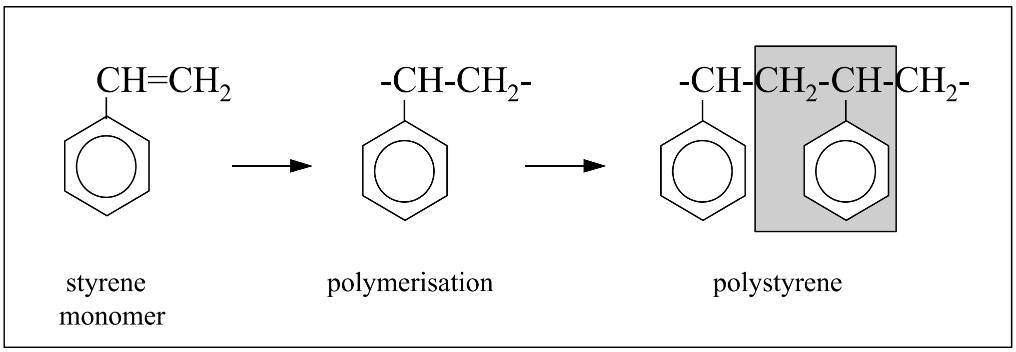
All systems modeling was performed using a combination SimaPro and in-house software; graphics were generated with standard data visualization packages. It must be noted that this type of data-intensive product modeling is highly dependent on the quality of the data and the assumptions, as well as to the overall system boundary of the product in question. Every effort has been made to ensure that the results are as robust as possible, but still they must be seen as transient, changing with improvements in technology and data reporting.

Recommendations were based on these quantitative results, as well as a survey of current best practices in the packaging industry.

2. Packaging Materials Descriptions

2.1 Polystyrene (PS)

Polystyrene (CASRN: 9003-53-6) is a commercial thermoplastic that is used in an extremely wide range of applications, particularly for packaging. It is created from the bulk polymerization of styrene ($C_6H_5CH{=}CH_2$), which was first isolated from the sap of styrax trees, though it is now industrially produced from the dehydrogenation of ethylbenzene. PS is sold in three forms: crystal or general purpose, high-impact, and expandable. This analysis focuses on general purpose PS, used in the manufacture of CD jewel cases. A simplified process diagram for the production of PS is shown here:



Source: Boustead, 2005a

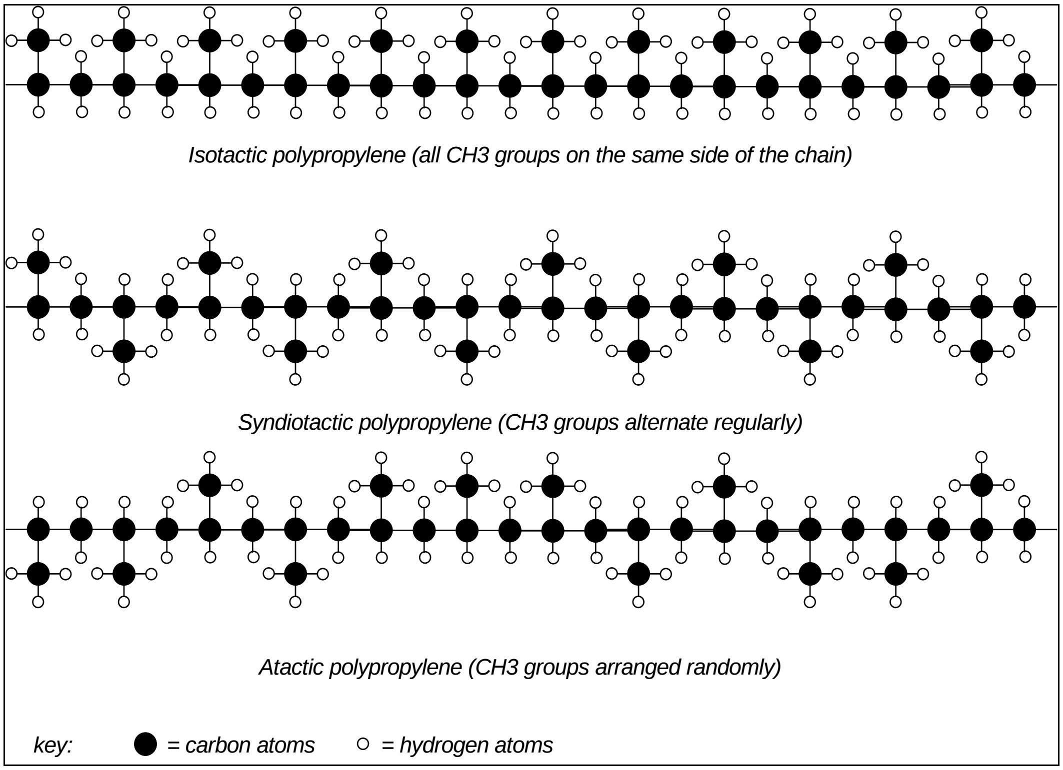
During polymerization, some small portion of styrene is liberated if the reaction takes place at high temperature (>280 ºC); this air emission is usually vented to the atmosphere.

At end-of-life, PS can be easily recycled or incinerated. The heat content of PS is nearly equal to that of fuel oil, and the absence of chlorine groups means that the production of dioxins during incineration is not an issue, as it is for other plastics (Maul *et al.*, 2007).

PS is the traditional polymer feedstock for jewel cases. Although many manufacturers have explored alternative polymers or classes of materials, the performance standards for clarity, durability, and brittleness are based on PS.

2.2 Polypropylene (PP)

Polypropylene (CASRN: 9003-07-0) is a polymer made from propene monomer (C_3H_6) and falls in the category of polyolefins (including polyethylene). Propene monomer is a non-toxic, highly flammable gas. There are three types of polypropylene, depending on the orientation of the methyl side groups:



Source: Boustead, 2005b

The polymerization process relies on metal-based catalysts and, unlike PVC, does not incorporate halogens (chlorine or bromine). Typically, gas phase polymerization is used, where the polymer particles are held in a fluidized bed by stirring or the introduction of high-velocity gas. Vessel parameters such as temperature, pressure, and agitation are used to control the size and shape of the final product (Boustead, 2005a).

Certain steps of PP polymerization have classically required peroxides for stabilization (0.05-0.2% by weight), which can produce volatile byproducts; newer classes of metallocene catalysts have obviated this requirement. All catalysts for PP manufacture use titanium tetrachloride ($TiCl_4$), which is highly energy intensive to produce and has toxicity concerns of its own. Some catalysts also use aluminum alkyls, which can be corrosive and is highly reactive in water. Other minor additives include antistatics, antacids, slip and antiblock agents, and chemicals that encourage crystallization. Pure PP is often blended with fibers and/or fillers to achieve desired properties. Blending agents include rubber, glass, chalk, and talc (Whiteley *et al.,* 2005).

Injection molding of polypropylene is similar to that of other polymers: resins and any additives are heated past their melting points and injected into a water cooled mold. As the product cools, it becomes solid and is ejected from the mold and the process repeated. Environmental information from PP injection molding is notoriously variable:

> "It is important to recognize that the performance of injection molding factories can be very variable because of factors such as rate of injection (kg/hour), the design and age of the molding machines, the general level of activity in the factory and the duration of a production sequence. As a consequence it is almost impossible to produce typical, representative figures for performance."
> (Boustead, 2005b)

Most of the PP generated as manufacturing scrap is recovered and recycled, while end-of-life scrap is incinerated or landfilled directly. PP waste has roughly the same calorific value as fuel oil but minimal air emissions concerns (particularly for sulfur) and thus makes excellent feedstock for waste-to-energy electricity plants (Whiteley *et al.,* 2005).

Jewel cases made from PP are widely seen as a viable alternative to PS, which is generally thought to be more energy- and water-intensive. PP also has some performance advantages: being softer at room temperature, it is less brittle and therefore less likely to crack.

2.3 Multi-panel paper

(Soft packs or Folded sleeves) CD packaging that make use of paper-based materials instead of relying on polymers are becoming increasingly popular. These packages are usually based on folded boxboard with various mixed of virgin and recycled material (either industry or post-consumer waste). Virgin material is solid bleached sulfate (SBS), a premium paperboard grade that is produced from a bleached pulp containing at least 80% virgin wood.

Most bleached paperboard is coated with a thin layer of clay to leave a smooth surface for printing.

Unlike plastic cases that have paper inserts in the front and back, artwork and album information are printed directly onto paperboard packages. These packages are also more susceptible to damage such as bending or scratching than plastic cases that protect the artwork. For this reason, paperboard packages usually receive some sort of coating or surface treatment. For paperboard, coatings are applied thinly and cured by ultra-violet (UV) light – for this reason, they are referred to as UV coatings. These coatings have varying levels of solids content, up to 100%; the higher the solids content, the lower the production of volatile organic compounds (VOCs) produced during curing.

The most significant environmental effects of paperboard production occur during the pulping process for virgin material. Wood chips must be digested with sulfurous chemicals at high temperature and pressure – this requires significant energy and water inputs and produces a complex effluent including tannins and methanol, some of which is subsequently used for energy production (EPA, 1995).

Waste management practices associated with paperboard packages after they are discarded are complex. Environmental impacts associated with recycling and disposal vary greatly according to local practices for collection, sorting, and transport of material. Paper is among the most recycled post-consumer materials in the United States, but recycling rates are constantly shifting as raw and scrap material prices fluctuate and recycling authorities search for the most economical contracts.

2.4 Polylactic Acid (PLA)

Polylactic acid (PLA) is a bio-based polymer that in the United States is generally derived from corn starch. It is biodegradable and has undergone a surge in demand in recent years as an environmentally preferable alternative to petroleum-based polymers. The largest producer in the United States currently is NatureWorks.

Lactic acid is produced either synthetically through the hydrolysis of lactonitrile or through the fermentation of carbohydrates. The use of lactic acid as a monomer, or building block, for PLA requires high purity, which is difficult to achieve using the synthetic pathway. For this and other reasons, all of the recent added capacity in lactic acid production has been fermentation facilities.

Though the primarily material for fermentation is natural biomass, there are several additives and reagents that must be added for proper processing. During fermentation, the pH of the broth must be controlled between 5.0 and 6.5. This requires basic chemical additives such as lime (calcium hydroxide), calcium carbonate, ammonium hydroxide, or sodium hydroxide to neutralize natural acids generated during fermentation. Lactic acid yields are typically between 85 and 95%. Purification steps are required to produce monomer-grade material: microorganisms are removed by flocculation, byproduct lactate salts are converted to lactic acid with the addition of sulfuric acid and subsequent natural precipitation of the resulting salt (Chahal and Starr, 2006).

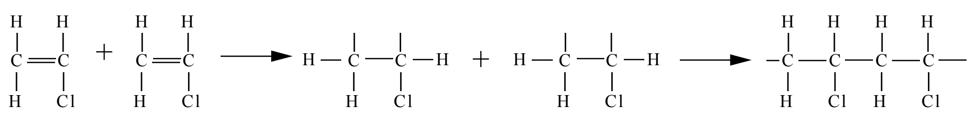
Considering the basic health and environmental impacts of PLA:

> "Lactic acid, a naturally occurring organic acid found in many different biological systems, is environmentally safe. Industrial fermentation of lactic acid produces a salt byproduct that is landfilled or incorporated into building materials or used in agriculture. It also produces an aqueous stream that can be treated in a typical wastewater treatment plant. As more lactic acid goes into making PLA, there are considerable environmental benefits of using PLA over conventional oil-based polymers, including lower CO_2 emissions and wider choice of disposal options that includes composting.
>
> **"**Lactic acid is a nontoxic naturally occurring edible acid used widely in the food industry as an acidulant. However, it is acidic and will cause discomfort if it should come into contact with eyes or broken skin. It can cause eye irritation and must be washed out immediately. The problem of oral toxicity should not arise unless a large quantity is swallowed (LD50: 3730 mg/kg in rats)." (Chahal and Starr, 2006)

One disadvantage of producing lactic acid through fermentation of corn starch is that it competes directly for feedstock with the ethanol and food/feed industries in the United States, and thus cannot be seen as a benign choice from a sustainability perspective.

2.5 Polyvinylchloride (PVC)

As with most polymers, PVC (CASRN: 9002-86-2) actually represents a class of materials with large variations in molecular size and viscosity. PVC is a chlorinated hydrocarbon polymer made from vinyl chloride monomer (VCM, CASRN: 75014):



Source: Ostermayer and Giegrich, 2006

The basic raw materials for VCM and hence PVC are petroleum (43% by polymer weight) and rock salt (57% by weight) (EU Commission, 2004). VCM is a gas at room temperature and its polymerization is highly exothermic (energy producing). Feedstock VCM is made by one of two processes worldwide (WHO, 1999):

1) Hydrochlorination of acetylene (~10% of world production)
2) Thermal cracking of 1,2-dichloroethane, made from ethylene (~90% of world production). Ethylene is the organic chemical with the highest production volumes worldwide, so there are no resource constraints associated with its use.

PVC is itself produced through three main processes: suspension (80%), emulsion (12%), and mass or bulk (8%). Most flexible products use PVC suspension resin. During polymerization, liquid vinyl chloride is agitated in water, producing suspended droplets. Polymerization normally takes place is pressurized vessels with catalysts and/or initiators, such as organic peroxides. Anti-coagulants prevent the polymer particles and the monomer droplets from agglomerating. When the polymerization reaction has neared completion, the batch is "blown down", the unreacted monomer is recovered and recycled, and the final polymer resin particles are dried (Ostermayer and Giegrich, 2006).

Pure vinyl chloride is a rigid and brittle material that degrades at approximately 100 degrees centigrade. By itself, PVC is problematic to produce, and so other materials are added to ease processing, including water, heat and UV stabilizers, pigments, flame retardants, granulating agents, lubricants, plasticizers, and fillers (Allsopp and Vianello, 2005). The proportion of pure polymer resin in PVC can range from 44-93% (Baitz *et al.*, 2004). These additives greatly influence the material characteristics of PVC as well as its environmental and toxicological effects.

PVC is used for a wide range of products, both consumable and durable. Durable products exist in use, sometimes for decades, before entering waste management. Recycling options for PVC are limited in most areas, and so almost all material at end-of-life is either landfilled or incinerated. In Europe, an estimated 82% of post-consumer PVC is landfilled, 15% is incinerated, and 3% is recovered for recycling (Baitz *et al.*, 2004).

3. Processing and Logistics Descriptions

As noted above, the functional unit for this assessment is the packaging necessary for a print run of 100,000 discs. This section briefly describes the major unit processes and logistics involved in the production of this functional unit.

CDs and CD packaging has been standardized by weight and dimensions; thus, all of the automated processes have been built to accommodate these specifications.

Different amounts of material are needed to construct CD packaging, and the mass of each material is a sensitive input into LCA models. The mass of each packaging component was determined from manufacturers or measured empirically.

Table 3.1

Packaging Component	Mass (g)
PS jewel case front and back panels (2pcs clear)	60
PS jewel case hub (1 pc clear or colored)	25
PP jewel case total	65
Paper inserts	10
Paperboard 4-panel (without booklet)	40
Paperboard 6-panel (without booklet)	60

Production of Feedstock and Components

For the polymer packages, the first step is the production of the polymer and its molding into transparent jewel cases. These are produced by injection molding, with any scrap being reincorporated into product. Jewel cases are produced as two panels, cases and trays, with a hub in the middle of the tray unit to hold the CD itself. Final jewel cases are packaged into bands of 50 units and sent to an assembly plant.

Paperboard is produced in a bleached white form, surface treated for smoothness, and cut into standard-sized sheets. These sheets are sent to a printing facility, where they are printed and creased into 4-, 6-, or 8-panel units. These are packaged and sent to an assembly plant.

Front and back inserts and booklets are printed on high-quality smooth paper and then cut down to size. Paper scrap is recycled. Several staples are used to keep the booklets together. Stickers are printed on lower-quality paper that has an adhesive backing and is affixed to a lightly waxed continuous roll of paper. These rolls of stickers and the boxed inserts and booklets are sent to an assembly plant.

Assembly

At the assembly plant, the plastic cases and trays are fed into automated assembly machines, along with the paper inserts, booklets, and CDs. All of the corrugated cardboard shipping boxes for these materials are recycled. Once assembled, a top spine sticker is applied with a strong adhesive. The plastic rolls of sticker backing are discarded without recycling. After assembly, the completed plastic packages are covered in cigarette wrapping, a thin plastic film that comes in widths made-to-order for this application. The wrapping is cold cut flush unit to unit so there is no wastage. The CD package is automatically wrapped and heat bar sealed on three sides.

For paperboard packages, assembly is done by hand, requiring approximately six times as much labor input as for plastic jewel cases. This additional labor contributes to the environmental burden of paperboard packaging in the process of commuting to and from the assembly plant. As most of the artwork is printed on the paperboard itself, front and back inserts are not necessary, but booklets are still generally added. This package does not receive a top spine sticker. Assembled packages are sent through a hot shrink wrap machine, which wraps the packages in a thick plastic sleeve. This sleeve is cut and heat sealed at the top and between the packages, generating significant wastage. Wrapped packages are then sent through an oven kept at several hundred degrees where the plastic wrapping shrinks to a tight fit. Plastic wrapping machines generate significant heat, which must be vented or offset by air conditioning.

Wastage

Typically there is a surplus of paper insert, booklets, and stickers at the end of a print run. According to one industry representative, wastage during production from stickers is about 3% of the total, paper items (including inserts, booklets, and paperboard packaging) is about 1%, and jewel cases have a 1% wastage rate. Upstream losses of polymers during jewel case production are assumed to be 5%. For printed materials, for each 100,000 unit run there is a large over-order of approximately 50,000 surplus units. Printers also send an over-print of approximately 15,000 units. There is also an estimated 10% loss during printing. So, for an order of 100,000 units of printed material, approximately 185,000 units of input materials are consumed in printing facilities. An estimated 75% of this overstock is eventually used for re-orders of the CDs; however, there is significant wastage which can be in the millions of units of paper stock discarded each month. Averaging over consecutive orders (the first will have 65,000 overstock units, the second will use 75% of this surplus but will also have its own overstock), it is assumed that 160,000 units of input materials are consumed in printing facilities per 100,000 unit order.

Packing and Shipping

After both types of packages have been wrapped, stickers are applied as well as security tags to approximately one-third of all units. These completed packages are boxed in cartons of 30, automatically loaded onto skids (168 cartons to a skid), and stretch wrapped for shipment by truck. Each carton weighs approximately 7 pounds. A full shipment carries approximately 192,000 units. Shipments are sent to distribution centers, and from there to retailers. As these external packaging, packing, and shipping operations are common to all types of packaging, they are not included in our relative assessment of environmental impacts.

4. Previous Life Cycle Assessments

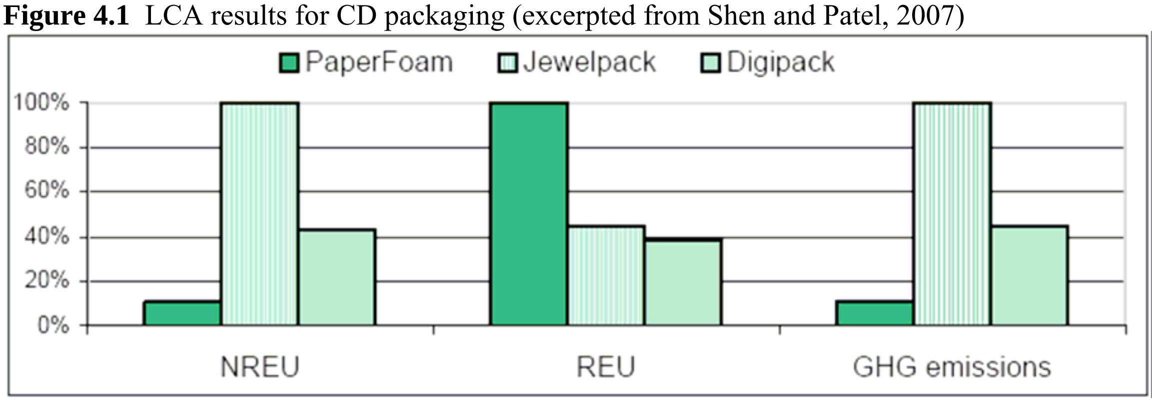
Literally hundreds of life cycle assessment studies have been done in the area of packaging, as it was and continues to be a huge source of waste. Most of this has been for ubiquitous products such as beverage containers. European regulations such as the German Packaging Ordinance have tried to address the use and fate of packaging, and European companies in general have been leaders in using life cycle assessment to make product decisions. For any product, the many alternative materials available to manufacturers and product designers need to be evaluated for their environmental performance, and consumers want to know what type of material they should choose for their own "packages", such as shopping bags or cups.

There is a limited number of LCA studies for CD packaging specifically. One LCA study from the Copernicus Institute at Utrecht University focused specifically on CD packaging, evaluating a bio-based material called Paper*Foam*®, a polystyrene jewel case, and a paperboard-polystyrene Digipak (Shen and Patel, 2007). The authors examined three environmental impact categories: non-renewable energy use (NREU), renewable energy use (REU), and greenhouse gas (GHG) emissions. The results are summarized below.

Table 4.1 LCA results for CD packaging per unit (excerpted from Shen and Patel, 2007)

CD Package	NREU (MJ)	REU (MJ)	GHG emissions (kg CO_2eq)
PaperFoam	0.83	0.36	0.03
Polystyrene	7.67	0.16	0.27
Digipak	3.32	0.14	0.12

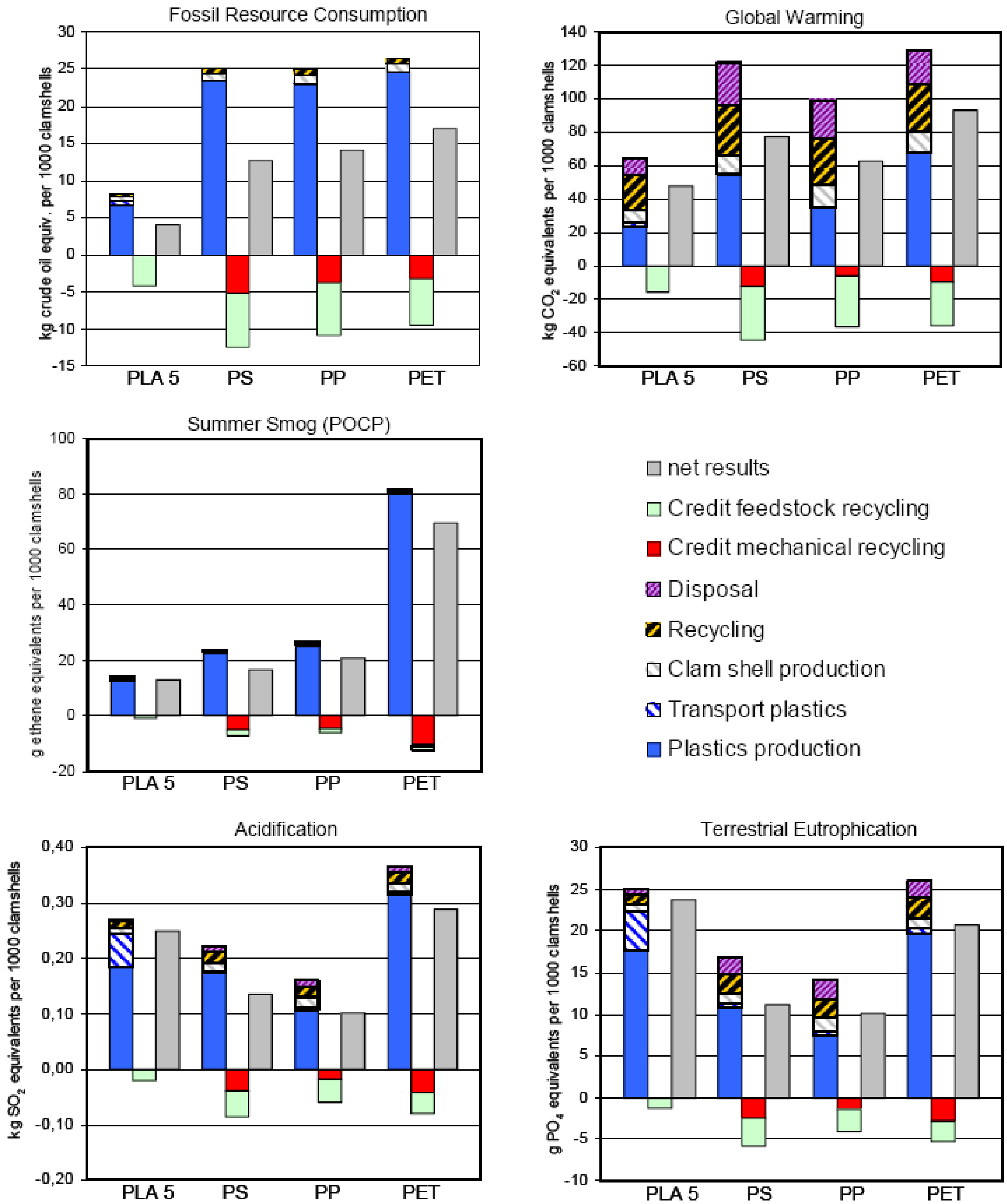
Figure 4.1 LCA results for CD packaging (excerpted from Shen and Patel, 2007)



This LCA showed that the bio-based material was the preferred choice in terms reducing energy use and GHG emissions. The other important result is that the Digipak required approximately half of the energy use and produced approximately half of the GHG emissions of an equivalent PS jewel case.

Another important LCA comparing bio-based and conventional polymers was performed by IFEU-Heidelberg entitled 'Life Cycle Assessment of PLA: A comparison of food packaging made from NatureWorks PLA and alternative materials'(Detzel and Krüger, 2007). The study was commissioned by NatureWorks to evaluate "clam shell" packaging for the German market. The analysis included various waste disposal scenarios and compared PLA with PP, PS, and polyethylene terephthalate (PET). Selected results are shown below.

Figure 4.2 LCA results for PLA comparison (excerpted from Detzel and Krüger, 2007)



These results show that PLA performs well compared to alternate materials in fossil energy use, GHG emissions, and photo-chemical smog formation, but is actually much less desirable in terms of its effects for acidification and eutrophication. This is because PLA is derived from cultivated biomass, which generally requires the application of fertilizers and thus has significant land impacts. Published LCA results for PLA have varied widely as the manufacturing processes have evolved (in the IFEU-Heidelberg study, PLA5 refers to the fifth generation of commercial product) and as different studies have used different scope and boundary definitions.

The other result that is important for the present report is the relative performance of PP and PS packaging. In the absence of recycling, PP and PS consume equivalent amounts of fossil fuels for the production of one unit of packaging (noting that PS is slightly more material efficient). For GHG emissions, however, PP has a lower impact than PS because of the energy intensive processes used to produce the latter. PP is also more desirable in terms of acidification and eutrophication, though these impact categories will not be considered here.

Another study compared conventional PS jewel cases with a PP alternative called VarioPac. This work was completed by the University of Lippe in Germany but cannot be independently confirmed. The report concluded that the PP VarioPac offered the following reductions over standard PS jewel cases:

- Greenhouse effect: 51%
- Acid potential: 67%
- Over-fertilization potential: 69%
- Ozone creation: 66%

(U.S. Digital Media, 2009)

5. Results: Environmental Impacts

CD packaging can have environmental effects at various stages and though many different pathways. Considered quantitatively in this section are:

- *Primary energy use*- The use and depletion of (primarily) non-renewable fossil fuel resources. This includes fossil fuels used to produce electricity;
- *Greenhouse gas emissions*- The release of gases in the atmosphere that contribute to the greenhouse effect, or a general warming of the Earth's surface from an increase in radiation absorbed by the atmosphere. Carbon dioxide is the most common greenhouse gas, but others such as methane and water vapor are far more potent;
- *Water use*- The use of treated water in industrial processes, as well as its subsequent treatment;

There are many other environmental aspects that result from the production, use, and waste management of polymers that are mentioned qualitatively below. Because of their different compositions and process chains, the use of the different types of CD packaging has varied environmental effects along the life cycle of each material. There are many similarities as well, particularly among the petroleum-based polymer options.

Table 5.1 Qualitative comparisons of environmental effects of CD packaging materials

Product Stage	Environmental Effect	Materials
Production	High energy consumption from the production of petroleum-derived monomers (including embodied energy)	PS, PP, PVC
	High energy consumption and greenhouse gas emissions from the production of chlorine, from rock salt mining to electricity for electrolysis and VCM chlorination	PVC
	Greenhouse gas emissions from fossil fuel combustion for electricity and process heat	All
	Land use and nitrogen impacts from unsustainable forestry and cultivations practices	Paperboard, PLA
	Various types of water pollution from pulping process effluent	Paperboard
	Large use of water for washing and processing	Paperboard, PS
	Production from a renewable feedstock	Paperboard, PLA
	Production of nitrogen oxides during refining and cracking into monomers	PVC, PP
	Volatile Organic Compound (VOC) generation from petroleum refining and cracking into monomers	PS, PP, PVC
	Feedstock monomers are almost entirely used or recovered	PS, PP, PVC, PLA
	Persistence of monomers in the environment	PVC
	Relatively low energy consumption during blow molding, spinning, and extrusion	PVC, PP, PLA
	Low energy consumption and environmental effects from the production of fillers	PS, PP, PVC

Product Stage	Environmental Effect	Polymers
Production	High energy consumption for the production of catalysts	PP
	Toxics use for the production of some catalysis	PVC
	Release of VOCs from glues and adhesives	Paperboard
	Low energy consumption and environmental effects from the production and use of pigments	PVC
Use	Jewel cases and sleeves are often used to protect CDs and is rarely discarded immediately	Paperboard, PS, PP, PVC
	High electricity use for shrink wrapping	Paperboard
	Hand assembly required, causing an increase in commuting traffic and idling of machinery	Paperboard
	Lightweight high-performing plastics enable dematerialization for some products	PP, PVC
Waste Management	Low densities mean that collection and transport for recycling requires large volumes per unit mass, making recycling economics unfavorable under most circumstances	PS, PP, PVC
	Generation of hazardous waste as bottom ash from incineration	PVC
	Limited generation of long-lived chlorine compounds and phthalates	Paperboard, PVC
	Cadmium use and deposition in landfills	PS, PP, PVC
	High calorific value for potential conversion to electricity	Paperboard, PS, PP, PVC
	Greenhouse gas emissions from incineration	Paperboard, PS, PP, PVC
	Heavy metals in leachate from flue-gas treatment	PVC
	Land use and maintenance for landfills	Paperboard, PS, PP, PVC
	Deposition of heavy metals (Cd, Pb, Zn, organotin) into landfills, either directly or in incinerator bottom ash	PVC

Note: Adapted from EU Commission, 2004

5.1 Energy Use, Greenhouse Gas Emissions, and Water Use

PS, PP, and PVC-based CD packaging is petroleum-derived and the energy inputs into production occur at several points. Fossil fuels are used as the feedstock monomer, for heat and production of electricity to process the material, for exploration and processing of the fuel itself, and for transport of fuels to the places of conversion. A life-cycle treatment of the energy inputs of polymer resins accounts for all of these energy inputs at the primary (or raw fuel) level. Table 5.2 shows the primary energy use that occurs at the first stage in the life cycle of polymer-based CD packaging, that is, the production of the polymer resins.

Table 5.2 Primary energy inputs to 1 kg polymer resin production

	Energy Inputs (MJ)							
	Electricity			Fossil Fuels				**Total**
Polymer	Fuel Prod	Energy Content	Trans-port	Fuel Prod	Energy Content	Trans-port	Feedstock Energy	
PS	2.58	1.13	0.01	3.15	31.98	0.37	47.53	**86.8**
PP	3.69	1.86	0.02	3.35	19.22	0.07	49.03	**77.2**
PVC (suspension)	7.83	3.66	0.04	2.1	20.38	0.19	22.92	**57.1**

Notes: Adapted from Boustead, 2003. Column headings refer to stages of production for each fuel, or for the input fuels to combustion in the case of electricity.

Of the two main polymer packaging options, PS and PP, the primary energy inputs needed for resin manufacture differ by more than 10%. The main source of this difference is in the high energy content of fuels needed for PS production compared to PP. Vinyl chloride, the building block of PVC, requires less than half of the energy than the building blocks of PS and PP to produce, with the result that the total primary energy needed for PVC is less than for the two main polymer packaging options.

Primary energy use during polymer production results in greenhouse gas emissions, depending on the fuel mix of local electricity generation and the types of fossil fuels used directly in production. The processing of polymer resins into final products also requires varying amounts of electricity, fossil fuel, and water inputs. Water can be used to control heating/cooling, for cleaning, finishing, or incorporation into the product (USEPA, 1995).

Table 5.3 Greenhouse gas emissions and water use from 1 kg polymer resin production

	GHG emissions (kg CO_2eq)					Water Use (liters)		
Polymer	Fuel Prod	Fuel Use	Trans-port	Processing	**Total**	Processing	Cooling	**Total**
PS	2.1	2.1	0.07	0.4	**4.6**	9.2	131	**141**
PP	0.9	0.9	0.01	0.6	**2.4**	4.8	38	**43**
PVC (suspension)	1.1	0.31	0.02	0.7	**2.1**	10	450	**460**

Table 5.4 Energy and material inputs to 1 kg of polymer processing

Polymer	Product	Process	Resin (kg)	Electricity (MJ)	Fossil Fuels (MJ)	Water (kg)
PS, PP	Misc	Injection molding	1.01	7.55	13.96	11.1
PVC	Misc	Injection molding	1.01	4.95	1.19	22.2

Notes: Adapted from Boustead, 2003a-e; Thiriez and Gutowski, 2006

The tables above are taken from sources that do not cover paperboard packaging, and so only show results for the polymer-based options. Life cycle inventory databases can have conflicting information, and so it is important to compare general results taken from different sources. In order to provide further comparison and to extend the assessment to paperboard packaging, raw inventory data were gathered from the Swiss Ecoinvent 2.0 database. Figure 5.1 shows results for primary energy use, greenhouse gas emissions, and water use involved in the production of the basic packaging materials.

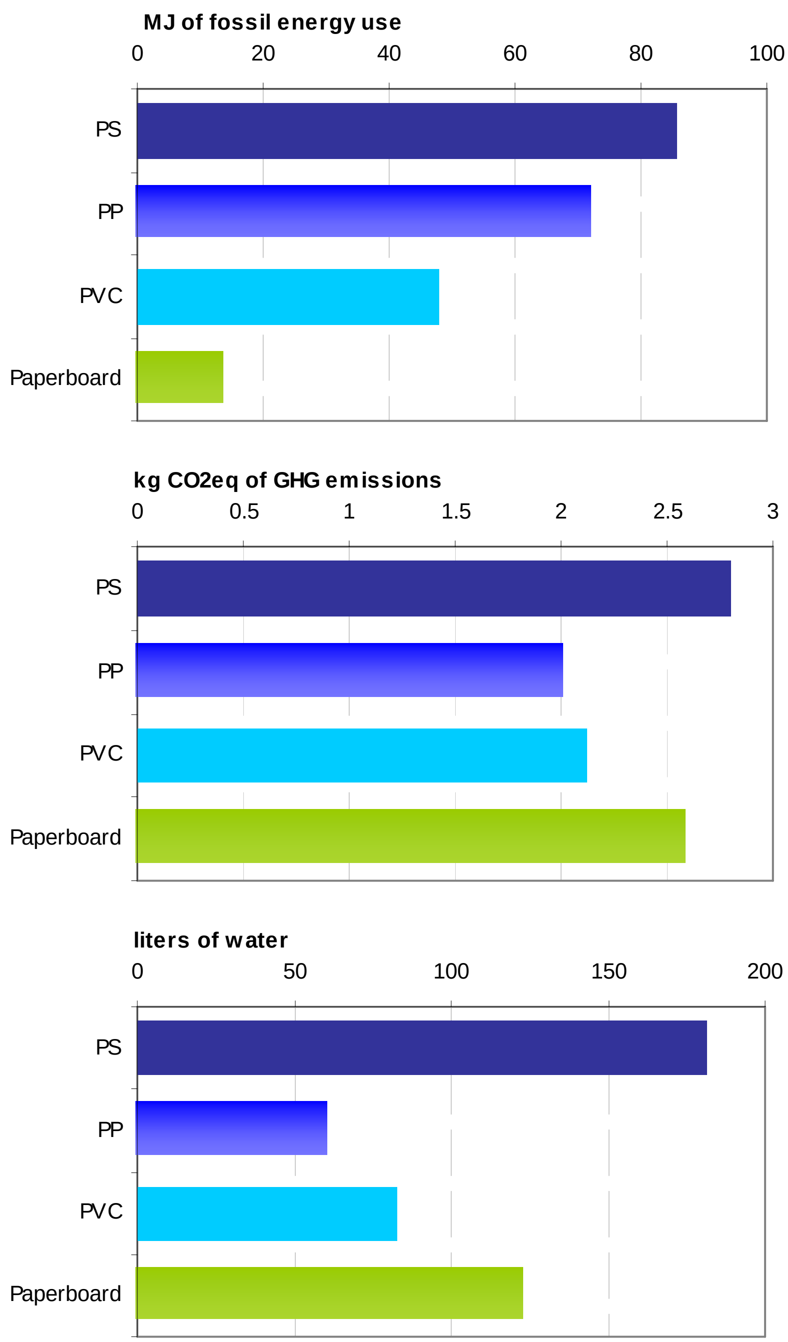


Figure 5.1 Comparative environmental impacts of packaging materials production

The life cycle climate change impacts of polymer resins are complex. Figures 5.2-5.5 show networks of greenhouse gas impacts from the life cycle of the following packaging options:

1. PS in the base case
2. PS for the U.S. average recycling scenario
3. PP in the base case
4. PP for the U.S. average recycling scenario
5. 6-panel virgin paperboard in the base case
6. 6-panel virgin paperboard for the U.S. average recycling scenario
7. 6-panel recycled paperboard in the base case
8. 6-panel recycled paperboard for the U.S. average recycling scenario

Again, the results only those process stages that are different among the various CD packaging options. Production and assembly of the package as well as waste management after discard are considered.

For a quantitative assessment, the greenhouse gas emissions of each major packaging option were calculated using the SimaPro LCA modeling software. The results are broken down by major process and the percentage due to each process is cumulative, including all of the inputs into that process. The assessment method used to calculate greenhouse gas emissions is TRACI 2002, a Tool for the Reduction and Assessment of Chemical and other environmental Impacts, developed by the U.S. Environmental Protection Agency (EPA) for impacts specific to the United States. A summary of results is shown in table 5.5 below.

Table 5.5

Option	Production (kg CO_2 eq)	Waste Mgmt (kg CO_2 eq)	Total (kg CO_2 eq)
PS, base case	31,300	6,400	37,700
PS, U.S. average recycling scenario	31,300	2,500	33,800
PP, base case	18,500	1,400	19,900
PP, U.S. average recycling scenario	18,500	-2,000	16,500
6-panel virgin paperboard, base case	49,700	-1,200	48,500
6-panel virgin paperboard, U.S. average recycling scenario	49,700	-24,000	25,700
6-panel recycled paperboard, base case	27,800	-1,200	26,600
6-panel recycled paperboard, U.S. average recycling scenario	27,800	-12,100	15,700

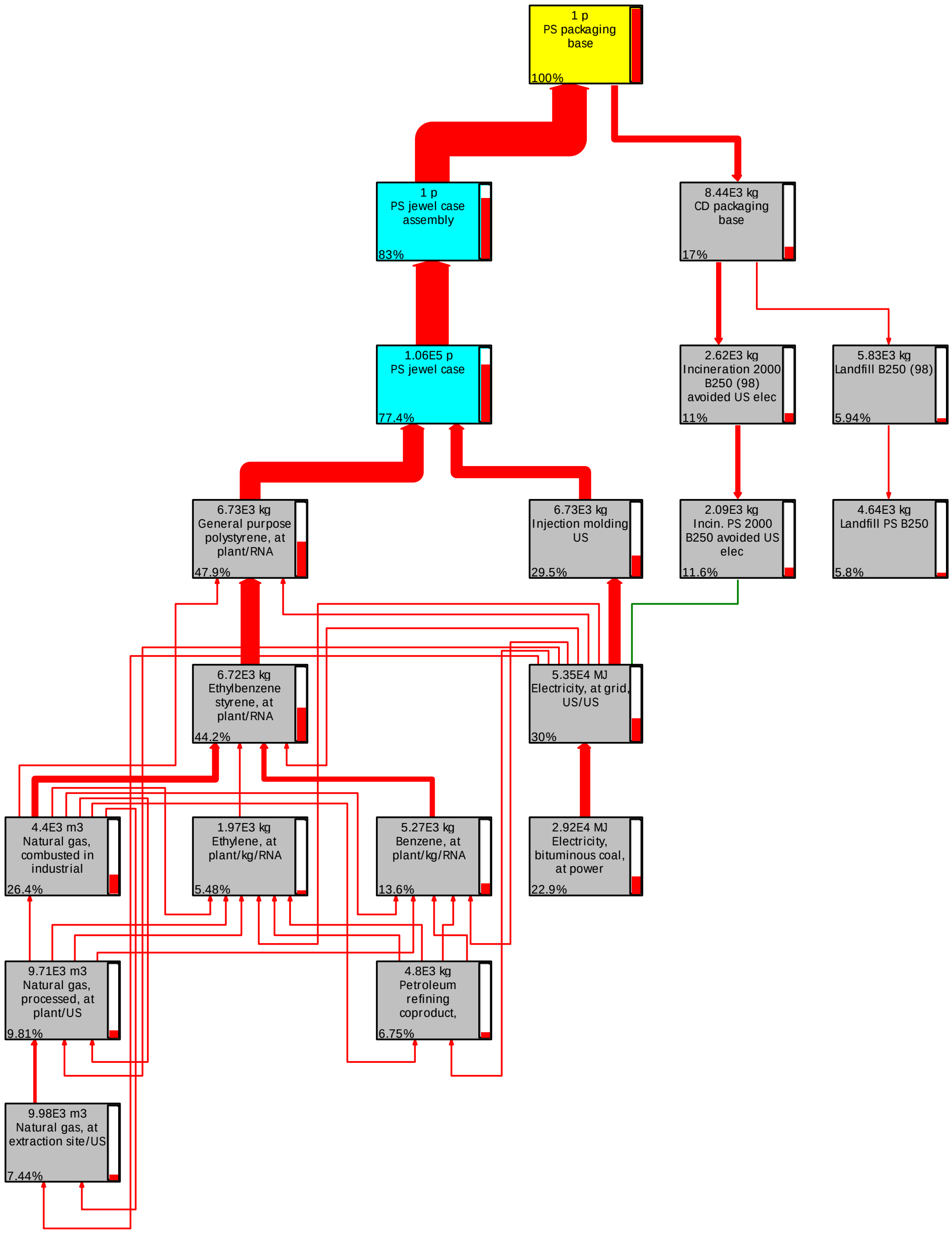


Figure 5.2a Life cycle greenhouse gas emissions from PS in the base disposal case (5% cutoff). Percentages refer to total emissions (in red) and total credits (in green), which must add to unity. The numbers at the top of each box refer to mass or volume of a particular input

Greenhouse gas emissions from the use of conventional PS jewel cases is clearly dominated by the production of ethylbenzene styrene monomer, contributing more than 44% of the life cycle emissions. The carbon embedded in the materials was emitted as CO_2 during incineration and methane during landfilling; emissions from these disposal options contributed approximately 17% of the life cycle emissions. The processes of over-wrapping and worker transportation contributed slightly less than 1% of emissions and are therefore not shown in figure 5.2a.

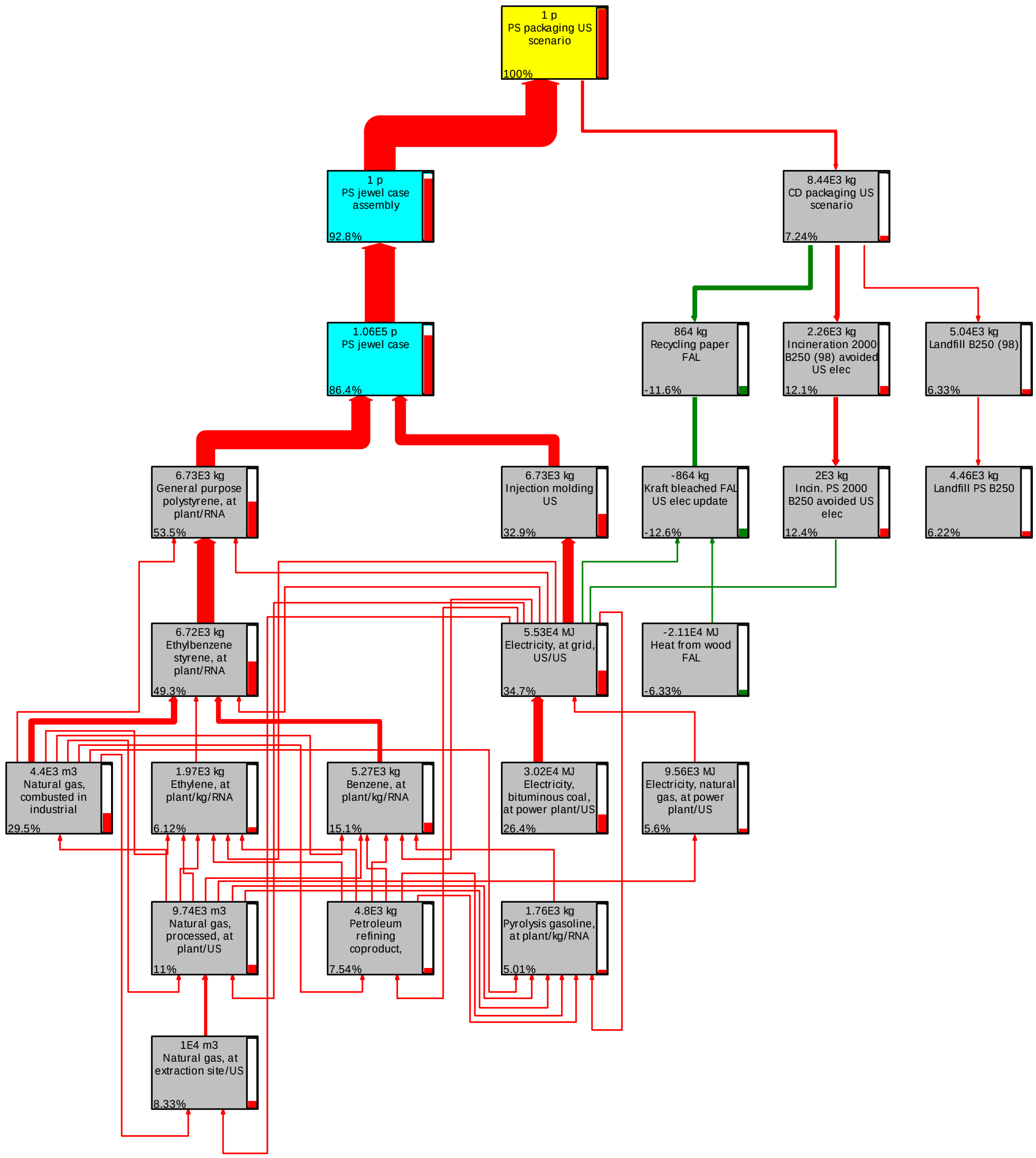


Figure 5.2b Life cycle greenhouse gas emissions from PS for the U.S. average recycling scenario (5% cutoff)

This scenario has largely the same characteristics as for PS in the base case. The major difference is that waste management contributes slightly less to life cycle emissions because of greenhouse gas credits from recycling. The credits are small both for paper, where the content is low (just the paper inserts) but the recycling rate is relatively high (54%), as well as for PS, where the content is high, but the recycling rate is low (4%).

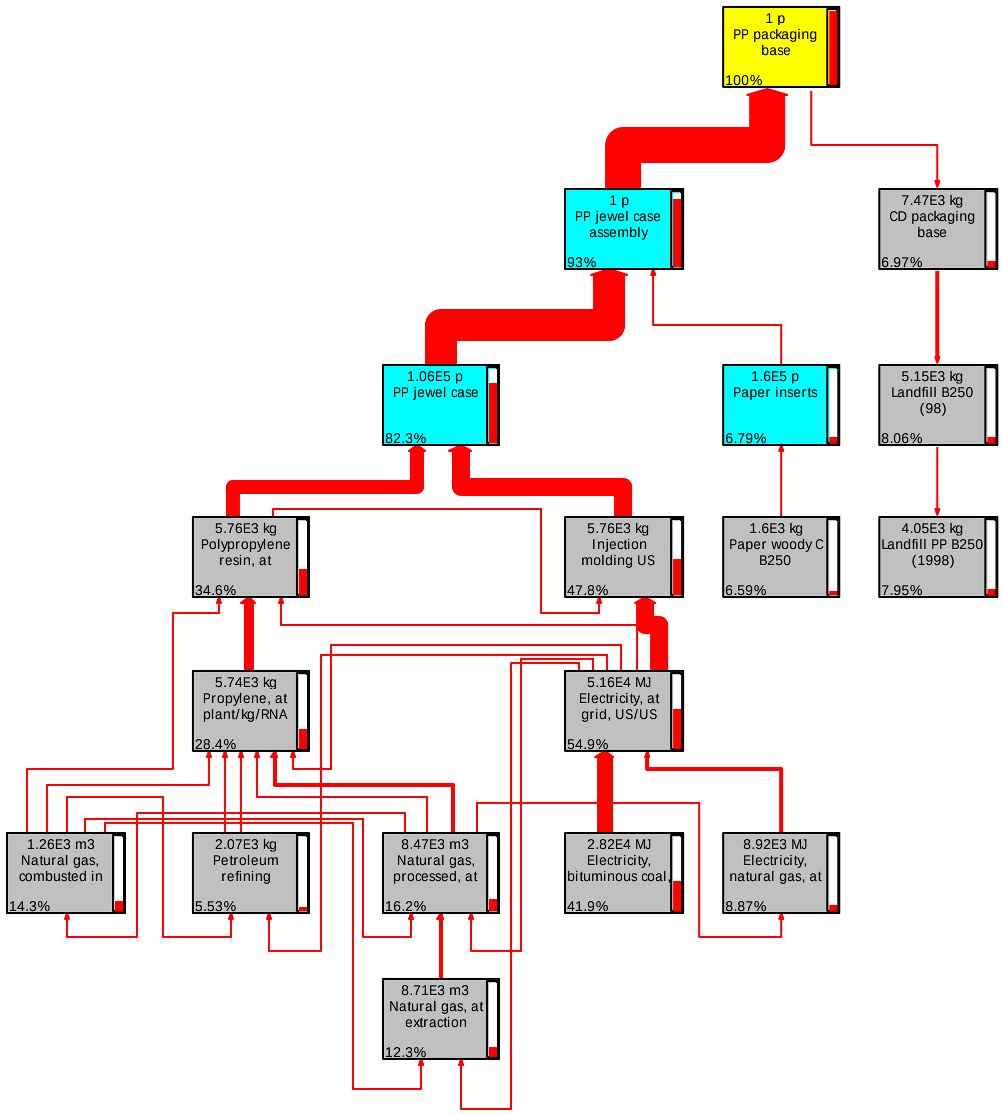


Figure 5.3a Life cycle greenhouse gas emissions from PP in the base case (5% cutoff)

In the case of PP packaging in the base case, more than 80 percent of the life cycle greenhouse gas is due to the production of the jewel case itself, which is actually dominated by the injection molding process and not the production of polymer resins. This is because injection molding relies on carbon intensive coal-fired electricity, whereas PP production relies primarily on natural gas. The eventual degradation of paper and PP in landfills contributed about 7% of emissions.

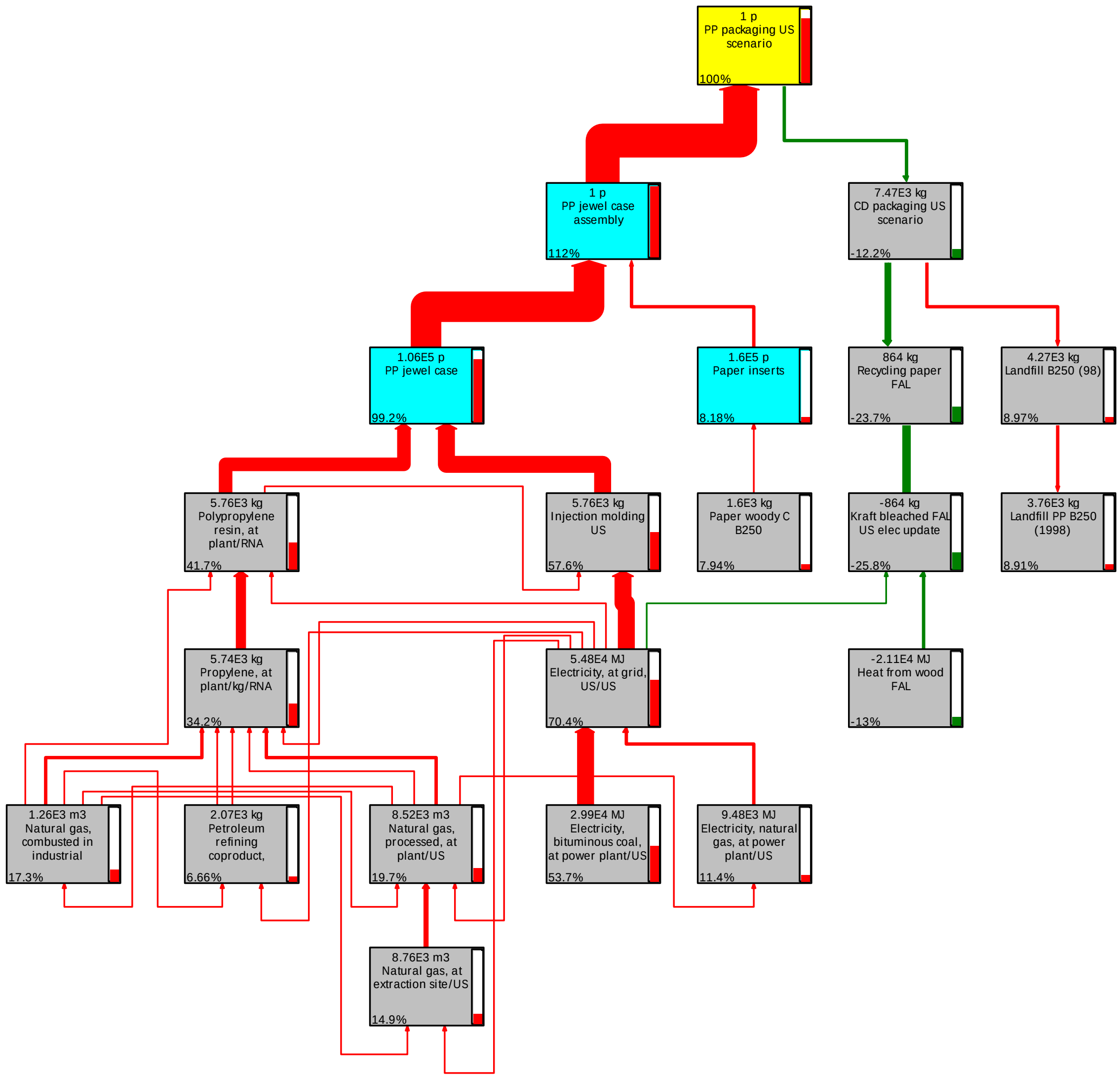


Figure 5.3b Life cycle greenhouse gas emissions from PP for the U.S. average recycling scenario (5% cutoff)

The PP packaging option with the average U.S. recycling scenario differs from the base case in the credit given to recycling of the paper inserts. This more than offsets greenhouse gas emissions that occur during incineration and landfill disposal, giving the entire waste management life cycle stage a credit (negative emission). PP jewel cases are both lighter than PS and less carbon intensive per unit mass; the combination results in greenhouse gas emissions for PP packaging that are approximately two-thirds that of PS.

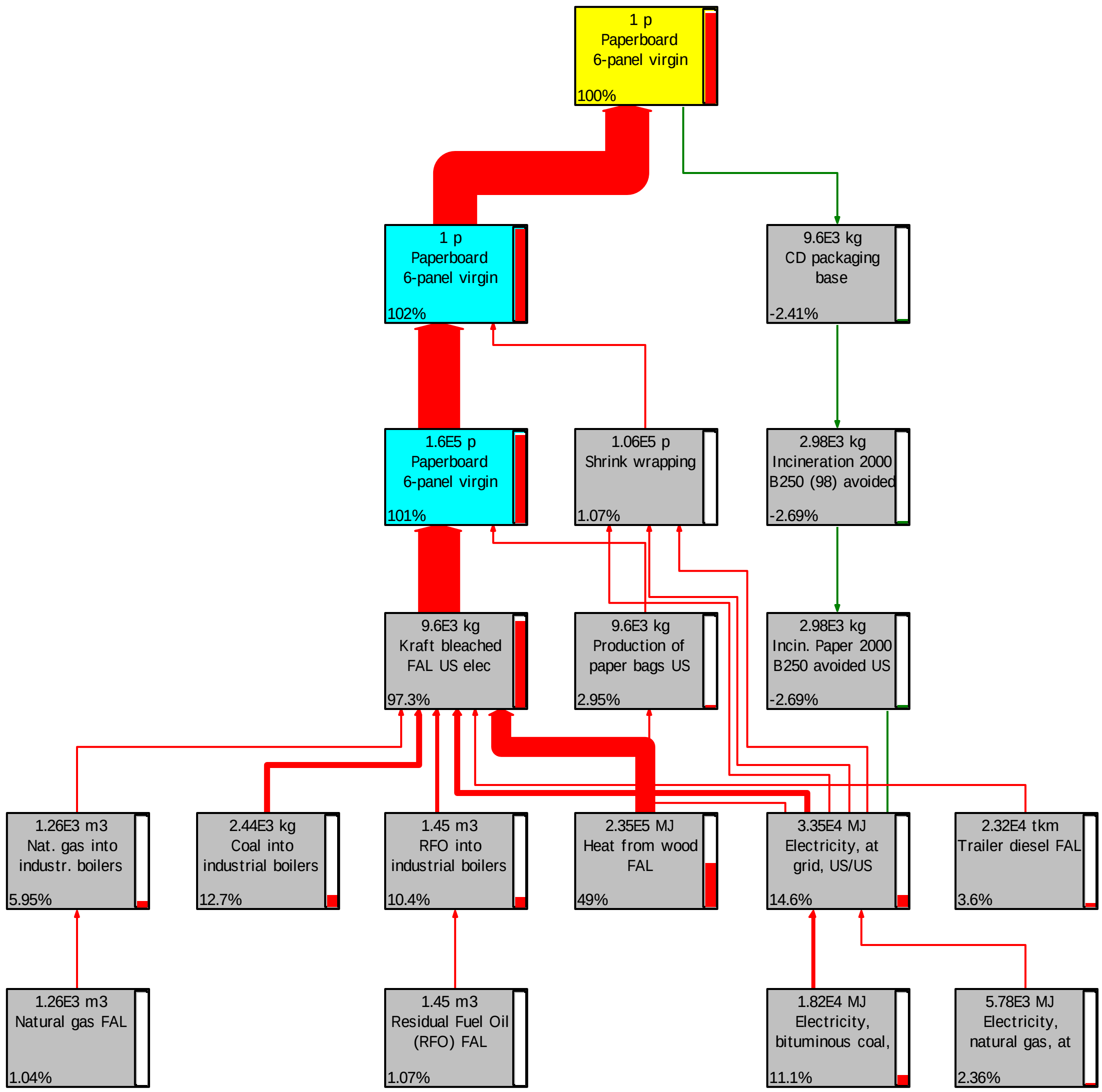


Figure 5.4a Life cycle greenhouse gas emissions from 6-panel virgin paperboard in the base case (1% cutoff)

In the relative contributions of each major process stage to life cycle greenhouse gas emissions, the 6-panel virgin paperboard base case does differ significantly from the polymer cases. The majority (97%) of emissions are a result of the production of the paper itself. The printing of the paperboard cases is relatively more important than for the printing of paper inserts for the plastic jewel cases, though neither is above the 1% threshold. Shrink wrapping also contributes less than 1% of emissions (and is therefore not shown), despite its perceived high energy use. The fuel consumed during commuting for the extra labor needed to hand-assemble the paperboard packages (as opposed to automated assembly of jewel cases) contributes approximately 0.5% of life cycle emissions.

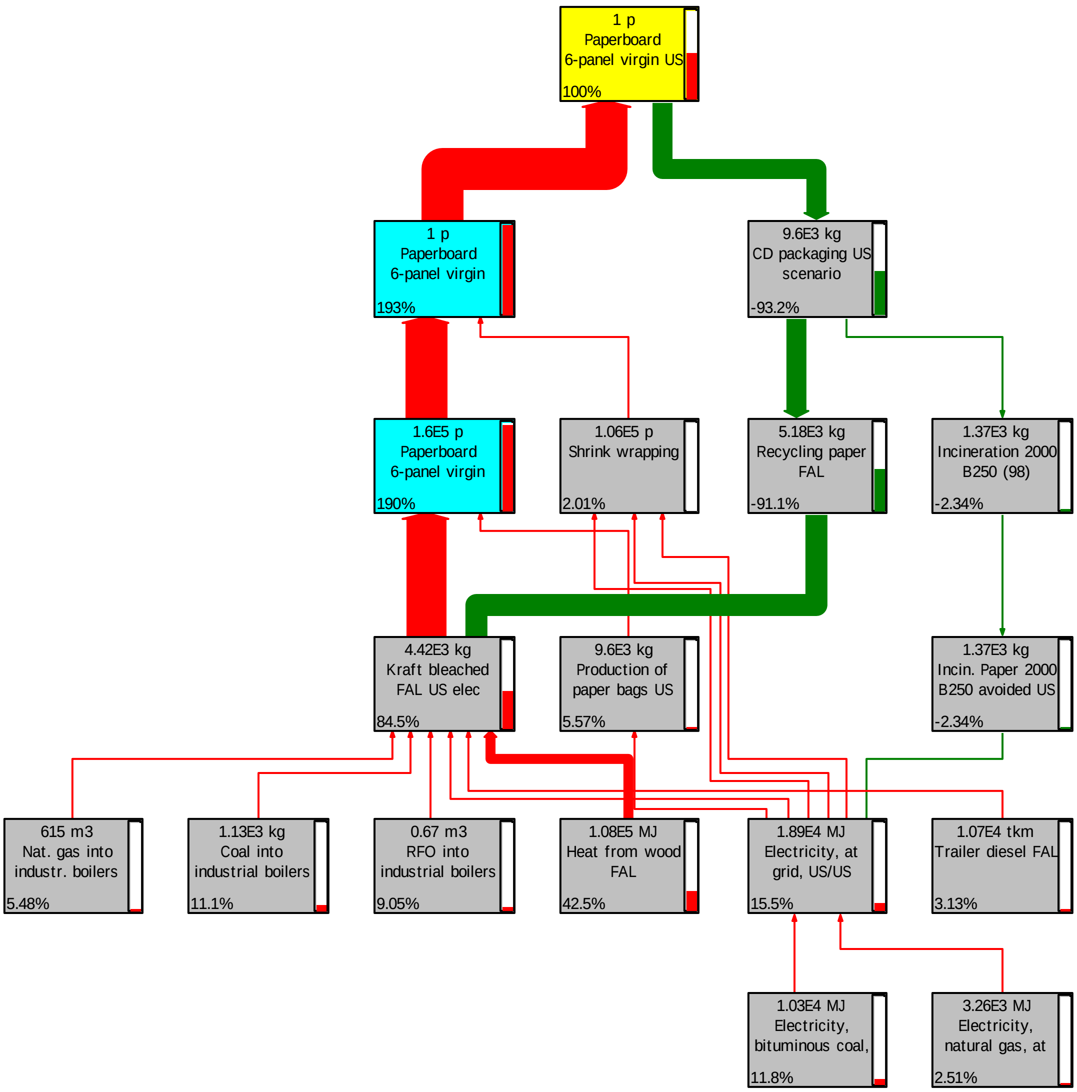


Figure 5.4b Life cycle greenhouse gas emissions from 6-panel virgin paperboard for the U.S. average recycling scenario (1% cutoff)

The difference between the base case and the U.S. average recycling scenario for the 6-panel virgin paperboard packaging is due to increased recycling (the U.S. average is 54%). This recycled paper displaces a significant amount of virgin paper, shown in the large green arrow in figure 5.4b. There is also a credit from electricity generation from incineration of paper, shown at the right of the figure.

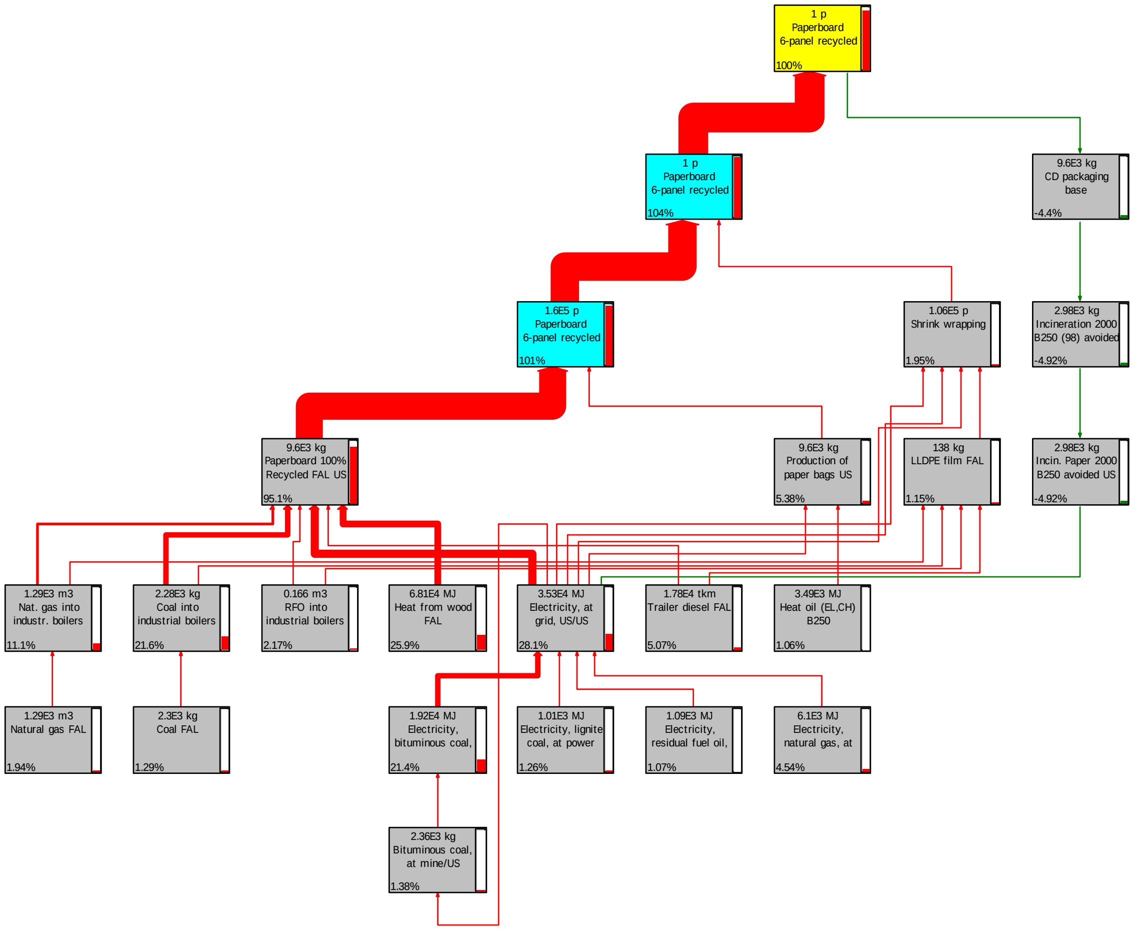


Figure 5.5a Life cycle greenhouse gas emissions from 6-panel recycled paperboard in the base case (1% cutoff)

The greenhouse gases emitted during the production of 100% recycled paperboard feedstock are much less than those emitted during the production of virgin paperboard. Therefore, the relative contribution of shrink wrapping to life cycle greenhouse gas emissions is greater for this packaging option. There is again a small credit due to the production of electricity during incineration of waste paper.

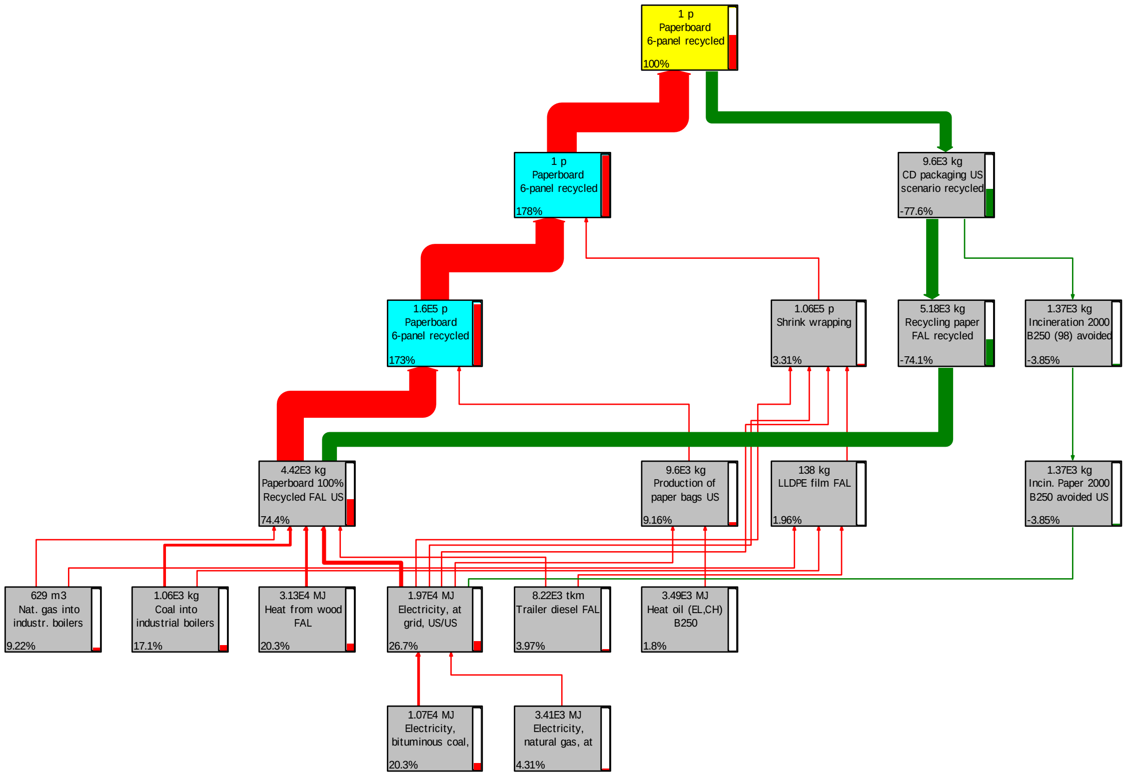


Figure 5.5b Life cycle greenhouse gas emissions from 6-panel virgin paperboard for the U.S. average recycling scenario (1% cutoff)

The main difference between this U.S. average recycling scenario and the previous base case is that the greenhouse gas credit is much larger for paper recycling here than it was for incineration. Therefore, the climate change impacts of this packaging option are very low compared to the others.

In addition to the direct emissions of greenhouse gases during the life cycle of CD packaging, there are many indirect effects. One example is the electricity consumed during online ordering packaging components from suppliers. While these indirect impacts are not explicitly included in the present report (as detailed in Section 1, above), we can make a rough estimate of their importance. This is done using an environmental economic tool called Environmental Input Output Life Cycle Assessment (EIO-LCA), developed by the Green Design Institute at Carnegie Mellon University, which considers all of the interactions among different sectors of the economy and is a frequently-used tool in assessing the environmental impacts of goods and services. The output of the tool is a list of all 491 sectors of the U.S. economy and their relative contribution to the output of a chosen sector (in this case, plastic or paper packaging), along environmental parameters such as GHG emissions.

The EIO-LCA results for plastic and paper packaging are shown in tables 5.6-5.7, below. All of the categories that make up >95% of the total greenhouse gas emissions are included, as this is regarded as an appropriate cut-off for EIO-LCA studies (Suh *et al*., 2004). Another interesting output of the tool is a map that shows environmental impacts of the production of packaging, using employment as a proxy:

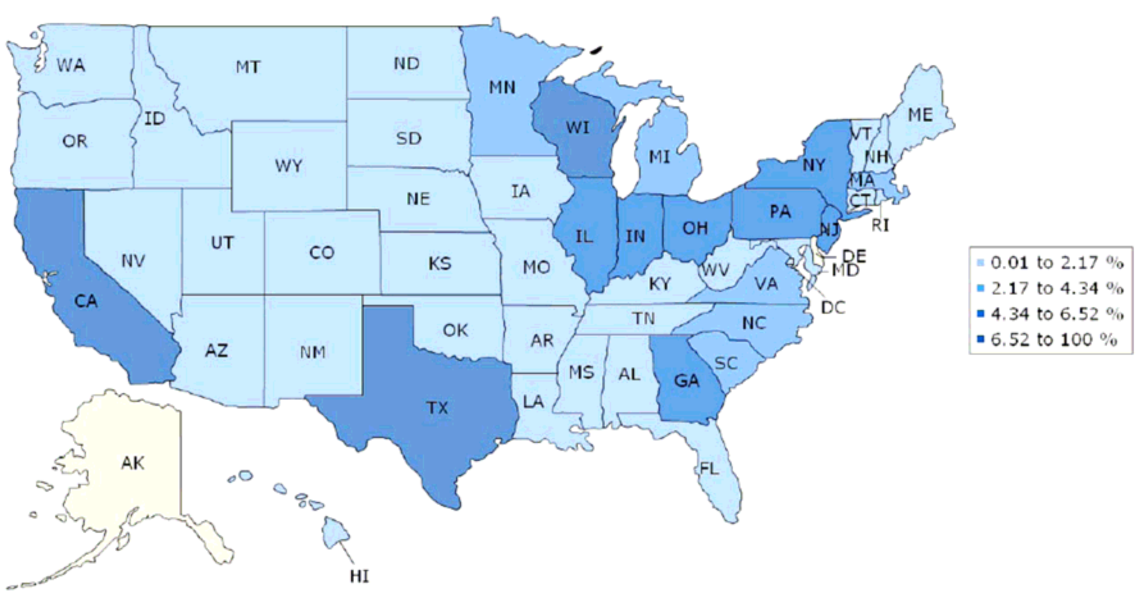


Figure 5.6 Distribution of employment due to the manufacturing of plastic packaging in the United States (Carnegie Mellon University Green Design Institute, 2008)

Table 5.6 EIO-LCA results for plastic packaging

	Economic Sector	Percent of Life Cycle GHG Emissions
	Power generation and supply	30.7%
	Plastics material and resin manufacturing	8.9%
*	Truck transportation	8.8%
	Other basic organic chemical manufacturing	5.9%
	Oil and gas extraction	4.7%
	Waste management and remediation services	4.3%
	Plastics packaging materials, film and sheet	4.3%
	Petroleum refineries	3.5%
	Petrochemical manufacturing	2.7%
	Paper and paperboard mills	2.2%
	Pipeline transportation	2.1%
*	Synthetic dye and pigment manufacturing	2.0%
	Other basic inorganic chemical manufacturing	1.7%
	Industrial gas manufacturing	1.7%
	State and local government electric utilities	1.3%
	Coal mining	1.0%
*	Air transportation	1.0%
*	Rail transportation	1.0%
	Grain farming	1.0%
	Nitrogenous fertilizer manufacturing	0.9%
*	Iron and steel mills	0.8%
	Natural gas distribution	0.6%
*	Wholesale trade	0.6%
*	Noncellulosic organic fiber manufacturing	0.6%
*	Warehousing and storage	0.5%
	Wet corn milling	0.4%
*	Petroleum lubricating oil and grease manufacturing	0.4%
*	Couriers and messengers	0.3%
*	Synthetic rubber manufacturing	0.3%
*	Scenic and sightseeing transportation and support activities for transportation	0.3%
*	Other nonmetallic mineral mining	0.3%
*	Cement manufacturing	0.2%
	Total	**95.1%**

* Not included in the present report

As explained elsewhere, transportation for shipping is common to all packaging types and so does not need to be included in a comparative study. Synthetic dye and pigment manufacturing were not included as the polymer-based CD packaging was assumed to be clear. Grain farming is primarily for the production of biofuels, which is included in the U.S. LCI process for energy production. All other economic sectors have impacts that are below the one percent threshold considered in this report.

Table 5.7 EIO-LCA results for paper packaging

	Economic Sector	Percent of Life Cycle GHG Emissions
	Power generation and supply	25.0%
	Paper and paperboard mills	18.4%
*	Truck transportation	9.5%
	Coated and laminated paper and packaging materials	8.1%
	Waste management and remediation services	4.0%
	Oil and gas extraction	2.4%
	Grain farming	2.2%
	Other basic organic chemical manufacturing	1.8%
	Plastics material and resin manufacturing	1.7%
	Petroleum refineries	1.6%
	Pipeline transportation	1.5%
*	Iron and steel mills	1.4%
	Other basic inorganic chemical manufacturing	1.4%
	Synthetic dye and pigment manufacturing	1.3%
	Coal mining	1.2%
	Rail transportation	1.2%
	Wet corn milling	1.2%
*	Air transportation	1.1%
	Pulp mills	1.1%
	Industrial gas manufacturing	1.0%
	State and local government electric utilities	1.0%
*	Wholesale trade	0.9%
	Natural gas distribution	0.8%
	Petrochemical manufacturing	0.7%
	Nitrogenous fertilizer manufacturing	0.6%
	Adhesive manufacturing	0.4%
	Lime manufacturing	0.4%
	Logging	0.4%
*	Warehousing and storage	0.4%
*	Primary aluminum production	0.4%
*	Couriers and messengers	0.4%
*	Petroleum lubricating oil and grease manufacturing	0.3%
*	Scenic and sightseeing transportation and support activities for transportation	0.3%
*	Other nonmetallic mineral mining	0.3%
*	Noncellulosic organic fiber manufacturing	0.2%
*	Cotton farming	0.2%
	TOTAL	**95.0%**

* Not included in the present report

Apart from transportation, the only economic sector that makes a contribution of more than one percent that is not included in the report is iron and steel mills, which produce the infrastructure and machinery necessary for pulp and paper production.

5.2 Other Air Emissions

While the above data reflects impacts largely associated with energy and water use, it is also useful to consider other environmental impacts from air pollution. Table 5.8 shows emissions of various air pollutants from incineration of the various polymers and paperboard, again derived from life-cycle inventory databases (Ecoinvent, 2007). The water content of the polymer greatly influences emissions per unit dry mass from incineration; this parameter has been carefully noted below.

The information presented here is on a unit basis, which means that air emissions are evaluated on a per unit mass incinerated across all materials. As mentioned above, the various CD packaging options require different masses of material; therefore, readers should exercise caution when making comparisons of these air pollutants.

On a unit basis, incineration of PVC releases the largest amounts of most air pollutants, with the exception of greenhouse gases. Of the two main polymer options, PS incineration releases more emissions across the board, though only slightly in some cases. Incineration of paperboard is largely comparable to that of plastic, except for greenhouse gases (lower) and chlorine (higher). This reflects the lower energy content of paper versus polymers, meaning fewer carbon atoms, and the use of bleaching to whiten paper, meaning more chlorine atoms.

Table 5.8 Air emissions from the incineration of CD packaging materials

Air Emission [mg/kg incinerated]	PS Incineration 0.2% water content	PP Incineration 15.9% water content	Paperboard Incineration 19.6% water content	PVC Incineration 0.2% water content
Ammonia	0.3	0.2	0.4	10.1
Cadmium	6.2 E-5	5.7 E-5	5.8 E-5	4.9 E-4
Carbon Dioxide Equivalents	3,167,700	2,535,400	24,900	2,221,700
Carbon Monoxide	28.7	28.1	30.8	283
CFC-11 Equivalents (steady state)	0.002	0.001	0.002	0.042
Chlorine	1.2 E-7	1.1 E-7	2.6 E-7	1.1 E-5
Dioxins	1.0 E-8	9.5 E-9	9.7 E-9	6.3 E-8
Ground Level Ozone	9.1	9.0	9.5	53.8
Lead	0.004	0.004	0.004	0.03
Nitrogen Dioxide Equivalents	535	498	578	2,094
Particulate Matter < 2.5 μm	1.18	1.13	1.31	21.4
Polycyclic Aromatic Hydrocarbons	0.0009	0.0009	0.001	0.022
Sulfur Dioxide Equivalents	329	305	382	3,147
Volatile Organic Compounds	2.8	2.7	3.2	61.8

Source: Ecoinvent, 2007; Data are for incineration in Switzerland; unspecified population densities

6. Results: Screening of Human and Ecosystem Toxicity

The goal of this section is to summarize the hazards associated with the manufacture, use and disposal of various CD packaging options. There are numerous tests and various hazard endpoints that can be considered for the ecological assessment of polymers; the information presented here is meant as an important subset (Hamilton and Sutcliffe, 1997).

The assessments here focus on toxicity and human health, but obviously impacts to human and ecosystem health from toxics will be mitigated if there is no route for exposure. Emissions from polymer production and incineration are both heavily regulated. Exposure during resin and polymer production occurs primarily for workers in those industries (EU Commission, 2000). Exposure during use occurs from weathering of polymers, for example, the leaching of chlorine from PVC to create hydrochloric acid. Exposure from polymer incineration is more diffuse, as some pollutants are deposited quickly in the area immediately surrounding the incinerator, while others can be carried extremely long distances in the atmosphere. The toxicological information presented here must be considered in conjunction with the exposure routes of the affected population in question.

First a qualitative screening is presented for the toxicological and human health impacts of the production of the various feedstock materials PS, PP, PVC, and paperboard. Following that is a quantitative assessment of the human health and toxicity of each CD packaging option over its entire life cycle, using generic material data.

Tables 6.1 –6.3 present information on human health and ecological toxicity impacts for emissions from polymer production as a general class.

Table 6.1 Summary of Human and Ecological Toxicity Hazards: *Polyaromatic Hydrocarbons*

Hazard Endpoint	Hazard outcome	References
Carcinogenic	Carcinogenic in animals and likely carcinogenic to humans; Genotoxic	EPA 1992 IARC, 2002 Wang and Busby, 1993 ATSDR 1999
Non-cancer endpoints	Respiratory effects; Reproductive effects	Gupta *et al.,* 1993
Aquatic toxicity	Increased tumors; Liver toxicity; Immune system impairments	Eisler, 1987 Fabacher, *et al.*, 1991 O'Conner and Huggett, 1989
Persistence and Bioaccumulation	Slightly persistent and bioaccumulative	Wilcock *et al.,* 1996

Table 6.2 Summary of Human and Ecological Toxicity Hazards: *Volatile Organic Compounds*

Hazard Endpoint	Hazard outcome	References
Carcinogenic	Certain individual compounds can be carcinogenic	IRIS, 2008
Non-cancer endpoints	Neurotoxic, carcinogenic	Snyder and Andrews, 1996
Aquatic toxicity	Insufficient data	
Persistence and Bioaccumulation	Compound dependent	

Table 6.3 Summary of Human and Ecological Toxicity Hazards: *Carbon Monoxide*

Hazard Endpoint	Hazard outcome	References
Carcinogenic	Insufficient data	
Non-cancer endpoints	Acutely toxic; Methemoglobinemia	Klaassen, 2008
Aquatic toxicity	Insufficient data	
Persistence and Bioaccumulation	Insufficient data	

Human Health and Ecological Toxicity of Polystyrene

<u>Potential release and exposure pathways</u>

The major routes of exposure to polystyrene and styrene is from the industrial manufacturing process, as well as indoor air contaminated with styrene from building materials, tobacco smoke, and the use of copying machines. Automobile exhaust is also a potential source of exposure (ATSDR, 2007).

<u>Human toxicity and risk</u>

Humans exposed to chronic high levels of styrene may experience neurotoxic effects such as fatigue, dizziness, and slowed reaction time (ATSDR, 2007). Acute exposure can also cause irritation of mucous membranes.

<u>Environmental hazards</u>

Styrene breaks down in the atmosphere on the order of days. Styrene in aquatic environments and soils is degraded by microorganisms, and does not bioaccumulate.

Table 6.4 Summary of Human and Ecological Toxicity Hazards: *Styrene monomer*

Hazard Endpoint	Hazard outcome	References
Carcinogenic	Possibly carcinogenic to humans	IARC, 2002
Non-cancer endpoints	Neurotoxic effects	ATSDR, 2007
Aquatic toxicity	Insufficient data	
Persistence and Bioaccumulation	Not expected to be persistent or bioaccumulate	ATSDR, 2007

Human Health and Ecological Toxicity of Polypropylene

Potential release and exposure pathways

Most of the exposure to polypropylene and propylene is part of the industrial manufacturing process.

Human toxicity and risk

Propylene is considered a primary asphyxiate at high concentration and is associated with few other toxic endpoints. Occupational exposure to the propene monomer is associated with respiratory effects (OECD, 2003).

Titanium tetrachloride is primarily a respiratory irritant in occupational situations (ATSDR 1997). Two investigations, one in humans and one in animals, found no association between exposure to titanium tetrachloride and cancer (ATSDR, 1997).

Environmental hazards

Environmental exposures to titanium tetrachloride are unlikely because of the rapid breakdown in aqueous systems to titanium oxide and hydrochloric acid (ATSDR, 1997).

Table 6.5 Summary of Human and Ecological Toxicity Hazards: *Polypropylene*

Hazard Endpoint	Hazard outcome	References
Carcinogenic	Not likely to mutagenic	OECD 2003
Non-cancer endpoints	No evidence of increase colo-rectal cancer in workers	Kaleja *et al.,* 1994
Aquatic toxicity	Insufficient data	
Persistence and Bioaccumulation	Not persistent	Vincoli, J.W., 1996

Table 6.6 Summary of Human and Ecological Toxicity Hazards: *Propene monomer*

Hazard Endpoint	Hazard outcome	References
Carcinogenic	Little supporting data for carcinogenicity in animals	Ciliberti *et al.,* 1988
Non-cancer endpoints	Respiratory, possible liver effects	Quest *et al.,* 1984; WV DEP, 2008
Aquatic toxicity	Moderate acute toxicity	WV DEP, 2008
Persistence and Bioaccumulation	Not expected to be persistent or bioaccumulate	WV DEP, 2008

Table 6.7 Summary of Human and Ecological Toxicity Hazards: *Titanium Tetrachloride*

Hazard Endpoint	Hazard outcome	References
Carcinogenic	Insufficient data	ATSDR, 1997
Non-cancer endpoints	Inhalation and respiratory hazard	ATSDR, 1997
Aquatic toxicity	Insufficient data	ATSDR, 1997
Persistence and Bioaccumulation	Insufficient data	

Human Health and Ecological Toxicity of Polyvinylchloride (PVC)

Potential release and exposure pathways

Effluents from PVC production facilities are a major source of vinyl chloride, VOCs, plasticizers, metals and other additives use in the production process (ATSDR, 1997). VOCs are primarily released through air because of their high volatility. Contamination of groundwater by VOCs and metals is a concern in the production of PVC (Freeze and Cherry, 1979).

Human toxicity and risk

There is little data on the risk associated with exposure to the PVC polymer. The vinyl chloride monomer is the most hazardous and most well studied of the two products therefore, most on the risk is associated with exposure to the workers in the manufacture of the product. A review of the risks associated with PVC throughout its life cycle can be found in Schreiber (2003).

Existing Regulatory Status

Vinyl chloride has been classified by the United States Environmental Protection Agency (ESWPA) as a Class A (known human) carcinogen (USEPA IRIS 2002; NTP, National report on Carcinogens, 1992). The International Agency for Research on Cancer has classified vinyl chloride as a Human carcinogen (IARC, 2002), as has the National Institute of Occupational Safety and Hygiene (NIOSH, 1997) and the American Conference of Government and Industrial Hygienists (ACGIH, 2000).

There are other non-cancer toxic effects associated with exposure to vinyl chloride (ATSDR 1997). Some of these effects include liver toxicity, pulmonary toxicity, neurotoxicity, dermal effects (scleroderma). Vinyl chloride has been identified as a testicular carcinogen (Hardell *et al.,* 1997; Ohlsen and Hardell, 2000).

Environmental hazards

One of the most unattractive features of polyvinyl chloride is its persistence in the environment as well as the production of toxic by-products from incineration and from environmental leaching. PVC is long lived in the environment but can breakdown and release additives that are part of the PVC final product.

The incineration of polyvinyl chloride results in the production of a variety of products including chlorinated dioxins and furans (Carroll *et al.,* 2001; Lemieux *et al.,* 2000; Yashuhara *et al.,* 2001; Katami *et al.,* 2002). Exposure to chlorinated dioxins and furans can result in carcinogenic and other toxic responses including immunotoxicity, developmental and reproductive deficits (ATSDR, 1997). Incineration can produce PAHs (Wang *et al.,* 2001). Some PAHs have been classified as carcinogens by USEPA and IARC (IRIS, 2002). Fires involving PVC generate HCL which is a pulmonary toxicant.

Phthalates are commonly added to PVC to increase flexibility and have their own hazard profile (NTP, 2000). Among the hazards associated with phthalates as a class is endocrine disruption.

Table 6.8 Summary of Human and Ecological Toxicity Hazards: *Polyvinyl Chloride*

Hazard Endpoint	Hazard outcome	References
Carcinogenic	Insufficient data	
Non-cancer endpoints	Insufficient data	
Aquatic toxicity	Insufficient data	
Persistence and Bioaccumulation	Very persistent; not bioaccumulative	ATSDR, 1997

Table 6.9 Summary of Human and Ecological Toxicity Hazards: *Phthalates*

Hazard Endpoint	Hazard outcome	References
Carcinogenic	Not classifiable	IRIS, 2008
Non-cancer endpoints	Developmental and reproductive effects; Asthma and other respiratory deficits	NTP 2000; Oie et al., 1997 Jaakkda *et al.*, 2000
Aquatic toxicity	Slight toxicity to aquatic species	EPA, 1987
Persistence and Bioaccumulation	Moderately persistent, low bioaccumulation potential	Staples *et al.*, 1997

Table 6.10 Summary of Human and Ecological Toxicity Hazards: *Vinyl Chloride*

Hazard Endpoint	Hazard outcome	References
Carcinogenic	Known human and animal carcinogen	ATSDR, 2006 IARC, 2002 Lewis, 1999 NTP, 1992 Maltoni and Cotti, 1988 Piratsu, *et al.*, 1990 Wang *et al.*, 2001 WHO, 1999
Non-cancer endpoints	Central Nervous System, peripheral nervous systems (Renaud –like syndrome); Liver effects; Developmental effects	USEPA, 2002 ATSDR, 2006 Freudinger, *et al.*, 1988 Jaeger *et al.*, 1974 Laplanche *et al.*, 1992 Thornton *et al.*, 2002
Aquatic toxicity	Toxic to fish and invertebrates	Lu *et al.*, 1977a,b
Persistence and Bioaccumulation	May persist in groundwater	Jacobs *et al.*, 2007

Table 6.11 Summary of Human and Ecological Toxicity Hazards: *Dioxins and Furans*

Hazard Endpoint	Hazard outcome	References
Carcinogenic	Increased incidence of neoplasms in humans and animals	Fingerhut and Halperin, 1991 NTP, 1982 Ott and Zober, 1996
Non-cancer endpoints	Chloracne; Hepatic effects; Immunotoxicity; Neurological effects; Reproductive and developmental effects	Jansing and Korff, 1994 Mocarelli and Needham, 1991 Oliver, 1975 EPA, 2004 NRC, 2006 Pocchiari, 1979
Aquatic toxicity	Reproductive and developmental deficits	Boening, 1998 Loonen *et al.,* 1996 Teraoka *et al.*, 2002
Persistence and Bioaccumulation	Persistent and bioaccumulative	EPA, 2008 Rand 1996

Human Health and Ecological Toxicity of Paperboard

Potential release and exposure pathways

The major toxic effects from paperboard are from the release of contaminants from pulp production into water bodies. This is highly regulated in the United States through wastewater treatment standards, but significant releases do occur. More than 200 millions pounds of chemicals listed by the EPA's Toxics Release Inventory were released or disposed of on-site in 2006, about half of which was methanol produced during digestion. Methanol is readily adsorbed in humans after oral, inhalation, or dermal exposure

Human toxicity and risk

Methanol is toxic to humans, leading to pain, visual degradation, and blindness from acute exposure. There is no evidence of tannic acid toxicity in humans; on the contrary, its positive health effects are often described when taken in low doses, such as in tea. The human health risks of dioxins and furans are described in the section above.

Environmental hazards

Methanol and tannins are readily degraded in the environment and through metabolization by organisms. Dioxins and furans are persistent and bioaccumulative, thus posing real threats to all organisms over long periods.

Table 6.12 Summary of Human and Ecological Toxicity Hazards: *Tannic acids*

Hazard Endpoint	Hazard outcome	References
Carcinogenic	Insufficient data	
Non-cancer endpoints	Developmental effects	Peaslee and Einhellig, 1972
Aquatic toxicity	Inhibited metabolism	Ali and Sreekrishnan, 2001
Persistence and Bioaccumulation	Not persistent, not bioaccumulative	Ali and Sreekrishnan, 2001

Table 6.13 Summary of Human and Ecological Toxicity Hazards: *Methanol*

Hazard Endpoint	Hazard outcome	References
Carcinogenic	No evidence	IRIS, 2008
Non-cancer endpoints	Neurotoxic effects, including visual degeneration and pain; narcosis	IRIS, 2008
Aquatic toxicity	Only at extremely high concentrations	IRIS, 2008
Persistence and Bioaccumulation	Not persistent, not bioaccumulative	IRIS, 2008

These human health hazards are only potential and depend crucially on actual exposure. Risk, the probability of manifesting adverse biological outcomes, is a function of the intrinsic hazard of a compound as well as the magnitude of exposure.

For a quantitative assessment, the ecotoxicity of each major packaging option was calculated using the SimaPro LCA modeling software. The results are broken down by major process, as the ultimate sources of pollutants that cause toxicity. The characterization method used to calculate toxicity is TRACI 2002. The units of ecotoxicity are kg 2,4 D eq, which refers to kilogram equivalents of 2,4-Dichlorophenoxyacetic acid, a common herbicide. The use of an herbicide reflects the high weight given to terrestrial organisms in this characterization method.

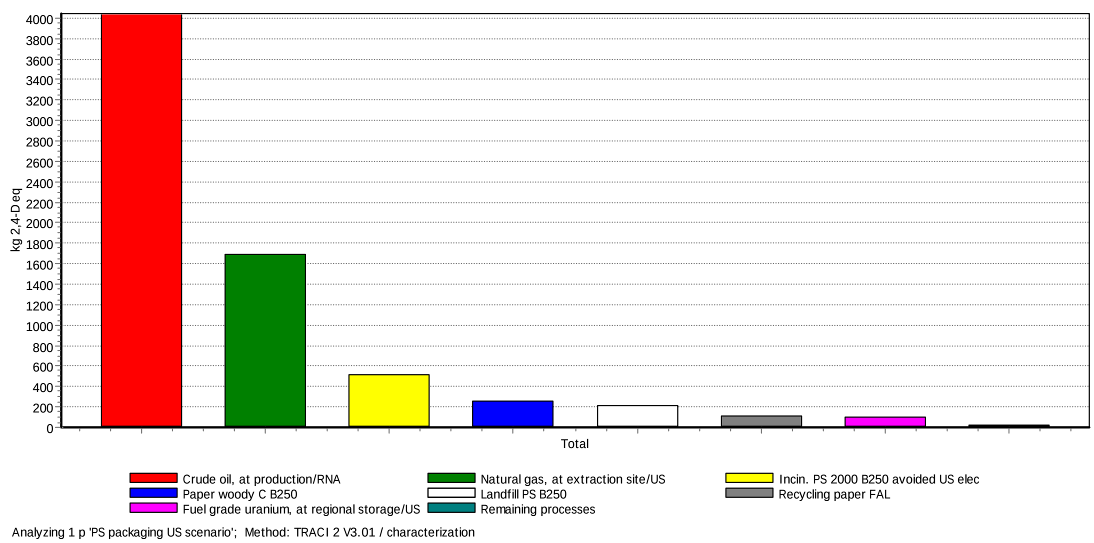


Figure 6.1 Life-cycle ecotoxicity of the PS package, U.S. average disposal scenario; 1% cutoff

Polystyrene production relies heavily on crude oil and natural gas as feedstock and energy sources and this is reflected in the ecotoxicity results. The incineration of PS also releases many air pollutants of concern (see Section 5.2), which account for the contribution of 'Incin. PS 2000 B250 avoided'. Interestingly, paper production and recycling of paper inserts are important factors in the ecotoxicity of PS-based jewel case packaging. The polymerization and manufacturing steps are not important for ecotoxicity.

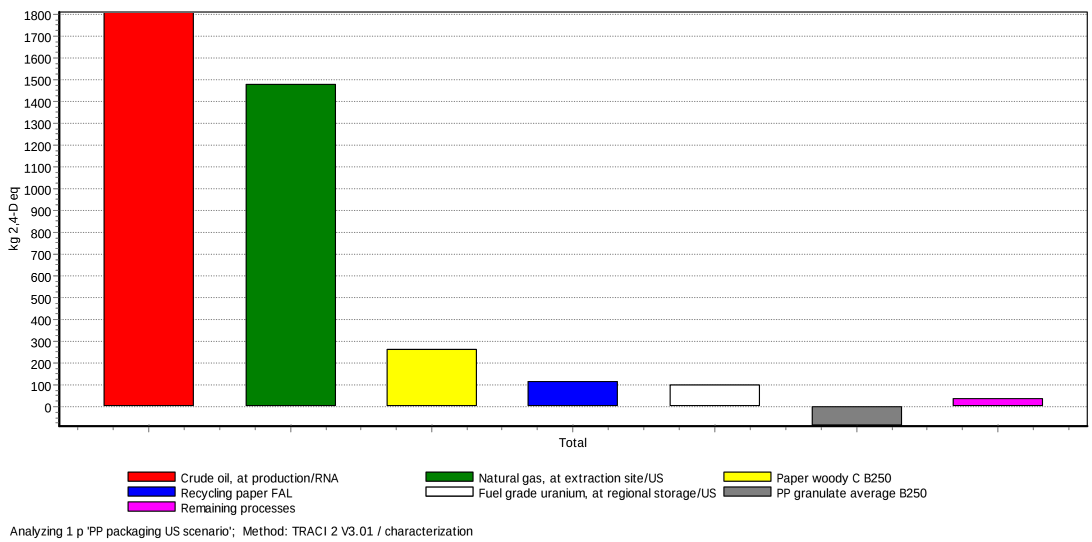


Figure 6.2 Life-cycle ecotoxicity of the PP package, U.S. average disposal scenario; 1% cutoff

PP's ecotoxicity impacts are also concentrated in fossil fuel production and use, as expected for a fossil-based polymer. Paper production and recycling are again important, but unlike the PS case, the recycling of PP jewel cases gives a large credit for ecotoxicity.

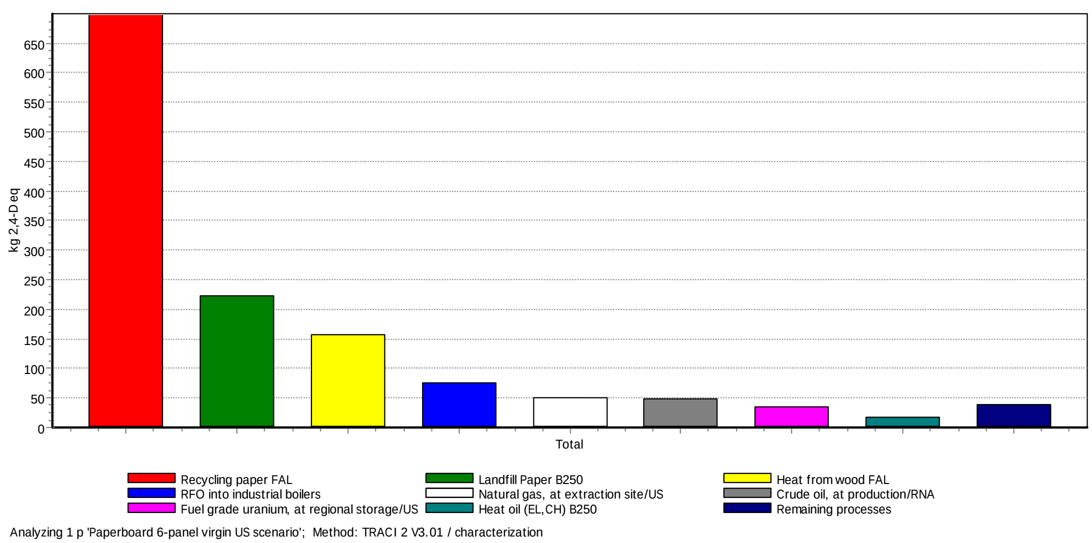


Figure 6.3 Life-cycle ecotoxicity of the 6-panel virgin paperboard package, U.S. average disposal scenario; 1% cutoff

In the case of virgin paperboard production, the major source of ecotoxicity is again fossil fuel combustion.

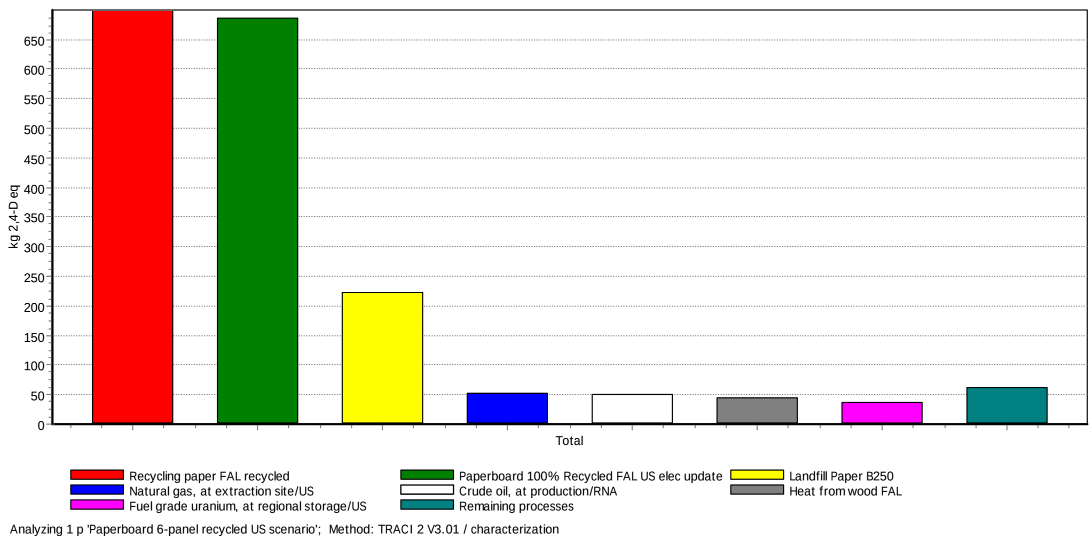


Figure 6.4 Life-cycle ecotoxicity of the 6-panel recycled paperboard package, U.S. average disposal scenario; 1% cutoff

The two largest toxicity impacts over the life cycle of the recycled paperboard packaging option are the production of paperboard and the recycling process itself, which uses some metal-based additives. A large credit is given in waste management for that paper that is recycled (54% in the U.S. average scenario). The impacts from landfilling paper (primarily methane generation and landfill leachate) are listed in the third place; most important processes are related to fossil fuel combustion.

For all CD packaging options, the largest contributors to ecotoxicity were fossil fuels, through processing as feedstock material, combustion of the fuels for energy, and the eventual incineration of plastics. The lifetime of CD packaging is difficult to discern as jewel cases and sleeves are often kept by consumers to protect the discs or for the artwork and information they contain, even in the case where the discs themselves are kept in binders. Recycling was only significant in decreasing ecotoxicity impacts for paper products, reflecting the much higher recycling rates for paper over plastic in the U.S.

7. Review of Design and Materials Innovations

Packaging has long been a major concern of policy makers and waste management officials because of its large contribution to municipal solid waste generation (about a third of the total), and because of its peculiar function. The main purpose of packaging is to protect a product until consumers are ready to use it, after which it serves no purpose. Not being amenable to reuse, packaging has come to represent a once-through material economy, where valuable materials are used for a short period and immediately discarded.

Packaging waste is also very visible, which has helped galvanize public opinion against it. Most of the litter on roadsides, on beaches, and on riverbanks is packaging waste of one kind or another. Dozens of academic, non-governmental, and industry groups have sprung up to address this topic, as clearinghouses of information, to lobby for the prohibition of certain substances and/or designs, and to provide guidance on choosing less impactful materials and methods for packaging.

There has also been formal legislation in some countries on this issue, primarily in Europe, such as the Europe Packaging Directive 2004/12/EC. In the United States, the most influential packaging waste legislation has been the container deposit laws passed by several states.

Most of the activity around packaging waste has not dealt directly with CD packaging, and so there is not much specific information to report from the waste management perspective. In recent years, however, the development of life cycle assessment and the realization and quantification of the environmental impacts of different materials has given rise to significant action from manufacturers of all types, including those that produce packaging. There has also been a surge in consumer demand for materials and products that are perceived as "green", somewhat assisted by an array of eco-labels that attest to specific environmental criteria. The criteria and best practices presented here blend broad sustainability objectives with business considerations and strategies that address the environmental concerns related to the life cycle of CD packaging, and are screened for relevance to the SPWG.

According to the Sustainable Packaging Coalition, sustainable packaging should have the following attributes:

1. Is beneficial, safe & healthy for individuals and communities throughout its life cycle;
2. Meets market criteria for performance and cost;
3. Is sourced, manufactured, transported, and recycled using renewable energy;
4. Maximizes the use of renewable or recycled source materials;
5. Is manufactured using clean production technologies and best practices;
6. Is made from materials healthy in all probable end of life scenarios;
7. Is physically designed to optimize materials and energy;
8. Is effectively recovered and utilized in biological and/or industrial cradle to cradle cycles. (SPC, 2008)

There are a number of organizations that have developed streamlined assessment tools to assist in choosing different types of packaging.

- The Paper Calculator was created by Environmental Defense in order to help purchasing agents and others determine the environmental impacts of a particular paper choice (www.edf.org/papercalculator/). The calculator covers several important impact categories, including primary energy and material use, greenhouse gas emissions, and waste generation. An example specific to paperboard choices for CD packaging is shown below:

Paper Type	Wood use (tons)	Energy use (MBtu)	GHG emissions (kg CO_2eq)	Wastewater (gal)	Solid waste (lbs)
SBS 100% Virgin	4	40	5627	20,123	2235
SBS 30% Recycled	3	34	5012	15,426	1931
SBS 40% Recycled	2	32	4807	13,860	1830
Coated Recycled 100%	0	17	3244	1,930	580

- The Sustainable Packaging Coalition in Australia has developed a Packaging Impact Quick Evaluation Tool (PIQET) as a part of the National Packaging Covenant, which is “the voluntary component of the national co-regulatory approach between government and industry to the life cycle management of packaging throughout the supply chain.” PIQET is a sophisticated tool that examines several process stages (material production, conversion and manufacturing, transportation, assembly, and waste management) and environmental impact categories (climate change, primary energy use, photochemical oxidation, water use, solid waste generation, and land use). Among the applications and benefits of the tool are:

    - “Assessment of the environmental impact of different packaging formats and scenario analysis;
    - Evaluation and comparison of new or existing packaging systems and materials i.e. easy exploration of improvement options;
    - Identification at an early development stage of any environmental issues;
    - For integrating environmental decision-making into the packaging design process;
    - Measurement and reporting of environmental performance to internal and external stakeholders particularly customers and regulators;
    - Benchmarking of packaging performance over time;
    - Setting targets, standards and specifications;
    - Identification of priority areas for improvement and identification of where impacts occur in the life cycle;
    - Identification of which packaging components or systems (e.g. the retail unit, merchandising unit, traded unit) have the highest impacts;
    - Evaluating the effect of recyclability and recycling rates on the environmental impact of packaging materials;
    - Due diligence and risk assessment step – especially relevant due to increasing regulatory and market drivers; and

- Education, awareness building and negotiation tool to facilitate discussions with supply chain partners and other stakeholders.

PIQET can also compare environmental impacts of different packaging scenarios that can be used for the same product. This can either be a comparison of a completely new packaging system with the existing system or it can be material/weight change of a specific level of packaging."

There are also several companies and organizations that set environmental criteria for green packaging. Among the most comprehensive is Diamond Packaging's Greenbox Initiative, which evaluates its suppliers of paperboard, inks, coatings, plastics, and films. Following is a list of the criteria the company highlights in reviewing each:

Inks

- Conventional inks are vegetable-based
- UV ink curing involves 100% solids
- No solvents or VOCs are released into the atmosphere during the curing process
- UV cured materials are fully repulpable
- UV cured materials are fully recyclable

Coatings

- UV and water-based (aqueous) coatings
- UV curing involves 100% solids
- No solvents or VOCs (volatile organic compounds) are released into the atmosphere during the curing process
- UV cured materials are fully repulpable
- UV cured materials are fully recyclable
- UV printed and coated paper waste can be completely broken down and recycled into low-grade or fine paper grades using common, commercially available recycling equipment
- As a solid waste class, printed materials, with or without UV coating, are considered by the EPA to be in the non-hazardous materials class for landfill purposes. They pose no unsafe conditions to the environment as a solid waste

SBS

- Dedicated to environmentally and socially responsible forest management
- Certified by the Forest Stewardship Council (FSC)
- CO2 equivalents/ton of production – want to be below the EPA standard for the industry
- Mix of natural and plantation forest management

- Invests in Continuing education for professional foresters, and has a college scholarship program for high schools located near its operation
- Lightweight but high-strength

Kraft and mixed sources

- U.S. forestlands and harvesting are independently certified to Sustainable Forestry Initiative (SFI) standards
- Cooperative Forest Management landowner assistance program is independently certified to the American Tree Farm Standard
- Natural, unbleached packaging that is 100% recyclable and made from a renewable resource
- Manufactured with high yield pulping strategy and byproduct conservation practices utilizing 58% percent biomass in fuel composition

Recycled

- Active environmental management program
- Programs to reduce water consumption, decrease waste going to landfills, reduce energy consumption and greenhouse gas emissions
- Made from 100% recycled fibers (minimum 55-95% PCW)

Plastic Films

- Fully integrated production processes allow control of all film attributes and complete traceability
- PVC now considered one of the more eco-friendly polymers, partially due to the amount of energy and fossil fuels (less than 50%) used to produce it
- PET film manufactured with 25% PCW (bottle scrap)

Plastics

- Use of polypropylene (PP), a polyolefin which can be made thinner and lighter than equivalent paper packaging; low production impacts; few waste products and readily recyclable

Considering just the printing process, the Sustainable Green Printing Partnership is an organization that offers membership to printers who are willing to undergo voluntary verification of a number of environmental actions, many of which have to do with processing and sourcing of environmentally preferable materials. A representative list is given below:

- Open a dialog with your suppliers to better understand and take measures to reduce impact associated with the sourcing of input materials. Discussion topics could include:
  1. Mechanisms to reduce or eliminate redundant shipping, including shipping distances and optimization of routing and delivery systems.
  2. Methods to reduce or eliminate outdated materials and associated obsolescence.
  3. Provisions to provide accurate environmental, health and safety data on all input materials, including information on volatile organic compounds (VOCs)/air toxic (hazardous air pollutants - HAPs) content, heavy metals, persistent bioaccumulative toxic compounds, including maintenance of material safety data sheets (MSDSs).
  4. Options to reuse and recycle unused materials and disposable packaging such as cores, cartons, drums and cans.
  5. Exploration of products that minimize or eliminate waste, use of minimal packaging, and establishment of take-back programs for unused materials.
  6. Awareness of substrate characteristics including: biodegradability, compostability, recyclability and recycled content, including pre-and post-consumer content, source of virgin fiber for paper, source and content of other substrates, and amount of renewable energy used in the manufacturing process.

- Investigate the use of solvent recovery system for solvent-based plate chemistry and cleaning solvents where applicable and economical.
- Incorporate environmental, health and safety considerations into equipment and material purchases and utilization.
- Minimize energy use under the constraints of your print process.
- Utilize a proofing system that minimizes impact and is compatible with your manufacturing process. Such systems include water-based, inkjet, dry sublimation and soft on-screen proofing systems.
- If using liquid photopolymer flexographic plates, collect and recycle any uncured polymer.
- Use perchloroethylene alternative solvent (PAS), water-washable, or dry plate development systems for flexographic operations.
- Recycle or treat metal-etching developers to remove metals when using bimetallic lithographic plates and embossing dies.
- Establish ink, coating, adhesive and solvent estimation methods that are as accurate as possible to reduce waste.
- Implement procedures to minimize fugitive emissions, such as properly covering, sealing, and storing partially used containers of materials that contain VOCs and HAPs.

- Use inks that meet the Council of Northeast Governors Coalition's (CONEG) requirements of no more than 100 ppm total for lead, mercury, cadmium and hexavalent chromium.
- Establish and follow operating procedures to minimize waste from equipment setup or finishing operations.

There are many companies that deal specifically in environmentally preferable CD packaging options, such as Oasis and Triple Disc. Some attributes that these companies advertise is exclusive reliance on Forest Stewardship Council (FSC) or Sustainable Forestry Initiative (SFI) certified wood and forestry practices, the use of vegetable-based inks, use of the lowest-VOC adhesives available, efficient recycling practices for scrap paper and plastic in the assembly plants, and in-house manufacturing as opposed to a dispersed supply chain (thus cutting down on transportation-based impacts).

One material type that has not received much attention in the environmental initiatives described above is the glue needed to bond panels of paper and/or plastic. Most product information comes from Material Safety Data Sheets (MSDSs), which are written by manufacturers to describe certain product parameters. These include substances of concern, human health impacts, and toxicology information. Due to confidentiality concerns, MSDSs almost never completely describe their product formulation, and quantitative information is rarely given. Many MSDSs indicate whether the product in question adheres to certain legal requirements. In the case of glues, these can include the presence of toxic metals, azo-dyes and pigments, animal byproducts, phthalates, and latex. This scattered list of criteria makes it difficult to evaluate and compare the environmental performance of different glues.

Eco-labels can give a sense of the general environmental criteria that companies should consider when examining products. Green Seal is a well-developed labeling organization and has a standard for adhesives (GS-36) that includes:

- Carcinogens: The product shall not be formulated with any carcinogens. Any carcinogen that is known to be present as a contaminant shall not exceed 0.1% by weight of the product.
- Reproductive Toxins: The product shall not be formulated with any reproductive toxins. Any reproductive toxin that is known to be present as a contaminant shall not exceed 0.1% by weight of the product.
- Persistent, Bioaccumulative, and Toxic Compounds: The product shall not be formulated with any persistent, bioaccumulative, and toxic compounds (PBTs). Any PBT that is known to be present as a contaminant shall not exceed 0.1% by weight of the product.
- Ozone-Depleting Substances: The product shall not be formulated with any ozone-depleting substances. Any ozone-depleting substance that is known to be present as a contaminant shall not exceed 0.1% by weight of the product.
- Volatile Organic Compounds: Limited dry content, depending on application
- Toxic Compounds: The solvent portion of the adhesive shall not be toxic to humans when inhaled.

None of the glues submitted for consideration in this report by SPWG members contained hazardous ingredients in concentrations greater than 0.01%, an order of magnitude below the limits prescribed by the Green Seal standard.

Several SPWG members have already instituted certain policies to decrease the environmental impacts of CD packaging, including:

- Converting all CD packaging to 30% PCW content
- Using FSC-certified feedstock
- Avoiding the use of paper produced from pulping processes that use mercury
- Avoiding the use of paper sourced from an important bioreserve in the Southeastern United States
- Increased recycling of paper packaging scraps

One executive has reported that these types of initiatives are considered success stories at his company, both for their environmental benefits as well as for "strengthening employee morale because they feel a part of this larger effort."

8. Recommendations

Based on the quantitative results detailed above and our qualitative assessment of the design problem facing the CD packaging industry, we can make a number of recommendations to decrease the overall environmental impact of packaging while maintaining an attractive product. These recommendations are presented by category, each addressing a different aspect of the packaging issue.

Feedstock material

- As is often the case with packaging, the environmental impacts from fossil fuel combustion during the production of feedstock material are the cause of most of the life cycle environmental impacts of all of the CD packaging options. Based on this result, no matter what the final decision is on material type, one goal of the industry should be to reduce the weight of each component of the CD package as much as possible. It is reported that for Entertainment Distribution Company (EDC), over a third of its packages use lightweight components such as thinner plastic and paper stock; increasing this ratio at EDC and other companies would have the most significant environmental benefits of any action the industry could plausibly take. It has been suggested that consumers would be resistant to lighter packaging, equating it with lower quality. In order to combat this unconscious tendency, packaging companies could advertise the decrease in weight and environmental impacts directly on the packaging, as Poland Spring has done on their new "eco-bottles":

  > "Our new bottle looks and feels different because it is purposely designed with an average of 30% less plastic to be easier on the environment. We can all make a difference, please recycle."

- Comparing PS and PP, across all of the environmental impact categories considered, PP has the better performance and should be considered as a straightforward replacement material. Substitution of PS with PP may add several cents to each package, but the environmental benefits of such a substitution are unambiguous. PP also has some performance advantages: being softer at room temperature, it is less brittle and therefore less likely to crack. Broken PS jewel cases were consistently cited as an annoyance and a packaging frustration among our small survey of consumers. Another advantage is that PP is more readily recyclable than PS in many communities.

- Comparisons between paperboard- and polymer-based CD packaging options are mixed, making it difficult to give a clear recommendation. Paperboard-based options result in more GHG emissions (approximately double in the case of virgin paperboard) and are clearly worse in terms of eutrophication (nitrogen loading), though this impact is not detailed for this report. On a mass basis, virgin paperboard production is less water-intensive than PS production, but more than for PP. 100% recycled paperboard uses much less water than all other options. Polymer-based packaging has higher environmental impacts than paperboard for respiratory effects and eco-toxicity because of its reliance on fossil fuels as a feedstock, given the significant impacts of fossil fuel production. 100% recycled content paperboard is less impactful than virgin across all major impact categories, particularly for water use. Based on these mixed results, we recommend moving to paperboard only when high recycled content material can be used and only when existing equipment can be used. Increased use of paperboard packages will entail more manual assembly and, if current designs cannot be adapted, may also require large capital expenditures on new processing equipment, which would be difficult in the current economic climate. For that portion of paperboard that is sourced from virgin timber, using FSC- or SFI-certified wood is an additional recommended measure, though the costs are not insignificant.

- The use of PVC as a substitute for PS in jewel cases or for polyethylene as shrink wrap film is not recommended. While PVC requires less fossil-based energy than either PS or PP on a mass basis, it has larger impacts than PP for GHG emissions and water usage. The major impacts of PVC are for its potential risks to human health and ecosystem toxicity. Vinyl chloride monomer has undergone extensive research showing a positive association with hazard endpoints, including cancer, neurotoxicity and liver effects in humans. Potential for exposure occurs primarily for workers in production and polymerization plants. PVC is known to persist in the environment, though it is not known to bioaccumulate. Of the possible air pollutants that are produced through incineration of polymers, dioxin from PVC is the most serious from a toxicological perspective, though its exposure can be reduced through effective combustion and pollution control measures. For all air pollutants considered, incineration of PVC resulted in greater emissions than PS or PP, usually by an order of magnitude.

- The use of PLA could be considered, though it is not specifically recommended. As it is based on a renewable material, PLA has significant advantages to PS and PP as a long-term substitute polymer as the world moves away from fossil fuel-derived products. It produces roughly 20% less greenhouse gas emissions over its lifecycle compared to PP; that difference is even higher for PS. As PLA is currently derived from corn starch, however, there are significant concerns over the land use impacts from intensive cultivation of corn, as well as the potential for competition with food and corn-based ethanol. Another much-advertised advantage of PLA is that it is compostable, whereas other polymers are not. This advantage does not matter, however, in cases where consumers do not have access to composting facilities or do not realize that the material is compostable and so discard it as they would ordinary plastic waste, which is frequently the case. Over the long-term, PLA does not behave significantly differently than paper in landfills.

Assembly

- Though the wrapping of jewel cases and paperboard packages is not significant compared to life cycle greenhouse gas emissions, it seems clear that facility-level electricity use could be reduced and some plastic wastage avoided by wrapping more CDs with polypropylene over-wrap as opposed to polyethylene shrink wrap. This will be true particularly if the industry moves to a higher proportion of paperboard packaging, as this has usually been shrink-wrapped. This will necessitate asking suppliers to develop paperboard packages with reinforced stiff corners or a clasping mechanism of some kind, as exists with plastic jewel cases. A paper sticker that joins open edges may also serve to make the packages stiffer. The quick warm-up times of over-wrap as opposed to shrink wrap machines means that they can be economically shut down during short breaks and meetings, thus saving even more electricity. While probably not feasible from a security and advertising perspective, the elimination of CD wrapping is also desirable.

- The increased reliance on hand-packaging of paperboard packages as opposed to automated assembly of plastic jewel cases does not have significant environmental consequences compared to the life cycle impacts of these packaging options. Nevertheless, there are clear benefits to reducing transportation energy use as much as possible, regardless of the product or process in question.

Dyes, Inks, and Glues

- While the amount of ink used in printing CD paper inserts or paperboard packages are small, there are some risks associated with potential heavy metal content and high-impact manufacturing. All inks used by suppliers and printers in the industry should adhere to CONEG or similar regulations certifying a minimal level of cadmium, hexavalent chromium, mercury and lead. Depending on brightness and color requirements, vegetable- or soy-based inks should be considered where possible.

- Moving from plastic to paperboard CD packaging will necessitate increases use of adhesives, to fasten paperboard front-to-back, affix liner notes, and/or affix plastic CD hubs in the base of digipak-style packages. Low- or no-VOC adhesives should be used in all cases. A number of current adhesives used by SPWG members contain chemicals known to cause cancer (such as acetaldehyde, methanol, and formaldehyde). While these substances are present in such small concentrations that the actual risks from exposure are probably very low, alternatives should be sought out so as to ensure an inherently safe product.

- The top-spine sticker relies on a strong adhesive that carries some risk from inhalation, mostly for workers in production and assembly facilities. While the main function of top-spine stickers is to provide security, they are present only for plastic jewel cases and not for paperboard packages. There are other security measures such as electronic tags on the outside wrapping of CD packages, as well as the external wrapping itself, that call into question the security necessity of top-spine stickers. These stickers are also important in sorting and finding CDs in racks at retailers. For this purpose, lower-strength adhesives can be used.

- Bleaching of paperboard stock can have water pollution impacts. Much of the pulp and paper industry has moved away from elemental-chlorine bleaching, but SPWG members should ensure that upstream suppliers do not use this practice.

Design

- For all packaging options, and especially the plastic jewel cases, waste management is a significant process for nearly all impact categories. The recycling of material can avoid air emissions and provide secondary material to offset virgin production. At present, however, it is not straightforward for consumers to recycle most CD packaging. There are no marks on jewel cases to indicate recyclability and it is not obvious that the CD tray and the case are made of the same polymer. The paper tray insert is difficult to remove. The only piece of a standard jewel case that is easy to recycle is the paper front panel and/or liner notes. It is much more straightforward to recycle full paperboard packages as they can be placed directly in mixed paper bins, but the use of plastic trays in paperboard packages such as digipaks complicates this. Currently, many people keep jewel cases to store CDs over the long-term, even if they are not in active use. Packages will eventually be discarded, though, and so we recommend that SPWG members adopt the following measures:

    1. Always use the same resin for plastic cases and trays
    2. Indicate that plastic pieces are recyclable by including standard resin labels:

    3. Advertise that paper packages are recyclable, and encourage this by placing labels to the effect of "Please recycle"

- A popular method the companies use for addressing greenhouse gas issues is to offer carbon offsets, which are credits derived from greenhouse gas reduction efforts. There are many commercial offset companies and it is straightforward to make purchases. These offsets can be taken out by SPWG members in order to address emissions that occur usually at their own facility. A less expensive option would be to advertise offsets to consumers that they would buy as individuals, either through a website or during the actual CD purchase, via retailers. Orbitz, the online travel company, offers a similar service, primarily for air travel, and there are many other successful commercial examples. Purchase of offsets on a website could be a way to advertise other environmental measures taken by

SPWG members, or even to offer them exclusive access to merchandise or special offers. Offsets need not be limited to physical CD purchases, as digital downloads also carry significant environmental impacts associated with running download servers and maintaining IT infrastructure, in addition to the amortized impacts of CD recording and production.

- For whatever measures are taken by SPWG to address the environmental impacts of CD packaging, we recommend that these are advertised on the packages themselves, such as that used by Oasis Disc Manufacturing:

made with CERTIFIED GREEN COMPONENTS

Green Components in this Package:

- Certified 100% green forestry practices board, minimum 10% post-consumer recycled content
- All vegetable inks
- Minimal plastic use
- Biodegradable, recyclable packaging

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If acted upon, these recommendations can help SPWG members to reduce the environmental impacts of CD packaging considerably and to build up brand image as companies that are acting proactively to address our common environmental problems.

These environmental recommendations must be considered in concert with economic and social factors as well. These include materials prices, the compatibility of existing machinery, the function of packaging in marketing and security, and the overall uncertainty and weakening demand for physical media in the music merchandising industry.

General References

ACGIH. 2000. American Conference of Governmental Industrial Hygenists: Cincinnati, OH. Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices.

Allsopp, M.W. and G. Vionello. 2005. Poly(Vinyl Chloride). In *Ullmann's Encyclopedia of Industrial Chemistry*, Wiley-VCH Verlag GmbH & Co. KGaA: Weinheim.

Baitz, M.; J. Kreißig; E. Byrne; C. Makishi; T. Kupfer; N. Frees; N. Bey; M.S. Hansen; A. Hansen; T. Bosch; V. Borghi; J. Watson; M. Miranda. 2004. Life Cycle Assessment of PVC and of principal competing materials. EU Commission: Brussels.

Boustead, I. 2003. Polymers and Energy. In *Plastics and the Environment*, A.L. Andrady, ed. Wiley-Interscience: Hoboken, NJ,

Boustead, I. 2005a..Eco-Profiles of the European Plastics Industry: General Purpose Polystyrene. PlasticsEurope: Brussels.

Boustead, I. 2005b..Eco-Profiles of the European Plastics Industry: Polypropylene. PlasticsEurope: Brussels.

Boustead, I. 2005c. Eco-Profiles of the European Plastics Industry: Polypropylene Injection Molding. PlasticsEurope: Brussels.

Boustead, I. 2005d. Eco-Profiles of the European Plastics Industry: PVC Injection Molding. European Council of Vinyl Manufacturers and PlasticsEurope: Brussels.

Boustead, I. 2005e. Eco-Profiles of the European Plastics Industry: Polyvinyl Chloride (Suspension Polymerization). European Council of Vinyl Manufacturers and PlasticsEurope: Brussels.

Carnegie Mellon University Green Design Institute. 2008. Economic Input-Output Life Cycle Assessment (EIO-LCA), US 1997 Industry Benchmark model [Internet], Available from:<http://www.eiolca.net> Accessed 20 December, 2008.

Carroll, W.F.; Jr.; T.C. Berger; F.E Borelli; F.J.Garrity; R.A Jacobs; J..Ledvina; J.W. Lewis; R.L. McCreedy; T.P. Smith; D.R. Tuhovan; A.F. Weston.. 2001. Characterization of emissions of dioxins and furans from ethylene dichloride, vinyl chloride momomer and polyvinyl chloride facilities in the United States. Consolidated Report. *Chemosphere*, 43, 689-700.

Ecoinvent. 2007. *Life Cycle Inventory Data, Version 2.0*. Swiss Centre for Life Cycle Inventories: Zurich, Switzerland.

US Environmental Protection Agency (EPA). 1995. Profile of the Pulp and Paper Industry. Office of Compliance, Sector Notebook Project: Washington DC.

The Economist. 'From Major to Minor.' January 10, 2008.

European Council of Vinyl Manufacturers (ECVM) and PlasticsEurope. 2008. Environmental Product Declarations of the European Plastics Industry: Polyvinylchloride (PVC) (Suspension Polymerization). Brussels.

EU Commission. 2000. Environmental Issues of PVC. Green Paper, COM(2000) 469. Brussels.

Franklin Associates. 2007. Cradle-to-Gate Life Cycle Inventory of Nine Plastic Resins and Two Polyurethane Precursors. Prepared for the Plastics Division of the American Chemistry Council.

Freeze, R.A. and J.A. Cherry. 1979. *Groundwater*. Prentice Hall: Englewood, NJ, 604.

Hamilton, J.D. and R. Sutcliffe, eds. 1996. *Ecological Assessment of Polymers: Strategies for Product Stewardship and Regulatory Programs.* Van Nostrand Reinhold: New York.

Maul, J.; B.G. Frushour; J.R. Kontoff; H. Eichenauer; K.-H. Ott; C. Schade. 2007. Polystyrene and styrene copolymers. In *Ullmann's Encyclopedia of Industrial Chemistry*, Wiley-VCH Verlag GmbH & Co. KGaA: Weinheim.

Moller, S.; J. Larsen; J.E. Jelnes; H. Faergemann ; L.M. Ottosen ; F.E. Knudsen. 1996. Environmental Aspects of PVC. Environmental Project 313. Danish Technological Institute: Copenhagen.

NIOSH. 1997. National Institute of Occupational Safety and Health: Atlanta, GA. Pocket guide.

NTP. 1992. National Toxicology Program: Research Triangle Park, NC. National report on Carcinogens.

NTP. 2000. National Toxicology Program: Research Triangle Park, NC. NTP-CERHR Expert panel report on Di(2-ethyl hexyl)phthalate'. NTP-CERHR-DEHP-00.

Ohlsen, C.G. and L. Hardell. 2000. Testicular cancer and occupational exposures with a focus on xenoestrogens in polyvinyl chloride plastics. *Chemosphere*, 40(9-11): 1277-1282.

Organisation for Economic Cooperation and Development (OECD). 2003. Draft initial hazard assessment of Propylene, CAS 115-07-1, for human health and the environment as a result of its investigation in the OECD HPV Chemicals Programme. OECD: Paris, France.

Ostermayer, A. and J. Giegrich. 2006. Eco-Profiles of the European Plastics Industry: Polyvinylchloride (PVC) (Suspension Polymerization). European Council of Vinyl Manufacturers and PlasticsEurope: Brussels.

Patel, S.H. and M. Xanthos. 1995. Volatile emissions during thermoplastic processing - A review. *Advances in Polymer Technology*. 14(1), 67-77.

Schreiber, J. 2003. Deposition in the case Resilient Floor Covering Institute and Tarkett, Inc v New York State Department of Environmental Conservation, Supreme Court of the State of New York, County of Albany.

Suh, S.; Manfred Lenzen,;Graham J. Treloar; Hiroki Hondo; Arpad Horvath; Gjalt Huppes; Olivier Jolliet; Uwe Klann; Wolfram Krewitt; Yuichi Moriguchi; Jesper Munksgaard; and

Gregory Norris. 2004. System Boundary Selection in Life-Cycle Inventories Using Hybrid Approaches. *Env. Sci. Technol.* 38(3), 657-664.

Thiriez, A. and T. Gutowski. 2006. An Environmental Analysis of Injection Molding. Proceedings of ISEE.

U.S. Digital Media. 2009. http://www.cdrom2go.com/Resource-Center/Product-Support/Packaging-Support-Article-Listing/Articles/variopac-green.asp

U.S. Environmental Protection Agency. 2002. Integrated Risk Information System (IRIS). Washington DC.

U.S. Environmental Protection Agency. 1995. Profile of the Rubber and Plastics Industry. EPA Office of Compliance Sector Notebook Project, EPA 310-R-95-016. Washington DC.

Vincoli, J.W. 1996. Risk management for hazardous chemicals, Volume II. *CRC press*: 3136.

Wang, D.; M. Piao; S. Chu; X. Xu. 2001. Polychlorinated aromatic hydrocarbons from polyvinyl chloride combustion. *Env. Contam. Toxicol*., 66, 326-333.

Whiteley, K.S.; T.G. Heggs; H. Koch; R.L. Mawer; W. Immel. 2005. Polyolefins. In *Ullmann's Encyclopedia of Industrial Chemistry*, Wiley-VCH Verlag GmbH & Co. KGaA: Weinheim.

WHO. 1999. World Health Organization. Vinyl chloride: Health and Safety Guide. International Programme on Chemical Safety, (IPCS), Health and Safety Guide No. 109.

Yashuhara, A.; T. Katami; T. Okuda; N. Ohno; T. Shibamoto. 2001. Formation of dioxins during the combusition of newspapers in the presence of sodium chloride and poly(vinyl chloride). *Env. Sci. Technol*., 35(7), 1373-1378.

Toxicology and Human Health References

Ali, M. and T.R. Sreekrishnan. 2001. Aquatic toxicity from pulp and paper mill effluents: a review. *Adv. Env. Res.* 5: 175-196.

ATSDR. 1997. Agency for Toxic Substances and Disease Registry. Toxicological Profile for Polyvinyl Chloride. United States Department of Health and Human Services, Public Health Service, Atlanta, GA.

ATSDR. 1997. Agency for Toxic Substances and Disease Registry. Toxicological Profile for Vinyl Chloride. U.S. Department of Health and Human Services, Public Health Service, Washington, DC.

ATSDR. 1997. Agency for Toxic Substances and Disease Registry. Toxicological Profile for Titanium Dioxide. U.S. Department of Health and Human Services, Public Health Service, Atlanta, GA.

ATSDR 1999. Agency for Toxic Substances and Disease Registry. Toxicological Profile for Polyaromatic Hydrocarbons. Department of Health and Human Services, Public Health Service, Atlanta, GA.

ATSDR. 2006. Agency for Toxic Substances and Disease Registry. Toxicological Profile for Vinyl Chloride. United States Department of Health and Human Services, Public Health Service, Atlanta, GA.

Boening, D.W. 1998. Toxicity of 2,3,7,8, tetrachloro-p-dioxin to Several Ecological Receptor Groups: a Short Review. *Ecotoxicol. Environ. Safety*, 39(3); 155-163.

Ciliberti, A.; C. Maltoni and G. Perino. 1988. Long-term Carcinogenicity Bioassays on Propylene Administered by Inhalation to Sprague-Dawley Rats and Swiss Mice. *Ann. NY Acad. Sci*., 534: 235-245.

Eisler, R. 1987. Polycyclic Aromatic Hydrocarbon Hazards to Fish, Wildlife, and Invertebrates: a Synoptic Review. *U.S. Fish Wildl. Serv. Biol. Rep*. 85(1.11).

EPA 1992. Environmental Protection Agency. Carcinogenicity Risk Assessment Verification Endeavor (CRAVE) Workgroup. Federal Register, 57 Fr 60848.

EPA, 2004. Environmental Protection Agency. EPA Reassessment-NAS Review Draft of the EPA's Exposure and Human Health Reassessment of 2,3,7,8, tetrachloro-p-dioxin (TCDD) and Related Compounds, NAS review draft.

EPA. 2008. Environmental Protection Agency. Persistent, Bioaccumulative and Toxicity Profiler.

EPA. 1987. Environmental Protection Agency. Water Quality Criteria for Phthalate esters, Office of Environmnetal Health and Assessment, Environmnetal Criteria and Assessment Office, Cincinnatti OH, EPA 440/5-80-067, NTIS PB 81-117780.

Fabacher, D. L.; J.M. Besser; C. J. Schmitt; J.C. Harshbarger; P.H. Peterman; and J. A. Lebo. 1991. Contaminated Sediments from Tributaries of the Great Lakes: Chemical Characterization and Cancer-causing Effects in Medaka (Oryzias latipes). *Arch. Environ. Contam. Toxic,* 20:17-35

Fingerhut, M.A.; W.E. Halperin; and D.A. Marlow. 1991. Cancer Mortality in Workers Exposed to 2,3,7,8, tetrachloro-p-dioxin, *New Eng. J. Med*., 324:212-218.

Freudinger, H. H.; Bounameaux; and J. Garcia. 1988. Acroosteolysis and Renaud's Phenomenon After Vinyl Chloride Exposure. *Vara*, 17:216-218.

Gupta, P.; D.K. Bhargava, *et al.* 1993. Prevalence of Impaired Lung Function in Rubber Manufacturing Factory Workers Exposed to benzo (a) pyrene and respirable matter. *Indoor Environ*., 2: 26-31.

Hardell, L.; C. Ohlson; M. Fredrikson. 1997. Occupational Exposure to Polyvinyl chloride as a risk factor for Testicular Cancer Evaluated in a Case-Controlled study. *Int. J. Cancer*, 73: 828-830.

IARC. 2002. IARC Monographs on the evaluation of the carcinogenic risk of chemicals to humans. International Agency for Research on Cancer: Lyon, France.

IRIS. 2008. Integrated Risk Information System, USEPA. www.cfpib..epa.gov/ncea/iris/index.cfm (accessed 12 December 2008).

Jaakkola, J.K.; P.K. Verkasalo; and N. Jaakola. 2000. Plastic wall materials in the home and respiratory health in young children. *Amer. J. Pub. Health*, (90)5.

Jacobs, Alan; A. Isam; F. Oliver. 2007. Persistence of vinyl chloride in ground water at the Woodlawn landfill Superfund site, northeastern Maryland, USA. *Environmental Geol*., 52(7) July 2007, 1253-1260(8).

Jaeger, R.J.; E.S. Reynolds; R.B. Connoly *et al*.. 1974. Acute hepatic injury by vinyl chloride in rates pre-treated with phenobarbitol. *Nature*, 252: 724-726.

Jansing, P.J. and R. Korff. 1994. Blood levels of 2,3,7,8, tetrachloro-p-dioxin and globulin in a follow-up investigation of employees with chloracne. *J. Reggiani*.

Katami, T.; A Yashuhara; T. Okuda; and T. Shibamoto. 2002. Formation of PCDDs, PCDFs and coplanar PCBs from polyvinyl chloride during combustion in an incinerator. *Env. Sci. Technol*., 36(6), 1320-1324.

Kaleja, R., L. Horbach and J. Amsel. 1994. Propylene production workers and colorectal cancer in Germany: a brief report. *Occ. Env. Med*., 51:784-785.

Klaassen, C.D., ed. *Casarett and Doull's Toxicology-The Basic Science of Poisons*, Seventh edition. McGraw-Hill: New York, 2008. 1310pp.

Laplanche, A., F ; Clavel-Chapelon; J.C. Contassot *et al*., 1992. Exposure to vinyl chloride monomer: results of a cohort study after a 7 year follow-up. *Br. J. Ind. Med*., 49(2): 434-437.

Lemieux, P; P. Lutes; J. Abbott; K. Aldous. 2000. Emissions of polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans from the open burning of household wastes in barrels. *Env. Sci. Tech*., 34, 377-384.

Loonen, H., C. van de Guchete; J.R. Parsons; P deVoogt and H.A. Govers. 1996. Ecological hazard assessment of dioxins:hazards to organisms at diffent levels od aquatic food webs (fish-eating birds and mammals, fish and invertebrates). *Sci. Total Env*., 182(1-3):93-103.

Lu, P.Y.; R.L. Metcalf; N. Plummer; and D. Mandel. 1977a. The Environmental Fate of Three Carcinogens: Benzo-(alpha)-pyrene, Benzidine, and Vinyl Chloride Evaluated in Laboratory Model Ecosystems. *Arch.Environ.Contam.Toxicol*, 6(2-3):129-142.

Lu, P.Y., R.L. Metcalf, N. Plummer, and D. Mandel. 1977b. The Environmental Fate of Three Carcinogens: Benzo-(alpha)-pyrene, Benzidine, and Vinyl Chloride Evaluated in Laboratory Model Ecosystems. *Arch.Environ.Contam.Toxicol*. 6(2-3):129-142.

Maltoni, C and G, Cotti. 1988. Carcinogenicity of vinyl chloride in Sprague-Dawley rats after prenatal and post-natal exposure. *Annals New York Academy of Sciences*, 534:145-159.

Mocarelli, P and L.L. Needham. 1991. Serum concentrations of 2,3,7,8, tetrachloro-p-dioxin and test results from selected residents of Sevaso, Italy. *J. Toxicol. Env. Health*, 32: 357-366.

NRC. 2006. National Research Council. Health Risks from Dioxin and related compounds: evaluation of the EPA reassessment committee on EPA's exposure and human health reassessment of 2,3,7,8, tetrachloro-p-dioxin (TCDD) and related compounds.

NTP 1982. National Toxicology Program. Carcinogenesis bioassay of 2,3,7,8, tetrachloro-p-dioxin (CAS No. 1746-01-6) on Swiss-Webster mice (dermal study), Carcinogenesis testing program, Bethesda MD, National Cancer Institute, RTP, NC, DHHS Publication Number 82-1757.

NTP 2000. National Toxicology Program. NTP-CERHR Expert panel report on Di(2-ethyl hexyl)phthalate. NTP-CERHR-DEHP-00, October 2000.

O'Conner, J. M. and R.J. Huggett. 1988. Aquatic pollution problems, North Atlantic coast, including Chesapeake Bay. *Aquatic Toxicology*, 11:163-190.

OECD. 2003. Organisation for Economic Co-operation and Development. OECD SIDS Initial assessment report for SIAM 16, May 2003 Draft.

Oie, L.; L.G. Hersoug and J.O. Madsen. 1997. Residential exposure to plasticizers and its possible role in the pathogenesis of asthma. *Env. Health Persp*., 105 (9).

Oliver, M..1975. Toxic effects of 2,3,7,8, tetrachloro-dibenzo-1-4-dioxin in laboratory workers. *Br. J. Ind. Med*., 32: 49-53.

Ott, M.G. and A. Zober. 1996. Course specific mortality and cancer incidence among employees exposed to 2,3,7,8-TCDD after a 1953 reactor accident. *Occ. Env. Med*., 53: 606-612.

Peaslee, M.H. and F.A. Einhellig. 1973. Tannic Acid-Induced Alterations in Mouse Growth and Pituitary Melanocyte-Stimulating Hormone Activity. *Toxicol. App. Pharm.* 25: 507-514.

Pocchiari, F. V. Silano and A. Zampieri. 1979. Human health effects from accidental release of 2,3,7,8, tetrachloro-p-dioxin (TCDD) at Sevaso, Italy, Ann. NY Academy of Sci., 320:311-320.

Quest, J.A.; J.E. Tomaszweski; J.K Haseman; G.A. Boorman; J.F. Douglas and W.J. Clark. 1984. Two year inhalation toxicity study of propylene in F344/N rats abd B6C3F mice. *Toxicol. Appl. Pharmacol*., 76: 288-295.

Snyder, R and L.S. Andrews. 1996. Toxic effects of solvents and vapors. In *Cassarett and Doul's Toxicology- The Basic Science of Poisons*, Fifth Edition, Curtis D. Klassen, Ed., McGraw-Hill, 1111pp.

Staples C.A.; Peterson D.R.; Parkerton T.F.; Adams W.J. 1997. The environmental fate of phthalate esters: a literature review. *Chemosphere*, 35, (4) 667-749(83).

Teraoka, H.; W. Dong; S. Ogawa; S. Tsukiyama; Y. Okuhara; M. Niiyama; N. Ueno; R.E. Pterson and T. Hiraag. 2002. 2,3,7,8, tetrachloro-p-dioxin toxixity in the zebra fish embryo: altered regional blood flow and impaired long jaw development. *Toxicol. Sci*., 65: 192-199.

Thornton, S.R.; R.E. Schroeder; R.L. Robison *et al.*, 2002. Embryo-fetal development and reproductive toxicology of vinyl chloride in rates. *Toxicol. Sci*., 68: 207-219.

Vincoli, J.W. 1996. Risk Management for Hazardous Chemicals, Volume II, CRC Press, 3136pp.

Wang, D.; M. Piao; S. Chu and X. Xu. 2001. Polychlorinated aromatic hydrocarbons from polyvinyl chloride combustion. *Env. Contam. Toxicol*., 66, 326-333.

Wang, J.S. and W.F. Busby. 1993. Induction of lung and liver tumors by fluoranthene in a pre-weanling CD-1 mouse assay. *Carcinogenesis*, 14(9) 1871-1874.

Wilcock, R.J.; G.A. Corban; G.L. Northcott; A.L. Wilkins; and A.G. Langdon. 1996. Persistence of polycyclic aromatic compounds of different molecular size and water solubility in surficial sediment of an intertidal sandflat. *Env. Toxicol. Chem*., 15(5), 670-676.

WV DEP. West Virginia Department of Environmental Protection. Toxics Release Inventory. *Propylene*. http://gis.wvdep.org/tri (accessed September 17, 2008).