Sustainable Plastics with Reduced Carbon Footprint & Reduced Waste

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Abstract
Plastic products can be made more sustainable by reducing carbon dioxide emissions, solid waste generation, and pollution during production of plastic products. Life cycle assessment (LCA) is used to compare the carbon emissions and waste generation while producing plastic products. The environmental impact of plastic bag manufacturing is compared to the environmental impact of paper bag manufacturing. Plastic bag manufacturing emits less carbon dioxide, consume less energy, produce much less waste, and require significantly less water than paper bag manufacturing. Plastics manufacturing operations can meet California's 50% diversion rate requirements by utilizing post industrial and post consumer plastics. Plastic manufacturing plants can certify their carbon reductions and waste diversion performance through a non-profit organization that performs energy and waste audits at the manufacturing operations. Increased recycling can provide carbon credits for manufacturing companies.

Introduction

Plastics are excellent materials for packaging in the world today. A key feature of plastics is the fact that the material can be heated and formed multiple times and then recycled. Recycling is one of the biggest advantages of plastic materials. Recycling plastics and using recycled plastics can result in lower carbon footprint and lower waste. Most of the carbon dioxide emissions come from the energy needed in the industrial plants to convert raw materials to plastic pellets. For LDPE, approximately 1.05 tonnes of CO_2 is released during production of 1 tonne of LDPE. [1] Producing polyethylene plastic pellets from recycled polyethylene requires less energy and emits less carbon dioxide. Thus, plastic bags using recycled polyethylene will generate less carbon dioxide emissions.

Two types of recycling are post-industrial and post-consumer recycling. Post-industrial recycling (PIR) is reusing the plastic scrap at the manufacturing facility to produce plastic products. Most commercial plastic processing plants reuse all of their plastic scrap in the production facility. Post-consumer recycled (PCR) plastics are given this name since the consumer has used the plastic product and sent it to a recycler. The majority of recycled plastic is polyester (PET or PETE) or high-density polyethylene (HDPE). PET is used for bottles of soda pop and other drinking fluids. In 2007, 1.4 billion pounds of PET was collected and sold as recycled flake in the U.S. [2] In 2007, PET and HDPE comprise 96.3% of the plastic bottle market and 99.2% of the plastic bottles recycled. [3] Recycled PET can be remolded for strapping materials or fibers for clothing or carpeting. The increase in collection of recycled plastic materials is a result of the improved curbside collection methods used in the United States over the last decade. In 2007, the total amount of plastic bottles collected for recycling plastic increased by 115 million pounds over 2006. [4]

Most of the recycling of plastics in the US involves PET and HDPE. Waste haulers companies usually collect the plastics with other recycled products. Plastics, metals, and glass are sorted from the refuse and sent to recyclers. In 2002, the recycling rates for the most common plastics are as follows: PET (#1)- 36%, HDPE (#2)- 42%, PVC (#3)- 1%, LDPE (#4)- 0.02%, PP (#5)- 1%, PS (#6)- 0.04%, Other (#7) - 0.20%.[5] Plastic packaging can involve plastic products made from polyethylene, polystyrene and PET. Plastic bags can be made from LDPE, LLDPE, and HDPE. The environmental effect of plastic packaging can be studied with the use of life cycle assessment.

Life Cycle Assessment

Life cycle assessment (LCA) is a process by which the environmental consequences of materials can be evaluated for the production, use, and end-of life aspects of products. The LCA process can provide a "cradle to grave" accounting of the energy, materials, water, land, and other resources needed to produce products. LCA also provides estimation of the waste and pollution that is created from the production, use, and disposal of products. The waste includes solid and liquid waste generation, air pollution, green house gas (GHG) emissions, and land usage.

The term 'life cycle' refers to the notion that a fair, holistic assessment requires the assessment of raw material production, manufacture, distribution, use and disposal including all intervening transportation steps necessary or caused by the product's existence. [6] The procedures of life cycle assessment (LCA) are part of the ISO 14000 environmental management standards: in ISO 14040:2006 and 14044:2006. [7]

Recycling can lower the carbon footprint of plastic packaging. The Institute for Energy and Environmental Research (IFEU), Heidelberg, Germany, analyzed clamshell packaging made from polyethylene terephthalate (PET) and recycled PET. [8] The life cycle analysis found that clamshells made from recycled PET had lower emissions and carbon footprint than those made from virgin PET. Typically, production of 1 tonne PET from natural gas or petroleum emits 3.4 tonnes of CO_2. Whereas, production of a tonne of PET pellets from recycled PET bottles emits 1.4 to 1.8 tonnes of carbon dioxide. Similarly, production of 1 tonne PP (polypropylene) from natural gas emits 2 tonnes of CO_2. Whereas, production of a tonne of PP pellets from recycled PP bottles emits 1.2 tonnes of carbon dioxide. [9] The production of 1 tonne of linear low density

polyethylene (LDPE) from natural gas emits 2 tonnes of CO_2. Typically, the carbon footprint of a plastic product can be reduced 30 to 50% by using recycled plastics. Also, waste can be reduced by 50 to 75% by using recycled plastics since the waste plastic is recycled and not sent to landfill.

Recently, the American Chemistry Council (ACC) sponsored a research project with Life Cycle Assessment (LCA) of grocery bags to determine the environmental impact of polyethylene, paper, and compostable bags. [10] The paper bag included 30% recycled paper and the compostable bag included compostable plastics and 25% calcium carbonate. The LCA included plastic and paper material production from raw materials, manufacturing conversion to grocery bag, distribution of bags to stores, and disposal aspects of the grocery bags. The grocery bags were normalized to equivalent carrying capacity with 1000 paper bags and 1500 plastic bags. The LCA produced results on energy consumption in electricity and natural gas usage, raw materials, and water consumption. The LCA also calculated the resulting air emissions of Green House Gases (GHG), water effluents, and solid waste. The LCA results were calculated with Boustead Model for LCA. [11] The results show that single use plastic bags have lower environmental input than compostable bags and 30% recycled paper bags. The polyethylene plastic bag has 10% of the mass of the paper bag. Table 1 lists the energy usage, fossil fuel usage, solid waste generation, and GHG emissions for 1000 paper bags and 1500 polyethylene plastic bags.

Table 1. LCA for paper bags and polyethylene bags [9]

	1000 Paper bag (30% recycled)	1500 Plastic Bags industry ave	% Reduction for Plastic Bag
Total Energy, MJ	2622	763	-70.90
Fossil fuel used, kg	23.2	14.9	-35.78
Municipal solid waste, kg	33.9	7	-79.35
Greenhouse emissions, Tonnes CO2	0.08	0.0400	-50.00
Fresh water usage, gal	1004	58	-94.22
Mass, g, per bag	51.82	5.78	-88.85

The ACC LCA study show that production of 1500 plastic bags requires 70% less energy, 35% less fossil fuel, and 94% less waster than production of 1500 paper bags. Also, the production of 1500 plastic bags generates 50% less carbon emissions and 79% less municipal waste than production of 1500 paper bags. The LCA study analyzed different end-of life scenarios for the plastic polyethylene plastic, compostable plastic and paper bags. Those scenarios include recycling, landfill and incineration. The LCA assumed that only 5% of the polyethylene plastic bags and 21% of paper bags were recycled in 2008 based on EPA data. The overall environmental impact of plastic bag production is less than for paper bag production.

Another LCA study from a different compostable plastic company also illustrated the favorable environmental impact of polyethylene plastic grocery bags and compostable plastic bags over the recycled paper bags. [12] The LCA results show that the starch-based plastic bag requires less energy to produce than polyethylene plastic bags and significantly less energy than the heavier recycled paper bags. The compostable plastic bags also emit less green house gases (GHGs) than polyethylene plastic bags and significantly less GHGs than the paper bags. The polyethylene bags were heavier in the second study than the ACC study. The paper bags were approximately the same mass is both studies. The plastic bags were not recycled in the LCA study but were incinerated.

Sustainable Green Packaging

LCA analysis can be used to create a certification for sustainable plastic packaging. Since the predominate factor in the carbon footprint of plastics manufacturing is the energy needed to produce the plastic pellet and the plastic packaging, companies can measure their carbon emission by the amount of electricity and energy consumed at the manufacturing plant. The environmental impact of the plastic packaging manufacturing can be evaluated by calculating the amount of green house gases generated during plastic production and the amount of plastic waste that is sent to the landfill. The “cradle to gate” analysis calculates the amount of energy used to make plastic packaging and how much carbon dioxide is released into the atmosphere during production. The LCA also calculates how much solid waste is produced that is typically sent to landfills. California AB 939 from 1989 requires all state agencies, cities, and schools to divert greater than 50% of the waste to recycling or compost facilities rather than landfills. In 2008, the city of San Francisco recorded a 70% diversion rate by diverting solid waste to recycling and compost. [13] Chico State University diversion rate in 2008 was over 50% thanks to recycling and composting efforts on campus.

A non-profit company was recently formed to provide a 3rd party certification of the environmental footprint of plastic packaging operations. [14] A sustainable plastic product is one that is produced with lower environmental impact than current plastic packaging and is certified by an independent 3rd party. The environmental audit ensures that the company produces plastic packaging products with lower carbon emissions, lower waste generation, higher recycling rates, lower water usage, low pollution, and low pellet loss. The audit process calculates the carbon dioxide emissions based on energy and natural gas usage in the manufacturing plant. It also calculates the recycling rate and diversion rate for the plant. The audit also tracks the water usage at the plant and makes recommendations for conservations. Lastly, the audit verifies that the plant is in regulatory compliance with air, water, and waste regulations and adheres to operation clean sweep (OCS) procedures in

the plant for pellet containment. The audit can result in a sustainable green packaging certificate with a logo listed in Figure 1.

Figure 1. Certified Sustainable Green Packaging

The sgp™ audit process requires completion of a pre-visit questionnaire of 30 items that lists yearly energy, fuel energy, and water usage for the previous two years. It also requires lists of the recycling activity at the plant including, post-industrial and post-consumer plastic, paper, oil, ink, metal, and glass. The audit also requires production numbers for the last two years. This information is used to calculate life cycle analysis for the last two years at the manufacturing plant. Thus, the amount of energy, fuel and water used to create one kg of plastic packaging for the current year is compared to the previous year. Also, the tons of carbon dioxide that were produced and the amount of waste generated per kg or plastic packaging is calculated. Lastly, the environmental audit includes an on-site visit to evaluate the regulatory compliance of the plastic operation and their use of Operation Clean Sweep (OCS) methods in the plant's production facility. Thus, the plastics manufacturing company can get an annual environmental footprint for the production of plastic packaging. The audit also results in a Sustainable Green Packaging rating that certifies the sustainability of the plastic packaging operation.

The following example illustrates the sustainable green packaging (sgp™) certification process. "WXYZ" company (**not a real company or actual manufacturing data) manufactures plastic bags with three extrusion lines and has 10 printing and conversion lines for grocery bags. The company and lists the following information for 2008 and 2007 on the pre-visit checklist.

Table 2. Pre-visit check list for "WXYZ" company **

Input sheet	**Value**
Electricity, kW-h 2008	7 million
Electricity, kW-h 2007	3.5 million
Natural Gas, Therms, 2008	250,000
Natural Gas, Therms, 2007	25,000
Car Travel, miles 2008	30,000
Car Travel, miles 2007	35,000
Air Travel, miles 2008	40,000
Air Travel, miles 2007	45,000
Solid waste to landfill, lbs	300,000
PIM used, lbs	3 million
PCR used, lbs	100,000
Waste oil recycled, lbs	400
Waste inks recycled, lbs	1,000
Paper recycled, lbs	100
Cardboard recycled, lbs	250
Other recycled, lbs	50
LDPE Production, lbs 2008	7.8 million
LDPE Production, lbs 2007	6.9 million
HDPE production, lbs 2008	0
HDPE production, lbs 2007	0

"WXYZ" plastic bag company produces LLDPE plastic bags at their Chico, CA plant. The plastic bag averages 51.9 g over the several product lines. The annual production at the plant is 200 million plastic bags. Based on the production checklist listed in Table 2, the life cycle assessment (LCA) can be calculated to determine the carbon dioxide footprint and waste diversion at the plant. The LCA includes the energy and waste generated when producing the LLDPE plastic pellets from natural gas. The LCA is a "cradle to gate" analysis that includes the manufacturing f the plastic bags but not the transportation, use, or "end-of-life" of the plastic bags.

The carbon footprint of the manufacturing operation is calculated based on the energy usage and pounds of plastic used at the manufacturing operation. The electricity usage in kW-h can be converted to tons of CO_2 generated with a factor that is available at the utility. For, PG&E electric company, I kW-h of electricity generates 0.524 lbs of CO_2.

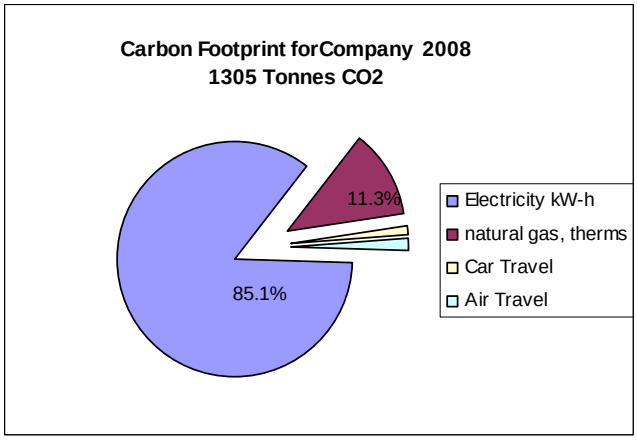
Also, 1 Therm of natural gas produces 13.446 lbs of CO_2. The CO_2 emissions from air and car travel are estimated with a calculator from Cool California web site. [15] The tons of CO_2 can be converted to metric tones of CO_2 by dividing tons of CO_2 by 2.205. Then the tones of CO_2 can be compared with other worldwide data. The carbon footprint for "XYZ" company is listed in Table 3 below.

Table 3. Carbon dioxide emissions for "WXYZ" Plant

Source	Tonnes of CO_2	%
Electricity kW-h	1111.0	85.13
Natural gas, therms	155.0	11.88
Car Travel	18.0	1.38
Air Travel	21.0	1.61
Total	1305	Tonnes CO_2 per year

Table 3 and Figure 2 demonstrate that 85% of the CO_2 emission from the plant are caused by the electricity used during the year. Natural gas consumption at the plant caused 11.88% of the carbon emissions. Car and air travel did not significantly contribute to the carbon emissions at the plant. The plant produced 1,305 metric tonnes , or 1439 US tons, of CO_2.

Figure 2. Carbon footprint for "WXYZ" company



LCA can be used to estimate the energy efficiency at the plant per kg by calculating the energy usage, fossil fuel usage, municipal solid waste generated, carbon dioxide emissions, and fresh water usage. The LCA for "WXYZ" plastic bag company is listed in Table 4 for the 51.9 g bag and also the LCA is generated for a normalized 5.78 g plastic bag. The lighter bag will enable the LCA for "XYZ" company to be compared to the plastics industry average and to paper bags. The LCA is listed for 1500 plastic bags and for 1000 paper bags of equal carrying capacity. The LCA for the plastic industry average and the paper is from the ACC. [9]

Table 4. LCA for "WXYZ" Plastic Bag Company [9]

	1500 "XYZ" Plastic bags	1500 "XYZ" Plastic bags, weighted to 5.78g	1500 Plastic Bag industry ave	1000 Paper bag (30% recycled)
Total Energy, MJ	3500	400	763	2622
Fossil fuel used, kg	131	14.5	14.9	23.2
Municipal solid waste, kg	4.94	0.51	7	33.9
Greenhouse emmissions, Tonnes CO2	0.09	0.011	0.04	0.08
Fresh water usage, gal	36.5	4.05	58	1004
Mass, g, per bag	51.9	5.78	5.78	51.82

Table 4 illustrates the efficiency of the plastic bag manufacturing at the Chico plant. The "WXYZ" company produces plastic bags that use much less energy and produces much less waste than the average plastic bag manufacturing company.

LCA can also be used to evaluate the sustainability of the plastic packaging. Sustainable plastic packaging is made from recycled or plant-based plastic materials, is heavy metal free, has low environmental impact, and utilizes Operation Clean Sweep practices during manufacturing. The plastic packaging can be certified as sustainable green packaging if during the last 12 months the plastic is made with reduced CO_2 emissions, the plastic is made with less solid and liquid waste, the plastic is made with significantly less environmental impact than the industry average for plastic packaging, and the plastic is made with regulatory compliance for air and water quality, and solid waste disposal.

"WXYZ" company can be evaluated for sustainability by computing the carbon emissions, water usage, waste generation per kg of plastic packaging produced in 2008 and in 2007. Table 5 lists the change in energy and water usage between 2007 and 2008. It also lists the CO_2 emissions and waste generation difference in the years.

Table 5 denotes that "WXYZ" company was more efficient in its manufacturing and used less energy, fossil fuels, and water in 2008 than it did in 2007. It also generated less CO_2 emissions and less solid waste. It therefore was more sustainable in 2008 and can be certified as producing "Sustainable Green Packaging". The sustainable process can also help the company achieve carbon credits by the producing less CO_2 emissions. Using recycled plastics can help companies gain additional carbon credits.

Table 5. Yearly Energy and Waste for "WXYZ" Company

	2008 "WXYZ",Per 1000 kg	2007 "WXYZ" Per 1000 kg	Yearly % change
Total Energy, MJ	40.00	38.00	5.26
Fossil fuel used, kg	7.00	6.50	7.69
Municipal solid waste, kg	75.00	73.00	2.74
Greenhouse emmissions, Tonnes CO2	0.2512	0.2456	2.28
Fresh water usage, gal	550.00	525.00	4.76

Conclusions

Plastics can be more sustainable if they are made from recycled or bio-based plastics and are made with lower CO_2 emissions and less solid waste. Sustainable green packaging can be certified with an audit process that calculates the life cycle assessment of the manufacturing process.

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