LCA of Degradable Plastic Bags

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Abstract

In 2002, Ron Clarke representing the Council for Encouragement of Philanthropy in Australia suggested that a levy should be placed upon shopping bags to reduce consumption. This was at a time when discuss and debate centred upon the consumption of 6.9 billion bags per year in Australia with many millions being littered and posing risks to aquatic and marine life through entanglement, ingestion and suffocation. It was also at a time when the introductions of different types of degradable polymers were entering the market and being touted as the solution to the plastic bag consumption. In 2002-3 the Department of Environment and Heritage funded two studies that investigated the impacts of degradable polymers in Australia. This paper presents background information on the types of degradable polymers and results from a streamlined life cycle assessment that compared degradable polymers and alternative materials such as HDPE, LDPE, PP, Kraft paper and calico. The paper concludes with a checklist for use in selecting degradable polymers.

Keywords: degradable polymers, life cycle assessment, plastic bags, waste management

1. INTRODUCTION

What are the issues associated with high density polyethylene (HDPE) plastic grocery shopping bags? Is it the consumption of 6.9 billion bags per year? Is it the 30 million that are littered in the environment each year? Or is it the issues of plastic bags entering marine and other aquatic environment each year where they can threaten aquatic life through entanglement, ingestion or suffocation? Will the introduction of degradable polymers solve any or all of these issues?

In October 2002, a national government working group was established to develop a comprehensive package of measures to combat plastic bag waste [1]. This was spurred by the suggestion originally made by Ron Clarke, representing the Council for Encouragement of Philanthropy in Australia that a levy should be placed upon shopping bags to reduce consumption. Following several studies e.g., [2, 3] and lengthy debate in the media, the industry in late 2003 in conjunction with government agreed upon an update of the voluntary code of practice for shopping bags [4] with stricter targets on reduction in HDPE singlet shopping bags and higher recycling rates.

In August 2003, the Sustainable Packaging Alliance[1] (SPA) held its second Roundtable titled "Think outside the bag – Product stewardship for risk management". This Roundtable explored business strategies and tools for managing risks associated with real and/or perceived environmental impacts of packaging. Via an alternating process of facilitated stakeholder panel considerations and participant discussions, the Roundtable sought to identify reasons why the plastic grocery bag debate suddenly increased in intensity and, more importantly, how such issues could grow into a risk for industry. Participants at this Roundtable agreed that plastic shopping bags are often a focus for environmental concern because [1]:

- They are symbolic of deeper concerns about our "throwaway society"
- They are used in high volume and often for single use applications
- They are not widely recycled
- Plastic bags have all the elements of a good media story
- The industry did not take the original Code of Practice for Shopping Bags seriously.

It was recognised that industry needs to understand supply chains and life cycle impacts, by undertaking some form of environmental assessment. This information should then be used to educate the community to help them make informed choices. Issues management means planning ahead and ensuring that any potential risks to the business are anticipated wherever possible. One of the benefits is that a proactive response is likely to be more scientifically sound than a reactive response, which is responding to public concerns [1].

In recent years degradable polymers have been marketed as a solution to the HDPE single use shopping bag through the reduction in non-renewable resources by its replacement with renewable resources (e.g., maize), its degradability properties when it enters the environment (e.g., break down in the action of sunlight or water soluble) thereby reducing demand upon landfills and littering through aquatic and marine environments. Though like any material, degradable polymers based upon renewable resources have environmental impacts and it is important to understand these impacts and the difference with non-renewable based polymers first before widely accepting them as the solution.

This remainder of this paper is divided into … sections. In section 2 a description of degradable polymers is given followed by updated results of a streamlined LCA conducted in 2003 on the impacts of degradable polymers in section 3. The paper concludes with a checklist for use when making decisions on the selection of degradable polymers.

2. DEGRADABLE POLYMERS

Degradability is the ability of materials to break down, by bacterial (biodegradable), thermal (oxidative) or ultraviolet (photodegradable) action. In order for degradable polymers to be made into functional plastic bags they must meet the following criteria [2]:

- Be able to be formed into film;
- Have adequate tensile strength and elongation;
- Have adequate puncture resistance;
- Have adequate tear resistance (not too splitty); and
- Generally possess properties that resemble low-density polyethylene (LDPE) or high-density polyethylene (HDPE) in overall physical properties and rheological characteristics.

Degradable plastics for bags are required to degrade rapidly at the end of their useful life while it is equally important that their mechanical properties remain essentially unchanged during use. There are three essential criteria for biodegradation of plastic bags [2]:

- They must disappear and leave no visible trace;
- This disintegration must occur in a reasonable timeframe (e.g. 3 months or 6 months); and
- They must not leave behind any toxic residues.

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[1] www.sustainablepack.org

2.1 Types of degradable plastic bags

Degradable bags can be classified in two ways [2]:

- According to the way that they degrade, for example whether they require the actions of micro-organisms (i.e. are biodegradable), or whether they require heat, ultraviolet light, mechanical stress or water in order to break down; and

- According to the materials they are manufactured from, for example whether they are made from natural starch polymers, from synthetic polymers or from a blend of a conventional polymer with an additive to facilitate degradation.

There are five different types of degradable polymers [2]:

- **Biodegradable polymers** are those that are capable of undergoing decomposition into carbon dioxide, methane, water, inorganic compounds or biomass in which the predominant mechanism is the enzymatic action of micro-organisms that can be measured by standardized tests, in a specified time, reflecting available disposal conditions.

- **Compostable polymers** are those that are degradable under composting conditions. To meet this definition they must break down under the action of micro-organisms (bacteria, fungi, algae), achieve total mineralization (conversion into carbon dioxide, methane, water, inorganic compounds or biomass under aerobic conditions) and the mineralization rate must be high and compatible with the composting process.

- **Oxo-biodegradable polymers** are those that undergo controlled degradation through the incorporation of 'prodegradant' additives (additives that can trigger and accelerate the degradation process). These polymers undergo accelerated oxidative define degradation initiated by natural daylight, heat and/or mechanical stress, and embrittle in the environment and erode under the influence of weathering.

- **Photodegradable polymers** are those that break down through the action of ultraviolet (UV) light, which degrades the chemical bond or link in the polymer or chemical structure of the plastic. This process can be assisted by the presence of UV-sensitive additives in the polymer.

- **Water-soluble polymers** are those that dissolve in water within a designated temperature range and then biodegrade in contact with microorganisms.

The composition of degradable bags also varies, with the main categories being [2]:

- **Thermoplastic starch-based polymers** made with at least 90% starch from renewable resources such as corn, potato, tapioca or wheat.

- **Polyesters** manufactured from hydrocarbons (oil or gas). All polyesters degrade eventually, with degradation rates ranging from weeks for aliphatic polyesters (e.g. polyhydroxyalkanoates) to decades for aromatic polyesters (e.g. PET).

- **Starch – polyester blends** that mix thermoplastic starch with polyesters made from hydrocarbons.

Table 1 provides a list of the different types of degradable polymers. This table classifies polymers according to both degradation pathway and composition.

Table 1 Types of degradable polymers

Polymer category, degradation pathway	Composition	From renewable or non-renewable resources
Biodegradable starch-based polymers	Thermoplastic starch derived from corn, potato or wheat, blended with additives (e.g. plasticizers)	Mostly renewable
	Thermoplastic starch derived from corn, potato or wheat, blended with polyester (PLA or PCL)	Starch component renewable, but hydrocarbon-based plastics and energy for agriculture are non-renewable.
	Thermoplastic starch derived from tapioca, corn, potato or wheat, blended with polyethylene	As above
	Thermoplastic starch derived from corn, blended with PVOH	As above
Biodegradable polyesters	Polybutylene succinate (PBS)	Non-renewable
	Poly (butylene succinate-co-adipate) (PBSA) copolymers	Non-renewable
	Polybutyrate adipate terephthalate (PBAT))	Non-renewable
	Adipic acid aliphatic/aromatic copolyesters (AAC)	Non-renewable
	Polylactic acid (PLA)	Renewable
	Polycaprolactone (PCL)	Non-renewable
	Polyhydroxy-butyrate-valerate) (PHB/V)	Renewable
	Blends of PHB with PCL	Combination renewable and non-renewable
	Modified PET	Non-renewable
Controlled degradation masterbatch additives	Polyethylene with a thermal and/or UV prodegradant additive	Non-renewable
Water soluble polymers	Polyvinyl alcohol (PVOH) and ethylene vinyl alcohol (EVOH)	Non-renewable
Photodegradable polymers	Thermoplastic synthetic polymers or copolymers	Non-renewable

Note: For further information on different polymers and commercial examples refer to [2].

3. STREAMLINED LIFE CYCLE ASSESSMENT

As reported in ExcelPlas Australia et al [2], a streamlined life cycle assessment (LCA) was undertaken on a selection of degradable plastics that are suitable for applications in film blowing and currently on the market as shopping bags against a selection of alternatives made form HDPE, LDPE, PP, Kraft paper and calico (see Table 2).

Table 2 Composition of all bags modelled including assumptions

Bag material[1]	Composition[2]	Assumptions made
Degradable polymers		
Starch Polybutylene succinate/adipate (PBS/A) (e.g., Bionelle™).	50% - starch from maize 25% - 1,4- butanediol 12.5% - succinic acid 12.5% - adipic acid	Adipic acid is manufactured from cyclohexane (40%) and (60%) nitric acid [5]. Succinic acid is formed through the fermentation of corn-derived glucose.
Starch with polybutylene adipate terephthalate (PBAT) (e.g., Ecoflex)	50% - starch from maize 25% - 1,4- butanediol 12.5% - adipic acid 12.5% - terephthalate acid	1,4-butanediol is derived either from natural gas or corn glucose [6].
Starch-polyester blend (e.g., Mater-Bi)	50% starch from maize 50% polycaprolactone (PCL)	Maize growing based upon data related to growing maize in the Netherlands. PCL is produced from cyclohexanone (95%) and acetic acid (5%) [7].
Starch-polyethylene blend (e.g., Earthstrength)	30% starch from cassava (tapioca) 70% high-density polyethylene	Cassava growing based upon data related to growing cassava in the Netherlands.
Polyethylene+prodegradant (e.g., TDPA)	97% high density polyethylene 3% additive	Additive modelled as stearic acid and small amount of cobalt metal to represent the presence of cobalt stearate.
Polylactic acid (PLA)	100% polylactic acid	Based upon maize growing in the USA.
Alternatives		
Singlet HDPE	HDPE	Production of HDPE film
Kraft paper handled	Kraft virgin pulp	Production of paper bags
PP fibre “green bag”	PP	Production of PP film
Woven HDPE “swag bag”	HDPE	Production of HDPE film
Calico	Cotton	Cotton processing
LDPE “bag for life”	LDPE	Production of LDPE film

Notes:

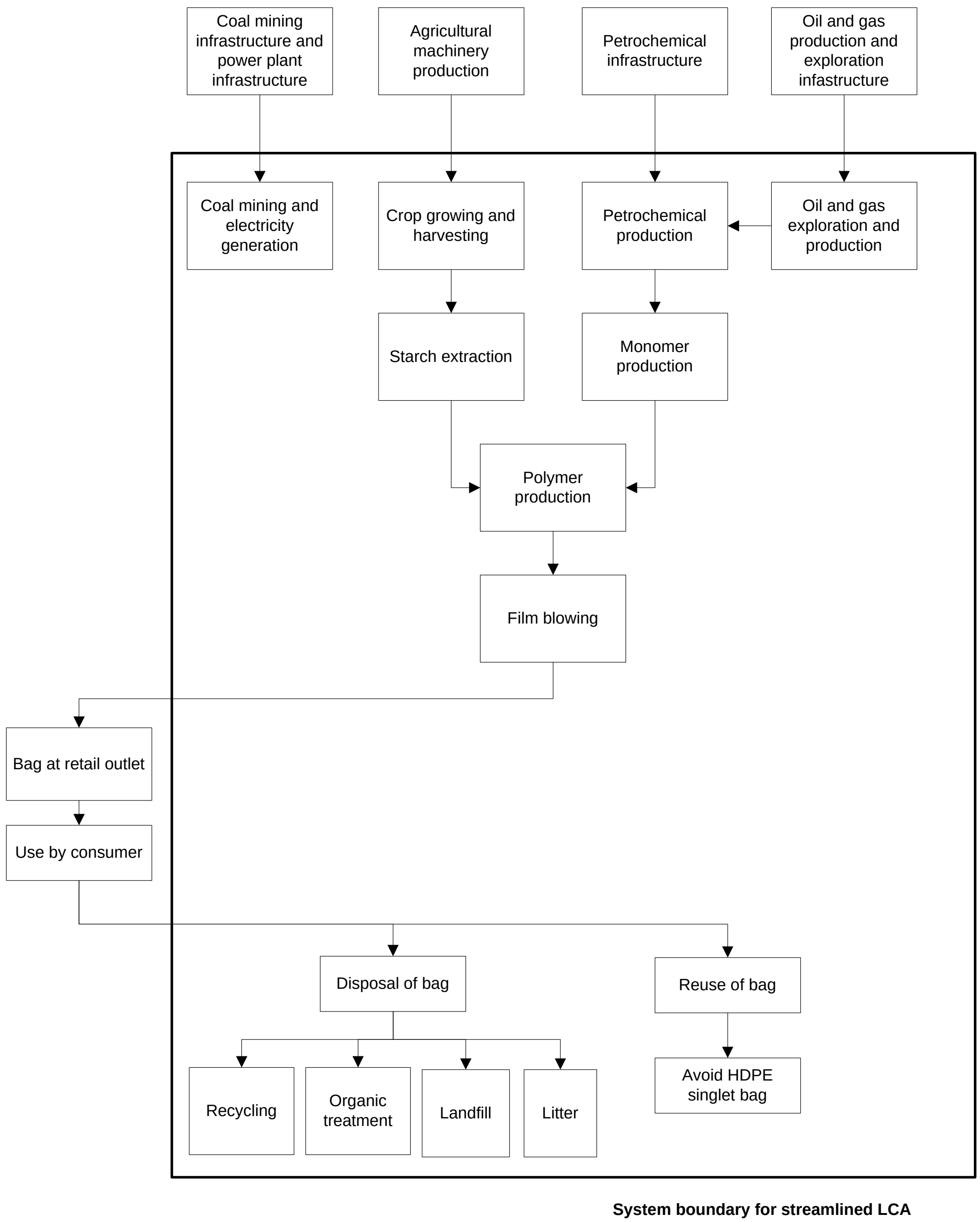
1. From [2].
2. The composition for each polymer is based upon materials that would be required to perform as material for film blowing and application as shopping bags (comparative in performance to the high-density polyethylene singlet bag). The streamlined LCA utilises generic life cycle inventory data for each material and do not refer to specific commercial products on the market or from companies that manufacture each polymer.

The goal of the study is to understand the life cycle environmental profile of degradable plastics in the application of film blown bags (i.e., shopping bags) and how they compare with alternative materials such as HDPE, LDPE, paper and calico.

The function of the study is the use of shopping bags to carry groceries and goods from a store to home. The number of single use bags required and the number of reusable bags required to carry goods home per person per year were calculated.

Any comparison of life cycle environmental impacts must be based on a comparable function. For the purpose of this study, the 'functional unit' is defined as **a household carrying approximately 70-grocery items home from a supermarket each week for 52 weeks.** See Table 3 for the characteristics of each bag in relation to the functional unit. Figure 1 provides illustration of the system boundaries for the streamlined study. Data sources used in this streamline study were from publicly available life cycle inventory data.

Figure 1 System boundaries of the study



The key assumptions in the modelling of all the bags are presented in Table 3.

Table 3 Characteristics of the use of all bags

Degradable polymers	Use of bags					
	Weight (g)(1)	Relative capacity	Quantity of bags per week in relation to relative capacity	Expected life	Quantity of bags per year adjusted in relation to expected life	Transport to Australia (km)
Starch-PBS/A	6	1 (6-8 items)	10	Single trip	520	From Japan (8,000 km)
Starch-PBAT	6	1 (6-8 items)	10	Single trip	520	50% from Germany (16,000 km) and 50% from USA (13,000 km)
Starch-polyester	8.1	1 (6-8 items)	10	Single trip	520	From Italy (16,000 km)
Starch-PE	6	1 (6-8 items)	10	Single trip	520	From Malaysia (6,000 km)
Oxo-biodegradable bag	6	1 (6-8 items)	10	Single trip	520	Concentrate from Canada (16,000 km) and 50% of bags from Malaysia (6,000 km)
PLA	8.1	1 (6-8 items)	10	Single trip	520	50% from USA (13,000 km) and 50% from Japan (8,000 km)
Singlet HDPE	6g	1 (6-8 items)	10	Single trip	520	Hong Kong (7,000 km)
Kraft paper handled	42.6g	1	10	Single trip	520	n/a
PP fibre “Green Bag”	PP 65.6g Nylon base 50.3g	1.2	8.3	104 trips (2 years)	4.15	n/a
Woven HDPE “swag bag	130.7g	3	3.3	104 trips (2 years)	1.65	Taiwan (7,000 km)
Calico	125.4g	1.1	9.1	52 trips (1 year)	9.1	Pakistan (11,000 km)
LDPE “bag for life”	40 g	2	-	10 trips (1 year)	26	Hong Kong (7,000 km)

Note: (1) Mass of bags based upon that required so that it performs the same function as a HDPE singlet bag.

3.1 End-of-life waste management modelling

Several different waste management treatment technologies were modelled to understand how degradable plastics degrade in aerobic and anaerobic environments. Using the work from Grant *et al* [8] the following treatment technologies were modelled:

- Landfill (anaerobic environment) - baseline landfill modelled upon Victorian landfills;
- Source separated green and food MBT composting (baseline for composting);
- Municipal solid waste MBT composting; and
- Municipal solid waste anaerobic digestion.

Assumptions were made to model the **baseline** end-of-life waste management destinations of the degradable plastics and they are presented in Table 4:

Table 4 End of life assumptions for the alternative bags

Alternative bags	Landfill %	Recycled %	Composting %	Litter %	Reuse (as a bin liner for household waste) (1) %
All degradable polymers	70.5	0	10	0.5	19
HDPE singlet bag	78.5	2	0	0.5	19
Kraft paper handled bag	39.5	60	0	0.5	0
PP fibre “green bag”	99.5	0	0	0.5	0
Woven HDPE “swag bag”	99.5	0	0	0.5	0
Calico bag	99.5	0	0	0.5	0
LDPE “bag for life	97.5	2	0	0.5	0

Note: (1) Subsequently avoids HDPE bin liners. In the landfill environment and in source separated organics composting it is assumed that the degradable polymers will degrade like food waste (i.e., 90% of the polymer will degrade).

Two different litter scenarios were modelled for each bag (Table 5):

- Litter aesthetics (calculated based upon the time the bag would be litter – m^2a); and
- Litter marine biodiversity (calculated based upon if the polymer floats and how long it would float, or if it sinks how long it will take to sink).

Table 5 Characteristics of all bags in different littering environments

	Litter by area	Litter by mass	Litter aesthetics	Litter marine biodiversity
Degradable polymer				
Starch-PBS/A	30*20 cm = 0.06 m^2	6 g	Assume bag litter lasts for 6 months (0.03 m2a)	Sink in 1 day (0.016 g/year)
Starch-PBAT	30*20 cm = 0.06 m^2	6 g	Assume bag litter lasts for 6 months (0.03 m2a)	Sink in 1 day (0.016 g/year)
Starch-polyester	30*20 cm = 0.06 m^2	8.1 g	Assume bag litter lasts for 6 months[2] (0.03 m2a)	Sink in 1 day (0.0221 g/year)
Starch-PE	30*20 cm = 0.06 m^2	6 g	Assume bag litter lasts for 6 months (0.03 m2a)	Float for 6 months (3 g/year)
Oxo-biodegradable	30*20 cm = 0.06 m^2	6 g	Assume bag litter lasts for 6 months (0.03 m2a)	Float for 3 months (due to prodegradant) (1.5 g/year)
PLA	30*20 cm = 0.06 m^2	8.1 g	Assume bag litter lasts for 6 months (0.03 m2a)	Sink in 1 day (0.016 g/year)
Alternative bags				
HDPE singlet bag	30*20 cm (0.06 m2)	6 g	Assume bag litter lasts for 2 years due to light film (0.12 m2a)	Will float for 6 months (3.5 g/year)
Kraft paper handled bag	20 * 30 cm (0.06 m2)	42.5 g	Assume bag litter lasts for 6 months (0.03 m2a)	Assume to sink in 1 day (0.116 g/year)
PP fibre "green bag"	42 * 42 cm (0.09 m2)	115.9 g	Assume bag litter lasts for 5 years (0.45 m2a)	Assume to float for 6 months (58 g/year)
Woven HDPE "swag bag"	50 * 50 cm (0.18 m2)	130.7 g	Assume bag litter lasts for 5 years (0.9 m2a)	Assume to float for 6 months (65 g/year)
LDPE "bag for life	42 * 42 cm (0.09 m2)	125.4 g	Assume bag litter lasts for 2 years (0.18 m2a)	Assume to float for 6 months (62 g/year)
Calico bag	42*42 cm (0.09 m2)	125.4 g	Assume bag litter lasts for 2 years (0.18 m2a)	Sinks in 1 day (0.34 g/year)

Source: [2].

[2] This is an assumption. There is limited data available on degradation rates in litter. Estimated 'shelf-life' is 6 months for TDPA - EPI plastics and 2 years for starch – polyester. Estimates of degradation times depend on both the resin and the environment, and range from 2 months to more than a year (see Table 3)

3.2 Life cycle impact assessment results

Table 6 presents the characterisation values for all bags across the indicators of greenhouse, abiotic depletion, eutrophication, litter marine biodiversity and litter aesthetics.

Table 6 Characterisation values for all bags

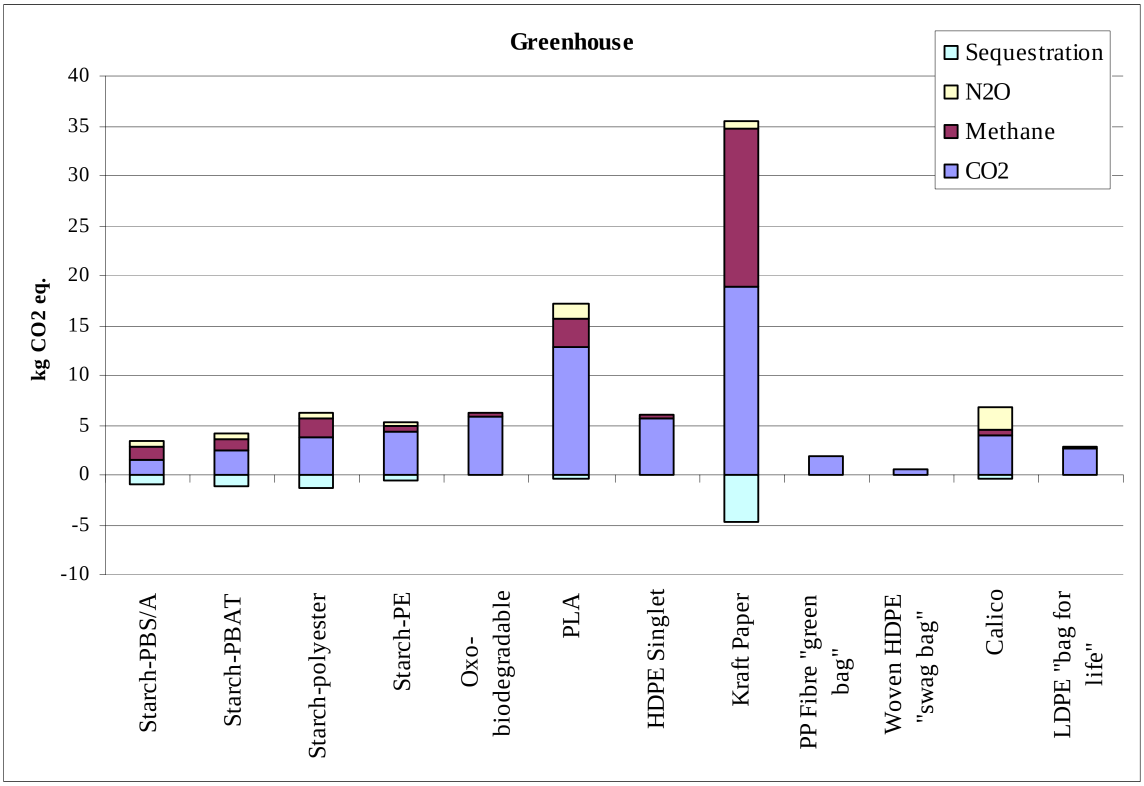
	Material consumption kg	Greenhouse kg CO2	Abiotic depletion kg Sb eq	Eutrophication kg PO4--- eq	Litter Marine Biodiversity kg.y	Litter Aesthetics m2.y
Starch-PBS/A	3.12	2.5	0.00487	0.00273	4.26E-05	0.078
Starch-PBAT	3.12	2.88	0.023	0.00406	4.26E-05	0.078
Starch-polyester	4.21	4.96	0.0409	0.00494	5.75E-05	0.078
Starch-PE	3.12	4.74	0.0694	0.00258	0.0078	0.078
Oxo-biodegradable	3.12	6.31	0.101	0.00236	0.0039	0.078
PLA	4.212	16.7	0.0776	0.00911	5.75E-05	0.078
HDPE Singlet	3.12	6.13	0.102	0.00246	0.0078	0.312
Kraft Paper	22.152	30.2	0.285	0.0266	0.000302	0.078
PP Fibre "green bag"	0.209	1.95	0.023	0.00126	0.000241	0.00187
Woven HDPE "swag bag"	0.216	0.631	0.00934	0.000231	0.000107	0.00148
Calico	1.141	6.42	0.0177	0.00795	3.09E-06	0.00164
LDPE "bag for life"	1.04	2.76	0.0422	0.00114	0.00257	0.00746

3.2.1 Greenhouse comparison between the degradable polymers and alternative materials

Figure 2 illustrates the greenhouse gas emission profile for the six degradable polymers compared with six alternative materials – two single-use materials (i.e., HDPE and Kraft paper) and four reusable materials (i.e., calico, PP fibre “green bag”, woven HDPE “swag bag” and LDPE “bag for life” bag). The findings in this streamlined LCA related to greenhouse indicate that reusable bags, with the exception of calico, still have a lower impact upon the environment, than HDPE singlet bags or degradable polymers. Greenhouse impacts are dominated by carbon dioxide through electricity and fuels consumption, methane emissions through degradation of materials in anaerobic conditions (e.g., landfill) and nitrous oxide (N_2O) emissions in fertilizer applications on crops (Figure 2). Degradable polymers with starch content have higher impacts upon greenhouse due to methane emissions during landfill degradation and N_2O emissions from fertilizing crops. A sensitivity analysis was performed to determine the effect of reusing kraft paper bags. In the results below it is assumed that the kraft paper bags are single trip bags. In the sensitivity it is assumed that each bag will be reused a second time[3] (therefore you only need 260 bags compared with 520 bags in one year). The impacts of the Kraft paper bag are halved if the bag is assumed to be used twice by the consumer (see column 9 in Figure 2).

[3] This is consistent with feedback from Coles Supermarkets that bags appear to be coming back at least once.

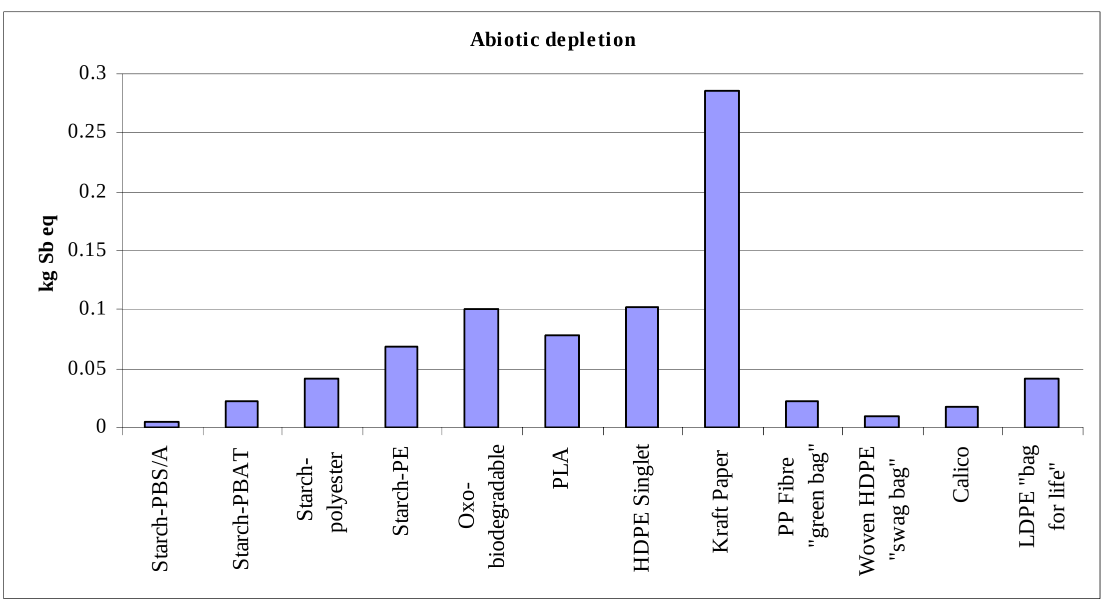
Figure 2 Greenhouse gas emissions breakdown for all bags



3.2.2 Resource (abiotic) depletion

Resource (abiotic) depletion refers to the consumption of non-living resources (e.g., coal, oil, gas). As most of the degradable polymers are based upon 50% starch their dependence upon fossil fuels as material feedstocks is reduced (Figure 3). The Kraft paper is high in this category due to the consumption of electricity and gas in paper production. The woven PP and HDPE reusable bags have the lowest impact.

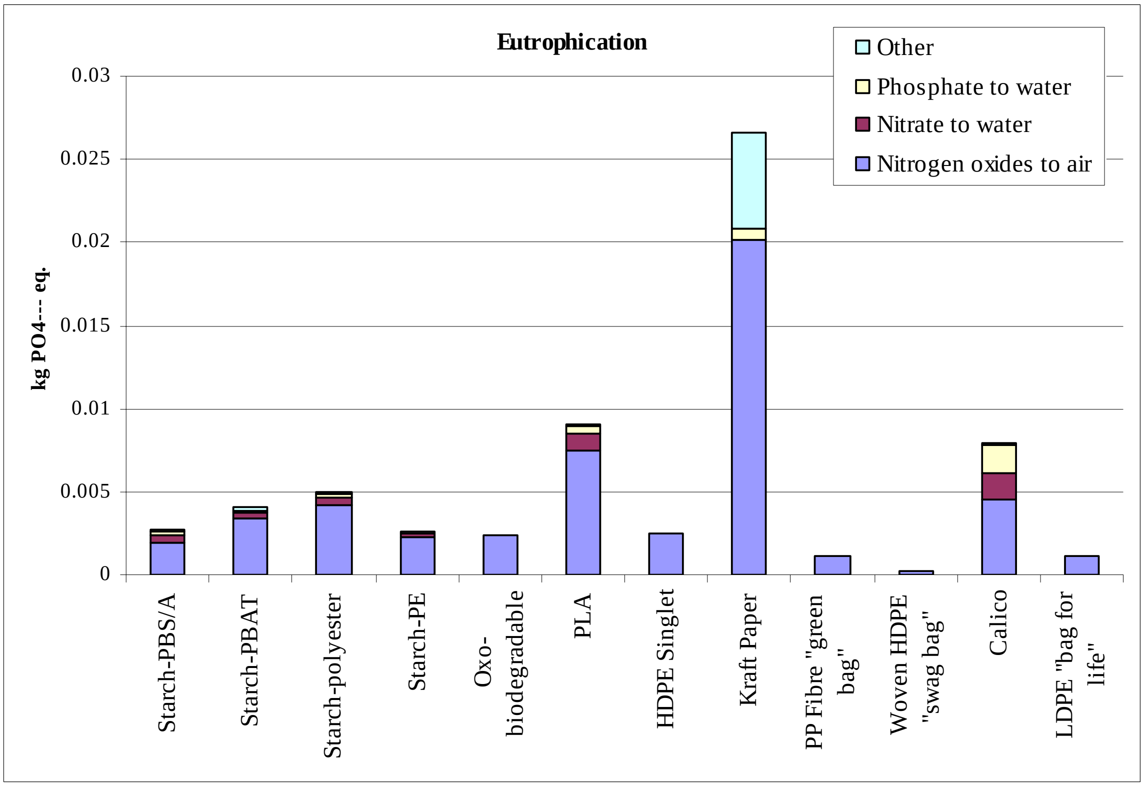
Figure 3 Resource depletion characterisation for all bags



3.2.3 Eutrophication

Eutrophication refers to the emissions of nitrates and phosphates into waterways. Figure 4 indicates that all eutrophication results are dominated by nitrogen oxides emitted to air from combustion processes. However the crop based material also have emission of nitrate and phosphate those materials from renewable resources (e.g., crops) have impacts upon eutrophication due to the application of fertilizers to land.

Figure 4 Eutrophication characterisation values for all bags

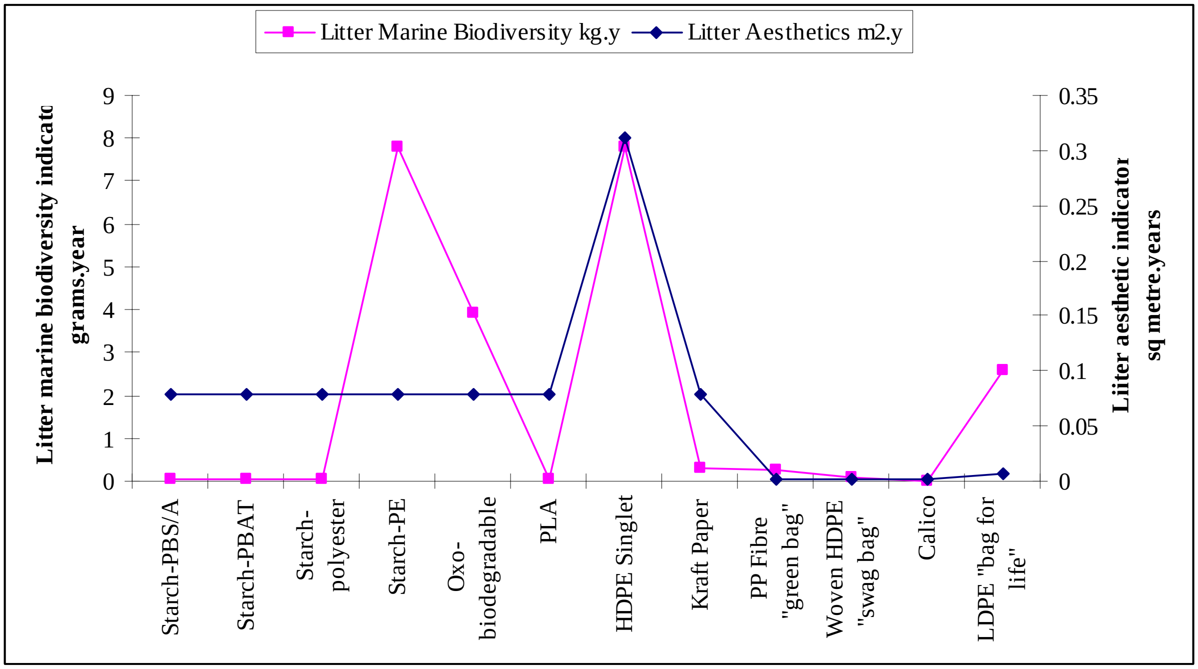


3.2.4 Litter categories

Two litter measurements were modeled in the streamlined LCA to provide some indication of the behaviour of the different materials as litter aesthetics and litter marine biodiversity (which refers to the potential for litter being ingested or entangled with marine fauna.). Table 5 lists the assumptions and values used in modelling the litter categories for each bag and

Figure 5 graphically presents the results for the different bag materials in the two litter categories. The single-use bags have higher litter values due to the higher possibility of them being littered compared with reusable bags. The marine biodiversity category is mostly effected by the propensity of the material to float or sink. Higher impacts are modelled in the marine biodiversity category if the material floats as it is assumed to float for 6 months (3 months for the oxo-biodegradable bag) and if it sinks the material is assumed to take around one day to sink.

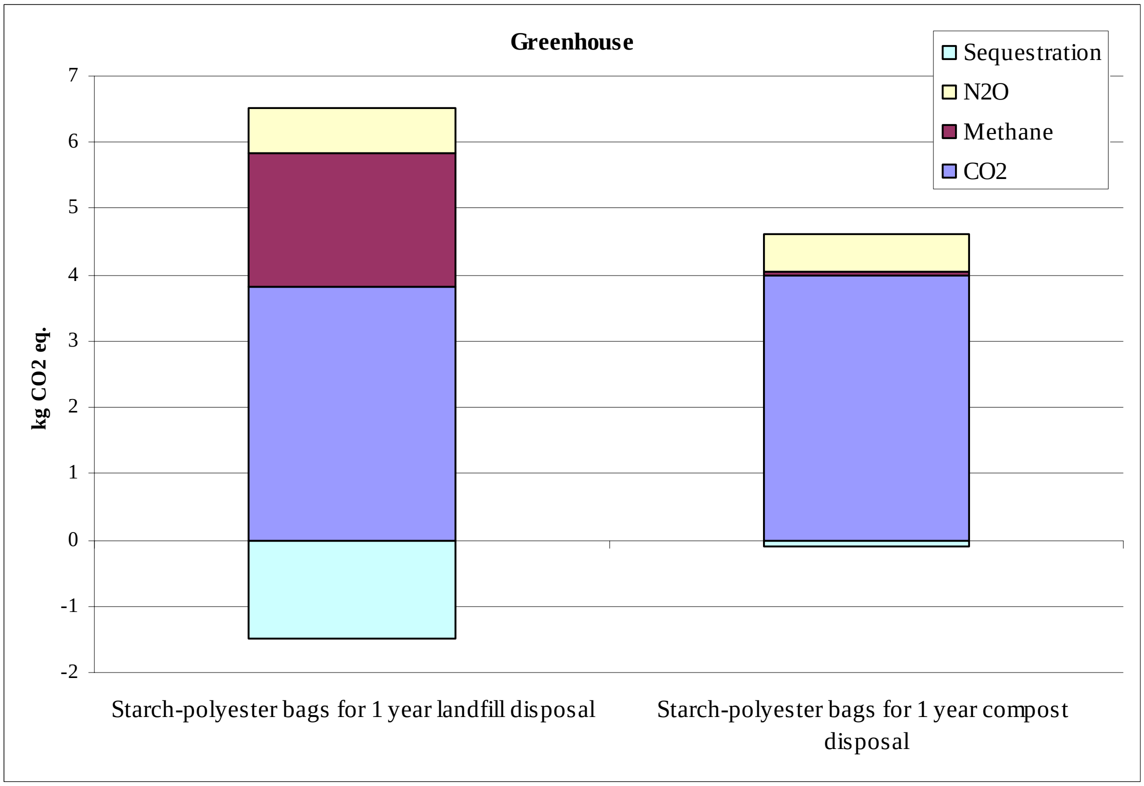
Figure 5 Litter characterisation values for all bags



Note: The values chosen here have been estimated in the absence of definitive data on the subject and are presented to show how the potential marine impact may vary under these assumptions.

The management of material at end of life has a significant effect on emissions from degradable polymers due to digestion of material in landfill which generates methane emissions. In the study methane emissions are assumed to be captured by landfill gas, with the remainder emitting to atmosphere. There is also an assumption that some portion of the biodegradable material fails to degrade in landfill as is counted as a sequestration of carbon if the material was derived from plant material. Figure 6 shows that these two effects almost cancel each other out in the comparison of biopolymer to landfill and compost, however the emissions from biopolymer in landfill are still half a kilogram higher than when composted (over 1years work of bags).

Figure 6 Litter characterisation values for all bags



4. SUMMARY OF LCA

Polymer based reusable bags have lower environmental impacts than all of the single-use bags. Degradable bags have similar greenhouse and eutrophication impacts to conventional HDPE bags. If the degradable material can be kept out of landfill, and managed through composting the greenhouse impacts will be reduced, but not eliminated. The synthetic polymer bags have higher impacts on resource impacts (abiotic depletion). The study developed a indicators for litter which attempt to represent some of the damage effects caused by litter. Litter impact are lowest for the reusables, but of all the single use bags, the biodegradable generally have lower emissions, although in the marine environment it is the density of the bridgeable material which matters and not its degradability.

5. FUTURE DIRECTIONS

Any decision to use a degradable polymer should:

- Be based on a good understanding of where and how the product will degrade
- Recognize and minimize life cycle environmental impacts (not just end of life)
- Deliver real commercial benefit (not just perceived benefit!)

The following checklist presented in Table 7 of things to consider when selecting a degradable polymer [9].

Table 7 Checklist for selecting degradable polymers

Question	Things to consider
Does degradability add real value?	• Does it provide added functionality (exploiting degradability e.g. controlled release of a substance from the resin)? • Does it provide reduced environmental impact e.g., reduce waste, litter, hazard to wildlife etc)? • If not, use an alternative strategy such as design for recyclability.
Where will the product be expected to degrade (in use or at end of life)?	• In the terrestrial environment, i.e..composting, buried in soil, above the ground, discarded (litter)? • In the aquatic environment, i.e. freshwater, seawater, sewerage system? Will it float or sink?
Where will the product be expected to degrade (in use or at end of life)?	• Will it contaminate an existing polymer recycling system?
What are the mechanical property requirements?	• How fast or slow do you want it to degrade? • How will it be processed?
What are the cost parameters?	• Can the market absorb a cost increase? • Does the material add sufficient value to justify a cost increase?
Design the product to ensure degradation and avoid dispersion of toxic substances in the environment	Critical issues for degradability: • Wall thickness • Pigments and coatings (particularly heavy over-printing & lacquers)
Critical issues for toxicity	• Heavy metals in pigments, e.g. lead, cadmium, mercury, chromium • Heavy metals in printing inks • Residues of pro-degradant additives
Design marketing and communications strategy	• Claims should be accurate and not mislead • Consumers should be advised on appropriate disposal route

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