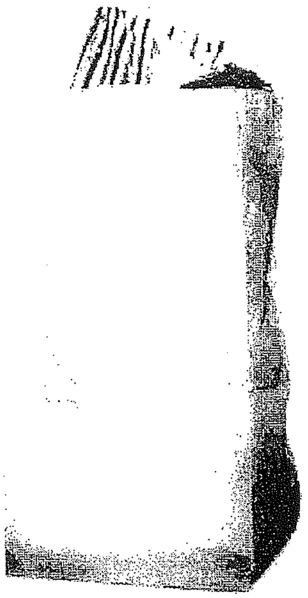
02/07/12 Item #: 12

SUPPORTING DOCUMENT F: Various Studies

Life Cycle Assessment Reports – Includes:

- "Paper or Plastic", Washington Post.com, http://www.washingtonpost.com/wp-dyn/content/graphic/2007/10/03/GR2007100301385.html?referrer=emaillink (June 25, 2008).
- The ULS Report, "Review of Life Cycle Data Relating to Disposable, Compostable, Biodegradable, and Reusable Grocery Bags", March 2008.
- Franklin Associates, LTD., "Resource and Environmental Profile Analysis of Polyethylene and Unbleached Paper Grocery Sacks", June 1990.
- Fund for Research into Industrial Development, Growth and Equity (FRIDGE), "Socio-Economic Impact of the Proposed Plastic Bag Regulations", excerpt related to the lifecycle analysis chapter of the report accessed from the City of San Francisco website at http://www.sfenvironment.org/downloads/library/asticlifecycleanalysis.pdf.pdf
- Boustead Consulting & Associates, "Life Cycle Assessment for Three Types of Grocery Bags – Recyclable Plastic; Compostable, Biodegradable Plastic; and Recycled, Recyclable Paper, June 2007.
- AEA Technology Environment, Scottish Executive Report, "Proposed Plastic Bag Levy – Extended Impact Assessment Final Report, June 2005.



MORE THAN MEETS THE EYE

An occasional feature that digs deeper into things you've been wondering about

Paper or Plastic?

We hear the question almost every time we go grocery shopping. Some shoppers answer automatically: plastic — convinced that they are making a better choice for the environment. Others ask for paper, believing the very same thing. The reality is that both paper and plastic bags gobble up natural resources and cause significant pollution. When you weigh all the costs to the environment, **you might just choose to reuse:**

PAPER **PLASTIC**

CONSUMPTION

Americans consume more than **10 billion paper bags** each year. Some **14 million trees** are cut down annually for paper bag production.

Four out of five grocery bags in this country are plastic. The U.S. uses 100 billion plastic bags annually, made from an estimated 12 million barrels of oil.

Worldwide, an estimated 4 billion plastic bags end up as litter each year. Tied end to end, **the bags could circle the Earth 63 times.**

PRODUCTION

Paper, of course, comes from trees. Trees are grown or found, then marked and felled.

①

1. Logs are moved from the forest to a mill, where there is a three-year wait for the logs to dry before they can be used.

②

2. Logs are stripped of bark and chipped into one-inch squares. The chips are "cooked" with tremendous heat and pressure.

③

3. Then, they are "digested" with limestone and sulfurous acid until the wood becomes pulp.

④

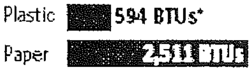
4. The pulp is washed, requiring thousands of gallons of fresh water and bleach, then pressed into finished paper.

5. Cutting, printing, packaging and shipping to make paper bags require additional time, labor and energy.

⑤

It takes more than four times as much energy to manufacture a paper bag as it does a plastic bag.

Energy to produce bags:



7 in 10 Americans do not know that plastic is made from petroleum products, primarily oil, according to a recent nationwide online survey.

* BTU = British thermal unit

Plastic is a by-product of oil refining. Plastic bags are made from polyethylene, which comes from oil refineries as small resin pellets.

1. A machine heats the pellet to about 340 degrees and pulls out from it a long, thin tube of cooling plastic.

2. A hot bar is dropped on the tube at intervals, melting a line.

3. Each melted line becomes the bottom of one bag and the top of another.

4. The sections are cut out and a hole for the bag's handles is stamped in each piece.

④

RESOURCE AND ENVIRONMENTAL PROFILE ANALYSIS OF POLYETHYLENE AND UNBLEACHED PAPER GROCERY SACKS

Final Report

Prepared for

THE COUNCIL FOR SOLID WASTE SOLUTIONS

by

FRANKLIN ASSOCIATES, LTD.

June 1990

Chapter 1

EXECUTIVE SUMMARY

BACKGROUND

Recently, much attention has been directed at packaging by a variety of interest groups including: environmentalists, government officials, commercial and retail businesses, and legislators. This attention toward packaging has been the result of two issues. First, there is an ever-decreasing landfill capacity in this country, which is being aggravated by an inability to site new landfills. Second, packaging accounts for roughly one-third of the weight of the municipal solid waste that is being landfilled.

Certain packaging materials have come under particular scrutiny and have been singled out by punitive measures such as bans or taxes. Before decisions are made regarding individual packages or materials, a full evaluation should be made of all packaging materials and alternatives. Objective data regarding the energy requirements, environmental emissions, recyclability, incineration impacts, and landfill impacts of different packaging will be crucial in determining solutions to our current and future environmental problems.

PURPOSE OF THE STUDY

The purpose of this study was to determine the energy and environmental impacts of polyethylene and paper grocery sacks. In this study, the term impact refers to the quantities of fuel and raw materials consumed and emissions released to the environment. The comparative recyclability, incineration, and landfill impacts of these sacks were also addressed in this analysis.

SCOPE

The packages examined in this study were chosen due to their predominant visibility and potential for restrictive legislation. The following packages were examined:

used throughout this study to mean the grocery sack itself and all secondary packaging such as overwrap and corrugated boxes.

The two sacks examined in this study are the same size. However, through surveys of major grocery chains, it was determined that more plastic sacks than paper sacks are used to hold the same amount of groceries. The practice of using more plastic to paper sacks is believed to hold true even after taking into account some stores' practices of using double (one sack inside the other) paper sacks.

One reason for the use of more plastic sacks seems to be inexperience on the part of grocery clerks and consumers on how to pack them so that they may hold their designed capacity. Another reason for the use of more plastic sacks could also be a mistaken comparison of smaller plastic sacks, for instance, 1/7 barrel plastic to the standard 1/6 barrel paper sack.

Since the ratio of polyethylene sacks to paper sacks used is crucial to the results of this study, considerable effort has been made to determine this number. Ratios ranging from 1.2:1 to 3:1 have been reported, but there is no industry-wide agreement on a representative ratio. Therefore, the results of this analysis are presented at ratios of 1.5:1 and 2:1 polyethylene to paper since most estimates fall within this range. These ratios were developed based on data collected from supermarket chains and other industry sources.

For this analysis, an equivalent basis of 10,000 uses was utilized. With a 1.5:1 polyethylene to paper sack ratio this equals 15,000 polyethylene sacks and 10,000 paper sacks. With a 2:1 polyethylene to paper sack ratio, this equals 20,000 polyethylene sacks and 10,000 paper sacks.

METHODOLOGY

A cradle-to-grave approach was used to determine the energy and environmental impacts of the packages examined in this study. This methodology measures energy consumption and environmental emissions at each stage of a product's "life cycle," beginning at the point of raw materials extraction from the earth and proceeding through processing, manufacturing, use, and final disposal, recycle, or reuse. A more thorough description of the methodology and assumptions used in this study are presented in Chapter 2.

Energy use was quantified in fuel or electric energy units and converted to British Thermal Units (Btu) for each of the many stages, or industrial processes, required to manufacture a grocery sack. Btu consumption was determined for six basic energy sources (natural gas, petroleum, coal, hydropower, nuclear, and wood) as well as the total for each sack. Since this analysis attempts to measure the total energy impacts associated with each sack, the fuel and electric energy conversion factors to Btu include not only the energy content of the fuels, but also an adjustment which accounts for the energy used to obtain, transport, and process that fuel into a usable form.

As with energy, the environmental wastes from each step or process were determined. Government documents as well as federal regulations, technical literature, and confidential industry sources form the basis for these data. These wastes represent actual discharges into the environment after control devices. The environmental impacts can be classified into three broad categories:

- Solid wastes
- Atmospheric emissions
- Waterborne wastes.

These categories include not only those readily identifiable wastes associated with a specific process, but also the pollutants associated with the fuels consumed in power generation or transportation. The solid waste category includes both industrial solid waste and postconsumer solid waste.

Energy and environmental impacts were determined for various postconsumer recycling rates for both the polyethylene sack and the paper sack. In this analysis the recycled polyethylene or paper is assumed to replace virgin materials in producing new products. Currently, recycled grocery sacks are being made into products which we assume are not further recycled. For this reason both the paper and polyethylene grocery sacks are considered to be recycled in an open-loop recycling system (further discussion can be found in Chapter 2).

The impacts of incineration were also included in this analysis. A national average for solid waste incineration of 15 percent has been determined in the 1990 U.S. EPA Municipal Solid Waste Characterization Study. Thus, the postconsumer solid waste for the sacks was adjusted for 15 percent incineration.

Solid waste in the form of ash resulting from this incineration was estimated from the ash inherent in the materials. However, the atmospheric emissions which result from incineration of the polyethylene and unbleached paper with solid waste could not be estimated due to lack of data. While emissions from municipal solid waste incinerators have been characterized, we have no way to attribute these emissions back to a given material. Some studies have characterized the changes in emissions of average MSW to those of MSW "spiked" with specific materials. However, these types of analyses have not been done for unbleached paper or polyethylene.

Most atmospheric emissions from municipal solid waste incinerators will be treated in the gas scrubbers used in these facilities. These atmospheric emissions will eventually be disposed of in scrubber blowdown as solid waste. Since the atmospheric emissions for paper and polyethylene cannot be quantified, the impact of these emissions on scrubber blowdown also cannot be determined.

For both sacks, the corrugated boxes (for the polyethylene sacks) and paper sleeves (for the paper sacks) are assumed to be recycled because grocery stores typically bale and market their corrugated (the paper sleeves are included with the corrugated material). Because this material is assumed to be recycled, no secondary packaging materials are available for incineration or land disposal.

The margin of error for this study is believed to be plus or minus 10 percent. Therefore, distinctions in energy and environmental impacts will only be noted between packages if the difference is greater than 10 percent. It must be noted that the nature of error in this analysis is systematic and not due to randomness. Thus the margin of error cannot be statistically determined.

RESULTS

The results of this analysis are organized by two categories: energy requirements and environmental impacts.

Energy Requirements

The energy requirements for polyethylene and paper grocery sacks are reported in Table 1-1. These energy impacts are reported in million Btu per 10,000 uses for both 1.5 to 1 and 2 to 1 polyethylene to paper sack ratios at varying recycling rates. Figure 1-1 is a graphic illustration of the energy requirements reported in Table 1-1.

Table 1-1 and Figure 1-1 show that at 0 percent recycling, polyethylene sacks require between 20 and 40 percent less energy than paper sacks. As recycling rates increase for both sacks, this energy difference decreases. This is because the recycling energy savings occur at a greater rate for paper than for polyethylene. As the recycling rate approaches 100 percent, the polyethylene sack continues to have less energy requirements than the paper sack at the 1.5 PE to 1 paper sack ratio. However, at recycling rates of over 60 percent, the paper sack and polyethylene sack have equivalent energy requirements within the margin of error of this study for the 2 PE to 1 paper sack ratio.

Table 1-1

ENERGY REQUIREMENTS FOR 1/6 BARREL POLYETHYLENE AND PAPER GROCERY SACKS AT VARIOUS RECYCLING RATES 1/

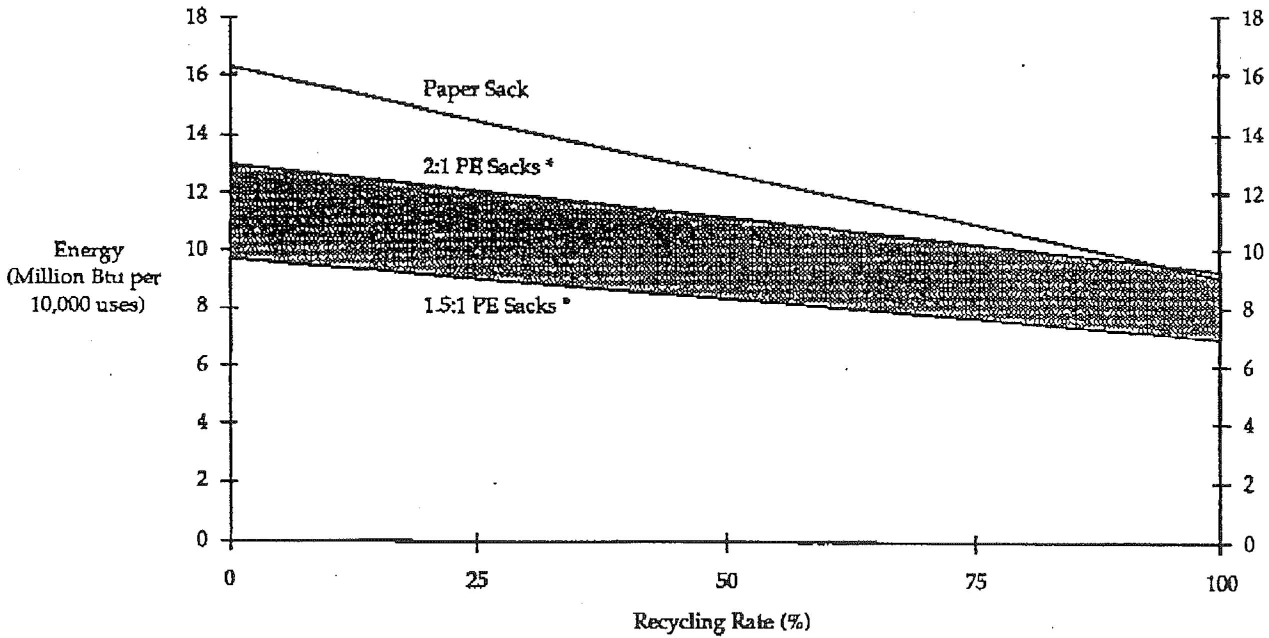
(Million Btu per 10,000 uses)

	Recycling Rates				
	0%	25%	50%	75%	100%
1.5 PE to 1 Paper Sack Ratio 2/					
Polyethylene	9.7	9.1	8.4	7.7	7.0
Paper	16.3	14.5	12.7	10.9	9.1
2.0 PE to 1 Paper Sack Ratio 2/					
Polyethylene	13.0	12.1	11.1	10.2	9.3
Paper	16.3	14.5	12.7	10.9	9.1

1/ Assumes 15 percent of postconsumer wastes are incinerated.
2/ Ratio indicates the number of polyethylene (PE) sacks used per one paper sack.

Source: Franklin Associates, Ltd.

Figure 1-1. Energy Requirements For Grocery Sacks
At Various Recycling Rates (Assumes 15 percent incineration.)



* Ratio indicates the number of polyethylene (PE) sacks used per one paper sack.

Environmental Impacts

The environmental impacts for the sacks are divided into three groups:

1. Solid wastes
2. Atmospheric emissions
3. Waterborne wastes.

These impacts are reported in Table 1-2.

Solid Wastes. The solid wastes generated by the grocery sacks are reported in Table 1-2 in cubic feet per 10,000 uses and include both postconsumer and industrial solid waste. Postconsumer solid waste volume was derived from weight by applying density factors reported in Chapter 4. A density of 24.8 pounds per cubic foot for polyethylene sacks and 27.4 pounds per cubic foot for paper sacks under landfill conditions were used for this study. Postconsumer solid waste is adjusted for 15 percent incineration of all materials not recycled. For industrial solid waste, a density of 50 pounds per cubic foot was used.

The solid waste data reported in Table 1-2 are also illustrated in Figure 1-2. Both show that at 0 percent recycling, polyethylene sacks contribute between 74 and 80 percent less solid waste by volume than paper sacks. Figure 1-2 also illustrates that the percent difference decreases as recycling increases. However, polyethylene sacks continue to contribute less solid waste than paper sacks at all recycling rates.

Atmospheric Emissions. Six components dominate the category of atmospheric emissions for paper and polyethylene sacks: particulates, nitrogen oxides, hydrocarbons, sulfur oxides, carbon monoxide, and odorous sulfur. For five of these six components, the polyethylene sacks produce less of each emission than do the paper sacks. Hydrocarbons are generated in greater quantities by the polyethylene sacks.

Table 1-2 lists atmospheric emissions for the grocery sacks in pounds per 10,000 uses. Figure 1-3 also illustrates these impacts for both packages. Table 1-2 and Figure 1-3 show that at 0 percent recycling the total atmospheric emissions are between 63 and 72 percent less for polyethylene than for paper sacks. From Figure 1-3, it can be seen that this difference decreases as recycling increases. However, the polyethylene sack continues to have less atmospheric emissions at all rates.

Waterborne Wastes. Four components dominate the category of waterborne wastes for the paper and polyethylene sacks: dissolved solids, biological oxygen demand (BOD), suspended solids, and acids. The polyethylene sack produces less of each of the four emissions than does the paper sack.

The waterborne wastes reported for 10,000 grocery sack uses in Table 1-2 are also graphed in Figure 1-4. Both show that at 0 percent recycling the polyethylene sack contributes over 90 percent less total waterborne wastes than the paper sack. Figure 1-4 shows that as the recycling rate increases for both grocery sacks, the difference in waterborne waste becomes greater because recycled paper contributes more waterborne wastes than paper made from virgin material.

Table 1-2

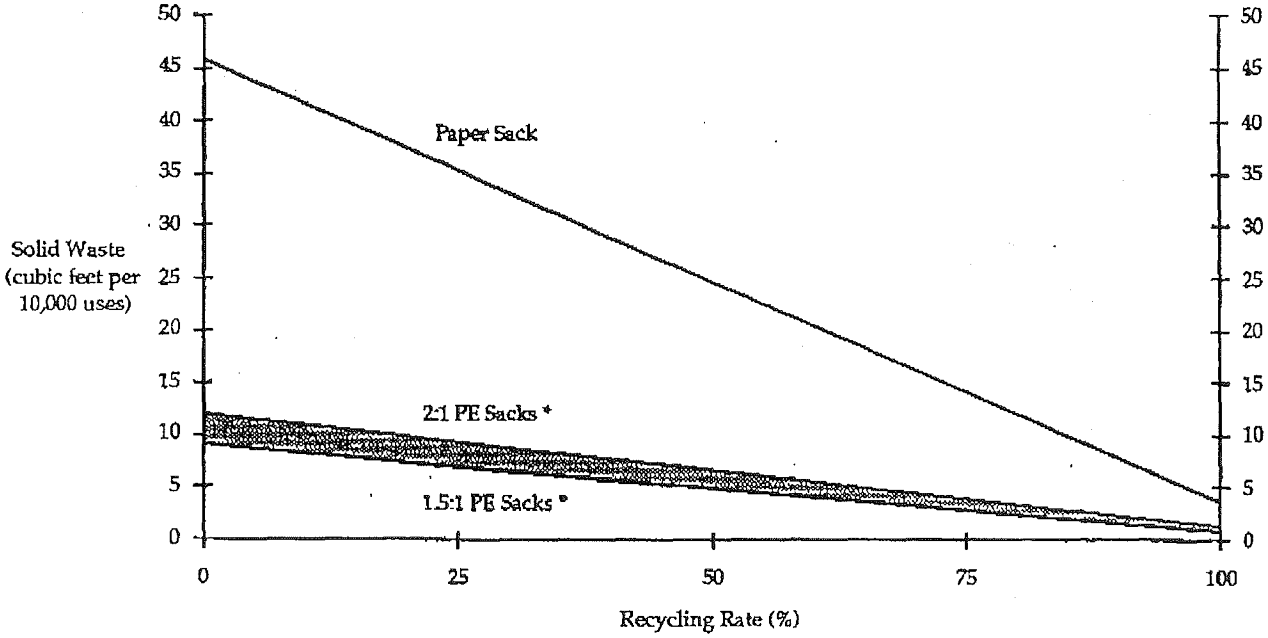
ENVIRONMENTAL IMPACT DATA FOR 1/6 BARREL GROCERY SACKS
(Impacts per 10,000 uses)

	Solid Waste (cu ft)	Atmospheric Emissions (pounds)	Waterborne Wastes (pounds)
1.5 Polyethylene to 1 Paper Sack Ratio 1/			
Polyethylene sack			
0% recycle	9.1	17.9	1.8
25% recycle	6.9	16.9	1.7
50% recycle	4.9	15.8	1.6
75% recycle	2.9	14.8	1.5
100% recycle	0.9	13.7	1.5
Paper Sack			
0% recycle	45.8	64.2	31.2
25% recycle	35.3	56.2	34.3
50% recycle	24.7	48.2	37.6
75% recycle	14.2	40.2	40.7
100% recycle	3.7	32.2	43.9
2.0 PE to 1 Paper Sack Ratio 1/			
Polyethylene sack			
0% recycle	12.1	23.9	2.4
25% recycle	9.4	22.5	2.3
50% recycle	6.6	21.1	2.2
75% recycle	3.9	19.7	2.0
100% recycle	1.2	18.3	1.9
Paper sack			
0% recycle	45.8	64.2	31.2
25% recycle	35.3	56.2	34.3
50% recycle	24.7	48.2	37.6
75% recycle	14.2	40.2	40.7
100% recycle	3.7	32.2	43.9

1/ Ratio indicates the number of polyethylene (PE) sacks used per one paper sack.

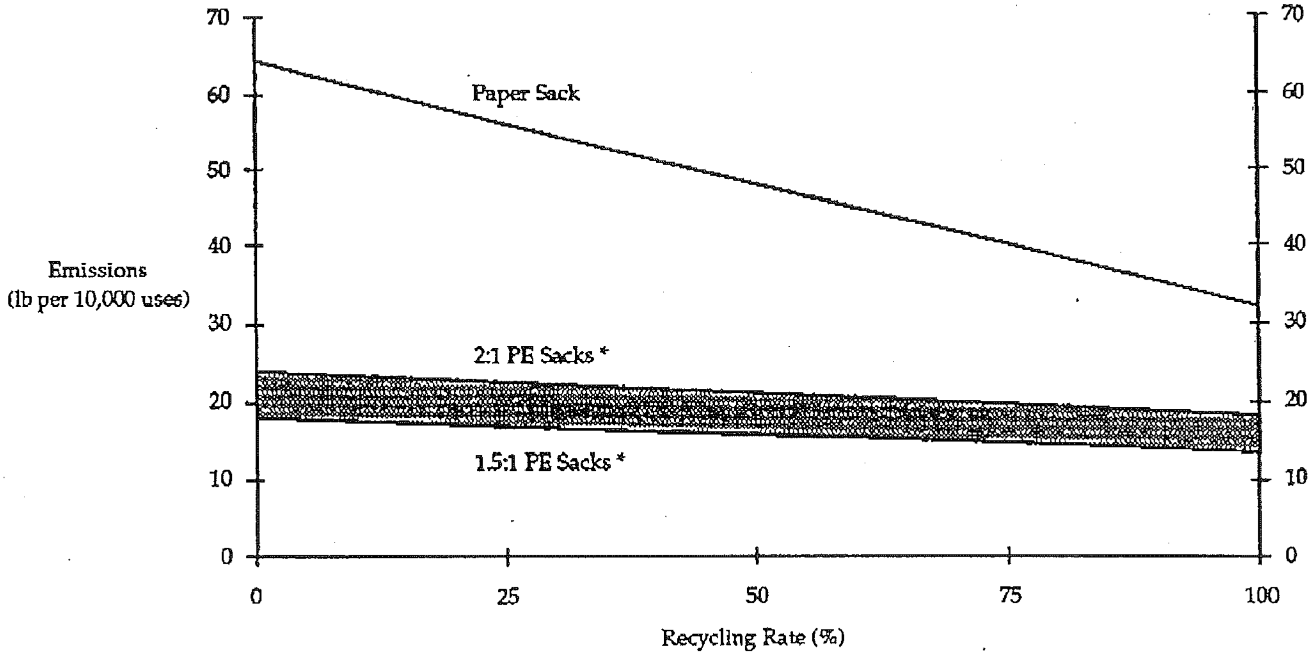
Source: Franklin Associates, Ltd.

Figure 1-2. Total Solid Wastes of Grocery Sacks
At Various Recycling Rates



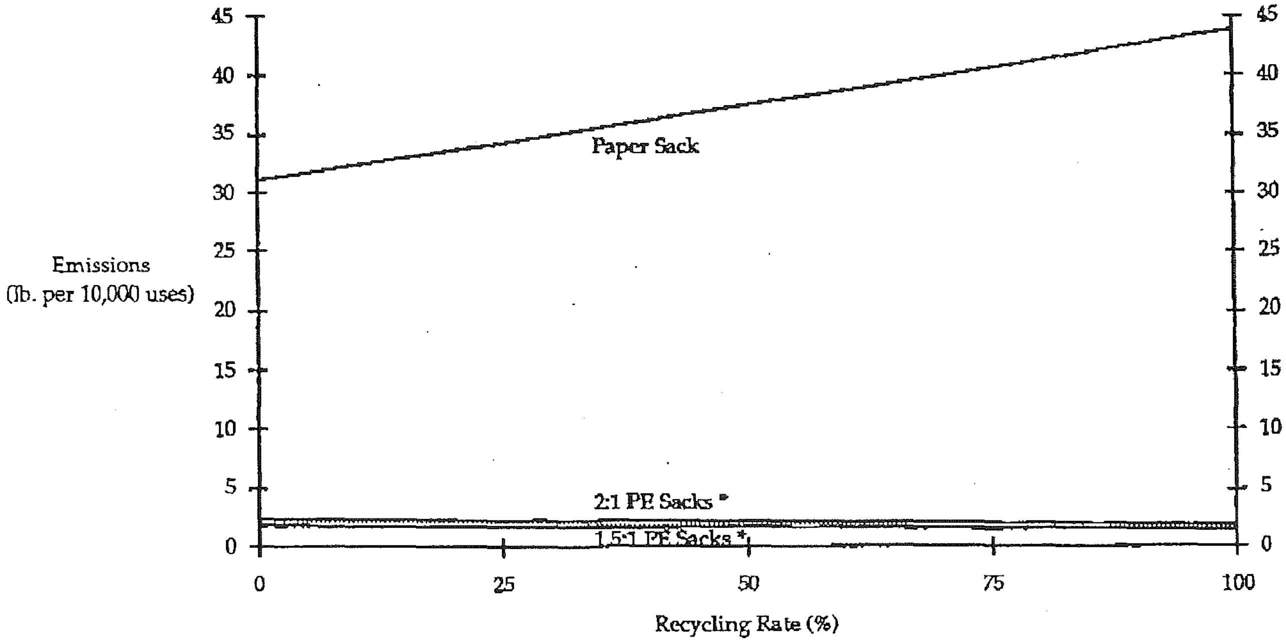
* Ratio indicates the number of polyethylene (PE) sacks used per one paper sack.

Figure 1-3. Atmospheric Emissions of Grocery Sacks
At Various Recycling Rates



* Ratio indicates the number of polyethylene (PE) sacks used per one paper sack

Figure 1-4. Waterborne Wastes For Grocery Sacks At Various Recycling Rates



* Ratio indicates the number of polyethylene (PE) sacks used per one paper sack.

CONCLUSIONS

The following conclusions were reached regarding the energy and environmental impacts for 10,000 equivalent uses of polyethylene and paper sacks.

Energy

The energy requirements for the polyethylene grocery sacks are between 20 to 40 percent less than for paper sacks at zero percent recycling of both sacks. As recycling increases for both polyethylene and paper sacks at the 2 PE:1 paper sack ratio, the energy requirements become equivalent at approximately a 60 percent recycling rate. At the 1.5 PE:1 paper sack ratio, the polyethylene sack continues to require 23 percent less energy than paper even at 100 percent recycling.

Environmental

1. Polyethylene sacks contribute between 74 and 80 percent less solid waste than paper sacks at zero percent recycling. Polyethylene sacks continue to contribute less solid waste than paper sacks at all recycling rates.

2. Atmospheric emissions for the polyethylene sack are between 63 and 73 percent less than for the paper sack at zero percent recycling. These lower impacts for the polyethylene sack continue throughout all recycling rates.

3. At zero percent recycling rate, the polyethylene sack contributes over 90 percent less waterborne wastes than the paper sack. This percent difference actually increases as the recycling rate for both grocery sacks increases.

Further conclusions regarding the recyclability, incineration, and landfill of these sacks were determined from the detailed discussion of these issues addressed in Chapter 3.

Recyclability

Both polyethylene and paper sacks are recyclable. Manufacturing scrap and trim from the fabrication of the sacks are typically recycled. Postconsumer recycling for both of these sacks has not been significant. In the case of paper sacks, they are most typically recycled during the collection of old newspapers. For polyethylene sacks, efforts are usually concentrated on industrial scrap film However, efforts have recently begun to collect both polyethylene and paper grocery sacks at the postconsumer level.

Incineration Impacts

On a per pound basis, polyethylene releases 2.75 times more energy upon incineration than unbleached paper. However, on an equal use basis, paper grocery sacks weigh 4 to 5 times more than polyethylene grocery sacks. Therefore, on an equivalent use basis, the paper sack has a greater potential for energy released from incineration than the polyethylene sack. The ash content per pound of unbleached paper is greater than that of polyethylene. Thus, even on an equivalent use basis, the paper sack has a greater potential for more ash from incineration than the polyethylene sack.

Landfill Impacts

Volume. The landfill volume occupied by the polyethylene sacks is 70 to 80 percent less than the volume occupied by paper sacks based on 10,000 uses. These landfill volumes were derived from general material's landfill densities determined by Franklin Associates, Ltd. in conjunction with The Garbage Project, University of Arizona, Tucson. Further details of the volume estimates are contained in the section entitled Landfill Volume in Chapter 3.

Degradability. While some degradation occurs in landfills, little data exist regarding what materials degrade and the rate of decomposition. Therefore, the degradability of both paper and polyethylene grocery sacks cannot be predicted. As a consequence, no estimates can be made regarding the potential for impact on landfill leachate or methane gas production.

Proposed Plastic Bag Levy - Extended Impact Assessment Final Report

Volume 1: Main Report

Final Report

James Cadman, Suzanne Evans
Mike Holland (ERMC)
Richard Boyd (Metroeconomica)

AEA Technology Environment

Scottish Executive 2005
Environment Group Research Report 2005/06

Contact

Further copies of this report are available:

- On the Scottish Executive website at:

  www.scotland.gov.uk/publications

ISBN: 0-7559-2685-4

Scottish Executive
St Andrew's House
Edinburgh
EH1 3DG

Produced for the Scottish Executive by Astron B42643 08/05

Published by the Scottish Executive, August, 2005

Further copies are available from
Blackwell's Bookshop
53 South Bridge
Edinburgh
EH1 1YS

The text pages of this document are printed on recycled paper and are 100% recyclable.

Acknowledgements

This report was commissioned by the Waste Strategy Team in the Environment and Rural Affairs Department at the Scottish Executive. The report was produced by AEA Technology Environment and associates.

The project managers for the Scottish Executive were:

Simon Stockwell, Tel 0131 244 0200, e-mail Simon.Stockwell@scotland.gsi.gov.uk

Gillian Smith, Tel 0131 244 0243, e-mail Gillian.C.Smith@scotland.gsi.gov.uk

AEA Technology Environment is grateful for the direction and support received from the steering committee throughout this project:

- Scottish Executive Waste Strategy Team
- Carrier Bag Consortium
- Convention of Scottish Local Authorities (CoSLA)
- Friends of the Earth Scotland
- Scottish Retail Consortium
- Scottish Environment Protection Agency (SEPA)

Glossary

ARA	Australian Retailers Association
BRA	Belgian Retail Association
BRC	British Retail Consortium
CBC	Carrier Bag Consortium
CoSLA	Convention of Scottish Local Authorities
Defra	Department for Environment, Food and Rural Affairs (London)
ERM	Environmental Resources Management
HDPE	high density polyethene (polyethylene)
INCPEN	Industry Council for Packaging and the Environment
KSB	Keep Scotland Beautiful
LCA	Life cycle assessment
LDPE	low density polyethene (polyethylene)
LEAMS	Local Environmental Audit and Management System
MCS	Marine Conservation Society
NO_x	nitrogen oxides
ONS	Office of National Statistics
RMIT	Royal Melbourne Institute of Technology
SME	small-to-medium enterprise
SRC	Scottish Retail Consortium
SWAG	Scottish Waste Awareness Group
UCD	University College Dublin
VOC	volatile organic compound
WRAP	Waste and Resources Action Programme

Executive Summary

Mike Pringle MSP has tabled a Members Bill in the Scottish Parliament to impose an environmental levy on lightweight plastic carrier bags as provided by shops and other retail outlets. It is understood that this would cover all bags made partially or completely of plastic, with the exception of those used for directly packing of fresh meat, fish, fruit and other foods.

This brief study, commissioned by the Scottish Executive and undertaken by AEA Technology Environment and associates, has addressed the likely impacts of such a levy and variants of it on:

- The environment.
- Consumers.
- Business.
- Waste.
- Local authorities.

Advocates of a levy on plastic bags cite the main benefits as being reduced littering (including marine litter), reduced use of resources and energy, lower pollutant emissions and increased public awareness of environmental issues.

Opponents argue that lightweight plastic carrier bags are hygienic, convenient and durable, that they are often reused for other purposes, that they form only a small part of the litter stream and that they have a lower overall environmental impact than paper bags. They also claim that a levy would impact unfairly on poorer households and would lead to job losses in Scotland (from reduced plastic bag manufacturing and importing).

The study has considered these and other arguments for and against a levy, quantifying the probable effects wherever possible. It considered a range of different scenarios:

- Scenario 0: No levy, i.e. business as usual.
- Scenario 1A: A levy of 10p on plastic but not paper bags, covering all businesses (as proposed in the Bill).
- Scenario 1B: A levy of 10p on plastic but not paper bags, covering all businesses except small and medium sized enterprises (SMEs) and charities.
- Scenario 2A: A levy of 10p on plastic and paper bags, covering all businesses.
- Scenario 2B: A levy of 10p on plastic and paper bags, covering all businesses except SMEs and charities.

A wide range of evidence has been used to inform the study. This includes experience from the PlasTax in Ireland and voluntary schemes in the UK along with results from life cycle analysis (LCA) studies from France and Australia.

The study does not make a judgement on whether, on balance, such a levy should be introduced, but provides evidence on the main effects expected under each of the four levy scenarios.

Overall Effects

A levy would cause a set of interacting effects. The study is predicated on evidence that a levy would stimulate a switch away from use of plastic bags (by typically 90%). If only plastic bags were to be levied (scenarios 1A and 1B), then studies and experience elsewhere suggest that there would be some shift in bag usage to paper bags (which have worse environmental impacts). This study is based on this experience of behaviour change.

In each of the areas considered – environment, consumers, business, waste and local authorities - there would therefore be a complicated set of effects, but in general:

Environment The environmental impact of each of the four levy scenarios was assessed using 8 indicators. These include energy, water, waste and litter. Under the levy as proposed (scenario 1A) 5 out of the 8 indicators show an improvement.

There are different impacts under each levy scenario. In particular, including paper bags increases the potential environmental benefits of a levy (e.g. scenario 2A or 2B) where all 8 indicators improve.

In all cases the changes in environmental indicators due to a levy are modest (i.e. 1% or less) in comparison to overall environmental impacts from other activities in Scotland (as shown in Table A3.7).

Consumers Consumers act to reduce the financial impact by switching away from use of carrier bags. This limits the detrimental financial impact for consumers to a maximum of £10 per person per year.

Business The impacts would be positive for food retailers, and detrimental for non-food retailers and other businesses such as plastic bag manufacturers.

Waste Under scenarios 1A and 1B waste increases due to a switch from plastic to paper bags. When paper bags are included in the levy (e.g. scenario 2A or 2B) waste arisings fall. The greatest increase, 5,409 tonnes, is for scenario 1A, while the greatest decrease, 4,993 tonnes, is for scenario 2A. These should be compared against total household waste arisings of 2,094,872 tonnes pa [SEPA], a 0.26% increase and a 0.24% decrease respectively.

In all scenarios litter reduces, but plastic bags are only a small percentage of reported litter.

Local authorities There will be set-up costs and on-going costs to administer the levy. In general the revenue from the levy is expected to cover the on-going administration costs. However there are important differences between the on-going costs and revenues between local authorities. For example smaller authorities could receive lower revenues without a proportional reduction in administration costs.

Impacts on the Environment (Section 4 in the main report)

The study used an LCA approach to evaluate the changes in a range of different environmental indicators (e.g. energy use, water use, waste etc). The analysis shows that there would be an environmental benefit for some of the indicators depending on what consumers choose to use were a levy to be introduced.

In all scenarios where the levy is applied, consumption of non-renewable energy, atmospheric acidification and formation of ground level ozone and the risk of litter would be considerably less than the current situation.

In scenarios 2A and 2B, where the levy is applied to paper bags as well as plastic bags, these environmental benefits increase. In addition there are reduced impacts in terms of consumption of water, emissions of greenhouse gases and eutrophication of water bodies (rivers, lakes, etc.). This is because paper bags have a higher environmental impact in these categories relative to plastic bags.

As these results depend on key assumptions we undertook a sensitivity analysis to assess how this changes the results. This shows that scenarios 1A and 1B, which increase use of paper bags, are more sensitive to key assumptions than scenarios 2A and 2B. Excluding SMEs in the levy (scenarios 1B and 2B) accentuates the impacts.

For each of the environmental indicators used in this study we have assessed the total impact from all activities in Scotland. This analysis shows that the environmental benefits in all indicators from a levy are modest (i.e. 1% or less) when compared to overall environmental impacts from other activities in Scotland.

Impacts on consumers (Section 5 in the main report)

Consumers would obviously have to pay the levy itself overtly, on levied bags they continue to use, but the true additional financial burden of a levy on consumers in Scotland depends on a number of other factors as well. This draws upon experience from Ireland of the change in behaviour and therefore bag use. The total cost was calculated from the amount of levy paid for carrier bags, the relative hidden costs of plastic and paper bags[1], the costs of buying additional heavyweight plastic carrier bags (so-called 'bags for life'), the costs of buying additional bin liners, and additional VAT.

The cost to the consumer also depends on whether or not certain costs (in particular the 'hidden costs/savings') are passed on to the consumer by the retailer.

This leads to a wide range of estimated costs to the consumers, depending on assumptions. In Scenarios 1A and 1B (no levy on paper bags) the estimates ranges from £7.41 to £10.58 per year. In Scenarios 2A and 2B (levy on paper bags as well) the range is from about £2.50 to £6.11 per year.

---

[1] Hidden costs cover the purchase, transport and storage of bags by a retailer, normally passed on to consumers through the price of goods.

Including paper bags in the levy would therefore reduce the financial burden. Indeed this has a bigger effect on the range than whether or not SMEs are included.

The estimates of financial impact on consumers should be compared with average household expenditure in Scotland, this is £365 per week.

Impacts on business (Section 5 in the main report)

a) Retailers

After taking set-up and administrative costs into account, the food retail industry would benefit from net cost savings from the proposed bag levy. Savings would result from having to buy far fewer plastic carrier bags (now usually given away for free[2]), while sales of 'bags for life' and bin liners would increase.

However, this would not be the case for non-food retailers (e.g. clothing), as experiences in the Republic of Ireland following the introduction of the so-called PlasTax has seen a more pronounced shift to paper bags in these stores.

In terms of systems needed to comply with the proposed levy, larger retailers are expected to find this easier, having computerised systems and greater resource available. Smaller retailers may well not have computerised systems and the levy would thus represent a greater burden

b) Other business

There are an estimated 15–20 manufacturers, importers and distributors of plastic carrier bags in Scotland, most of which are SMEs. All will be affected by the proposed levy. It is believed that the imposition of a plastic bag levy in Scotland would lead to job losses, as it is considered unlikely that plants that currently manufacture plastic carrier bags would switch to alternative products (e.g. production of bin liners). Losses have been estimated at between 300 to 700 direct jobs, with further indirect jobs being affected (e.g. in support and distribution services).

Impacts on Waste (Sections 4 and 5 in the main report)

In all four levy scenarios, the total number of carrier bags (lightweight and heavyweight plastic and paper) used in Scotland per year would decline as a result of the levy. However, if paper carrier bags are not subject to the levy (as in scenarios 1A and 1B), the total tonnage of all carrier bags used and requiring disposal actually increases by 5,409 tonnes for scenario 1A (the proposed levy). Scenario 2A (including paper in the levy) would yield the greatest reduction in the tonnage of waste relative to current levels (a reduction of 4,993 tonnes per year). For comparison, in 2002/03 household waste in Scotland was 2,094,872 tonnes [SEPA] and 5,409 tonnes extra represents a 0.26% increase, whilst 4,993 tonnes less equates to a 0.24% decrease.

---

[2] Some stores in independent initiatives already charge for their lightweight carrier bags.

This analysis suggests some potential for an increase in solid waste generation for scenarios that favour a switch to paper bags. This is due to different assumptions about the relative weight of plastic and paper bags, and the fact that the LCA looks at solid waste impacts throughout the bag life cycle rather than just the end-of-life disposal phase.

Impacts on local authorities (Section 6 in the main report)

To determine the costs of set up and administration for local authorities would require a detailed specification of the systems and wider discussions. Our preliminary estimates suggest that the application of the levy to all businesses could cost Scottish local authorities, collectively, about £3–4 million to set up and £3.5 million per year to manage. This would reduce to £1.5–2.5 million to set up and £1.75 million per year to manage if the levy was applied selectively, i.e. based on retailer size or function.

These costs could be more than offset by revenues from the levy estimated at £7.75 million per year for all businesses and £5.5 million per year if applied selectively. However, smaller local authorities could receive lower revenues without a proportional reduction in administrative costs.

The Convention of Scottish Local Authorities (CoSLA) has reservations about the duty of collection falling to the local authorities and its concerns regarding the magnitude and potential administrative costs of the Levy, which they believe needs a full investigation.

Alternatives to the levy (Section 3 in the main report)

In addition to the assessment of the impacts of the levy scenarios, the study examined the details of alternatives to the levy.

The Carrier Bag Consortium (CBC) has developed a draft voluntary code to develop waste reduction and reuse initiatives and to continue product engineering to make further savings in the production, transportation and storage of plastic carrier bags. This has been submitted to the Voluntary Code of Conduct working group set up by the British Retail Consortium (BRC) and the Scottish Retail Consortium (SRC).

A voluntary approach has already been adopted in Australia, where use of carrier bags fell by 20.4% between 2002 and 2004.

Report Structure

This summary provides a brief introduction to the analysis methodology and results of the study. The main sections of the report are:

Volume 1

Section 1 reviews the context for the study.

Section 2 sets out background information on the various types of carrier bags and why they would be subject to a potential levy and reviews experience in Ireland.

Section 3 presents an assessment of the views for and against a levy based on experiences from around the world and from a variety of stakeholders.

Section 4 presents the life cycle assessment (LCA) analysis undertaken for different plastic bag levy scenarios.

Section 5 analyses the impacts a levy would have on consumers and businesses.

Section 6 gives a brief review and commentary on levy collection and its potential impact on local authorities.

Section 7 presents our conclusions.

Volume 2

Appendix 1 reviews international experience.

Appendix 2 provides details of the retail context.

Appendix 3 provides detail information on the LCA approach including the sensitivity analysis.

Appendix 4 provides graphs on the distribution of revenue to local authorities.

Both volumes include a glossary and a full set of references.

Contents

1 Report Context

Mike Pringle MSP (www.mikepringlemsp.com) tabled a Members Bill in the Scottish Parliament for a Member's Bill to enable local authorities in Scotland to impose an environmental levy on specified plastic bags [Pringle]. If passed, this legislation would cover all plastic bags provided by retailers at point-of-sale or from other outlets. The inspiration for this bill was taken from the experience of the plastic bags levy (the so-called PlasTax) in the Republic of Ireland.

The Scottish Executive commissioned this brief study from AEA Technology Environment and associates in order to investigate and assess the range of environmental, business and consumer impacts related to the proposal to introduce a plastic bag levy in Scotland. In doing so, other potential options or variants on the proposed levy have also been researched.

In this study, we used the Irish definition of a lightweight plastic carrier bag, i.e. 'any bag made wholly or in part of plastic, suitable for use by a customer at point of sale in a supermarket, service station or retail outlet'. Heavier weight plastic carrier bags, the so-called 'bags for life', costing more than €0.70 (around £0.48) are excluded from the Irish levy.

This Volume of the report is structured as follows:

Section 2 sets out background information on the various types of carrier bags and why they would be subject to a potential levy.

Section 3 presents an assessment of the views for and against a levy based on experiences from around the world and from a variety of stakeholders.

Section 4 presents the life cycle assessment (LCA) analysis undertaken for different plastic bag levy scenarios. As well as the bill tabled by Mike Pringle, we assessed scenarios that looked at the effect of applying the levy to paper bags as well as plastic bags and focusing only on larger retailers. No new LCA was undertaken for this report. Instead, the results from other suitable LCAs were adapted with Scottish data to show the relative environmental effects of a levy or variants thereof.

Section 5 analyses the impacts a levy would have on consumers and businesses.

Section 6 reviews and comments on levy collection and impacts on local authorities.

Section 7 presents our conclusions.

Volume 2 of the report contains the following Appendices:

Appendix 1 reviews international experience.

Appendix 2 provides details of the retail context.

Appendix 3 provides details on the LCA approach including the sensitivity analysis.

Appendix 4 provides graphs on the distribution of revenue to local authorities.

References are designated in square brackets, e.g. [CBC].

2 Introduction

The estimates for the number of lightweight plastic carrier bags issued in the UK vary from 8 billion [Defra 2003] to 10 billion [WRAP 2005]. From these, a range of 690–860 million has been estimated for use in Scotland based on population statistics. The calculations and assumptions behind this range are given in Section 4.3. The estimated cost of these bags to UK retailers also varies. Some sources suggest the cost to UK retailers is around £1 billion per year [BBC, WRAP 2004b], whereas the Carrier Bag Consortium (CBC) suggests that, based on the unit price of bags, the cost is closer to £64–80 million.

2.1 The Different Types of Carrier Bags

Most outlets currently provide free lightweight bags[3] made from conventional polyethene (polyethylene) plastic or bags made from degradable plastic (some outlets do make a charge[4]). Most major supermarket retailers also offer heavyweight reusable bags known as 'bags for life', for which they charge a small sum. Some shops also provide paper bags free of charge. The main types of carrier bags are described below; Table 2.1 summarises their key features.

Disposable High-Density Polyethene (HDPE) Bags

These plastic bags offer a thin, lightweight, high strength, waterproof and reliable means of transporting shopping. Research and development by the industry has reduced the average weight of such a bag by 60% compared with 20 years ago, while retaining the same strength and durability. Such bags are currently found in supermarkets and other food retail outlets.

Disposable Low-Density Polyethene (LDPE) Bags

These bags are currently given away free by many UK retailers (e.g. clothing shops). Like their HDPE counterparts, they are made from a by-product of oil refining.

Reusable Low-Density Polyethene (LDPE) Bags,

These are heavier gauge plastic carrier bags, often called 'bags for life'. Retailers charge for these (typically around 10p). The intention is that the customer uses them repeatedly and then returns them to the store for recycling when they are worn out, receiving a free replacement. Such bags are offered in many UK supermarkets.

---

[3] Throughout this report, the term 'lightweight' plastic carrier is used to describe 'disposable' plastic carrier bags available at the checkout as opposed to reusable bags such as 'bags for life'. Bags will vary in size depending upon products purchased. We understand, and have taken into account, the fact that lightweight plastic carrier bags are often reused for a second purpose.

[4] For example, Lidl and B&Q (see Appendix 2).

Paper Bags

The paper bags issued by shops range from very simple ones for small items (e.g. from newsagents and greengrocers) to larger ones (e.g. issued by fashion and shoe retailers). Some paper bags have plastic handles or plastic coatings. Under the terms of the Irish definition of plastic carrier bags (i.e. a bag with a plastic content), it is assumed that paper bags with a plastic content would be subject to the levy.

It is a misconception that paper bags are environmentally friendly because they are biodegradable. The increased volume of waste and the impact of their manufacture and transportation all need to be taken into account.

Polypropylene Bags

Polypropylene[5] has many uses for producing rigid and flexible containers, as well as furniture, and is also derived from oil resources. Non-woven polypropylene bags are available at shops such as Marks and Spencers in the UK, where they retail at more than £1. They are strong and durable and, like 'bags for life', are intended to be used many times.

Woven polypropylene bags are available at J Sainsbury in the UK as well as in the Republic of Ireland at Tesco and Dunnes stores. Woven bags are produced by stretching the polypropylene in production to form "fibres", the result is a stronger bag.

Degradable Bags

Bags that can be broken down by chemical or biological processes are described as degradable. Intuitively, degradable bags are expected to be environmentally friendly and a number of retailers are actively pursuing this option. Thus, there is often some surprise when reports suggest that degradable bags are not such an 'environmentally friendly' option. Waste management protocols emphasise the need to prevent, reduce, reuse, recycle and then recover energy. Encouraging disposal via degradation runs counter to this approach.

It can also be difficult to agree whether a particular type of bag is degradable or not. This could become significant if biodegradable bags were to be exempt from the levy.

Types of degradable bags

There are two main kinds of degradable bags[6].

- **Biodegradable** bags are made from natural starch sources such as maize and synthetic polyesters that degrade through the enzymatic action of micro-organisms (bacteria, fungi and algae), essentially rotting down like vegetable matter. However, starch-based biodegradable carrier bags are not available in significant numbers in the UK. They would only be covered by a potential levy on plastic carrier bags if they contained some plastic (some do for bag-strengthening reasons).

---

[5] Correct chemical name is polypropene

[6] Biodegradable bags can be properly classified by how they decompose (either by microbes or through heat, ultraviolet light and water) and by the material they are made from (e.g. natural starch sources such as maize or wheat, or synthetic polymers from oil). Blended materials are also available, e.g. starch with HDPE or polyester [RMIT].

- **Bioerodable** bags are made from synthetic plastics (oil-based) with trace degradation initiators (HDPE with an approximately 3% content of heavy metals such as manganese and iron[7]) and, as such, would be covered by a plastic bags levy. They bioerode primarily by oxidation and erosion of the plastic through the action of light and heat until very small particles of plastic remain (these often degrade biologically). It is reported that, in an anaerobic environment, the degradation process is halted for some types of bioerodable bags [RMIT, Symphony Plastic Technologies].

Concerns Regarding Bioerodable Bags

- **Recycling.** Conventional polyethene plastic bags (HDPE and LDPE) can be recycled into new products such as other bags and solid items such as 'plastic' wood (known as plaswood). It will be difficult to keep the different kinds of bag apart (HDPE and LDPE bags for recycling and bioerodable bags for composting), especially if both are available in the same community. Inevitably, bioerodable bags will get into this plastic bag waste stream and thus contaminate the recyclate. If the resulting recycled item contains a certain percentage derived from bioerodable bags, it will have inherently lower functional properties (i.e. it will start to degrade when in contact with water, ultraviolet light, etc.). This could have serious implications if the recycled plastic is used for pipes for water, gas supply or as fencing posts or seats [RMIT]. Some types of bioerodable bags[8] are reported not to damage the overall value of the reclaimed material as the degradant initiator is destroyed during reprocessing.

- **Shelf-life and storage.** Bioerodable bags may start to decompose early if exposed to high temperatures, light or moisture. This compromises their carrying ability, though vacuum packaging is reported to prevent this [Symphony Plastic Technologies].

- **A solution to littering problems.** This claim is felt to send the wrong message to the consumer, i.e. it is acceptable to discard these bags because they will eventually rot down. The argument is that consumers should be informed of the need to reuse bags to reduce litter and resource consumption [RMIT]. In addition, the Marine Conservation Society (MCS) reports that any littered bioerodable bags based on HDPE will still cause problems to wildlife as they will break down into smaller pieces that can be ingested [MCS 2005]. This is questioned by Symphony Plastic Technologies, which suggests that degradation to carbon dioxide, water and humus is likely and that, should an animal ingest these smaller pieces, the degradation process will actually continue in its gut.

---

[7] Also copper, nickel, cobalt and cerium as well as photoactive compounds such as ferrocene.

[8] Oxo-biodegradable plastic bags produced by Symphony Plastic Technologies plc

- **Provision of appropriate conditions for planned benign degradation.** Bioerodable bags are designed to decompose through the action of sunlight, water, stress and, ultimately, the enzymatic action of microbes in an aerobic environment. Where degradable bags are simply disposed of alongside other 'household waste' and then landfilled (like most household waste in Scotland [SEPA]), then the necessary conditions to allow degradation may well be absent and thus the environmental 'benefits' lost.

Certification and Labelling

Manufacturers of degradable polymers have signed a voluntary agreement with the European Commission to use environmentally friendly polymers in packaging that "*will effectively guarantee a biodegradability standard for products such as plastic bags, cups and plant pots, enabling them to be turned into compost and soil improvers.*" The agreement includes a certification and labelling scheme to help consumers and manufacturers identify products made from degradable polymers [EU Commission].

Key Features of Carrier Bags

Table 2.1 summarises some of the key features of the various types of carrier bags available, including their costs and relative sizes compared with conventional lightweight plastic carrier bags.

Table 2.1 Key features of carrier bags

Bag type	Features	Average cost to the retailer per thousand bags *	Average weight per thousand bags (kg)*	Relative bag storage volume**	Recyclability
Lightweight plastic carrier	Light, strong, durable, effective when wet	£7.47	8.4	1	Yes – but not all stores have facilities
'Bag for life'	Light, strong, durable, effective when wet	£60.88	47.4	4	Yes – system of replacement actively encouraged
Fully degradable plastic bag	Light, strong, durable, effective when wet	£6 to £8	6.5	1	Degradable under the right conditions. Problematic if contaminate conventional plastic recycling.
Paper, without handles §	Convenient	£50	51	8	Yes – kerbside collections available
Paper, with handles §	More appealing to customers e.g. for shoes and clothes	£220	124	10	Yes – kerbside collections available but can be more problematic due to mixed materials
Non-woven polypropylene	Durable, strong, effective when wet	£333.33	138.7	20	Not at present
Woven polypropylene	Durable, strong, effective when wet	£433.33	226	20	Not at present

* Data provided by CBC and Symphony Plastic Technologies plc. Based on average price of an average bag.

**The relative volume of bags (to a conventional lightweight bag) is important for transportation and storage units required compared with plastic carrier bags.

§ The average weight of all paper bags available is 99g (arithmetic mean of 51, 81 and 166g). The values of 51g and 99g are used in the LCA in Section 4 for various analysis sensitivities.

2.2 Summary of the Irish Experience

A key motivator for the introduction of a levy on plastic bags in Scotland is the experience from the Republic of Ireland, where a levy known as the PlasTax was introduced in 2002. We consulted the Department of Environment, Heritage and Local Government in the Republic of Ireland for its views on the introduction and operation of the PlasTax. The Department said:

- The PlasTax was primarily an anti-litter measure with the secondary aims of increasing public awareness and changing behaviour. Introduction of the levy coincided with introduction of Ireland's Waste Strategy.
- No documented evidence is available showing a reduction in visible litter in the Republic of Ireland because of the levy. The Department has commented that "*littering of plastic carrier bags is no longer a problem*".
- Approximately €1 million are raised each month from the levy.
- The decrease in bag usage was initially 90% and is now 95%.
- The main cost to retailers was updating their software so that till receipts would itemise the sale of plastic carrier bags.
- Theft was reported to increase at the outset but, when the Department investigated these claims, they were unable to substantiate them.
- Some increased control measures were introduced to stop trolleys being taken away from stores.
- Although use of paper bags has increased, it is not felt that their exclusion from PlasTax has been to the detriment of the scheme. Paper bags are reported as being used mainly by fashion and shoe shops. The grocery sector has switched largely to reusable bags.
- The advertising campaign, which was high profile and intensive, was considered a successful element in smoothing introduction of the levy.
- There are approximately 30,000 accountable persons registered in the Republic of Ireland. An accountable person is responsible for submitting the required information to the Revenue Commissioners.
- Compliance levels are reported to be very good. There is a facility for 'estimating levy liability' if retailers fail to submit returns or if the return is considered too low.
- There have not been any prosecutions. Any retailer not complying with the law has been visited, their non-compliance verified and a warning issued.

- Funds have been used to support waste recycling infrastructure, ongoing running costs and the introduction of dedicated staff to enforce waste legislation (with a particular focus on illegal waste dumping).

- An independent review of the scheme will be undertaken during 2005, three years after its introduction.

- A voluntary code was considered but the advice received suggested that this would be less effective.

3 The Arguments For and Against a Levy

The focus on plastic bags, in particular, is supported by:

- The high volume used.
- The perception that they are generally supplied 'free of charge'.
- The fact that they are a secondary form of packaging.
- The assertion that they add to litter in a highly visible manner.
- Their persistence in the environment.
- The view that they are potentially easy to replace.
- The view that they represent an 'easy target for visible success'.

3.1 The Arguments For a Levy

A bill for levy for certain plastic carrier bags in Scotland has been presented by Mike Pringle MSP [Pringle] following the introduction of the Irish PlasTax as a means of altering behaviour to help protect the environment. A further benefit stressed by Mike Pringle is the reduction of litter while encouraging the reuse of plastic bags. He argues that many plastic bags are not reused but end up in landfill sites or, worse still, as litter on the streets of Scotland.

Proponents of a levy cite the following potential benefits:

- Reduced resource consumption.
- Reduced energy consumption.
- Reduced emissions of greenhouse gases.
- Less litter.
- Increased public awareness of environmental issues in general.
- Strong message to change behaviour.

A Throwaway Society

Mike Pringle asserts that plastic bags contribute significantly to our throwaway culture of waste and argues that their use needs to be curbed, resulting in benefits for both the environment and business. He hopes that, by extension, people would be encouraged to think more about the other products and services they use and become more aware of reuse and recycling issues in general.

The proponents of a levy suggest that plastic carrier bags are only used twice at the most – to take purchases home and then, largely, for rubbish disposal. As such, they argue that plastic carrier bags are a needless waste of resources. This waste includes both the crude oil by-product resource from which the bags are made and the transport resources to deliver them from the manufacturing site[9] to the retail outlets where they will ultimately be distributed.

---

[9] Approximately 90% of plastic carrier bags used in the UK are imported from the Far East/China [CBC, Pringle]

Recycling levels for plastic carrier bags are low in Scotland and supporters of the levy argue that those that are not disposed of responsibly could increase the problems of litter. They often quote the sight and impact of wind-blown bags caught in trees and bushes to illustrate this point.

Litter and Damage to Wildlife

Further problems with littered carrier bags, especially in marine environments, are also cited. The Marine Conservation Society (MCS) conducts annual surveys every September in the UK to collect and remove litter from beaches. During this work, the MCS catalogues the amounts and types of litter found. The results are given in the MCS's Beachwatch reports [MCS 2003, MCS 2004, Independent].

In 2003, the survey covered 135 km of UK coastline and, in 2004, this rose to 145 km. Table 3.1 presents the survey data relevant to plastic bags. This category includes supermarket carrier bags as well as other kinds of plastic bags.

Table 3.1 MCS beach litter survey results

Year	Total number of plastic bags collected	Percentage of total litter	Plastic bags per km of coastline
2003	5,831	2.10%	43.2
2004	5,592	2.03%	38.5

The results show a drop of 4% from 2003 to 2004 in the numbers of plastic bags of all kinds collected. However, it is difficult to say whether this figure is statistically significant as it will depend on which beaches were visited.

It is also stated that a range of marine life such as whales, dolphins and turtles are severely injured or killed because they ingest or become entangled in plastic – as many as a million birds and 100,000 marine mammals worldwide every year [Envt Canada, MCS 2005]. One of the reasons given for why marine wildlife consume plastic bags is that they may mistake them for jellyfish, a main source of food for marine mammals. The consequence of this error is that the bags block the throat preventing normal feeding [Envt Canada, MCS 2005]. In 2004, the helpline run by Scottish Society for the Prevention of Cruelty to Animals (Scottish SPCA) received nine calls relating to animals that had become trapped in plastic bags, this is 0.01% of all calls taken. The Scottish SPCA note that the number of calls received will only represent a fraction of the actual number of wild animals who become entangled.

A survey undertaken in the Bay of Biscay during the early 1990s reported that plastic bags of all kinds, including lightweight plastic carrier bags that had been washed out to sea from land-based sources, accounted for 95% of all litter in sub-surface tows [Galgani].

Charting Progress - An Integrated Assessment of the State of UK Seas [Defra 2005] states:

> *"Marine litter can pose a hazard to beach users and recreational water users. Fish, seals, cetaceans and seabirds can become trapped (e.g. in sections of discarded fishing nets and plastic or rubber rings). They can also ingest plastic particles and objects, which can be fatal. Marine litter can also degrade the aesthetic quality of the environment, particularly in tourist areas."*

Clearly, this is not all due to plastic carrier bags as they make up only a proportion of this litter.

3.2 The Arguments Against a Levy

A number of organisations have lobbied against imposing taxes on plastic bags in many countries. These include the CBC in the UK, the Australian Retailers Association (ARA) and the Belgian Retail Association (BRA).

The Benefits of the Plastic Carrier Bag

The advantages highlighted by proponents of plastic carrier bags [ARA, CBC, EuroCommerce] include:

- Hygiene.
- Convenience.
- Reliability/efficacy/durability (paper bags often rip and are 'double-bagged').
- They can be reused for other purposes in and around the home, e.g.
  - as bin liners;
  - for storing shoes;
  - for collecting pet mess.
- Their disposal results in lower greenhouse gas emissions compared with disposal of bioerodable bags of paper, starch or plastic origin.
- There are lower environmental effects compared with paper bags in terms of production and transport as plastic bags use fewer resources, take up less volume and weigh less.

Hygiene is an important issue and, as is the case in Republic of Ireland, bags for wrapping fresh meat, fish, poultry and loose fruit would need to be excluded and remain free of charge because of their hygienic functional role[10].

Negligible Impacts on the Waste Stream

Plastic films, which include carrier bags and other plastic packaging, make up 4.37% of the household waste stream on average[11] in Scotland [SEPA]. To put these figures in context, paper and card makes up almost 25% of the household waste stream by weight while putrescibles (e.g. waste food) nearly 32%. Furthermore, plastic bags alone constitute about 0.3% of the municipal waste stream in the UK [HM Treasury].

The amount of municipal solid waste (household and commercial waste) collected by local authorities across Scotland for disposal in 2002/03 was 2,589,702 tonnes[12]. Using the UK data, 0.3% of the municipal waste stream by weight equals 7,769 tonnes per year of plastic bags. Any reduction in the amount of plastic bags disposed of would have very little effect on the overall waste disposal figures. Further analysis of the waste issues is provided in sections 4.6 and 5.2.

---

[10] It is a statutory requirement under the Food Safety (General Food Hygiene) Regulations 1995 SI 1763 that meats are packed appropriately before supply to the customer

[11] Range of 1.84–6.08% for 2002/03 [SEPA]

[12] Scottish local authorities collected a total of 3,345,458 tonnes of controlled waste (household, commercial and industrial) for disposal or recycling in 2002/03 [SEPA].

One of the aims of the EU Landfill Directive is to reduce the amount of biodegradable municipal waste going to landfill. The imposition of a levy that excluded paper bags is expected to increase the number of paper bags used and disposed. Although some would be recycled by consumers (e.g. through kerbside collections), there would ultimately be more paper bags going to landfill where they would degrade giving off greenhouse gases.

Single Trip or Multi-trip?

The Scottish Waste Awareness Group (SWAG) survey *Public Attitudes to Reduce, Reuse, Recycle in Scotland* (2001) stated that:

> "*The number of people engaging in this range of practices [reuse] was limited, the most commonly practised behaviour was the reuse of materials. This was achieved primarily through the reuse of plastic bags (84% of respondents), although the majority of these were ultimately used as bin liners*". [SWAG]

A Waste Watch study for the UK reported that 54% of people questioned said that they reuse plastic carrier bags, with secondary reuse as bin liners a typical example [Waste Watch]. This study states that:

> "*Recent research suggests that four out of five people reuse products. Plastic bags and glass jars or bottles are reused by around half the public and plastic containers or bottles by one in five.*"

Both the SWAG and Waste Watch studies suggest that a proportion of respondents reuse lightweight plastic carrier bags, often as bin liners. If so, the majority of bags would only be reused once. It must also be made clear that, when the SWAG survey states that 84% of respondents reuse bags, this does not mean that 84% of bags are reused. What it means is that 84% of people reuse some of their carrier bags at some point; a similar logic applies to the results of the Waste Watch study.

A more recent study undertaken by the Waste and Resources Action Programme (WRAP) found that, of the 1,048 people interviewed, 59% said they reuse all their lightweight plastic bags with a further 16% saying they reuse most of them [WRAP 2005]. The main use by far was as a surrogate bin liner, though other uses were reported such as other shopping, collecting pet mess or carrying other things when going out.

Litter Culprits?

A Local Environmental Audit and Management System (LEAMS) report by Keep Scotland Beautiful (KSB) states that the main items of litter in Scotland are:

- Cigarette litter (cigarette ends, matches, matchboxes, cigarette packaging) found at 70% of sites inspected.
- Confectionary litter (sweet wrappers, chewing gum wrappers and crisp packets) found at 50% of the sites inspected.
- Drinks-related litter (cans, bottles, cups, straws and lids) found at 34% of sites.
- Fast food packaging litter (fish & chip wrappers, polystyrene cartons, burger wrappers, plastic cutlery) found at 10% of sites.

Even though those plastic carrier bags that are littered are visible and persistent in the environment, the report did not mention them specifically [KSB].

Windblown plastic litter in the environment is often from other plastic sources such as the agricultural wrappings for hay bales, etc. [CBC]. WRAP has commented that a reduction in plastic bags used would not result in a noticeable improvement in the overall litter situation [WRAP 2004a].

These results have been echoed elsewhere in the UK by ENCAMS[13]. Its surveys have also shown that the main littering problems in England are from smoking products, food and drinks containers (plastic and glass) and dog mess, with the most prominent commercial litter coming from elastic bands dropped by postmen [ENCAMS].

A further recent survey conducted in England, commissioned by the Industry Council for Packaging and the Environment (INCPEN) and carried out by ENCAMS collected 37 carrier bags out of a total of 58,041 items, which equates to 0.064% of all items of litter found [INCPEN-ENCAMS]. The chief culprits were confirmed as chewing gum and cigarette ends. The data show that lightweight plastic carrier bags are not major contributors to reported land litter in Scotland.

A Finite Resource

Plastic bags are made from a by-product of crude oil refining. Supporters of plastic bags would argue that they maximise the benefits from a finite resource, rather than flaring off the excess gases (including ethene) produced by the crude oil cracking process.

Behavioural Change?

Countries that have not introduced a levy have argued that it is people's littering behaviour which needs to be changed and that this will not necessarily come about from the imposition of a levy [ARA]. The Belgian Retail Association agrees; it believes that the main problem and cause of litter is not in the plastic bag per se, but the public's behaviour in simply discarding it rather than disposing of it properly. Education and awareness raising are seen as the key to the litter problem rather than levying the use of lightweight plastic carrier bags [EuroCommerce].

Job Losses

Those against the levy argue that it will lead to job losses in an industry that has successfully developed and optimised its product to provide an efficient and effective means of transporting goods from place of purchase to the home. This topic is discussed in more detail in Section 5.2.

---

[13] The Keep Britain Tidy Group

3.3 The Voluntary Approach

The introduction of a levy at a UK level was reviewed and rejected in 2003. The Department for Environment, Food and Rural Affairs (Defra) has stated that "*...we have no current plans for a plastic bag tax, but the Government keeps all taxation under review*" [Defra 2003, Hansard 2004]. Various voluntary mechanisms are currently being investigated.

WRAP is working with the British Retail Consortium (BRC) on a 'reusable bags' project. The aim of this project is to achieve a united approach across retailers through the creation of a retail partnership. This will provide a high level exposure of 'reusable bags' to the consumer at most retail outlets. It is hoped that the 'reusable bags' concept can be presented more effectively to consumers, actively encouraging behavioural change in a self-sustaining way that will avoid the introduction of a levy. Actions under consideration include:

- In-store awareness promotions.
- High visibility of store 'reusable bags'.
- Loyalty points for carrier bag reuse.
- Staff training in carrier bag advice.
- Checkouts without lightweight carrier bags.
- A pilot project in Edinburgh and Bristol in Autumn 2005.

In addition, BRC and the Scottish Retail Consortium (SRC) have formed a working group to look at the possibility of developing a voluntary code of conduct. They will be working with members and other key stakeholders including the CBC. The CBC has submitted a draft Voluntary Code on Best Environmental Practice for the Provision, Use and Disposal of Plastic Retail Carrier Bags for consideration by the working group. While the draft code is not yet available, the CBC note that the draft proposal outlines plans for:

- Encouraging industry and retailers to work together to find ways of further reducing energy, material and environmental impacts in the production, transportation and storage of plastic carrier bags.
- Active support and participation in waste reduction and reuse initiatives.
- Development of new schemes to promote recycling.
- A commitment for separate film collection for degradable bags.
- Development of a customer information campaign.
- An independently audited scheme to monitor, measure and report success.

The CBC strongly supports a voluntary approach for Scotland and the UK as a whole. It suggests that reusable bags should be offered, but that free, disposable lightweight plastic carrier bags should also be available so that consumers can make their own choice.

The imposition of a levy in Australia was considered and then postponed for two years (until the end of 2004) to see if the voluntary take-up of reusable bags and increased rates of recycling could reduce the number of lightweight plastic carrier bags by a target of 50%. A report from the Australian consultants Nolan-ITU published in March 2005 states that bag usage fell by 20.4% between 2002 and 2004 through the voluntary code of conduct agreed by retailers [Nolan-ITU].

This reduction is broken down into supermarkets reducing usage by 25% and non-supermarket retailers reducing usage by 10–15%. This result shows that a voluntary scheme can have a significant effect, given the support and time to get its message across. The Australian Government is determined to continue this trend to the extent of reducing use to 50% by the end of 2005 and ultimately phasing out plastic bag use completely by 2008 [Aus Govt].

3.4 Other Alternatives to a Levy for Reducing the Impacts of Plastic Bags

Degradable bags have been suggested as a possible solution. The issues surrounding their disposal, recycling and littering implications are discussed in Section 2.1.

Other ways of reducing usage include promoting the **reuse** of lightweight plastic bags, the purchase of thicker 'bags for life' or rigid boxes as well as recycling plastic bags (either within shops or by local authorities). These alternatives are all fully feasible and in operation, but have only had a small uptake so far.

Recycling is one option for polyethene plastics as a way of reducing their environmental burdens. This would be achieved through replacing raw materials (virgin polymer) with recycled polymer (see Dixons case study below), as well as reducing the (albeit very small) load on landfill at their end-of-life. Recycling of all plastic films – not just carrier bags – currently stands at 300,000 tonnes per year in the UK [CBC].

Dixons plc, in association with Nelson Packaging introduced the UK's first **fully recycled carrier bag** in 2003 [Dixons]. Rather than being sent to landfill, waste plastic collected from commercial back-of-store and post-consumer in-store sources in the UK is used to make bags for Dixons. An independent LCA of these bags has been undertaken by Nottingham University. This estimates that every tonne of recycled bags produced saves around 1.8 tonnes of oil compared with a tonne of bags made from virgin material [Nottingham]. Dixons argues that using recycled material to produce plastic carrier bags not only reduces the environmental burden directly (through the use of less crude oil by-products and less waste being discarded), but it also educates the consumer to some extent.

Some retailers have adopted **voluntary charging**. Lidl currently charges 5p per bag in its UK stores. B&Q has piloted a scheme in its shops in Scotland at the same level, while IKEA charges 5p per lightweight plastic carrier bag at its Edinburgh store with good success (see Appendix 2 for more details). There is a similar story in Australia where European companies based there such as Aldi and IKEA already charge for their bags [RMIT], although this is a voluntary approach rather than mandatory. Consequently, some shoppers are already aware of, and accustomed to, the idea of paying for carrier bags for their goods.

Where incineration is the main disposal method in preference to landfilling, carrier bags offer high calorific values equal to or greater than that of oil. Hence, energy can be recovered from the bags and put back into the national electricity grid. This would reduce the need for conventional fossil fuels for power – again albeit by a small degree. However, there are currently only two energy-from-waste incinerators in Scotland [SEPA].

4 Life Cycle Assessment

A number of LCAs have been undertaken that compare the environmental impacts of the reusable, plastic, degradable and paper bags typically available in high street shops. The studies have been carried out in the USA, France and Australia (see Appendix 3 for a full list). No studies have been carried out based on data from Scotland or the UK.

We reviewed the studies and identified the French study (carried out by Ecobilan for the retailer Carrefour) as the most relevant to the situation in Scotland (the rationale used for this selection is presented in Appendix 3). We believe that the information available from this study is sufficient to provide a good indication of the likely life-cycle environmental impacts of changing plastic bag usage in Scotland. The Carrefour study (as it will be referred to in this report) is used in the following analysis.

4.1 Stages of the LCA for this Report

The analysis proceeds through the following stages:

1. Development of scenarios that will influence the numbers and types of bag used.
2. Quantification of the number of bags of each type (lightweight plastic, reusable plastic, paper, and bin liners) used under each scenario.
3. Review of the Carrefour study to extract the most relevant data for application in Scotland.
4. Sensitivity analysis -- designed to test the robustness of base case results to plausible variations on the assumptions made.

4.2 Plastic Bag Levy Scenarios

Table 4.1 gives details of the five scenarios investigated for this study, including 'business as usual'.

Table 4.1 Scenarios investigated for this study

Scenario	Summary	Description
0	Current situation	Business as usual
1A	As in the proposed Bill	Based on the introduction of a levy on all lightweight plastic carrier bags including degradable plastic bags, but NOT paper bags. It includes all distribution points: shops, petrol stations, charity shops, on-street promotional give-aways, etc.
1B	As in the proposed Bill, but excluding small-to-medium enterprises (SMEs), charities and promotions	Recognises the logistical problems of collecting a levy from all retail outlets. It assesses the extent of the environmental gain for the anticipated large-scale additional effort. The idea is to focus on the larger companies that use the greatest amount of bags and have the resources to enable them to comply more readily with a levy.
2A	As in the proposed Bill + paper bags	Based on applying the levy to all lightweight carrier bags including plastic, degradable plastic and paper. Includes all distribution points: shops, petrol stations, charity shops, on-street promotional give-aways, etc. Recognises that the levy is aiming to achieve behavioural change and encourage the use of re-usable bags and not simply a switch to, for example, paper bags.
2B	As in the proposed Bill + paper bags but excluding SMEs, charities and promotions	This scenario is the same as scenario 2A, but excludes SMEs, charities and promotions. Like scenario 1B, it looks at the extent of the environmental benefits without the logistical problems of trying to police and enforce the levy across the board.

4.3 Consumption Data Used to Quantify Environmental Impacts

To understand plastic bag consumption, we used published data to produce consumption figures for the different scenarios in conjunction with data on the impacts on consumers (see Section 5). These figures were derived as follows.

Existing Lightweight Carrier Bag Usage

- A Defra report stated that 8 billion plastic bags were used in the UK in 2000 [Defra 2003].
- Other sources [BBC, WRAP 2005] put this figure at 10 billion per year, from which it has been stated that Scotland's consumption is 1 billion plastic carrier bags per year [Pringle]. This estimate presumes an approximate factor of 10%.
- There are no actual figures available for the consumption of plastic bags in Scotland. Therefore, we used population statistics [Stats Scot, Stats UK] to scale UK bag

consumption data to Scotland. Population statistics show that 8.6% of the UK's population lives in Scotland.

- Average annual lightweight plastic carrier bag use in Scotland is estimated at 775 million[14].
- In consultation with the BRC and its members, it was agreed that reusable bag consumption ('bags for life') constitutes an additional 1%[15].
- There were no statistics available on the level of consumption of paper bags[16]. We estimated that paper bag consumption is about 5% of all plastic carrier bag consumption[17].

Consumer Behaviour

In essence, the success of the levy will depend upon consumers' wish to avoid paying the levy and the consequent reduction in the use of plastic carrier bags. If fewer people pay the levy, less revenue will be generated.

If a levy is introduced and does not include paper bags, it is anticipated that there will be an increased take-up of paper bags as well as 'bags for life'. Our estimate of the take-up of alternative carrier bag options is based on 'assumed percentage reductions' as used in Australian [DEH] and South African [FRIDGE] studies.

Our interpretation of consumer behaviour is based on the following assumptions:

- A levy would be charged at £0.10 per bag on lightweight plastic or paper carrier bags. This would lead to a 90% reduction in demand for each type of carrier bag, based on the experience in the Republic of Ireland.

- Under scenarios 1A and 1B (in which paper bags are not subject to the levy), it is assumed that of consumers not purchasing a lightweight plastic carrier bag:
  - 30% will not require any type of carrier bag ('no bag');
  - 45% will switch to heavyweight plastic carrier bags (or similar);
  - 25% will switch to paper carrier bags[18].

- Under scenarios 2A and 2B (which include paper bags in the levy base), it is assumed that of consumers not purchasing a lightweight plastic bag:
  - 42.5% of consumers will not require any type of carrier bag;
  - 57.5% of consumers will switch to heavyweight carrier bags (or similar)[19].

---

[14] Calculated using population scaling on the upper and lower UK bag consumption figures: 8.6% of 8 billion equals 690 million bags, while 8.6% of 10 billion equals 860 million. The average of these two numbers is 775 million

[15] Waitrose quoted as 1-2%; J Sainsbury's at 0.3%.

[16] Paper bags are normally used in the non-food retail sector for clothing, shoes, etc.

[17] From consultation with BRC

[18] It is assumed that 30% of the total reduction in the use of lightweight plastic and paper carrier bags is transferred to 'no bag', as adopted for a 15 cent levy in the Australian report [DEH]. The remaining 70% reduction is assumed to be split between paper carrier bags and heavyweight plastic carrier bags. Using information from the UK Expenditure and Food Survey 2002/03 [ONS], we calculated expenditure likely to require a carrier bag and then split it according to (a) those retail categories (e.g. footwear, clothing, etc.) thought most likely to accommodate a switch to paper carrier bags (as seen in the Republic of Ireland) and (b) those retail categories (e.g. food, beverages, etc.) most likely to accommodate a switch to heavyweight plastic carrier bags. On this basis, 36% of total household expenditure is sourced from (a) and 64% from (b). It has therefore been assumed that 25% is transferred to paper carrier bags (i.e. 36% × 70% = 25%) and 45% is transferred to heavyweight plastic carrier bags (i.e. 64% × 70% = 45%).

- Under scenarios 2A and 2B, the estimated reduction in paper bags is assumed to result in a 70% switch to heavyweight carrier bags (or similar).

- It has been assumed that a typical heavyweight carrier bag is used 20 times before replacement[20]. Therefore, the 45% of consumers who choose to switch to a heavyweight carrier bag will purchase five such bags in place of 100 lightweight carrier bags. This gives a 1/20th ratio for calculating the numbers of heavyweight carrier bags used under the levy scenarios.

- Spending at SMEs has been assumed to account for 30% of total household expenditure[21]. In order to exclude SMEs from being subject to the levy, we have simply reduced total expenditure by households on items likely to involve the acquisition of a carrier bag (of any type) by 30%.

Bin Liner Consumption

- We included bin liner consumption to account for the displacement effect of people switching to or using additional purpose-made bin liners instead of carrier bags in the event of a levy.

- As no UK or Scotland specific data were available for current bin liner use, Irish data were used and scaled for Scotland along population ratios. An Australian study [DEH] reports a 77% increase bin liner consumption in the Republic of Ireland, from around 91 million to 161 million , following the introduction of the PlasTax. We have assumed a similar 77% increase in bin liner use for Scotland, i.e. from 118 million/year currently to 208 million/year post-levy[22].

- We have not included black refuse sacks and disposable nappy sacks as information on the relevant sales volumes was not available. In addition, there were no statistics available for bags made of polypropylene in Scotland. Although retailers felt that a levy would instigate an increase in sales of kitchen swing bin liners, they did not feel that it would alter their sales of black refuse sacks to any great extent [Nolan-ITU Pty Ltd, personal communication].

We combined the assumptions and data discussed above to give the annual bag and bin liner consumption shown in Table 4.2 for the different scenarios.

---

[19] It is assumed that, of those consumers who transferred to paper bags under Scenarios 1A and 1B, half now transfer to heavyweight plastic bags and half transfer to 'no bag'. We made this assumption because no other suitable evidence was available. Thus, the total proportion of the reduction in lightweight carrier bags now transferred to heavyweight bags is equal to 57.5% (i.e. 45% + (50% x 25%)).

[20] Taken from the Carrefour study [Carrefour]

[21] This is based on share of turnover in SIC(92)52, i.e. the retail trade with less than 250 employees, as determined by the Institute of Retail Studies, University of Stirling. Hence, in scenarios 1B and 2B, the levy is assumed to apply to 70% of the retail base in scenarios 1A and 2A. By adjusting the retail base in this fashion, it has been assumed that a £1 expenditure equals a £1 turnover and that the number of bags issued per £ expenditure at a SME equals the number of bags issued per £ expenditure at a non-SME. This is a crude assumption, but necessary without any data available

[22] Scaled for population [CSO.ie2005, Stats Scot]

Table 4.2 Estimated annual carrier bag consumption under the different scenarios[23]

	Total number of bags consumed under each scenario (millions/year)[24]				
	0	1A	1B	2A	2B
Plastic carrier bag (HDPE, lightweight)	775	78	287	78	287
Plastic reusable bag (LDPE, heavyweight)	8	23	19	29	23
Paper bag (single use)	39	213	161	4	14
Total bags used	**822**	**314**	**467**	**111**	**324**
Bin liners	*118*	*208*	*181*	*208*	*181*

It is predicted that:

- Under scenarios 1A and 2B, there would be a drop in lightweight plastic carrier bag usage of 697 million/year.
- This decrease would not be so profound if SMEs were excluded (scenarios 1B and 2B) when it would be 488 million/year.
- If paper bags were not included in the levy, there would be annual increases of 174 million paper bags under scenario 1A and 122 million bags under Scenario 1B.
- 'Bags for life' would only increase by 11–21 million/year due to them being reused 20 times.
- Bin liner consumption would increase by 90 million/year if SMEs were included in the levy (scenarios 1A and 2A), or 63 million/year if not (scenarios 1B and 2B).

We combined these data on bag consumption with information on the life-cycle environmental impacts of different types of bags to determine the relative environmental impacts of each scenario in Scotland (Sections 4.5–4.7).

4.4 Relevant Results from the Carrefour LCA

The assumptions and scope of the Carrefour analysis are summarised in Appendix 3.

The Carrefour study considered four types of carrier bag:

- HDPE bags made from virgin polymer (lightweight plastic carrier bags).
- Reusable LDPE bags made from virgin polymer ('bags for life').
- Paper bags made from recycled fibres.
- Biodegradable starch-based bags.

---

[23] Numbers calculated as described in Section 4.3

[24] Example calculations. For lightweight carrier bags under scenario 1B: (30% × 775) + (70% × 10% × 775) = 287. For heavyweight carrier bags under scenario 2A: 8 + [(775 − 78) × 58% × 5%] + [(39 − 4) × 70% × 5%] = 29

We have not considered biodegradable starch-based bags in the analysis of the Scottish situation because they are not thought to be used in any great numbers. Numbers for plastic bioerodable bags (made from HDPE polymer with trace degradant additives) are used at a few outlets, but considerably more conventional HDPE bags are used. We have assumed that the environmental life-cycle impacts of bioerodable bags are comparable to conventional plastic bags as they are both made from HDPE, albeit with a small addition of degradation-promoting compounds. The consumption of bioerodable bags is included within the consumption of lightweight plastic bags.

The Carrefour study examined energy, resource use and pollutant emissions over the whole lifecycle of the bags, i.e. it included production of the raw materials, manufacture of the bags, transport of the bags to the retailer, and disposal at the bags' end-of-life. For plastic bags, for example, the lifecycle begins with extraction and refining of oil and the production of plastic, pigments ink and glue.

In the Carrefour study, the lightweight plastic bags are manufactured in Malaysia, Spain and France, and the heavyweight 'bags for life' are manufactured in France. Paper bags made from recycled paper are produced in Italy for Carrefour. It has been assumed that the bags are produced from old newspapers/magazines.

The Carrefour study examined both incineration and landfilling of bags at the end of their life. For the base case, we selected data that reflect landfilling of the bags as a large proportion of all waste is sent to landfill in Scotland[25]. However, we have also performed a sensitivity analysis that considers an alternative waste management strategy (see below).

The Carrefour study assessed the environmental impact of the energy use, resource use, waste generation and pollutant emissions from the lifecycle of each type of bag by examining their contribution to eight environmental indicators (see Appendix 3). Table 4.3 shows the environmental indicator score for each of the different types of bags, relative to the lightweight plastic bag, for the base case with all material sent to landfill at the end of the lifecycle.

The lightweight plastic bag has been given a score of 1 in all categories as a reference point. A score greater than 1 indicates that another bag ('bag for life' or paper) makes more contribution to the environmental problem than a lightweight plastic bag when normalised against the volume of shopping carried. A score of less than 1 indicates that it makes less of a contribution, i.e. it has less environmental impact than a lightweight plastic bag.

The indicators take account of emissions which occur over the whole lifecycle. They can therefore occur in different locations depending on where different parts of the lifecycle are located. For global environmental problems such as climate change, the location of the emission is not important in assessing the potential environmental impact. For other regional or local environmental impacts, however, it can be significant. For example, the impact of eutrophication of a water body will depend on the water characteristics. This is a well-known limitation of lifecycle impact assessment methodology: LCA quantifies the potential risk of environmental damage rather than actual harm.

---

[25] 88.2% was landfilled in 2002/03. Only 2.2% was incinerated, 5.9% was recycled, 2% was composted and the remaining 1.7% was treated by other means [SEPA].

Table 4.3 Environmental impacts of different types of carrier bag relative to a lightweight plastic carrier bag[26]

Indicator of environmental impact	HDPE bag (lightweight)	Reusable LDPE bag (used 2x)	Reusable LDPE bag (used 4x)	Reusable LDPE bag (used 20x)	Paper bag (single use)
Consumption of non-renewable primary energy	1.0	1.4	0.7	0.1	1.1
Consumption of water	1.0	1.3	0.6	0.1	4.0
Climate change (emission of greenhouse gases)	1.0	1.3	0.6	0.1	3.3
Acid rain (atmospheric acidification)	1.0	1.5	0.7	0.1	1.9
Air quality (ground level ozone formation)	1.0	0.7	0.3	0.1	1.3
Eutrophication of water bodies	1.0	1.4	0.7	0.1	14.0
Solid waste production	1.0	1.4	0.7	0.1	2.7
Risk of litter[27]	1.0	0.4	0.4	0.4	0.2

There are two key stages in the overall production process as laid out in the LCA:

i) Winning the raw materials from nature (e.g. drilling for and then refining crude oil) and converting them into commodities (e.g. polyethene granules).
ii) Manufacturing the bags themselves from these commodities.

The Carrefour study concluded that, for all bags, the main environmental impacts come from the first of these stages, i.e. the extraction and production of the materials (polyethene and paper) that are then used to make bags. The second stage (i.e. the manufacture of the bags themselves) is generally of less importance though not negligible. The study found that transport contributed very little to the environmental impacts. The end-of-life phase also makes a significant contribution to some indicators – most notably, the production of solid waste.

The overall conclusion from the Carrefour study was that reusable plastic bags (so-called 'bags for life') are more sustainable than all types of lightweight carrier bags (plastic, paper, or degradable) if used four times or more (columns 4 and 5 in Table 4.3), offering the greatest environmental benefits over the full lifecycle of any bags used.

---

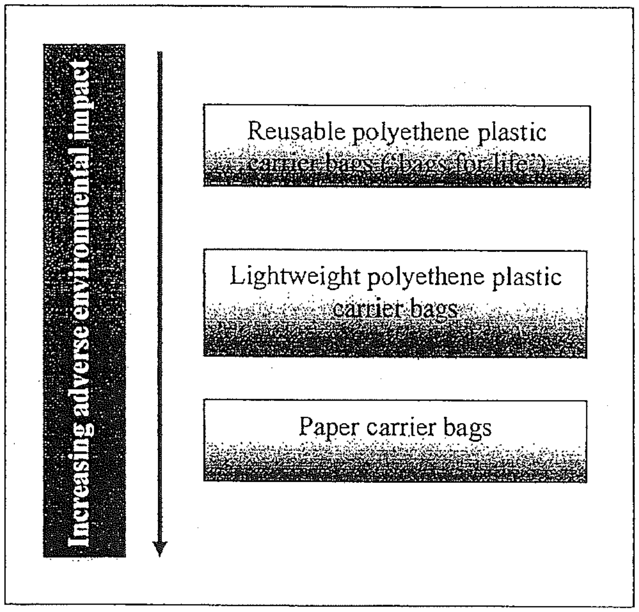
[26] From Table 18 in the Carrefour study. Numbers *greater* than one indicate a *greater* environmental impact compared with lightweight plastic carrier bags and numbers *less* than one indicate a *lesser* environmental impact.

[27] The Carrefour study used the terms 'strong', 'medium–weak' and 'weak' to describe the risk of littering for each of the bags. We interpreted these terms numerically as 1.0, 0.4 and 0.2, respectively, in order to be able to show graphically how the risk of littering may change under the different levy scenarios.

Figure 4.1 summarises these findings. Paper carrier bags have a bigger environmental impact than lightweight plastic bags in all categories apart from risk of litter. Paper bags have a particularly high impact on the environment in terms of[28]:

- Eutrophication of water bodies (rivers, lakes, etc.) due to pollutants released to water during the manufacture of the paper.
- Water consumption.
- Greenhouse gas emissions
- Production of solid waste.

Figure 4.1 Summary of the environmental impacts of different carrier bags from the Carrefour LCA



---

[28] As noted in Appendix 3, the scores against these environmental indicators reflect potential risk than actual harm. Some indicators such as eutrophication are very site-specific in terms of actual impact, depending on the level of wastewater treatment employed and the state of the receiving environment. Others (e.g. climate change impacts from greenhouse gas emissions) are not site-specific.

4.5 Applying the Results to Scotland

We used data from Table 4.2 on plastic bag and bin liner consumption in conjunction with the relative environmental impact scores in Table 4.3 to assess the relative environmental impacts of the four levy scenarios compared with the current situation (scenario 0. 'business as usual'). We used the assumption from the Carrefour study that a reusable bag is reused 20 times[29].

To allow an assessment of the predicted change in bin liner consumption, it was assumed that the lifecycle impact of manufacturing bin liners is the same as for HDPE carrier bags per unit weight[30]. This is an approximation, which may overestimate the environmental impact of bin liners, and hence underestimate the benefits of the four levy scenarios. More details about the calculations are given in Appendix 3.

The results of the base case comparison are shown in Figure 4.2. The base case applies the results from the Carrefour study (Table 4.3) directly to the bag use data in Table 4.2. This implicitly accepts the use of French data on bag weights and volumes. The results give the percentage change in the environmental impact score for each of the levy scenarios compared with the current situation (scenario 0). In all scenarios where the levy is applied, consumption of non-renewable energy, atmospheric acidification, the formation of ground level ozone and the risk of litter fall considerably compared with the current situation.

In scenarios 1A and 1B where paper bags are exempt from the levy, the impacts are greater than the current situation for the consumption of water and eutrophication. However, they are approximately equivalent for the emission of greenhouse gases and the production of solid waste. This is due to a trade-off between the impacts from the additional paper bags consumed and the environmental benefits from the reduction in the use of lightweight plastic bags. The overall environmental impact from scenarios 1A and 1B is therefore predicted to remain very similar to today's situation. This is because the benefits of reducing plastic carrier bag use are displaced by the increased use of paper bags.

It is only in scenarios 2A and 2B, where the levy is applied to paper as well as plastic carrier bags, that consumption of water, emission of greenhouse gases, eutrophication of water bodies and production of solid waste are significantly reduced. This is because paper bags have a high score in these environmental categories relative to plastic bags (see Table 4.3 and Table A3.1 in Appendix 3).

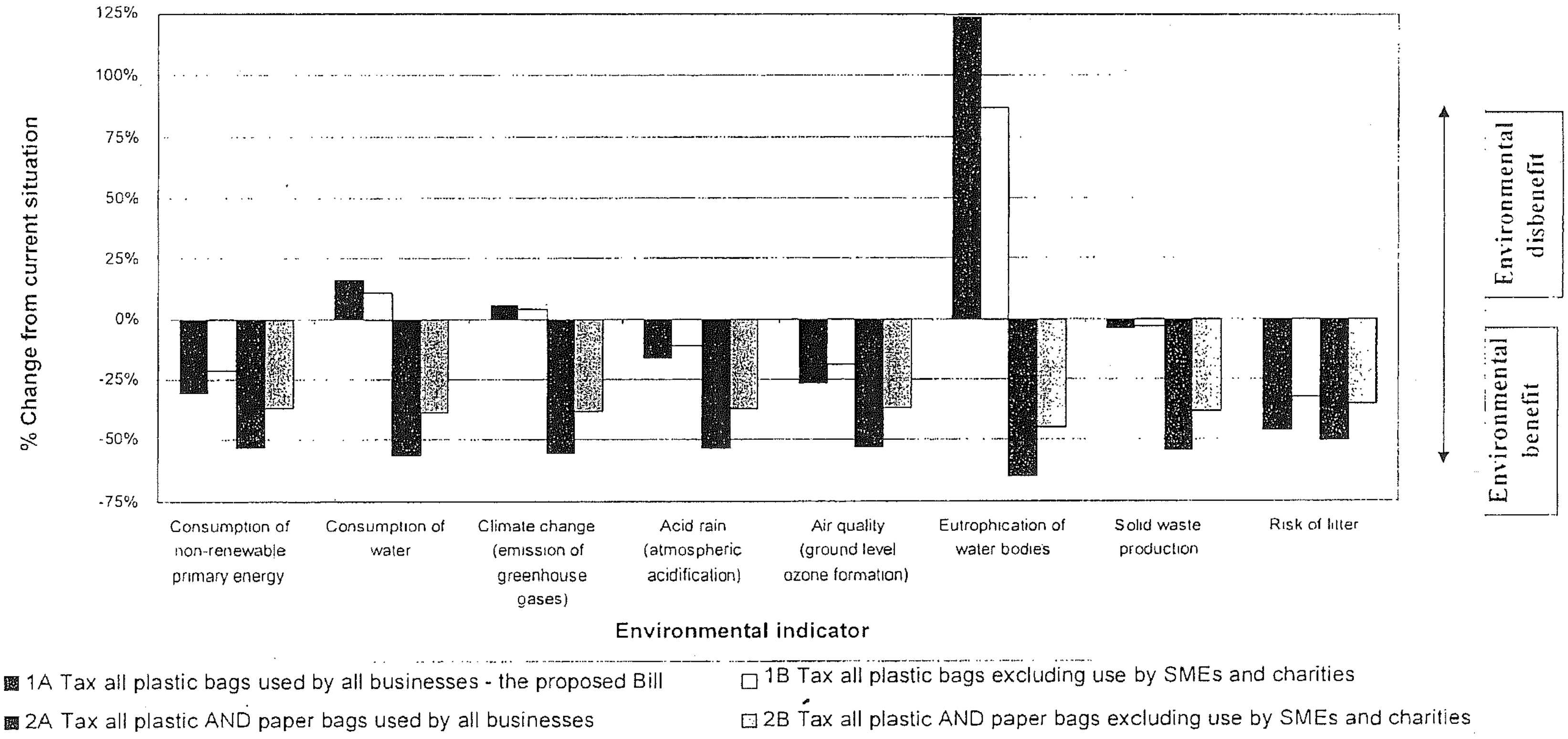
In all cases, the environmental benefits increase (and environmental impacts reduce) when SMEs are included in the levy.

---

[29] For comparison, the Australian study assumed that reusable 'bags for life' are reused around 52 times before being recycled, i.e. once a week in a given year [Nolan-ITU].

[30] On average, bin liners weigh 15g each and lightweight plastic carrier bags 8g each. Thus, the environmental impacts of a bin liner were assumed to be 1.9 (=15/8) times greater than a lightweight plastic bag, giving an approximate ratio of 2:1 We have used this ratio throughout our analysis.

Figure 4.2 Change in environmental indicators due to a levy



Key assumptions: In scenarios 1A and 1B, there is a 25% switch from lightweight plastic bags to paper bags. In scenarios 2A and 2B, there is a 90% reduction in paper bag use.

These environmental effects will occur at different locations around the globe depending on where the raw materials are derived, where the bags are manufactured and how far they have to travel. The bulk of plastic bags for the Scottish market are made in the Far East and imported, whereas Scotland has a considerable paper bag manufacturing sector. Furthermore, some of the effects (e.g. ground level ozone formation) are more localised and some are regional (e.g. the consumption of water and emission of acidic gases), while others such as climate change resulting from fossil fuel combustion are global problems.

While we believe these broad messages about relative environmental impacts are applicable to the Scottish situation, there are differences between France and Scotland that mean that specific environmental impacts will differ. This is due to inherent France-specific assumptions in the original LCA work such as the characteristics and usage of bags, and to differences in the environmental impacts of manufacturing and waste disposal in the two countries. In particular, we note the following differences between the assumptions made in the French LCA and the situation in Scotland:

- The Carrefour study assumed that plastic bags weigh 6g as opposed to 8g in Scotland.
- The French study states that the paper checkout bags used by Carrefour weigh 52g. Paper checkout bags[31] in Scotland weigh 51g [CBC]. In the LCA base case, the Carrefour value was taken as representative for Scotland as it was assumed that checkout bags would be more affected by a levy, in terms of numbers and nationwide coverage, than boutique paper carriers with handles. In the sensitivity analyses (see below), the test used the average weight of 99g for all types of paper bags.[32]
- The Carrefour study assumed that a plastic bag has a volume of only 14 litres while a paper bag has a volume of 20.5 litres. This means fewer paper bags are required for the same amount of shopping. For Scotland, however, we would expect no significant difference on average in the volume of shopping carried in the two types of bag. One reason for this is the tendency for 'double bagging', where customers use two paper bags instead of one because they are concerned that a single paper bag may rip open.
- The Carrefour study takes for its base case an average waste management scenario for France, i.e. 45% of paper bags being recycled, 25% being incinerated and 26% landfilled. For the base case in this study, we used one of the Carrefour sensitivity analyses in which all waste is sent to landfill; this is much closer to the current Scottish position where 88% of waste is landfilled[33] [SEPA].

---

[31] Information provided by the CBC showed that there are three kinds of paper bags in general used in Scotland, depending on size and whether they have handles or not. These weigh 51g (checkout bag, no handles), 81g (carrier bag with handles) and 166g (carrier bag with handles). The arithmetic mean of these is 99g.

[32] This analysis suggests some potential for an increase in solid waste generation for scenarios that favour a switch to paper bags. This is due to different assumptions about the relative weight of plastic and paper bags, and the fact that the LCA looks at solid waste impacts throughout the bag life cycle rather than just the end-of-life disposal phase.

[33] Most recent published data (2002/03).

Various sensitivity analyses are presented in Appendix 3 to demonstrate the robustness of results against these factors. These analyses are:

- Sensitivity analysis 1: Assume paper bags weigh 99g instead of 52g.
- Sensitivity analysis 2: Assume on average that paper and plastic bags are used to carry the same volume of shopping.
- Sensitivity analysis 3: Assume lightweight plastic bags weigh 8g instead of 6g.
- Sensitivity analysis 4: Combined effects of sensitivity analyses 2 and 3.
- Sensitivity analysis 5: Assume the same split across recycling, incineration and landfill as in France.

The main results of the sensitivity analyses are:

- Repeating the analysis using a higher bag weight or 'effective' volume of paper bags led to a significant worsening in the performance of scenarios 1A and 1B for all categories except for 'risk of litter'. The categories of solid waste generation and acid rain, for which a small benefit was originally recorded under the base LCA (Carrefour, 100% of end-of-life bags landfilled), became a disbenefit (to a lesser extent for acid rain). The effect on solid waste generation is driven by the greater weight of paper bags compared with plastic bags (this feeds directly through to waste generation at the end of the lifecycle) and by the waste produced during paper production.

- Such effects are counteracted to a large degree by the assumption that lightweight plastic bags in Scotland are 8g compared to 6g in France.

- The assumptions on alternative waste management strategies (sensitivity analysis 5) have little effect on the results.

- The results for scenarios 1A and 1B are affected significantly by the sensitivities explored. This is as a result of encouraging people to switch from plastic bags to paper. Whereas, the results for scenarios 2A and 2B, where paper bags are also subject to the levy, show little change. In all cases studied and for all environmental indicators, scenarios 2A and 2B improved on the business as usual case by between 30% and 70%. The most restrictive scenario (2A, where all outlets including SMEs and charities are subject to the levy) shows a uniform improvement over scenario 2B of around 16% relative to business as usual.

It is important to recognise that the scores from the LCA represent *potential risk* and not actual environmental damage. Quantification of actual damage would require an impact pathway assessment that traces emissions from source to exposure to the quantification of impacts from specific industrial and waste management facilities. Such analysis is outside the scope of this report. It is noted, however, that some categories of effect are much more site-sensitive than others. For example, eutrophication of water bodies is only a problem where effluents are discharged untreated to a nutrient-sensitive water body. Climate change impacts, in contrast, are not sensitive to the site of the greenhouse gas release.

4.6 Displacement of Plastics in Scotland

In this section, we calculate the changes in tonnages of materials consumed in the scenarios based on the bag numbers data from Table 4.2 and the unit weights[34] for bags given in Table 4.4.

Table 4.4 Unit bag weights used in this study

	Weight (grams per unit)
Lightweight plastic carrier bags	8
Paper bags	51
Heavyweight plastic carrier bags	47
Bin liners	15

Table 4.5 shows the estimated changes in the weight of carrier bags (tonnes) used across Scotland in scenario 1A compared with the current pre-levy situation (scenario 0). Note that paper bags are not subject to the levy in scenario 1A.

Table 4.5 Change in annual consumption of materials for scenario 1A*

Bag	Pre-levy consumption (tonnes)	Expected post-levy consumption (tonnes)	Expected absolute change[35] (tonnes)	Expected % change
Lightweight plastic carrier bags	6,200	620	-5,580	-90%
Heavyweight plastic bags; 'bags for life'	364	1,102	+738	+203%
Bin liners	1.764	3,122	+1,358	+77%
Total for polyethene	**8,328**	**4,844**	**-3,484**	**-42%**
Total for paper	**1,976**	**10,869**	**+8,893**	**+450%**

* Numbers have been rounded so may not add up exactly. Negative numbers mean less material used and positive numbers mean more material is used.

For Scotland, there would be a saving of 5.580 tonnes of polyethene from 90% fewer lightweight plastic carrier bags being used. This has to be balanced, however, against the increase in 'bags for life' and bin liners – a total of 2,096 tonnes. Taken together, these data show an estimated net decrease of 3.484 tonnes of polyethene consumed per year in Scotland. Paper bag usage would increase under this scenario by 8,893 tonnes per year.

The summary information for all four levy scenarios is summarised in Table 4.6.

---

[34] Data from CBC and SRC For paper bags the checkout bag weighing 51g was used for consistency with the LCA base case. If the average weight of 99g, see footnote 31, was used then the waste implications would be greater

[35] As stated earlier, data on black refuse sacks and disposable nappy sacks were not available. If these figures were included, the net decrease in resource consumption would be less.

Table 4.6 Change in annual consumption of materials for all four levy scenarios across Scotland

	1A: Proposed levy	1B: Proposed levy excluding SMEs	2A: Proposed levy + paper bags	2B: Proposed levy + paper bags excluding SMEs
Decrease in polyethene consumption (tonnes)*	-3,484	-2,439	-3,214	-2,250
Change in paper consumption (tonnes)*	+8,893	+6,225	-1,779	-1,245
Net change (tonnes)	+5,409	+3,786	-4,993	-3,495

* Does not account for black refuse sacks or nappy bags.

In summary, it is predicted that polyethene amounts would reduce across all four levy scenarios, but that paper amounts would increase in scenarios 1A and 1B and decrease in scenarios 2A and 2B.

If paper carrier bags are not subject to the levy (as in scenarios 1A and 1B), the total tonnage of carrier bags used actually increases. This is because shoppers will switch from the relatively lighter plastic carrier bags to the much heavier paper carriers. Where paper is included in the levy, both show a decrease in the overall tonnage of waste material (paper and plastic) needing disposal. Scenario 2A, where paper and all businesses are levied, shows the best overall reductions (4,993 tonnes) relative to the situation today. Scenario 1A performs worst – waste actually increases by 5,409 tonnes per year.

4.7 Conclusions on Lifecycle Impacts

This study has used an existing published lifecycle study from France to gain an indication of the relative lifecycle environmental impacts of different types of bag. This has then been combined with estimates of changes in bag use under four levy scenarios to examine the resulting changes in environmental impacts from bag usage.

Using the Carrefour study introduces an element of uncertainty into the results owing to national differences between Scotland and France affecting the lifecycle, i.e. the way in which electricity is generated, the amount of transport required and final disposal methods.

However, based on the results of our various sensitivity analyses, we believe the pattern of environmental impacts described in the Carrefour study will be similar to those in Scotland. It is our view that the results described above are sufficiently relevant to Scotland to serve as a useful guide to decision-making on policies concerning carrier bags. However, for the reasons presented above, the findings in this report cannot be used for a precise quantification of environmental impacts. This would require a full lifecycle analysis based on the Scottish situation, which is outside the scope of this study.

The main conclusions from our analysis are:

- The analysis shows that there would be an environmental benefit for some of the indicators depending on what consumers choose to use were a levy to be introduced.
- More specifically, the biggest environmental improvement is seen in scenarios 2A and 2B where paper bags are included in the levy. These occur for all environmental indicators
- In scenarios where paper bags are excluded, the environmental benefits of reduced plastic bag usage are negated for some indicators by the impacts of increased paper bag usage. This is because a paper bag has a more adverse impact than a plastic bag for most of the environmental issues considered. Areas where paper bags score particularly badly include water consumption, atmospheric acidification (which can have effects on human health, sensitive ecosystems, forest decline and acidification of lakes) and eutrophication of water bodies (which can lead to growth of algae and depletion of oxygen).
- Heavyweight, reusable plastic bags (the so-called 'bags for life') are more sustainable than all types of lightweight plastic carrier bags **if used four times or more.** They give the greatest environmental benefits over the full lifecycle.
- Paper bags are anywhere between six to ten times heavier than lightweight plastic carrier bags and, as such, require more transport and its associated costs. They would also take up more room in a landfill if they were not recycled.
- The analysis demonstrates that SMEs and paper bags should be included to maximise the potential environmental benefit of the levy. The inclusion of paper bags in the levy makes a greater contribution to maximising environmental benefits than inclusion of SMEs.

5 Impacts on Consumers and Business

Our base assumptions (i.e. scenario 0) are as shown in Table 5.1 and stated below.

Table 5.1 Bag consumption by type in Scotland

Bag type	Annual consumption (millions)	Per capita consumption
Plastic carrier	775	153
Paper	38.75	8
Multi-use	7.75	2
Total	**821.5**	**163**

- The population of Scotland is taken as 5,062,011 (from the 2001 census) and the grossed number of households as 2.14 million. This is 2.33 people per household.
- The UK Expenditure and Food Survey 2002/03 [ONS] states that total weekly expenditure in Scotland averaged £365 per household. Of this figure, approximately £110 per week is spent on goods that are likely to be sold with the option of acquiring a carrier bag[36].
- It has been assumed that a £ spent by lower income households requires the same number of bags for purchases as a £ spent by higher income households[37].
- The two largest sources of carrier bags are 'food' and 'clothing' retailers, followed by 'catering services' (e.g. takeaway).
- Current consumption of bin liners is around 118 million per year.

5.1 Determining the Financial Burden on Consumers

We made the following assumptions concerning unit costs:

- A levy would be set at £0.10 on each bag. We derived the amount that would be paid from this value and the numbers of bags used as given in Table 4.2. We have accounted for the fact that, under scenarios 1B and 2B, SMEs are not included in the levy base.
- Consumers are currently not charged for carrier bags[38]. This cost element to retailers (which includes the purchase, transport and storage costs of the bags) is known as the 'hidden' cost and is accounted for. It is passed on to the consumer, embedded within the price of goods.

---

[36] We assessed the categories within the survey and made a judgement on whether a carrier bag might be required for purchases, e.g. insurance and holidays would not, but household goods and hardware would

[37] In reality it is more likely that a £ spent by a lower income household buys more goods and this requires more bags than a £ spent by higher income households, since the price paid per unit by the latter will be higher. Sufficiently detailed data were not available however to accommodate this complexity

[38] Except in some stores such B&Q and Lidl (see Appendix 2).

- The 'hidden' cost of lightweight plastic carrier bags to the retailer is £7.51 per 1,000 bags[39].
- The 'hidden' cost of paper carrier bags to the retailer is £163.69 per 1,000 bags[40].
- Heavyweight plastic carrier bags (or similar) are assumed to sell for £0.65 per bag[41].
- A bin liner is assumed to cost £0.05 per liner. This is the unit price averaged over ten products sold by Tesco.
- For scenarios 1A and 1B, it has been assumed that the additional 'hidden' costs incurred by stores are passed on to consumers as they increase due to additional purchase, transport and storage of paper carrier bags.
- Spending at SMEs has been assumed to account for 30% of total household expenditure[42]. In order to exclude SMEs from being subject to the levy, we have simply reduced total expenditure by households on items likely to involve the acquisition of a carrier bag (of any type) by 30%.

The total additional financial burden incurred by Scottish consumers as a result of the levy is therefore made up of the elements shown in Equation 5.1.

Equation 5.1 Financial burden to consumers

Total additional financial burden of levy
=
Payment of the levy on each levyable plastic carrier bag consumed post-levy
+
'Hidden' cost of carrier bags
+
Cost of **buying additional heavy use carrier bags** (or similar)
+
Cost of **buying additional bin liners** (or similar)
+
Payment of net **additional VAT**[43]

---

[39] Derived from data provided by the CBC and survey data reported by researchers from University College Dublin [UCD] The average cost of lightweight carrier bags to the retailer is £7.47 per 1,000 excluding storage and transport [CBC].

[40] Derived from data provided by the CBC and survey data reported by researchers from UCD. The average cost of paper bags to the retailer is £163.33 per 1,000 [CBC]. The switch to paper bags is largely assumed to be by the clothing and shoe retailers

[41] It is recognised that shoppers will have a wide range of options with an equally wide range of unit costs (e.g. currently from £0.10 for a 'bag for life' to £2.00 for an unbleached cotton carrier bag purchased privately). CBC suggested a range from 65p to £1.50; we used the lower figure. In addition, only those bags sold for more than €0.70 (approximately £0.48) are excluded from the levy in Republic of Ireland.

[42] Based on share of turnover in SIC(92) 52 retail trade with less than 250 employees determined by the Institute of Retail Studies, University of Stirling. Hence, in scenarios 1B and 2B, the levy is assumed to apply to 70% of the tax base in scenarios 1A and 2A. By adjusting the tax base in this fashion, it has been assumed that: a £ expenditure = a £ turnover and the number of bags issued per £ expenditure at a SME = the number of bags issued per £ expenditure at a non-SME. This is a crude assumption, but necessary without any data to the contrary.

[43] HM Revenue and Customs levy VAT on environmental taxes such as the climate change levy, the aggregates levy, the landfill tax and the oil duties. It is expected that the proposed carrier bags levy would likewise be subject to VAT

We calculated the total additional financial burden to consumers for the four levy scenarios using:

- Equation 5.1.
- Bag use data under the scenarios from Table 4.2.
- The assumptions outlined above.

Table 5.2 shows how the numbers were derived for scenario 1A.

Table 5.2 Incremental cost to consumers of the levy under scenario 1A

Cost element for Scottish consumers in an average year	**Annual cost under scenario 1A (£ million)**
Amount of levy paid by consumers (= local authority revenue)	7.75
Additional 'hidden' cost of bags	23.31
Cost of additional heavyweight bags	10.20
Cost of additional bin liners	4.34
Additional VAT	7.98
Total additional financial burden of scenario 1A in Scotland	53.58
Total additional financial burden of levy per person	**£10.58/person/year**

Table 5.3 shows the results for all four levy scenarios. The greatest effect on the results is from the additional 'hidden' costs, which can vary significantly. In the first instance, we have assumed that, for all four scenarios, any additional 'hidden' costs or savings are passed on to the consumer (see columns 2–5).

The 'hidden' costs increase significantly for scenarios 1A and 1B as, despite fewer plastic bags being used, far more paper carriers are being used. However, costs go down in the scenarios (2A and 2B) where paper is included in the levy (i.e. *hidden cost savings*), as both paper and plastic carrier bag use declines in these cases. At the discretion of the retailer, these savings could be passed on to the consumer, thus reducing the financial load on consumers (see columns 4 and 5). We have added to Table 5.3 the resulting costs in scenarios 2A and 2B assuming that the retailer does not pass on any savings they may accrue (see shaded columns 6 and 7).

Table 5.3 Incremental cost of the levy to consumers for all scenarios, with sensitivity on 'hidden' costs

	Scenario					
	1A	1B	2A	2B	2A – sensitivity	2B – sensitivity
	'Hidden' costs or savings passed on to consumers				*'Hidden' savings **not** passed on to consumers*	
Total additional financial burden of levy in Scotland (£ million/year)	53.58	37.51	18.05	12.63	30.91	21.64
Total additional financial burden of levy per person (£ /person/year)	10.58	7.41	3.57	2.50	6.11	4.27

The scale of the estimates of financial burden can be gauged by reference to the results in the UK Expenditure and Food Survey 2002/03 [ONS]. This shows that average weekly household expenditure is £365. Our examination of the categories of expenditure shows that £110 of this is likely to require use of a carrier bag. This can be compared with an annual cost of the levy of between £3.57 and £10.58 per person.

Based on data from the annual UK Expenditure and Food Survey 2002/03 [ONS], it is estimated that the costs given in Table 5.3 will represent a higher proportion of final income for households with lower incomes than for higher income households. Excluding paper bags from the levy base increases the financial burden (compare 1A with 2A and 1B with 2B), more than excluding SMEs (compare 1A with 1B and 2A with 2B).

5.2 Impact on the Business Sector

The proposed levy on plastic carrier bags will affect the economy as well as the environment. Our conclusions on the business and industry effects of the proposed levy are based on:

- Contact with industry.
- Examination of raw data.
- Evidence from previous studies on similar measures worldwide.

Scotland and the Plastic Carrier Bag Industry

CBC estimates that there are 15–20 plastic manufacturers, importers and distributors in Scotland, most of which are SMEs. We have validated this estimate through study of the online Applegate directory of plastics companies in the UK [Apgate]. The geographical distribution of these businesses shown in Table 5.4 indicates their wide distribution in Scotland. Both importers and/or distributors of carrier bags, as well as manufacturers, will be affected by the levy. In the Republic of Ireland, one manufacturer closed after PlasTax was introduced.

Table 5.4 Plastics and plastic bag manufacturers, importers and distributors in Scotland by postcode

Postcode	Total plastic	Plastic bags
AB	11	1
DD	8	1
DG	5	1
EH	22	4
FK	6	1
G	36	3
HS	0	0
IV	4	2
KA	9	0
KW	1	0
KY	11	3
ML	6	1
PA	5	0
PH	0	0
TD	5	0
Total	**129**	**17**

Smaller enterprises are considered more likely to suffer greater impacts from a levy as it is anticipated that they have less capacity to adapt. Discussion with industry suggests most of the bin liners produced in the UK are manufactured in England. It is considered unlikely that production could be switched to Scotland to compensate for some of the lost plastic carrier bag production.

Industry estimates that anywhere between 300 to 700 direct jobs could be lost in Scotland alone as a result of a levy being imposed on lightweight plastic carrier bags [CBC]. This estimate is made up of:

- Some 400 jobs at BPI's Greenock plant.
- Some 100 or so jobs at Simpac's plant in Glasgow.
- Jobs at other smaller manufacturers and importers that would either have to:
  - close;
  - move operations to elsewhere in the UK (as in Simpac's case to Hull) or abroad;
  - diversify where possible into other plastic film products.

Another important company that would be affected by a levy is Smith Anderson in Fife[44], which manufactures large volumes of paper bags from both virgin and recycled sources.

There would also be knock-on effects elsewhere in an industry that employs around 2,500 people in the manufacture, import and distribution of carrier bags and around 12,000 in the wider plastic films sector in the UK.

---

[44] www.smithanderson.com

Paper Sector

The extent to which lightweight plastic carrier bags may be replaced by paper carrier bags is an issue of contention. In the Republic of Ireland, some sectors (e.g. fashion and shoes) have switched to paper bags [BRC]. In the scenarios where paper bags are excluded from the levy (1A and 1B), a 25% switch to paper carrier bags has been assumed. A move towards greater use of paper carrier bags would have consequences for those sectors involved in their manufacture, transport, waste management and import. As mentioned above, Smith Anderson is a major company in the paper recycling and bag manufacturing industry in Scotland.

Retail Sector

The estimated cost to UK supermarkets of giving away lightweight **plastic** carrier bags is reported in Section 2 (see Table 2.1).

Evidence from Republic of Ireland and BRC suggests that the food retail industry would benefit from net cost savings from a levy after taking set-up and administrative costs into account. Savings would result from having to buy far fewer plastic carrier bags, which are then given away for free, while sales of 'bags for life' and bin liners would increase [BRC, ERM, UCD].

However, this would not be the case for non-food retailers. Evidence from the Republic of Ireland from those retailers that switched to paper bags (mainly 'high street' non-food retailers) suggests that greater storage space and more frequent deliveries are now required. This has increased their overhead costs for material purchase and transport by over four-fold [BRC]. There are also different consumption patterns between food and non-food retailers. For the former, people often shop regularly and can thus plan to take reusable bags with them. For the latter, it is often more of an impulse purchase [WRAP 2005].

Larger retailers are expected to find it easier to implement the system needs for compliance as they tend to have computerised systems and greater resources available. There will be a cost associated with administration of the levy, but the experience in the Republic of Ireland suggests that the effects were generally positive or neutral [UCD].

The levy would represent a greater burden to smaller retailers (e.g. newsagents, butchers, etc.) as they may not have computerised systems. As a minimum, it is anticipated that retailers will need to have an auditable system for:

- Recording carrier bags sales.
- Accounting for bags in stock.
- Reconciling sold versus stock remaining.
- Submitting records (quarterly in Republic of Ireland).
- Submitting payments.

Shoplifting and Theft

Theft, as an unwanted side effect of introducing a levy, is often raised as a problem for retailers. Although levels of theft were initially reported to have risen in the Republic of Ireland, they have since gone back to pre-levy levels and are even dropping further (information from the Department of Environment, Heritage and Local Government, Republic of Ireland).

The reported levels of 'shrinkage' (the industry term for theft) are calculated each year in the EU [Retail Research]. Table 5.5 shows shrinkage in percentage terms of turnover for 2003 and 2004 for the UK and Republic of Ireland. It is evident that both countries saw a drop in retail theft between 2003 and 2004.

Table 5.5 Changes in retail theft as a percentage of overall turnover for the UK and Republic of Ireland

Retail Shrinkage (as % of turnover)	2003	2004
UK	1.69%	1.59%
Republic of Ireland	1.35%	1.34%

Increased trolley and basket theft has been highlighted by some as a potential cost to industry caused by people wishing to save on paying for bags. Five months after the introduction of the PlasTax, the Retail, Grocery, Dairy and Allied Trades' Association (RGDATA) for the Republic of Ireland reported that 50 baskets per month were disappearing from shops at a total cost of €450/month.

Impacts for Waste Management

This section uses the changes in the weight and volume of bags under each levy scenario to assess the changes in waste arisings, changes in waste management costs and changes in waste volumes. Note that this is only part of the total waste due to carrier bags, the total waste impact (including waste in the winning of raw materials and production, which will often take place outside of Scotland) is considered in more detail in the LCA and is presented in Figure 4.2 and Appendix 3.

The change in consumption of materials under each levy scenario is considered in section 4.6. To assess the impacts on waste management we then need to add in details of the waste disposal routes.

In 2002/03[45], 88.2% of all waste arisings in Scotland were disposed of to landfill, 2.2% were incinerated, 5.9% were recycled, 2% were composted and the remaining 1.7% was treated by other means [SEPA].

---

[45] SEPA informed us that recycling rates for 2003/04 were 12.3% nationwide (data to be published in June 2005). However, 2002/03 SEPA statistics were used for consistency

For plastic bags we have assumed that there is a low level of recycling of post-consumer bags and that this would not change significantly if a levy were introduced. Thus, for the purpose of this calculation, all plastic bags would eventually be landfilled or incinerated[46]. We assumed that 97.6% of plastic bags were landfilled and 2.4% were incinerated[47]. It was not possible to estimate the quantity of lightweight plastic carrier bags or heavyweight plastic carrier bags going to each disposal route[48]. Instead, we applied the shares of landfill and incineration in total waste disposal equally to each.

For paper bags we were able to account for recycling in the calculations of waste management using Scottish waste statistic [SEPA][49]. Paper comes under the heading of 'paper and card' in SEPA data. As paper bags are not accounted for separately in SEPA waste statistics, we assumed that recycling rates for paper bags are the same as "paper and card". We made the following calculation:

- 24.26% of household 'bin' waste in Scotland is paper and card.
- 2,094,872 tonnes of household (controlled) waste were collected in 2002/03.
- This means that 508,216 tonnes of paper and card were collected from household waste for disposal (to landfill or incineration).
- 67,660 tonnes of paper and card were collected separately for recycling.
- Therefore, 13.3% of paper and card was recycled (67.660 tonnes/508,216 tonnes).
- The remaining paper is either landfilled (84.6%) or incinerated (2.1%)[50].

We estimated the change in paper bags waste for each disposal route using:

- Our calculation ratios for landfilling, incineration and recycling of paper in Scotland.
- The net total change in annual paper consumption (and hence waste production) under the four levy scenarios given in Table 4.6.

The amounts shown in Table 5.6 represent changes in the disposal of residual household waste and recycling in an average year under each of the levy scenarios.

Table 5.6 Estimated annual changes in waste disposal routes for residual waste in Scotland under the different scenarios

Scenario	Disposal route (tonnes per year)			
	Landfill	Incineration	Recycling	Net change
1A	4,122	103	1,184	5,409
1B	2,886	72	829	3,786
2A	-4,640	-116	-237	-4,993
2B	-3,248	-81	-166	-3,495

---

[46] Plastic *films* are recycled in large amounts, though this is mainly back-of-store packaging, estimated at 300,000 tonnes per year [CBC]. There is very little post-consumer recycling of plastic carrier bags and there are very few facilities to do so. For example, the recycling rate for lightweight carrier bags in Australia in 2002 was 2.7% [DEH].

[47] Step 1: 88.2% (landfilled) + 2.2% (incinerated) = 90.4% Step 2: 88.2% / 90.4% = 97.6%

[48] The facility is known to exist in many food retail outlets for the take-back and recycling of heavyweight bags-for-life, but no data on the level or rate of this was available.

[49] Recycling of paper bags was not considered for the LCA in Section 4 due to the assumptions in the Carrefour study. This will lead to a difference in the results presented here with those in section 4 under the 'solid waste' environmental indicator.

[50] 13.3% of paper is recycled. This leaves 86.7% going to another route. 97.6% will be landfilled 97.6 % × 86.7% = 84.6% overall. 2.4% will be incinerated: 2.4% × 86.7% = 2.1 % overall.

Table 5.7[51] shows estimated changes in landfill and incineration costs for household waste in Scotland as a whole, under each levy scenario. Costs increase under scenarios 1A and 1B, while costs decrease under scenarios 2A and 2B. These cost increases or decreases apply to local authorities who are responsible for household waste disposal.

Table 5.7 Estimated changes in waste management costs for Scotland due to the levy[52]

Scenario	Cost (£ per year)		
	Landfill	**Incineration**	**Total**
1A	227,000	7,000	**233,000**
1B	159,000	5,000	**163,000**
2A	-255,000	-8,000	**-263,000**
2B	-179,000	-5,000	**-184,000**

The amount of solid waste generated can also be quantified in terms of volume. The Carrefour study only gives information on weight for the full life cycle, though it is clear that this is dominated by the end of life stage. Using data on relative bag storage volume from Table 2.1 it is possible to estimate the relative difference in volume of material sent for disposal (see Table 5.8), though this ignores wastes generated at stages other than end of life disposal. Results show a significant increase for scenarios 1A and 1B for volume relative to the base case. For scenarios 2A and 2B, however, the volume of bags disposed of relative to the base case falls significantly.

Table 5.8 Estimated changes in waste volumes in Scotland due to the levy

Change in Volume – assuming 50 g paper bag occupying 8 times the volume of HDPE lightweight bags					
As % of base case	100%	167%	148%	20%	44%

Charities

In a submission to Mike Pringle MSP, the Association of Charity Shops expressed its belief that the ability of some charity shops to operate successfully would be jeopardised by the proposed levy[53]. The Association is also concerned that donations by the public would become difficult, as donated stock delivered to shops is usually in plastic carrier bags. These bags are then reused for customer purchases.

---

[51] Figures have been rounded.

[52] Savings based on landfill costs of £55/tonne and incineration costs of £65/tonne. The unit costs include collection, transfer and gate fees (including landfill tax in the case of landfill). However, it has not been possible to separate the fixed from the variable elements of the costs. Given the relatively small scale of the changes in waste tonnages, only the latter will be saved. The cost savings will therefore tend to be overestimates. However, landfill costs are likely to rise during the same period as a result of the landfill tax escalator.

[53] Response by the Association of Charity Shops to consultation paper issued by Mike Pringle MSP.

6 Administration of the Levy

The mechanism by which local authorities would administer the levy falls within an exception to the reservations in the Scotland Act 1998 (Section A1, Part II, Schedule 5 Fiscal, economic and monetary policy). This states that local taxes to fund local authority expenditure fall within devolved competence. It is this exception which is being investigated by Mike Pringle MSP. We have not considered the validity of this exception, but have considered some of the implications for administering the levy should the Bill proceed.

6.1 System Requirements

A system will be required which will allow for:

- Monies to be collected from 'retailers' and held in a local authority account.
- Keeping records of customer transaction.
- Auditing and inspection.
- System checks and interrogation re anticipated income, documentation files and generation of customer queries.
- Development of an appeals system.
- Development of systems to pursue debt and non-payment.

Businesses would need advice on:

- How the levy would operate.
- Definitions of what types of bags the levy covered.
- What information they would be required to submit, e.g. stock of bags at outset, stock remaining at end of submission period and records of bags sold.
- How and when the monies collected should be transferred (ideally electronically) to the administration body.
- The penalties for non-compliance.

System in the Republic of Ireland

In the Republic of Ireland, businesses submit quarterly returns. There are separate and distinct roles and bodies for collection and enforcement. Payment is by electronic debiting of the retailer's bank account. An online system that allowed this, the Revenue Online System (ROS), was in place prior to the introduction of the PlasTax.

So far, there has been one prosecution for non-compliance. Any retailer not complying with the legislation has been visited, their non-compliance verified and a warning issued. Warnings have been issued to a few hundred out of around 50,000 retailers [communication from Terry Sheridan, the Department of Environment, Heritage and Local Government, Republic of Ireland].

Small changes in the way we perform everyday tasks can have huge impacts on Scotland's environment.

Walking short distances rather than using the car, or being careful not to overfill the kettle are just two positive steps we can all take.

This butterfly represents the beauty and fragility of Scotland's environment. The motif will be utilised extensively by the Scottish Executive and its partners in their efforts to persuade people they can do a little to change a lot.

ISBN 0-7559-2685-4
9 780755 926855

100% of this document is printed on recycled paper and is 100% recyclable

This document is also available on the Scottish Executive website www.scotland.gov.uk
Astron B42643 08/05

BOUSTEAD CONSULTING & ASSOCIATES

"FINAL REPORT"

Life Cycle Assessment for Three Types of Grocery Bags - Recyclable Plastic; Compostable, Biodegradable Plastic; and Recycled, Recyclable Paper

Prepared for the Progressive Bag Alliance

Chet Chaffee and Bernard R. Yaros
Boustead Consulting & Associates Ltd.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

In the pursuit to eliminate all that is not green, plastic seems to be a natural target. Its widespread use in products and packaging, some say, has contributed to environmental conditions ranging from increased pollution to overloaded landfills to the country's dependence on oil. In response, some cities have adopted legislation that bans plastic grocery bags made from polyethylene in favor of bags made from materials such as cloth, compostable plastics, or paper.

But will switching from grocery bags made from polyethylene to bags made from some other material guarantee the elimination of unfavorable environmental conditions? We know that every product—through its production, use, and disposal—has an environmental impact. This is due to the use of raw materials and energy during the production process and the emission of air pollutants, water effluents, and solid wastes.

More specifically, are grocery bags made other materials such as paper or compostable plastics really better for the environment than traditional plastic grocery bags? Currently, there is no conclusive evidence supporting the argument that banning single use plastic bags in favor of paper bags will reduce litter, decrease the country's dependence on oil, or lower the quantities of solid waste going to landfills. In addition, there is limited information on the environmental attributes of compostable plastics and how they fare against traditional plastic grocery bags or paper bags.

To help inform the debate about the environmental impacts of grocery bags, the Progressive Bag Alliance contracted with Boustead Consulting & Associates (BCAL) to conduct a life cycle assessment (LCA) on three types of grocery bags: a traditional grocery bag made from polyethylene, a grocery bag made from compostable plastics (a blend of 65% EcoFlex, 10% polylactic acid or PLA, and 25% calcium carbonate), and a paper grocery bag made using at least 30% recycled fibers. The life cycle assessment factored in every step of the ~~manufacturing, distribution~~, and disposal stages of these grocery bags. It was recognized that a single traditional plastic grocery bag may not have the same carrying capacity as a paper bag, so to examine the effect of carrying capacity, calculations were performed both on a 1:1 basis as well as an adjusted basis (1:1.5) paper to plastic.

BCAL compiled life cycle data on the manufacture of polyethylene plastic bags and compostable plastic bags from the Progressive Bag Alliance. In addition, BCAL information on the compostable plastic resin EcoFlex from the resin manufacturer BASF. BCAL completed the data sets necessary for conducting life cycle assessments using information extracted from The Boustead Model and Database as well as the technical literature. BCAL used the Boustead Model for LCA to calculate the life cycle of each grocery bag, producing results on energy use, raw material use, water use, air emissions, water effluents, and solid wastes.

The results show that single use plastic bags made from polyethylene have many advantages over both compostable plastic bags made from EcoFlex and paper bags made with a minimum of 30% recycled fiber.

what is assumed recycle rate →

what is a typical bag made of? →	Impact Summary of Various Bag Types		
	(Carrying Capacity Equivalent to 1000 Paper Bags)		
	Paper (30% Recycled Fiber)	Compostable Plastic	Polyethylene
Total Enegy Usage (MJ)	2622	2070	763
Fossil Fuel Use (kg)	23.2	41.5	14.9
Municipal Solid Waste (kg)	33.9	19.2	7.0
Greenhouse Gas Emissions (CO2 Equiv. Tons)	0.08	0.18	0.04
Fresh Water Usage (Gal)	1004	1017	58

When compared to 30% recycled fiber paper bags, polyethylene grocery bags use less energy in terms of fuels for manufacturing, less oil, and less potable water. In addition, polyethylene plastic grocery bags emit fewer global warming gases, less acid rain emissions, and less solid wastes. The same trend exists when comparing the typical polyethylene grocery bag to grocery bags made with compostable plastic resins—traditional plastic grocery bags use less energy in terms of fuels for manufacturing, less oil, and less potable water, and emit fewer global warming gases, less acid rain emissions, and less solid wastes.

The findings of this study were peer reviewed by an independent third party with significant experience in life cycle assessments to ensure that the results are reliable and repeatable. The results support the conclusion that any decision to ban traditional polyethylene plastic grocery bags in favor of bags made from alternative materials (compostable plastic or recycled paper) will result in a significant increase in environmental impacts across a number of categories from global warming effects to the use of precious potable water resources. As a result, consumers and legislators should re-evaluate banning traditional plastic grocery bags, as the unintended consequences can be significant and long-lasting.

Introduction

In the national effort to go green, several states, counties, and cities are turning their attention to plastic grocery bags made from polyethylene because of the perception that plastic bags contribute to local and global litter problems that affect marine life, occupy the much needed landfill space with solid waste, and increase U.S. dependence on oil.

To address these environmental issues, and perhaps in seeking to follow the example of other countries such as Australia and Ireland, legislators in several cities across the United States have proposed or have already passed ordinances banning single use polyethylene plastic grocery bags in favor of bags made from alternative materials such as cloth, paper, or compostable plastic. Legislators state that they believe that these new laws and proposals will reduce litter, reduce the use of fossil fuels, and improve the overall environmental impacts associated with packaging used to transport groceries.

Before we examine whether plastic bags cause more environmental impacts than the alternative materials proposed, we should first consider the most commonly proposed alternatives, which tend to include: cloth bags, compostable plastic bags, and paper bags.

Reusable cloth bags may be the preferred alternative, but in reality, there is no evidence that most, or even a majority of, customers will reliably bring reusable bags each time they go shopping.

Compostable plastic bags, although available, are in short supply as the technology still is new, and therefore cannot currently meet market demand. So it appears that the proposed laws banning plastic grocery bags may simply cause a shift from plastic bags to the only alternative that can immediately supply the demand—paper bags.

Therefore, is legislation that mandates one packaging material over another environmentally responsible given that all materials, products, and packaging have environmental impacts? The issue is whether the chosen alternatives will reduce one or several of the identified environmental impacts, and whether there are any trade-offs resulting in other, potentially worse, environmental impacts.

To help inform the debate on the environmental impacts of grocery bags, and identify the types and magnitudes of environmental impacts associated with each type of bag, the Progressive Bag Alliance contracted Boustead Consulting & Associates (BCAL) to conduct a life cycle assessment (LCA) on single use plastic bags as well as the two most commonly proposed alternatives: the recyclable paper bag made in part from recycled fiber and the compostable plastic bag.

Life cycle assessment is the method being used in this study because it provides a systems approach to examining environmental factors. By using a systems approach to analyzing environmental impacts, one can examine all aspects of the system used to produce, use, and dispose of a product. This is known as examining a product from cradle (the extraction of raw materials necessary for producing a product) to grave (final disposal of the product). LCA has been practiced since the early 1970s, and standardized through several organizations including SETAC (Society of Environmental Toxicology and Chemistry) and ISO (International Standards Organization). LCA studies examine the inputs (resources and energy) and outputs (air emissions, water effluents, and solid wastes) of each system and thus identifies and quantifies the effects of each system, providing insights into potential environmental impacts at local, regional, and global levels.

To compile all the information and make the calculations, BCAL uses the Boustead Model and Database. The Boustead Model and Database is an LCA software model with a database built over the past 25 years, containing a wide variety of data relevant to the proposed study. Dr. Boustead has pioneered the use of life-cycle methods and has conducted hundreds of studies, including those for the plastics industry; which have been reviewed by US and European industry as well as life-cycle practitioners.

Study Goal

According to ISO 14040, the first steps in a life cycle project are defining the goal and scope of the project to ensure that the final results meet the specific needs of the user. The purpose of this study is to inform the debate on the environmental impacts of grocery bags, and identify the types and magnitudes of environmental impacts associated with each type of bag. In addition, the study results aim to inform the reader about the potential for any environmental trade-offs in switching from grocery bags made from one material, plastic, to another, paper.

The life cycle assessment was conducted on three types of grocery bags: a traditional grocery bag made from polyethylene, a grocery bag made from compostable plastics (a blend of 65% EcoFlex, 10% polylactic acid or PLA, and 25% calcium carbonate), and a paper grocery bag made using at least 30% recycled fibers. It is important to note that the study looked at only one type of degradable plastic used in making grocery bags, which is the bag being studied by members of the Progressive Bag Alliance. Since this is only one of a number of potential blends of plastic that are marketed as degradable or compostable, the results of this study cannot be used to imply that all compostable bags have the same environmental profile.

Scope

The scope of the study is a cradle to grave life cycle assessment which begins with the extraction of all raw materials used in each of the bags through to the ultimate disposal of the bags after consumer use, including all the transport associated with the delivery of raw materials and the shipping and disposal of final product.

The function of the product system under study is the consumer use and disposal of a grocery bag. The functional unit is the capacity of the grocery bag to carry consumer purchases. A 1/6 BBL (Barrel) size bag was selected for all three bags in this study because that is the commonly used bag in grocery stores. Although the bags are of equal size, previous studies (Franklin, 1990) pointed out that the use of plastic bags in grocery stores was not equal to the use of paper bags. According to Franklin (1990), bagging behavior showed that plastic to paper use ranged from 1:1 all the way to 3:1, depending on the situation. In contrast, data collected by the Progressive Bag Alliance shows that plastic and paper bags are somewhat equal in use once the baggers have been properly trained. In this study BCAL used both 1:1 and 1.5:1 plastic to paper ratios, allowing for the possibility that it still takes more plastic bags to carry the same amount of groceries as a paper bag. The 1.5:1 ratio equates to 1500 plastic bags for every 1000 paper bags.

BCAL prepared LCA's for the three types of grocery bags. The data requirements for BCAL and for the Progressive Bag Alliance are outlined below.

1. *Recyclable Paper Bag LCA……… The following operations are to be included in the analysis:* To start, BCAL provided data on the extraction of fuels and feedstocks from the earth, including tree growing, harvesting, and transport of all materials. BCAL added process operations in an integrated unbleached kraft pulp & paper mill including recycling facility for old corrugated containers; paper converting into bags; closed-loop recycling of converting bag waste; packaging and transport to distribution and grocery stores; consumer use; and final disposal. Data for most of the above operations in one form or another are in the Boustead Model and Database. Weyerhaeuser reported that its unbleached kraft grocery bag contains about 30% post consumer recycled content and the use of water-based inks[1]. Therefore, in this study BCAL used 30% recycled material. This is also somewhat reflective of current legislation where minimum recycled content in paper bags is required (see Oakland City Council Ordinance requiring 40% recycled material). In the operations leading to final disposal BCAL estimated data for curbside collection and generation and recovery of materials in MSW from government agencies and EPA data, which for 2005 showed paper bag recycling at 21%, paper bag MSW for combustion with energy recovery at 13.6%, resulting in 65.4% to landfill[2]. The following final disposal options will also be considered: composting and two landfill scenarios.

Can we require ↑ recycled paper in bags

2. *Recyclable Plastic Bag LCA……… The following operations are to be included in the analysis:* The extraction of fuels and feedstocks from the earth; transport of materials; all process and materials operations in the production of high and low density polyethylene resin[3]; converting PE resin into bags; packaging and transport of bags to distribution centers and grocery stores; consumer use; and final disposal. In the operations leading to final disposal, BCAL estimated data for curbside collection and generation and recovery of materials in MSW from government agencies and EPA data, which for 2005 showed plastic bag recycling at 5.2 %, plastic bag MSW for combustion with energy recovery at 13.6%, resulting in 81.2% to landfill[2]. The following final disposal options will also consider two landfill scenarios.

   Data for the converting operation was collected specifically from a member of the Progressive Bag Alliance that makes only plastic grocery bags. The data obtained, represents the entire annual production for 2006. All waste is reprocessed on site, so that is how the calculations were conducted. All inks are water-based, and the formulas provided. The production and supply of all PE resin is based on materials produced and transported from a Houston based supplier. The corrugated boxes were included as made from recycled material to reflect the fact that the supplier to the PBA member reported using between 30% and 40% post consumer recycled fiber[1].

3. *Degradable Plastic Bag (EcoFlex and PLA mix) LCA……… The following operations are to be included in the analysis:* The extraction of fuels and feedstocks from the earth; production and transport of materials for all process and materials operations in the production of polylactide resin; EcoFlex from BASF (data provided by BASF)[4]; and calcium carbonate, converting the EcoFlex/PLA resin mixture into bags; packaging and transport of bags to distribution centers and grocery stores; consumer use; and final disposal. Again, most of the above operations are contained in the Boustead Model and Database. The production data for PLA was obtained from NatureWorks[5] and the data for EcoFlex was obtained from BASF[4]. Both NatureWorks and BASF use the Boustead Model for their LCA calculations, so the data BCAL requested and received was compatible with other data used in the study. In addition, BCAL sent its calculated results to BASF for confirmation that the data and the calculations on bags made from the EcoFlex compostable resin was accurate. BASF engineers confirmed that BCAL's use of the data and the calculated results were appropriate. In the operations leading to final disposal, BCAL estimated data for curbside collection and generation and recovery of materials in MSW from government agencies and EPA data[3], which for 2005 showed plastic bag recycling at 5.2 %, plastic bag MSW for combustion with energy recovery at 13.6%, resulting in 81.2% to landfill[2]. The following final disposal options will be also be considered: composting and two landfill scenarios.

   Data for the converting operation of the EcoFlex/PLA resin mixture was collected at the same PBA member facility during a two-week period at the end of May 2007. The production and supply of the PLA polymer is from Blair, NE. The production and supply of Ecoflex polymer is from a BASF plant in Germany. The trial operations at the PBA member's facility indicate that the overall energy required to produce a kilogram of EcoFlex/PLA bags may be lower than the overall energy required to produce a kilogram of PE bags, based on preliminary in-line electrical measurements conducted by plant engineers. However, these results still are preliminary, and need to be confirmed when full scale operations are implemented. As a result, this study will assume that the overall energy required to produce a kilogram of EcoFlex/PLA bags is the same as the overall energy required to produce a kilogram of PE bags. The plastic bag recycling at 5.2 %, will be assumed to go to composting. The inherent energy of the degradable bags has been estimated from NatureWorks and BASF sources.

The following are some detailed specifications for the LCA study:

	Recyclable Plastic	Degradable Plastic	Recyclable Paper
Size/type	1/6 BBL	1/6 BBL	1/6 BBL
Length (inches)	21.625	22.375	17
Width (inches)	12	11.5	12
Gusset (inches)	7.25	7.25	6.75
Gauge (Mil)	0.51	0.75	20 lb /1000 sq ft
Film Color	White	White	Kraft
Material	HDPE (film grade blend)	Degradable Film Compound (EcoFlex/PLA mix)	Unbleached Kraft Paper
Jog Test (strokes)	45	20	n/a
Tensile Strength (lb)	50	35	n/a
Weight per 1000 bags in lbs	13.15 (5.78 kg)	34.71 (15.78 kg)	114 (51.82 kg)

Human energy and capital equipment will not be included in the LCA; detailed arguments for this decision are presented in the proposal appendix.

Methodological Approach

BCAL followed the sound scientific practices as described in ISO 14040, 14041, and 14042 to produce the project results. BCAL is well versed in the requirements of the ISO standards as Dr. Ian Boustead has and continues to be one of the leading experts participating in the formation of the ISO standards. The procedures outlined below are consistent with the ISO standards and reflect BCAL's approach to this project.

Calculations of LCAs

The Boustead database contains over 6000 unit operations on the processes required to extract raw materials from the earth, process those materials into useable form, and manufacture products. These operations provide data on energy requirements, emissions and wastes.

The "Boustead Model" software was used to calculate the consumption of energy, fuels, and raw materials, and generation of solid, liquid, and gaseous wastes starting from the extraction of primary raw materials. The model consists of a calculating engine that was developed 25 years ago and has been updated regularly based on client needs and technical innovations. One important consequence of the modeling is that a mass balance for the entries system is calculated. Therefore, the resource use and the solid waste production are automatically calculated.

Fuel producing industry data are available for all of the OECD countries and some non-OECD countries. The United States and Canada are further analyzed by region; the US is divided into 9 regions and Canada is sub-divided in 5 regions, corresponding to the Electric Reliability Council. For both the US and Canada, there also is a national average. Since the whole of the Model database can be switched from one country to another, any operation with data from outside the US can be adjusted for energy from non-US energy inputs to "USA adjusted" energy inputs. Assuming that the technology is the same, or very similar, this allows BCAL to fill any data gaps with data from similar operations in non-US locations.

Another important aspect of calculating LCAs is the use of allocation procedures when differentiating the use of energy and raw materials associated with individual products within a single system. In many cases, allocation methods that defy or at the very least, ignore sound scientific practice (such as economics) have been used when they benefit clients. These types of errors or biases are important to avoid as they are easily discovered by peer reviewers or technical experts seeking to use the results in subsequent studies (such as building applications), which unfortunately can cause the rest of the work to be discounted due to unreliability. BCAL has considerable experience in this arena having published several technical papers on the appropriate allocation principles in the plastics industry. Utilizing sound scientific principles and objective measures to the greatest extent possible, BCAL has been able to avoid most problems associated with allocation decisions and produce accurate and reliable LCA data for a wide variety of plastics. Proof of this is the widespread use of PlasticsEurope data (produced by Boustead Consulting) in almost every life cycle database available worldwide as well as in life cycle studies in numerous product and building applications.

Calculated data are readily aggregated and used to produce the final LCA data set which includes the impact assessment step of LCA. These resulting data sets address specific environmental problems.

Using LCA data....BCAL scientific viewpoint

Life cycle assessment modeling allows an examination of specific problems as well as comparisons between systems to determine if there are any serious trade-offs between systems. In every system there are multiple environmental parameters to be addressed scaling from global to local issues. No single solution is likely to address all of the issues simultaneously. More importantly, whenever choices are being made to alter a system or to utilize an alternative system, there are potential trade-offs. Understanding those trade-offs is important when trying to identify the best possible environmental solution. Hopefully, decisions to implement a change to an existing system will consider the potential trade-offs and compromises. While LCA can identify the environmental factors and trade-offs, choosing the solution that is optimal is often subjective and political. Science can only help by providing good quality data from which decisions can be made. The strength of the proposed LCA assessment system is that these unwanted side effects can be identified and quantified.

A life cycle assessment can:

1. Quantify those parameters likely to be responsible for environmental effects (the inventory component of life cycle analysis).

2. Identify which parameters are likely to contribute to a specific environmental problem (characterization or interpretation phase of impact assessment). An example would be identifying that carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are greenhouse gases.
3. Aggregate the parameters relating to a specific problem (the valuation or interpretation phase of impact assessment). An example would be producing carbon dioxide equivalents for the components of greenhouse gases.

LCA derived data provide a compilation of information from which the user can address specific problems, while also examining potential trade-offs. For example, if interested in addressing specific conservation issues such as the conservation of fossil fuels, the user would examine the mass and energy data for only coal, oil, and natural gas; and ignore the other information. If the user would like to examine the potential impacts the grocery bag system has on global warming, acid rain, and municipal solid waste one can address these issues both individually and cooperatively by examining the specific parameters which are likely to contribute to each. In so doing, the user can strive to achieve the optimum reduction in each parameter because of a better understanding of how these parameters change in association with the grocery bag system as a whole and each other individually.

Data Sources and Data Quality

As noted above, data sources included published reports on similar materials, technical publications dealing with manufacturing processes, and data incorporated into the Boustead Model and Database, most of which has been generated through 30 years of industrial studies on a wide range of products and processes.

ISO standards 14040, 14041, and 14042 each discuss aspects of data quality as it pertains to life cycle assessments. In general, data quality can be evaluated using expert judgment, statistics, or sensitivity analysis. In LCA studies, much of the data do not lend itself to statistical analyses as the data are not collected randomly or as groups of data for each input variable. Instead, most LCA data are collected as single point estimates (i.e., fuel input, electricity input, product output, waste output, etc). Single point estimates are therefore only able to be evaluated through either expert judgment or sensitivity analysis. Since the reliability of data inevitably depends upon the quality of the information supplied by individual operators, BCAL used its expert judgment to carry out a number of elementary checks on quality. BCAL checked mass and energy balances to ensure that the data did not violate any of the basic physical laws. In addition, BCAL checked data from each source against data from other sources in the Boustead Model and Database to determine if any data fell outside the normal range for similar products or processes.

Data reporting

To enhance the comparability and understanding of the results of this study, the detailed LCA results are presented in the same presentation format that was used for the series of eco-profile reports published by the Association of Plastics Manufacturers in Europe

(APME). A set of eight tables, each describing some aspect of the behavior of the system, shows the results of the study. Five tables in the data set are useful in conservation arguments and three tables are indications of the potential pollution effects of the system.

The performance of the grocery bag systems is described by quantifying the inputs and outputs to the system. The calculation of input energy and raw materials quantifies the demand for primary inputs to the system and these parameters are important in conservation arguments because they are a measure of the resources that must be extracted from the earth in order to support the system.

Calculation of the outputs is an indication of the potential pollution effects of the system. Note that the analysis is concerned with quantifying the emissions; it does not make any judgments about deleterious or beneficial properties.

The inputs and outputs depend on the definition of the system—they are interrelated. Therefore, any changes to the components of the system means that the inputs and outputs will likely change as well. One common misconception is that it is possible to change a single input or output while leaving all other parameters unchanged. In fact, the reverse is true; because a new system has been defined by changing one input or output, all of the inputs and outputs are expected to change. If they happen to remain the same, it is a coincidence. This again illustrates the fact that common perceptions about environmental gains from simple changes may be misleading at best, and detrimental to the environment at worst.

Increasingly there is a demand to have the results of eco-profile analyses broken down into a number of categories, identifying the type of operation that gives rise to them. The five categories that have been identified are:

1. Fuel production
2. Fuel use
3. Transport
4. Biomass
5. Process

Fuel production operations are defined as those processing operations which result in the delivery of fuel, or energy; to a final consumer whether domestic or industrial. For such operations all inputs, with the sole exception of transport, are included as part of the fuel production function.

Fuel use is defined as the use of energy delivered by the fuel producing industries. Thus fuel used to generate steam at a production plant and electricity used in electrolysis would be treated as fuel use operations. Only the fuel used in transport is kept separate.

Transport operations are easily identified and so the direct energy consumption of transport and its associated emissions are always separated.

Biomass refers to the inputs and outputs associated with the use of biological materials such as wood or wood fiber.

LCA RESULTS TABLES

RECYCLABLE PAPER BAG SYSTEM

The results of the LCA for the recyclable paper bag system are presented below, each describing some aspect of the behavior of the systems examined. In all cases, the following tables refer to the gross or cumulative totals when all operations are traced back to the extraction of raw materials from the earth and are based on the consumer use and collection of 1000 bags. The subsequent disposal operations of recycling, composting, incineration with energy recovery and landfill are not included in these results tables and will be discussed separately.

Table 1. Gross energy (in MJ), required for the recyclable PAPER bag LCA. Based on consumer use & collection of 1000 bags. Totals may not agree because of rounding.

Fuel type	Fuel prod'n & delivery	Energy content of fuel	Transport energy	Feedstock energy	Total energy
Electricity	461	185	3	0	649
Oil	17	143	30	1	191
Other	15	777	1	990	1783
Total	493	1105	34	991	2622

Table 2. Gross primary fossil fuels and feedstocks, expressed as energy (in MJ), required for the recyclable PAPER bag LCA. Based on consumer use & collection of 1000 bags. Totals may not agree because of rounding.

	Fuel prod'n	Fuel use	Transport	Feedstock	Total
Coal	229	94	1	0	324
Oil	23	150	33	1	207
Gas	113	278	0	0	391
Hydro	15	6	0	-	21
Nuclear	90	36	0	-	127
Lignite	0	0	0	-	0
Wood	0	533	0	988	1521
Sulfur	0	0	0	2	2
Hydrogen	0	0	0	0	0
Biomass (solid)	18	7	0	0	24
Recovered energy	0	-1	0	-	-1
Geothermal	0	0	0	-	0
Unspecified	0	0	0	-	0
Solar	0	0	0	-	0
Biomass (liqd/gas)	1	0	0	-	1
Industrial waste	1	0	0	-	1
Municipal Waste	3	1	0	-	4
Wind	0	0	0	-	0
Totals	493	1105	34	991	2622

Table 3. Gross primary fossil fuels and feedstocks, expressed as mass (in milligrams), the recyclable PAPER bag LCA. Based on consumer use & collection of 1000 bags. Totals may not agree because of rounding.

Crude oil................	4,591,000
Gas/condensate........	7,432,000
Coal.....................	11,210,000
Metallurgical coal......	25,900
Lignite	79
Peat	444
Wood (50% water).....	274,000,000
Biomass (incl. water)...	2,880,000

Table 4. Gross water resources (in milligrams) required for the recyclable PAPER bag LCA. Based on consumer use & collection of 1000 bags. Totals may not agree because of rounding.

Source	Use in process	Use in cooling	Totals
Public supply	3,895,000,000	-	3,895,000,000
River/canal	5,260	1,920	7,190
Sea	8,490	1,092,000	1,100,000
Unspecified	14,600,000	2,910,000	17,500,000
Well	200	50	250
Totals	3,909,000,000	4,000,000	3,913,000,000

Note: total cooling water reported in recirculating systems = 404.

Table 5. Gross other raw materials (in milligrams required for the recyclable PAPER bag LCA. Based on consumer use & collection of 1000 bags. Totals may not agree because of rounding.

Raw material	Input in mg
Air	4,080,000
Animal matter	0
Barites	211
Bauxite	469
Bentonite	51
Biomass (including water)	0
Calcium sulphate (CaSO4)	0
Chalk (CaCO3)	0
Clay	46,300
Cr	31
Cu	0
Dolomite	792
Fe	64,800
Feldspar	0
Ferromanganese	59
Fluorspar	9
Granite	0
Gravel	239
Hg	0
Limestone (CaCO3)	385,000
Mg	0
N2	6,050
Ni	0
O2	1,180
Olivine	608
Pb	395
Phosphate as P205	147,000
Potassium chloride (KCl)	7
Quartz (SiO2)	0
Rutile	0
S (bonded)	1
S (elemental)	233,000
Sand (SiO2)	101,600
Shale	1
Sodium chloride (NaCl)	712,000
Sodium nitrate (NaNO3)	0
Talc	0
Unspecified	0
Zn	14

Table 6. Gross air emissions (in milligrams) resulting from the recyclable PAPER bag LCA. Based on consumer use & collection of 1000 bags. Totals may not agree because of rounding.

Air emissions/mg	Fuel prod'n	Fuel use	Transport	Process	Biomass	Fugitive	Total
Dust	32,900	4,440	1,930	89,000	-	-	128,000
CO	59,500	16,300	23,000	21,900	-	-	121,000
CO2	43,100,000	22,600,000	2,330,000	1,066,000	-63,600,000	-	5,507,000
SOX	168,000	166,000	6,030	239,000	-	-	579,000
NOX	151,000	86,400	26,500	600	-	-	264,000
N2O	<1	<1	-	-	-		<1
Hydrocarbons	49,000	16,000	7,300	60	-		72,300
Methane	266,000	16,200	10	3,500	-		286,000
H2S	<1	-	<1	2,750	-	-	2,750
Aromatic HC	6	-	98	1	-	-	105
HCl	6,440	42	4	622	-		7,110
Cl2	<1	-	<1	<1	-		<1
HF	242	2	<1	<1	-		244
Lead	<1	<1	<1	<1	-		<1
Metals	25	105	-	<1	-		131
F2	<1	-	<1	<1	-		<1
Mercaptans	<1	<1	<1	802	-	-	802
H2	124	<1	<1	91	-	-	215
Organo-chlorine	<1	-	<1	<1	-		<1
Other organics	<1	<1	<1	<1	-		1
Aldehydes (CHO)	-	-	-	13	-		13
Hydrogen (H2)	152	-	-	3,130	-		3,280
NMVOC	2	-	<1	<1	-		2

Table 6B. Carbon dioxide equivalents corresponding to the gross air emissions (in milligrams) resulting from the recyclable PAPER bag LCA. Based on consumer use & collection of 1000 bags. Totals may not agree because of rounding.

Type/mg	Fuel prod'n	Fuel use	Transport	Process	Biomass	Total
20 year equiv	59,850,000	23,690,000	2,400,000	1,330,000	-63,560,000	23,710,000
100 year equiv	49,460,000	23,060,000	2,400,000	1,190,000	-63,560,000	12,550,000
500 year equiv	45,200,000	22,800,000	2,400,000	1,130,000	-63,560,000	7,970,000

Table 7. Gross water emissions (in milligrams), resulting from the recyclable PAPER bag LCA. Based on consumer use & collection of 1000 bags.. Totals may not agree because of rounding.

	Fuel prod'n	Fuel use	Transport	Process	Total
COD	55	-	35	396,000	396,000
BOD	14	-	<1	75,000	75,000
Acid (H+)	11	-	<1	1	13
Al+compounds as Al	<1	-	<1	<1	<1
Ammonium compounds as NH4	19	-	2	<1	22
AOX	<1	-	<1	<1	<1
As+compounds as As	-	-	<1	<1	<1
BrO3--	<1	-	<1	<1	<1
Ca+compounds as Ca	<1	-	<1	19	20
Cd+compounds as Cd	-	-	<1	-	<1
Cl-	25	-	35	10,400	10,400
ClO3--	<1	-	<1	97	97
CN-	<1	-	<1	<1	<1
CO3--	-	-	3	30	34
Cr+compounds as Cr	<1	-	<1	<1	<1
Cu+compounds as Cu	<1	-	<1	<1	<1
Detergent/oil	<1	-	2	3	6
Dichloroethane (DCE)	<1	-	<1	<1	<1
Dioxin/furan as Teq	-	-	<1	-	<1
Dissolved chlorine	<1	-	<1	<1	<1
Dissolved organics (non-HC)	23	-	<1	<1	23
Dissolved solids not specified	1	-	9	3,700	3,710
F-	<1	-	<1	<1	<1
Fe+compounds as Fe	<1	-	2	<1	3
Hg+compounds as Hg	<1	-	<1	<1	<1
Hydrocarbons not specified	<1	<1	2	<1	3
K+compounds as K	<1	-	<1	<1	<1
Metals not specified elsewhere	3	-	<1	3,060	3,060
Mg+compounds as Mg	<1	-	<1	<1	<1
Mn+compounds as Mn	-	-	<1	<1	<1
Na+compounds as Na	10	-	22	7,510	7,540
Ni+compounds as Ni	<1	-	<1	<1	<1
NO3-	1	-	<1	76	78
Organo-chlorine not specified	<1	-	<1	6	6
Organo-tin as Sn	-	-	<1	-	<1
Other nitrogen as N	3	-	<1	7,950	7,950
Other organics not specified	<1	-	<1	<1	<1
P+compounds as P	<1	-	<1	879	880
Pb+compounds as PB	<1	-	<1	<1	<1
Phenols	<1	-	<1	<1	<1
S+sulphides as S	<1	-	<1	344	344
SO4--	<1	-	8	1536	1,544
Sr+compounds as Sr	-	-	<1	<1	<1
Suspended solids	2,850	-	3,870	219,800	226,500
TOC	<1	-	<1	<1	<1
Vinyl chloride monomer	<1	-	<1	<1	<1
Zn+compounds as Zn	<1	-	<1	<1	<1

Table 8. Generation of solid waste (in milligrams resulting from the recyclable PAPER bag LCA. Based on consumer use & collection of 1000 bags. Totals may not agree because of rounding.

Solid waste (mg)	Fuel prod'n	Fuel use	Transport	Process	Total
Construction waste	<1	-	<1	<1	<1
Inert chemical	<1	-	<1	275	276
Metals	<1	-	<1	1,350	1,350
Mineral waste	2.590	-	38.500	1889,000	230,000
Mixed industrial	-26,300	-	1.550	22,900	-1,860
Municipal solid waste	-383,000	-	-	-	-383,000
Paper	<1	-	<1	<1	<1
Plastic containers	<1	-	<1	-	<1
Plastics	<1	-	<1	389	390
Putrescibles	<1	-	11	<1	11
Regulated chemicals	67,500	-	3	85	67,600
Slags/ash	921,000	5.290	15,000	5,380	947,000
Tailings	81	-	1,290	4	1,380
Unregulated chemicals	51,200	-	51	820	52,040
Unspecified refuse	55,300	-	<1	282,000	337,000
Waste returned to mine	2,202,000	-	1,420	345	2,203,000
Waste to compost	-	-	-	1,290,000	1,290,000
Waste to incinerator	1	-	18	16	35
Waste to recycle	<1	-	<1	2,544,000	2,544,000
Wood waste	<1	-	<1	306,000	306,000
Wood pallets to recycle	<1	-	<1	-	<1

RECYCLABLE PLASTIC BAG SYSTEM

The results of the LCA for the recyclable plastic bag system are presented below, each describing some aspect of the behavior of the systems examined. In all cases, the following tables refer to the gross or cumulative totals when all operations are traced back to the extraction of raw materials from the earth and are based on the consumer use and collection of 1000 bags and 1500 bags. The subsequent disposal operations of recycling, composting, incineration with energy recovery and landfill are not included in these results tables and will be discussed separately.

Table 9A. Gross energy (in MJ), required for the recyclable PLASTIC bag LCA. Based on consumer use & collection of 1000 bags. Totals may not agree because of rounding.

Fuel type	Fuel prod'n & delivery	Energy content of fuel	Transport energy	Feedstock energy	Total energy
Electricity	103	42	3	0	148
Oil	2	35	7	156	199
Other	2	37	0	123	162
Total	106	114	11	279	509

Table 9B. Gross energy (in MJ), required for the recyclable PLASTIC bag LCA. Based on consumer use & collection of 1500 bags. Totals may not agree because of rounding.

Fuel type	Fuel prod'n & delivery	Energy content of fuel	Transport energy	Feedstock energy	Total energy
Electricity	154	63	5	0	222
Oil	3	53	11	233	299
Other	2	55	1	185	242
Total	159	171	16	418	763

Table 10A. Gross primary fossil fuels and feedstocks, expressed as energy (in MJ), required for the recyclable PLASTIC bag LCA. Based on consumer use & collection of 1000 bags. Totals may not agree because of rounding.

	Fuel prod'n	Fuel use	Transport	Feedstock	Total
Coal	43	21	1	0	65
Oil	5	37	8	155	206
Gas	23	46	1	116	186
Hydro	4	2	0	-	6
Nuclear	26	11	1	-	38
Lignite	0	0	0	-	0
Wood	0	3	0	7	9
Sulfur	0	0	0	0	0
Hydrogen	0	0	0	-	0
Biomass (solid)	3	1	0	0	4
Recovered energy	0	-7	0	-	-7
Geothermal	0	0	0	-	0
Unspecified	0	0	0	-	0
Solar	0	0	0	-	0
Biomass (liqd/gas)	0	0	0	-	0
Industrial waste	0	0	0	0	0
Municipal Waste	1	0	0	-	1
Wind	0	0	0	-	0
Totals	106	114	11	279	509

Table 10B. Gross primary fossil fuels and feedstocks, expressed as energy (in MJ), required for the recyclable PLASTIC bag LCA. Based on consumer use & collection of 1500 bags. Totals may not agree because of rounding.

	Fuel prod'n	Fuel use	Transport	Feedstock	Total
Coal	65	31	2	0	98
Oil	8	56	12	233	309
Gas	35	69	2	175	279
Hydro	6	3	0	-	9
39	16	1	1	-	57
Lignite	0	0	0	-	0
Wood	0	4	0	10	14
Sulfur	0	0	0	0	0
Hydrogen	0	0	0	-	0
Biomass (solid)	4	2	0	0	6
Recovered energy	0	-11	0	-	-11
Geothermal	0	0	0	-	0
Unspecified	0	0	0	-	0
Solar	0	0	0	-	0
Biomass (liqd/gas)	0	0	0	-	0
Industrial waste	0	0	0	0	0
Municipal Waste	1	0	0	-	1
Wind	0	0	0	-	0
Totals	159	171	16	418	763

Table 11A. Gross primary fossil fuels and feedstocks, expressed as mass (in milligrams), required the recyclable PLASTIC bag LCA. Based on consumer use & collection of 1000 bags. Totals may not agree because of rounding.

Crude oil................	4,571,000
Gas/condensate.........	3,065,000
Coal......................	2,259,000
Metallurgical coal......	6,060
Lignite	670
Peat	7,920
Wood (50% water).....	809,000
Biomass (incl. water)...	498,000

Table 11B. Gross primary fossil fuels and feedstocks, expressed as mass (in milligrams), required the recyclable PLASTIC bag LCA. Based on consumer use & collection of 1500 bags. Totals may not agree because of rounding.

Crude oil................	6,857,000
Gas/condensate.........	4,598,000
Coal......................	3,388,000
Metallurgical coal......	9,100
Lignite	1,010
Peat	11,900
Wood (50% water).....	1,212,000
Biomass (incl. water)...	746,000

Table 12A. Gross water resources (in milligrams) required for the recyclable PLASTIC bag LCA. Based on consumer use & collection of 1000 bags. Totals may not agree because of rounding.

Source	Use in process	Use in cooling	Totals
Public supply	31,900,000	1,230,000	33,150,000
River/canal	4,970,000	2,520,000	7,480,000
Sea	819,000	58,600,000	59,400,000
Unspecified	5,120,000	105,400,000	110,600,000
Well	425,000	66,000	138,000
Total	43,250,000	167,800,000	211,100,000

Table 12B. Gross water resources (in milligrams) required for the recyclable PLASTIC bag LCA. Based on consumer use & collection of 1500 bags. Totals may not agree because of rounding.

Source	Use in process	Use in cooling	Totals
Public supply	47,900,000	1,850,000	49,700,000
River/canal	7,460,000	3,780,000	11,200,000
Sea	1,230,000	87,900,000	89,100,000
Unspecified	7,680,000	158,000,000	166,000,000
Well	638,000	99,000	207,000
Total	64,900,000	252,000,000	317,000,000

Table 13A. Gross other raw materials (in milligrams required for the recyclable PLASTIC bag LCA. Based on consumer use & collection of 1000 bags. Totals may not agree because of rounding.

Raw material	Input in mg
Air	1,436,000
Animal matter	<1
Barites	343
Bauxite	111
Bentonite	231
Calcium sulphate (CaSO4)	22
Clay	235
Cr	7
Cu	<1
Dolomite	184
Fe	15,000
Feldspar	<1
Ferromanganese	14
Fluorspar	3
Granite	<1
Gravel	56
Hg	<1
Limestone (CaCO3)	542,000
Mg	<1
N2	823,000
Ni	<1
O2	110,000
Olivine	141
Pb	87
Phosphate as P205	743
Potassium chloride (KCl)	252
Quartz (SiO2)	0
Rutile	272,000
S (bonded)	13
S (elemental)	1,520
Sand (SiO2)	935
Shale	63
Sodium chloride (NaCl)	51,200
Sodium nitrate (NaNO3)	0
Talc	<1
Unspecified	<1
Zn	266

Table 13B. Gross other raw materials (in milligrams required for the recyclable PLASTIC bag LCA. Based on consumer use & collection of 1500 bags. Totals may not agree because of rounding.

Raw material	Input in mg
Air	2,154,000
Animal matter	<1
Barites	515
Bauxite	166
Bentonite	347
Calcium sulphate (CaSO4)	33
Clay	353
Cr	10
Cu	<1
Dolomite	276
Fe	22,600
Feldspar	<1
Ferromanganese	21
Fluorspar	4
Granite	<1
Gravel	83
Hg	<1
Limestone (CaCO3)	812,000
Mg	<1
N2	1,235,000
Ni	<1
O2	165,000
Olivine	212
Pb	131
Phosphate as P205	1,120
Potassium chloride (KCl)	379
Quartz (SiO2)	0
Rutile	408,000
S (bonded)	20
S (elemental)	2,270
Sand (SiO2)	1,400
Shale	94
Sodium chloride (NaCl)	76,700
Sodium nitrate (NaNO3)	0
Talc	<1
Unspecified	<1
Zn	399

Table 14A. Gross air emissions (in milligrams) resulting from the recyclable PLASTIC bag LCA. Based on consumer use & collection of 1000 bags. Totals may not agree because of rounding.

Air emissions/mg	Fuel prod'n	Fuel use	Transport	Process	Biomass	Fugitive	Total
Dust (PM10)	6,340	540	430	7,000	-	-	14,300
CO	10,800	48,900	5,110	2,570	-	-	67,400
CO2	8,570,000	5,390,000	551,000	953,000	-427,000	-	15,030,000
SOX as SO2	35,700	9,130	2,000	3.640	-	-	50,500
H2S	<1	-	<1	14	-	-	14
Mercaptan	<1	<1	-	4	-		4
NOX as NO2	28,500	10,000	6,060	870	-	-	45,400
Aledhyde (-CHO)	<1	-	<1	<1	-	-	<1
Aromatic HC not spec	1	-	22	380	-	-	403
Cd+compounds as Cd	<1	-	<1	-	-		<1
CH4	40,900	1,660	3	20,700	-	-	63,300
Cl2	<1	-	<1	29	-	-	29
Cr+compounds as Cr	<1	-	<1	-	-	-	<1
CS2	<1	-	<1	<1	-		<1
Cu+compounds as Cu	<1	-	<1	-	-	-	<1
Dichlorethane (DCE)	<1	-	<1	<1	-	<1	<1
Ethylene C2H4	-	-	<1	-	-	-	<1
F2	<1	-	<1	<1	-	-	<1
H2	68	2	<1	754	-	-	824
H2SO4	<1	-	<1	<1	-	-	<1
HCl	1,220	95	<1	3	-	-	1,320
HCN	<1	-	<1	<1	-	-	<1
HF	46	1	<1	<1	-	-	47
Hg+compounds as Hg	<1	-	<1	<1	--	-	<1
Hydrocarbons not spec	7,430	920	1,670	13,100	-	-	23,100
Metals not specified	6	5	<1	3	-	-	14
Methylene chloride CH2	<1	-	<1	<1	-	-	<1
N2O	<1	<1	<1	-	-	-	<1
NH3	<1	-	<1	8	-	-	8
Ni compounds as Ni	<1	-	<1	-	-	-	<1
NMVOC	<1	-	<1	993	-	-	994
Organics	<1	<1	<1	367	-	-	367
Organo-chlorine not spec	<1	-	<1	<1	-	-	<1
Pb+compounds as Pb	<1	<1	<1	<1	-	-	<1
Polycyclic hydrocarbon	<1	-	<1	<1	-	-	<1
Sb+compounds as Sb	-	-	<1	-	-	-	<1
Vinyl chloride monomer	<1	-	<1	<1	-	<1	<1
Zn+compounds as Zn	<1	-	<1	<1	-	-	<1

Table 14B. Carbon dioxide equivalents corresponding to the gross air emissions (in milligrams) resulting from the recyclable PLASTIC bag LCA. Based on consumer use & collection of 1000 bags. Totals may not agree because of rounding.

Type/mg	Fuel prod'n	Fuel use	Transport	Process	Biomass	Total
20 year equiv	11,100,000	5,590,000	566,000	2,280,000	-427,000	19,200,000
100 year equiv	9,550,000	5,530,000	566,000	1,470,000	-427,000	16,700,000
500 year equiv	8,900,000	5,500,000	566,000	1,140,000	-427,000	15,700,000

Table 14C. Gross air emissions (in milligrams) resulting from the recyclable PLASTIC bag LCA. Based on consumer use & collection of 1500 bags. Totals may not agree because of rounding.

Air emissions/mg	Fuel prod'n	Fuel use	Transport	Process	Biomass	Fugitive	Total
Dust (PM10)	9,500	811	644	10,500	-	-	21,500
CO	16,100	73,400	7,670	3,850	-	-	101,000
CO2	12,900,000	8,082,000	826,000	1,429,000	-640,000	-	22,550,000
SOX as SO2	53,500	13,700	3,000	5,460	-	-	75,700
H2S	<1	-	<1	21	-	-	22
Mercaptan	<1	<1	-	6	-		6
NOX as NO2	42,700	15,100	9,090	1,310	-	-	68,100
Aledhyde (-CHO)	<1	-	<1	<1	-	-	<1
Aromatic HC not spec	2	-	33	570	-	-	604
Cd+compounds as Cd	<1	-	<1	-	-		<1
CH4	61,400	2,490	4	31,090	-	-	95,000
Cl2	<1	-	<1	43	-	-	43
Cr+compounds as Cr	<1	-	<1	-	-	-	<1
CS2	<1	-	<1	<1	-		<1
Cu+compounds as Cu	<1	-	<1	-	-	-	<1
Dichlorethane (DCE)	<1	-	<1	<1	-	<1	<1
Ethylene C2H4	-	-	<1	-	-	-	<1
F2	<1	-	<1	<1	-	-	<1
H2	102	2	<1	1,130	-	-	1,240
H2SO4	<1	-	<1	<1	-	-	<1
HCl	1,830	142	1	5	-	-	1,980
HCN	<1	-	<1	<1	-	-	<1
HF	69	2	<1	<1	-	-	71
Hg+compounds as Hg	<1	-	<1	<1	--	-	<1
Hydrocarbons not spec	11,100	1,380	2,510	19,700	-	-	34,700
Metals not specified	9	7	<1	5	-	-	21
Methylene chloride CH2	<1	-	<1	<1	-	-	<1
N2O	<1	<1	<1	-	-	-	<1
NH3	<1	-	<1	12	-	-	12
Ni compounds as Ni	<1	-	<1	-	-	-	<1
NMVOC	<1	-	<1	1,490	-	-	1,490
Organics	<1	<1	<1	551	-	-	551
Organo-chlorine not spec	<1	-	<1	<1	-	-	<1
Pb+compounds as Pb	<1	<1	<1	<1	-	-	<1
Polycyclic hydrocarbon	<1	-	<1	<1	-	-	<1
Sb+compounds as Sb	-	-	<1	-	-	-	<1
Vinyl chloride monomer	<1	-	<1	<1	-	<1	<1
Zn+compounds as Zn	<1	-	<1	<1	-	-	<1

Table 14D. Carbon dioxide equivalents corresponding to the gross air emissions (in milligrams) resulting from the recyclable PLASTIC bag LCA. Based on consumer use & collection of 1500 bags. Totals may not agree because of rounding.

Type/mg	Fuel prod'n	Fuel use	Transport	Process	Biomass	Total
20 year equiv	16,700,000	8,390,000	849,000	3,420,000	-641,000	28,800,000
100 year equiv	14,300,000	8,300,000	849,000	2,210,000	-641,000	25,100,000
500 year equiv	13,400,000	8,250,000	849,000	1,710,000	-641,000	23,600,000

Table 15A. Gross water emissions (in milligrams), resulting from the recyclable PLASTIC bag LCA. Based on consumer use & collection of 1000 bags. Totals may not agree because of rounding.

	Fuel prod'n	Fuel use	Transport	Process	Total
COD	9	-	8	5390	5,410
BOD	2	-	<1	543	545
Acid (H+)	4	-	<1	9	13
Al+compounds as Al	<1	-	<1	4	4
Ammonium compounds as NH4	5	-	<1	11	17
AOX	<1	-	<1	<1	<1
As+compounds as As	-	-	<1	<1	<1
BrO3--	<1	-	<1	<1	<1
Ca+compounds as Ca	<1	-	<1	20	20
Cd+compounds as Cd	-	-	<1	-	<1
Cl-	3	-	8	3,060	3,070
ClO3--	<1	-	<1	15	15
CN-	<1	-	<1	<1	<1
CO3--	-	-	<1	181	182
Cr+compounds as Cr	<1	-	<1	<1	<1
Cu+compounds as Cu	<1	-	<1	1	1
Detergent/oil	<1	-	<1	39	40
Dichloroethane (DCE)	<1	-	<1	<1	<1
Dioxin/furan as Teq	-	-	<1	-	<1
Dissolved chlorine	<1	-	<1	<1	<1
Dissolved organics (non-HC)	3	-	<1	44	47
Dissolved solids not specified	2	-	2	947	952
F-	<1	-	<1	<1	<1
Fe+compounds as Fe	<1	-	<1	<1	<1
Hg+compounds as Hg	<1	-	<1	<1	<1
Hydrocarbons not specified	26	<1	<1	3	30
K+compounds as K	<1	-	<1	11	11
Metals not specified elsewhere	<1	-	<1	54	55
Mg+compounds as Mg	<1	-	<1	<1	<1
Mn+compounds as Mn	-	-	<1	<1	<1
Na+compounds as Na	2	-	5	3,136	3,143
Ni+compounds as Ni	<1	-	<1	<1	<1
NO3-	1	-	<1	13	13
Organo-chlorine not specified	<1	-	<1	<1	<1
Organo-tin as Sn	-	-	<1	-	<1
Other nitrogen as N	<1	-	<1	46	47
Other organics not specified	<1	-	<1	<1	<1
P+compounds as P	<1	-	<1	7	7
Pb+compounds as PB	<1	-	<1	<1	<1
Phenols	<1	-	<1	10	10
S+sulphides as S	<1	-	<1	2	2
SO4--	<1	-	2	4,097	4,098
Sr+compounds as Sr	-	-	<1	<1	<1
Suspended solids	573	-	861	78,300	79,800
TOC	<1	-	<1	60	60
Vinyl chloride monomer	<1	-	<1	<1	<1
Zn+compounds as Zn	<1	-	<1	<1	<1

Table 15B. Gross water emissions (in milligrams), resulting from the recyclable PLASTIC bag LCA. Based on consumer use & collection of 1500 bags. Totals may not agree because of rounding.

	Fuel prod'n	Fuel use	Transport	Process	Total
COD	14	-	12	8,080	8,110
BOD	3	-	<1	814	817
Acid (H+)	6	-	<1	13	19
Al+compounds as Al	<1	-	<1	5	5
Ammonium compounds as NH4	7	-	<1	17	25
AOX	<1	-	<1	<1	<1
As+compounds as As	-	-	<1	<1	<1
BrO3--	<1	-	<1	<1	<1
Ca+compounds as Ca	<1	-	<1	30	30
Cd+compounds as Cd	-	-	<1	-	<1
Cl-	5	-	11	4,590	4,610
ClO3--	<1	-	<1	22	22
CN-	<1	-	<1	<1	<1
CO3--	-	-	1	272	273
Cr+compounds as Cr	<1	-	<1	<1	<1
Cu+compounds as Cu	<1	-	<1	2	2
Detergent/oil	<1	-	<1	59	60
Dichloroethane (DCE)	<1	-	<1	<1	<1
Dioxin/furan as Teq	-	-	<1	-	<1
Dissolved chlorine	<1	-	<1	1	1
Dissolved organics (non-HC)	4	-	<1	66	70
Dissolved solids not specified	3	-	3	1,420	1,430
F-	<1	-	<1	<1	<1
Fe+compounds as Fe	<1	-	<1	<1	<1
Hg+compounds as Hg	<1	-	<1	<1	<1
Hydrocarbons not specified	39	<1	<1	4	45
K+compounds as K	<1	-	<1	16	16
Metals not specified elsewhere	1	-	<1	81	83
Mg+compounds as Mg	<1	-	<1	<1	<1
Mn+compounds as Mn	-	-	<1	<1	<1
Na+compounds as Na	3	-	8	4,700	4,710
Ni+compounds as Ni	<1	-	<1	<1	<1
NO3-	<1	-	<1	19	19
Organo-chlorine not specified	<1	-	<1	<1	<1
Organo-tin as Sn	-	-	<1	-	<1
Other nitrogen as N	1	-	<1	69	70
Other organics not specified	<1	-	<1	<1	<1
P+compounds as P	<1	-	<1	10	10
Pb+compounds as PB	<1	-	<1	<1	<1
Phenols	<1	-	<1	15	15
S+sulphides as S	<1	-	<1	3	3
SO4--	<1	-	3	6,150	6,150
Sr+compounds as Sr	-	-	<1	<1	<1
Suspended solids	860	-	1,290	117,500	119,600
TOC	<1	-	<1	90	90
Vinyl chloride monomer	<1	-	<1	<1	<1
Zn+compounds as Zn	<1	-	<1	1	1

Table 16A. Generation of solid waste (in milligrams resulting from the recyclable PLASTIC bag LCA. Based on consumer use & collection of 1000 bags. Totals may not agree because of rounding.

Solid waste (mg)	Fuel prod'n	Fuel use	Transport	Process	Total
Construction waste	<1	-	<1	<1	<1
Inert chemical	<1	-	<1	3,446	3,446
Metals	<1	-	<1	301	301
Mineral waste	974	-	8,564	324,200	333,700
Mixed industrial	-11,800	-	345	5,520	-5,950
Municipal solid waste	-79,800	-	-	22,500	-57,300
Paper	<1	-	<1	<1	<1
Plastic containers	<1	-	<1	-	<1
Plastics	<1	-	<1	53,600	53,600
Putrescibles	<1	-	2	7	10
Regulated chemicals	9,040	-	<1	4,720	13,800
Slags/ash	180,000	4,460	3,330	1,660	189,000
Tailings	16	-	287	1,048	1,350
Unregulated chemicals	6,810	-	11	7,190	14,000
Unspecified refuse	7,350	-	<1	62,900	70,200
Waste returned to mine	443,000	-	316	872	444,400
Waste to compost	-	-	-	9,290	9,290
Waste to incinerator	<1	-	4	4,370	4,380
Waste to recycle	<1	-	<1	33,200	33,200
Wood waste	<1	-	<1	2,330	2,330
Wood pallets to recycle	<1	-	<1	298,000	298,000

Table 16B. Generation of solid waste (in milligrams resulting from the recyclable PLASTIC bag LCA. Based on consumer use & collection of 1500 bags. Totals may not agree because of rounding.

Solid waste (mg)	Fuel prod'n	Fuel use	Transport	Process	Total
Construction waste	<1	-	<1	<1	<1
Inert chemical	<1	-	<1	5,170	5,170
Metals	<1	-	<1	452	452
Mineral waste	1,460	-	12,800	486,000	501,000
Mixed industrial	-17,700	-	517	8,280	-8,930
Municipal solid waste	1119,700	-	-	33,800	-85,900
Paper	<1	-	<1	<1	<1
Plastic containers	<1	-	<1	-	<1
Plastics	<1	-	<1	80,400	80,400
Putrescibles	<1	-	4	11	14
Regulated chemicals	13,600	-	<1	7,080	20,600
Slags/ash	270,000	6,680	4,990	2,480	284,000
Tailings	24	-	430	1,570	2,030
Unregulated chemicals	10,200	-	17	10,800	21,000
Unspecified refuse	11,030	-	<1	94,300	105,400
Waste returned to mine	665,000	-	475	1,310	667,000
Waste to compost	-	-	-	13,900	13,900
Waste to incinerator	<1	-	6	6,560	6,560
Waste to recycle	<1	-	<1	49,800	49,800
Wood waste	<1	-	<1	3,500	3,500
Wood pallets to recycle	<1	-	<1	447,000	447,000

THE COMPOSTABLE PLASTIC BAG SYSTEM

The results of the LCA for the compostable plastic bag system are presented below, each describing some aspect of the behavior of the systems examined. In all cases, the following tables refer to the gross or cumulative totals when all operations are traced back to the extraction of raw materials from the earth and are based on the consumer use and collection of 1000 bags and 1500 bags. The subsequent disposal operations of recycling, composting, incineration with energy recovery and landfill are not included in these results tables and will be discussed separately.

Table 17A. Gross energy (in MJ), required for the COMPOSTABLE PLASTIC bag LCA. Based on consumer use & collection of 1000 bags. Totals may not agree because of rounding.

Fuel type	Fuel prod'n & delivery	Energy content of fuel	Transport energy	Feedstock energy	Total energy
Electricity	221	103	1	0	325
Oil	29	279	36	1	345
Other	15	277	1	417	710
Total	265	659	38	418	1380

Table 17B. Gross energy (in MJ), required for the COMPOSTABLE PLASTIC bag LCA. Based on consumer use & collection of 1500 bags. Totals may not agree because of rounding.

Fuel type	Fuel prod'n & delivery	Energy content of fuel	Transport energy	Feedstock energy	Total energy
Electricity	331	154	2	0	487
Oil	44	418	54	1	518
Other	22	416	2	625	1065
Total	398	988	57	627	2070

Table 18A. Gross primary fossil fuels and feedstocks, expressed as energy (in MJ), required for the COMPOSTABLE PLASTIC bag LCA. Based on consumer use & collection of 1000 bags. Totals may not agree because of rounding.

	Fuel prod'n	Fuel use	Transport	Feedstock	Total
Coal	113	48	1	0	161
Oil	34	281	37	1	353
Gas	44	301	1	360	705
Hydro	7	2	0	-	9
Nuclear	62	11	0	-	74
Lignite	0	0	0	-	0
Wood	0	7	0	18	26
Sulfur	0	0	0	0	0
Hydrogen	0	0	0	0	0
Biomass (solid)	6	2	0	39	47
Recovered energy	-2	-5	0	-	-8
Geothermal	0	0	0	-	0
Unspecified	0	0	0	-	0
Solar	0	0	0	-	0
Biomass (liqd/gas)	0	0	0	-	0
Industrial waste	1	0	0	-	1
Municipal Waste	1	0	0	-	1
Wind	0	11	0	-	11
Totals	265	659	38	418	1,380

Table 18B. Gross primary fossil fuels and feedstocks, expressed as energy (in MJ), required for the COMPOSTABLE PLASTIC bag LCA. Based on consumer use & collection of 1500 bags. Totals may not agree because of rounding.

	Fuel prod'n	Fuel use	Transport	Feedstock	Total
Coal	169	72	1	0	241
Oil	51	422	55	1	529
Gas	65	451	1	540	1,057
Hydro	11	3	0	-	14
Nuclear	94	17	0	-	111
Lignite	0	0	0	-	0
Wood	0	11	0	27	38
Sulfur	0	0	0	0	0
Hydrogen	0	0	0	0	0
Biomass (solid)	9	4	0	58	71
Recovered energy	-4	-8	0	-	-11
Geothermal	0	0	0	-	0
Unspecified	0	0	0	-	0
Solar	0	0	0	-	0
Biomass (liqd/gas)	0	0	0	-	0
Industrial waste	1	0	0	-	1
Municipal Waste	1	1	0	-	2
Wind	0	16	0	-	16
Totals	398	988	57	627	2,070

Table 19A. Gross primary fossil fuels and feedstocks, expressed as mass (in milligrams), required the COMPOSTABLE PLASTIC bag LCA. Based on consumer use & collection of 1000 bags. Totals may not agree because of rounding.

Crude oil................	7,840,000
Gas/condensate.........	14,020,000
Coal......................	5,760,000
Metallurgical coal......	17,000
Lignite	0
Peat	7
Wood (50% water).....	2,210,000
Biomass (incl. water)...	986,000

Table 19B. Gross primary fossil fuels and feedstocks. expressed as mass (in milligrams), required the COMPOSTABLE PLASTIC bag LCA. Based on consumer use & collection of 1500 bags. Totals may not agree because of rounding.

Crude oil................	11,760,000
Gas/condensate.........	21,030,000
Coal......................	8,630,000
Metallurgical coal......	25,000
Lignite	0
Peat	10
Wood (50% water).....	3,310,000
Biomass (incl. water)...	1,480,000

Table 20A. Gross water resources (in milligrams) required for the COMPOSTABLE PLASTIC bag LCA. Based on consumer use & collection of 1000 bags. Totals may not agree because of rounding.

Source	Use in process	Use in cooling	Totals
Public supply	2,540,000,000	19,200,000	2,560,000,000
River/canal	3,870	1,690,000	1,700,000
Sea	13,100	2,710,000	2,720,000
Unspecified	36,600,000	6,270,000	42,900,000
Well	564,000	49	564,000
Totals	2,580,000,000	29,900,000	2,607,000,000

Table 20B. Gross water resources (in milligrams) required for the COMPOSTABLE PLASTIC bag LCA. Based on consumer use & collection of 1500 bags. Totals may not agree because of rounding.

Source	Use in process	Use in cooling	Totals
Public supply	3,810,000,000	28,800,000	3,840,000,000
River/canal	5,810	2,540,000	2,550,000
Sea	19,650	4,065,000	4,080,000
Unspecified	54,900,000	9,410,000	64,350,000
Well	846,000	74	846,000
Totals	3,870,000,000	44,900,000	3,910,000,000

Table 21A. Gross other raw materials (in milligrams) required for the COMPOSTABLE PLASTIC bag LCA. Based on consumer use & collection of 1000 bags. Totals may not agree because of rounding.

Raw material	Input in mg
Air	1,460,000
Animal matter	0
Barites	1,700
Bauxite	4,000
Bentonite	99
Calcium sulphate (CaSO4)	<1
Clay	34,200
Cr	19
Cu	0
Dolomite	513
Fe	47,300
Feldspar	0
Ferromanganese	38
Fluorspar	3
Granite	0
Gravel	155
Hg	0
Limestone (CaCO3)	4,230,000
Mg	0
N2 for reaction	17,900
Ni	0
O2 for reaction	1,030
Olivine	394
Pb	260
Phosphate as P205	12,300
Potassium chloride (KCl)	23,000
Quartz (SiO2)	0
Rutile	0
S (bonded)	401,000
S (elemental)	23,700
Sand (SiO2)	22,400
Shale	2
Sodium chloride (NaCl)	261,000
Sodium nitrate (NaNO3)	0
Talc	0
Unspecified	0
Zn	9

Table 21B. Gross other raw materials (in milligrams) required for the COMPOSTABLE PLASTIC bag LCA. Based on consumer use & collection of 1500 bags. Totals may not agree because of rounding.

Raw material	Input in mg
Air	2,190,000
Animal matter	0
Barites	2,550
Bauxite	6,010
Bentonite	148
Calcium sulphate (CaSO4)	<1
Clay	51,300
Cr	28
Cu	0
Dolomite	769
Fe	71,000
Feldspar	0
Ferromanganese	57
Fluorspar	5
Granite	0
Gravel	232
Hg	0
Limestone (CaCO3)	6,350,000
Mg	0
N2 for reaction	26,800
Ni	0
O2 for reaction	1,550
Olivine	591
Pb	390
Phosphate as P205	18,400
Potassium chloride (KCl)	34,500
Quartz (SiO2)	0
Rutile	0
S (bonded)	602,000
S (elemental)	35,500
Sand (SiO2)	33,600
Shale	3
Sodium chloride (NaCl)	392,000
Sodium nitrate (NaNO3)	0
Talc	0
Unspecified	0
Zn	14

Table 22A. Gross air emissions (in milligrams) resulting from the COMPOSTABLE PLASTIC bag LCA. Based on consumer use & collection of 1000 bags. Totals may not agree because of rounding.

Air emissions mg	Fuel prod'n	Fuel use	Transport	Process	Biomass	Fugitive	Total
Dust (PM10)	9,120	520	1,500	42,200	-	-	53,400
CO	16,000	4,900	16,900	4,100	-	-	41,900
CO2	13,860,000	2,620,000	2,580,000	41,800,000	-4,230,000	-	56,600,000
SOX as SO2	54,900	7,210	21,100	192,000	-	-	275,000
H2S	0	0	1	40	-	-	41
Mercaptan	0	0	0	11	-		11
NOX as NO2	50,000	8,260	24,500	221,500	-	-	304,000
Aledhyde (-CHO)	0	0	0	0	-	-	0
Aromatic HC not spec	2	-	67	4	-	-	74
Cd+compounds as Cd	0	-	0	-	-		0
CFC/HCFC/HFC not sp	0	-	0	0	-		0
CH4	59,600	1,060	98	224,000	-	-	284,000
Cl2	0	-	0	0	-	-	0
Cr+compounds as Cr	0	-	0	-	-	-	0
CS2	0	-	0	0	-		0
Cu+compounds as Cu	0	-	0	-	-	-	0
Dichlorethane (DCE)	0	-	0	0	-	0	0
Ethylene C2H4	-	-	0	-	-	-	0
F2	0	-	0	0	-	-	0
H2	38	0	0	226	-	-	264
H2SO4	0	-	0	0	-	-	0
HCl	2,140	6	3	871	-	-	3,020
HCN	0	-	0	0	-	-	0
HF	81	0	0	0	-	-	81
Hg+compounds as Hg	0	-	0	0	-	-	0
Hydrocarbons not spec	13,800	1,720	6,400	100	-	-	22,000
Metals not specified	8	4	0	0	0	-	12
Molybdenum	-	-	-	1	-	-	1
N2O	0	0	0	53,100	-	-	53,100
NH3	0	-	0	39	-	-	39
Ni compounds as Ni	0	-	0	-	-	-	0
NMVOC	0	72	410	46,400	-	-	46,900
Organics	0	0	0	119	-	-	119
Organo-chlorine not spec	0	-	0	16	-	-	16
Pb+compounds as Pb	0	0	0	0	-	-	0
Polycyclic hydrocarbon	0	-	0	0	-	-	0
Titanium	-	-	-	119	-	-	119
Vinyl chloride monomer	0	-	0	0	-	-	0
Zn+compounds as Zn	0	-	0	0	-	-	0

Table 22B. Carbon dioxide equivalents corresponding to the gross air emissions (in milligrams) from the COMPOSTABLE PLASTIC bag LCA. Based on consumer use & collection of 1000 bags. Totals may not agree because of rounding.

Type/mg	Fuel prod'n	Fuel use	Transport	Process	Biomass	Total
20 year equiv	17,630,000	2,700,000	2,640,000	70,200,000	-4,230,000	89,000,000
100 year equiv	15,300,000	2,660,000	2,640,000	62,640,000	-4,230,000	79,000,000
500 year equiv	14,300,000	2,640,000	2,400,000	51,600,000	-4,230,000	67,000,000

Table 22C. Gross air emissions (in milligrams) resulting from the COMPOSTABLE PLASTIC bag LCA. Based on consumer use & collection of 1500 bags. Totals may not agree because of rounding.

Air emissions/mg	Fuel prod'n	Fuel use	Transport	Process	Biomass	Fugitive	Total
Dust (PM10)	13,700	780	2,260	63,400	-	-	80,100
CO	24,000	7,360	25,300	6,150	-	-	62,900
CO2	20,800,000	3,930,000	3,880,000	62,700,000	-6,340,000	-	84,900,000
SOX as SO2	82,400	10,800	31,600	288,000	-	-	413,000
H2S	0	0	2	60	-	-	62
Mercaptan	0	0	0	17	-		17
NOX as NO2	74,900	12,400	36,700	332,000	-	-	456,000
Aledhyde (-CHO)	0	0	0	0	-	-	0
Aromatic HC not spec	3	-	101	7	-	-	111
Cd+compounds as Cd	0	-	0	-	-		0
CFC/HCFC/HFC not sp	0	-	0	0	-		0
CH4	89,500	1,590	147	335,000	-	-	426,000
Cl2	0	-	0	0	-	-	0
Cr+compounds as Cr	0	-	0	-	-	-	0
CS2	0	-	0	0	-		0
Cu+compounds as Cu	0	-	0	-	-	-	0
Dichlorethane (DCE)	0	-	0	0	-	-	0
Ethylene C2H4	-	-	0	-	-	-	0
F2	0	-	0	0	-	-	0
H2	57	0	0	339	-	-	397
H2SO4	0	-	0	0	-	-	0
HCl	3,220	8	5	1,310	-	-	4,540
HCN	0	-	0	0	-	-	0
HF	121	0	0	0	-	-	122
Hg+compounds as Hg	0	-	0	0	--	-	0
Hydrocarbons not spec	20,600	2,580	9,590	150	-	-	33,000
Metals not specified	13	5	0	0	0	-	18
Molybdenum	-	-	-	2	-	-	2
N2O	0	0	0	79,600	-	-	79,600
NH3	0	-	0	59	-	-	59
Ni compounds as Ni	0	-	0	-	-	-	0
NMVOC	1	108	615	69,600	-	-	70,300
Organics	0	0	0	178	-	-	178
Organo-chlorine not spec	0	-	0	24	-	-	24
Pb+compounds as Pb	0	0	0	0	-	-	0
Polycyclic hydrocarbon	0	-	0	0	-	-	0
Titanium	-	-	-	178	-	-	178
Vinyl chloride monomer	0	-	0	0	-	-	0
Zn+compounds as Zn	0	-	0	0	-	-	0

Table 22D. Carbon dioxide equivalents corresponding to the gross air emissions (in milligrams) from the COMPOSTABLE PLASTIC bag LCA. Based on consumer use & collection of 1500 bags. Totals may not agree because of rounding.

Type/mg	Fuel prod'n	Fuel use	Transport	Process	Biomass	Total
20 year equiv	26,400,000	4,050,000	3,960,000	105,300,000	-6,350,000	134,000,000
100 year equiv	23,000,000	3,990,000	3,960,000	94,000,000	-6,350,000	119,000,000
500 year equiv	21,500,000	3,960,000	3,600,000	77,400,000	-6,350,000	101,000,000

Table 23A. Gross water emissions (in milligrams), resulting from the COMPOSTABLE PLASTIC bag LCA. Based on consumer use & collection of 1000 bags. Totals may not agree because of rounding.

	Fuel prod'n	Fuel use	Transport	Process	Total
COD	15	2	57	59,700	59,800
BOD	4	-	4	3,190	3,200
Acid (H+)	2	-	0	0	4
Al+compounds as Al	0	-	0	2	2
Ammonium compounds as NH4	5	-	2	0	7
AOX	0	-	0	10	10
As+compounds as As	-	-	0	0	0
BrO3--	0	-	0	0	0
Ca+compounds as Ca	0	-	0	201	201
Cd+compounds as Cd	-	-	0	-	0
Cl-	7	-	670	27,500	28,100
ClO3--	0	-	0	2	2
CN-	0	-	0	0	0
CO3--	-	-	2	5	7
Cr+compounds as Cr	0	-	0	0	0
Cu+compounds as Cu	0	-	0	0	0
Detergent/oil	0	-	2	3	5
Dichloroethane (DCE)	0	-	0	0	0
Dioxin/furan as Teq	-	-	0	-	0
Dissolved chlorine	0	-	0	0	0
Dissolved organics (non-HC)	6	-	0	0	6
Dissolved solids not specified	2	-	6	59	67
F-	0	-	6	0	6
Fe+compounds as Fe	0	-	1	20	22
Hg+compounds as Hg	0	-	0	0	0
Hydrocarbons not specified	0	0	1	334	337
K+compounds as K	0	-	0	2	2
Metals not specified elsewhere	0	-	0	52	52
Mg+compounds as Mg	0	-	0	2	2
Mn+compounds as Mn	-	-	0	0	0
Na+compounds as Na	3	-	15	1,270	1,290
Ni+compounds as Ni	0	-	0	0	0
NO3-	0	-	0	1,910	1,910
Organo-chlorine not specified	0	-	0	0	0
Organo-tin as Sn	-	-	0	-	0
Other nitrogen as N	0	-	0	4,300	4,300
Other organics not specified	0	-	0	0	0
P+compounds as P	0	-	0	41	41
Pb+compounds as PB	0	-	0	0	0
Phenols	0	-	0	0	0
S+sulphides as S	0	-	0	5	5
SO4--	0	-	5	6,287	6,290
Sr+compounds as Sr	-	-	0	0	0
Suspended solids	945	-	2,660	396,000	399,000
TOC	0	-	15	2,460	2,480
Vinyl chloride monomer	0	-	0	0	0
Zn+compounds as Zn	0	-	0	0	0

Table 23B. Gross water emissions (in milligrams), resulting from the COMPOSTABLE PLASTIC bag LCA. Based on consumer use & collection of 1500 bags. Totals may not agree because of rounding.

	Fuel prod'n	Fuel use	Transport	Process	Total
COD	22	2	86	89.500	89,600
BOD	6	-	6	4,790	4,800
Acid (H+)	4	-	0	1	5
Al+compounds as Al	0	-	0	3	3
Ammonium compounds as NH4	7	-	2	1	11
AOX	0	-	0	15	15
As+compounds as As	-	-	0	0	0
BrO3--	0	-	0	0	0
Ca+compounds as Ca	0	-	0	302	302
Cd+compounds as Cd	-	-	0	-	0
Cl-	10	-	1,010	41,200	42,200
ClO3--	0	-	0	2	2
CN-	0	-	0	0	0
CO3--	-	-	3	7	10
Cr+compounds as Cr	0	-	0	0	0
Cu+compounds as Cu	0	-	0	0	0
Detergent/oil	0	-	2	4	7
Dichloroethane (DCE)	0	-	0	0	0
Dioxin/furan as Teq	-	-	0	-	0
Dissolved chlorine	0	-	0	0	0
Dissolved organics (non-HC)	9	-	0	1	10
Dissolved solids not specified	2	-	10	89	101
F-	0	-	9	0	9
Fe+compounds as Fe	0	-	2	31	33
Hg+compounds as Hg	0	-	0	0	0
Hydrocarbons not specified	1	1	2	501	505
K+compounds as K	0	-	0	3	3
Metals not specified elsewhere	0	-	0	76	76
Mg+compounds as Mg	0	-	0	3	3
Mn+compounds as Mn	-	-	0	0	0
Na+compounds as Na	4	-	23	1.900	1,930
Ni+compounds as Ni	0	-	0	0	0
NO3-	0	-	0	2,860	2,860
Organo-chlorine not specified	0	-	0	0	0
Organo-tin as Sn	-	-	0	-	0
Other nitrogen as N	0	-	0	6.440	6,440
Other organics not specified	0	-	0	0	0
P+compounds as P	0	-	0	62	62
Pb+compounds as PB	0	-	0	0	0
Phenols	0	-	0	0	0
S+sulphides as S	0	-	0	7	7
SO4--	0	-	8	9,430	9,440
Sr+compounds as Sr	-	-	0	0	0
Suspended solids	1,420	-	3.990	594,000	599,000
TOC	0	-	23	3,690	3.710
Vinyl chloride monomer	0	-	0	0	0
Zn+compounds as Zn	0	-	0	0	0

Table 24A. Generation of solid waste (in milligrams) resulting from the COMPOSTABLE PLASTIC bag LCA. Based on consumer use & collection of 1000 bags. Totals may not agree because of rounding.

Solid waste (mg)	Fuel prod'n	Fuel use	Transport	Process	Total
Construction waste	0	-	0	0	0
Inert chemical	0	-	0	5	5
Metals	0	-	0	822	822
Mineral waste	1,110	-	26,500	405,000	433,000
Mixed industrial	-12,800	-	1,100	2,620	-9,080
Municipal solid waste	-130,000	-	-	205,000	75,000
Paper	0	-	0	0	0
Plastic containers	0	-	0	-	0
Plastics	0	-	0	1,580	1,580
Putrescibles	0	-	7	1	8
Regulated chemicals	18,400	-	4,830	133	23,400
Slags/ash	308,000	660	10,300	2,690,000	3,009,000
Tailings	27	-	15,900	284	16,300
Unregulated chemicals	14,000	-	0	82,400	96,400
Unspecified refuse	15,100	-	0	171,700	186,800
Waste returned to mine	731,000	-	980	108	732,100
Waste to compost	-	-	-	25,400	25,400
Waste to incinerator	0	-	12	67	80
Waste to recycle	0	-	0	32,500	32,500
Wood waste	0	-	0	6,370	6,370
Wood pallets to recycling	0	-	0	812,700	812,700

Table 24B. Generation of solid waste (in milligrams) resulting from the COMPOSTABLE PLASTIC bag LCA. Based on consumer use & collection of 1500 bags. Totals may not agree because of rounding.

Solid waste (mg)	Fuel prod'n	Fuel use	Transport	Process	Total
Construction waste	0	-	0	0	0
Inert chemical	0	-	0	6	6
Metals	0	-	0	1,230	1,230
Mineral waste	1,660	-	39,800	608,000	649,000
Mixed industrial	-19,200	-	1,650	3,940	-13,600
Municipal solid waste	-195,000	-	-	308,000	113,000
Paper	0	-	0	0	0
Plastic containers	0	-	0	-	0
Plastics	0	-	0	2,380	2,380
Putrescibles	0	-	11	<1	11
Regulated chemicals	27,600	-	7,250	199	35,100
Slags/ash	462,000	985	15,500	4,035,000	4,510,000
Tailings	40	-	23,900	427	24,400
Unregulated chemicals	20,900	-	52	124,000	145,000
Unspecified refuse	22,600	-	0	258,000	280,000
Waste returned to mine	1,097,000	-	1,470	162	1,098,000
Waste to compost	-	-	-	38,000	38,000
Waste to incinerator	0	-	18	101	120
Waste to recycle	0	-	0	48,800	48,800
Wood waste	0	-	0	9,550	9,550
Wood pallets to recycling	0	-	0	1,220,000	1,220,000

Final Disposal Solid Waste Options: Recycling, Combustion with Energy Recovery, Landfill and Composting

Recycling

A major goal of recycling is to reduce the generation of solid waste. The bag making process for grocery bags generates paper and plastic waste. The majority of this waste, known as mill waste, is recycled internally. Therefore, in this study BCAL treated mill waste as a closed loop recycling effort that returned the waste to the production process.

All of the grocery bags are recyclable to other paper and plastic products. EPA data from 2005 show that 21% of the kraft paper grocery bags are recycled and 5.2 % of the plastic grocery bags are recycled. The allocation decision for these recycled materials is that the recycled materials are not burdened with any inputs or outputs associated with their previous manufacture, use, disposal prior to recycling.

BCAL used this allocation approach, and treated the recycled materials as diverted waste. Diverted waste, like raw materials, are burdened with their intrinsic feedstock value and are subsequently burdened with the resource use, energy consumption, and environmental releases associated with their collection, cleaning and reprocessing, use, and disposal. Therefore, the inherent feedstock energy value of the recycled material is assigned to the diverted waste.

With respect to the degradable plastic bags, BCAL assumed that initially the same rate that applies to recycling of standard plastic bags (5.2%) would be appropriate for the rate sent to composting. This reflects a conservative approach using only data that currently reflect consumer behavior with regard to plastic bags. It is expected that the percentage of degradable plastic bags sent to composting will actually be higher once they are made available and collection can occur within municipalities, making it easier for the general consumer to send these bags through a different route of disposal. Recycling of plastic bags is currently low. This may be for a number of reasons, not the least of which appears to be the lack of infrastructure and poor consumer awareness about the inherent recycleability of plastic bags.

Solid Waste Combustion With Energy Recovery

In previous years, a controlled burning process called combustion or incineration was used solely to reduce volume of solid waste. However, energy recovery became more prevalent in the 1980s. Therefore, today, most of the municipal solid waste combustion in the US incorporates recovery of energy. EPA data from 2005 show that 13.6% of MSW was combusted with energy recovery.

The gross calorific values for the various grocery bags are estimated as follows:

For kraft paper bags	17.7 MJ/kg
For recyclable plastic bag	40.0 MJ//kg
For degradable plastic bag	19.6 MJ/kg

These materials are used as fuels in the waste to energy plants, however the thermal efficiencies for mass-burn WTE plants varies from 15% to 23% in the newer plants.[6] This study used 23% thermal efficiency for energy recovery.

Assuming complete combustion, the resulting estimated CO2 emissions are:

For kraft paper bags	1,650,000 mg/kg paper bag
For recyclable plastic bags	3,150,000 mg/kg recyclable plastic bag
For degradable plastic bags	1,360,000 mg/kg degradable plastic bag

The recovered energy (23% thermal efficiency) is as follows:

For kraft paper bags	4.07 MJ/kg paper bag
For recyclable plastic bags	9.20 MJ/kg recyclable plastic bag
For degradable plastic bags	4.51 MJ/kg degradable plastic bag

Therefore, using the above information, the following table is prepared on the basis of 1000 grocery bags and shows the recovered energy and resulting carbon dioxide emissions when 13.6% of the 1000 grocery bags are combusted with energy recovery.

Table 25. Recovered energy (MJ) and resulting carbon dioxide emissions (mg) when 13.6% of the 1000 grocery bags are combusted with energy recovery.

	Kraft Paper Bag	Recyclable Plastic Bag	Degradable Plastic Bag
Recovered energy	28.7 MJ	7.2 MJ	9.7 MJ
CO2 emissions	11,640,000 mg	2,150,000 mg	2,920,000 mg

Table 25 shows that the kraft paper bag has the highest recovered energy and the highest CO2 emissions. The recyclable and compostable plastic bags have significantly lower recovered energy and CO2 emissions.

Solid Waste to Landfill

A landfill has various phases of decomposition. Initially, aerobic decomposition will take place where oxygen is consumed to produce carbon dioxide gas and other by-products. During the first phase of anaerobic decomposition, carbon dioxide is the principal gas generated. As anaerobic decomposition proceeds toward the second phase, the quantity of methane generated increases until the methane concentration reaches 50% to 60%. The landfill will continue to generate methane at these concentrations for 10 or 20 years, and possibly longer[7].

Methane emissions from landfills in the United States were estimated at 8.0 million metric tons in 2001. In addition, 2.5 million tons were recovered for energy use and 2.4 million tons were recovered and flared. Therefore, more than 60% of the methane produced in landfills is not recovered.[8]

The precise fate of paper deposited in a landfill site is unknown. Paper may decompose entirely in a short space of time or it may remain intact for long periods.[9] This depends on a variety of factors such as temperature, pH, the presence of bacteria and nutrients. the composition of the waste and the form of the paper-shredded paper is much more likely to decompose than is a whole telephone book. To account for this variability. two scenarios were used to calculate emissions associated with the disposal of paper bags (both adjustment for 40% of the recovered methane noted above). The first scenario is a worst-case scenario that follows the basic decomposition reaction for cellulose and the second scenario is one that estimates carbon sequestration for paper in MSW landfills.

Scenario 1 for Paper Bags

The basic decomposition reaction for cellulose is well known and follows the form of:

$$C_6H_{10}O_5 + H_2O = 3CH_4 + 3CO_2 \qquad (1)$$

It is therefore expected that only one half of the carbon present in kraft paper bags will result in methane formation during decomposition. Typically carbon represents 45% of the mass of paper. Thus. the carbon content of 1 kg of paper will be 0.45 kg. That proportion giving rise to methane, assuming 100 % decomposition, would then be 0.225 kg. Based on this, the mass of methane produced would be 0.30 kg and the corresponding mass of the coproduct carbon dioxide would be 0.83 kg.

Scenario 2 for Paper Bags

Although cellulose decomposition in landfill is well documented, there remains significant uncertainty in the maximum extent of cellulose decomposition that can be realized under landfill conditions. Several studies indicate that significant carbon sequestration occurs in landfills because of the limited degradation of wood products. In one study[10] a carbon storage factor (CSF) was calculated that represented the mass of carbon stored (not degraded) per initial carbon mass of the component. For the following MSW paper refuse components the CSF was calculated: old newsprint = 0.42 kg C sequestered, coated paper = 0.34 kg C sequestered, and old corrugated = 0.26 kg C sequestered.

For this scenario the partial decomposition that the paper bags go through is assumed to be aerobic or the initial anaerobic phase, resulting principally in carbon dioxide emissions. In this scenario, we have assumed that the paper bags are similar to old corrugated, and therefore have assigned the same value of 0.26 kg C sequestered. Given that 0.26 kg of the kraft paper bag is assumed to be sequestered, 0.74 kg of the kraft paper bag results in carbon dioxide emissions of 1.23 kg.

Recyclable plastic bags are not considered to degrade in landfills, suggesting that all the inherent feedstock energy and emissions will be sequestered. Therefore, there are no carbon dioxide or methane emissions associated with the recyclable plastic bags sent to landfills.

Many types of biodegradable polymers are available to degrade in a variety of environments, including soil, air, or compost. The biodegradable products degrade under aerobic conditions to carbon dioxide and water in the presence of oxygen. The biodegradable, compostable plastic bags in this study are made from a blend of Ecoflex and PLA. Ecoflex is made from aliphatic-aromatic copolyester blended with equal amounts of starch. According to information provided by BASF, Ecoflex meets the requirements for biodegradable polymer classification based on European, US, and Japanese standards because Ecoflex can be degraded by micro-organisms.[11] PLA is a biodegradable polymer made from corn and is converted completely to carbon dioxide and water by micro-organisms. In addition, compostable plastic bags have been found to degrade as designed within an allowable timeframe in appropriate composting facilities[13]. In composting facilities, decomposition of biodegradable plastic bags made from a blend of Ecoflex and PLA are expected to release primarily carbon dioxide emissions and water. However, if sent to a landfill, biodegradable plastic will either not degrade at all, or may follow similar pathways as paper bags (a combination of both aerobic and anaerobic degradation). BCAL treated these bags in both ways in this study to examine all possibilities.

Solid Waste Composting

The biodegradable, compostable plastic bags in this study have demonstrated biodegradation in several standardized tests in several countries. Ecoflex and PLA meet US, European, Australian, and Japanese standards by degrading in 12 weeks under aerobic conditions in a compost environment and by breaking down to carbon dioxide and water. The extent of the degradation for Ecoflex was 2 to 6 months in compost depending upon temperature, and for PLA was 1 to 3 months in compost depending upon temperature. [11] Therefore, in the composting environment, decomposition of biodegradable plastic bags made from a blend of Ecoflex and PLA is expected to degrade over time with the release primarily of carbon dioxide emissions and water.

LCA Calculations of Environmental Impacts

As noted under the section on LCA methodology, life cycle assessment modeling allows an examination of specific problems as well as comparisons to determine if there are any serious side effects to any of the systems under study. In every system there are multiple environmental parameters to be addressed scaling from global to local issues, and no single solution is likely to address all of the issues simultaneously. In addition, almost every change to a system creates trade-offs, and it is the identification of these trade-offs that is important when trying to determine the best solution for any given problem.

To reiterate, a life cycle assessment can:

1. Quantify those parameters likely to be responsible for environmental effects (the inventory component of life cycle analysis).
2. Identify which parameters are likely to contribute to a specific environmental problem (characterization or interpretation phase of impact assessment). An

example would be identifying that carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are greenhouse gases.
3. Aggregate the parameters relating to a specific problem (the valuation or interpretation phase of impact assessment). An example would be producing carbon dioxide equivalents for the components of greenhouse gases.

The LCA calculations provide a compilation of information from which the user can address specific problems such as the conservation of fossil fuels, global warming, acid rain, and municipal solid waste. In addition, the user also is able to determine what trade-offs exist between systems and to examine the specific parameters which are likely to contribute to these problems. In so doing, the user can strive to achieve the optimum reduction in each parameter because of a better understanding of how these parameters change in association with each grocery bag system.

GLOBAL WARMING

One important issue that is currently being addressed using LCA studies is an examination of the contribution that industrial systems make to climate change. The work of the Intergovernmental Panel on Climate Change (IPCC)[12] provides a framework for aggregating data on those air emissions that are thought to be significant contributors to global warming. The aggregated effect of any system can be summarized as a parameter known as Global Warming Potential (GWP) or carbon dioxide equivalent. Any gaseous emission that is thought to contribute to global warming is assigned a value equal to the equivalent amount of CO_2 that would be needed to produce the same effect. Multiplying each gaseous emission by its CO_2 equivalent allows the separate effects of different emissions to be summed to give an overall measure of global warming potentials.

The major greenhouse gases of importance in this eco-profile are carbon dioxide, methane and nitrous oxide. The results tables provided previously (see Section on LCA Results) showed the global warming impacts (with carbon dioxide equivalents) up to the collection of the grocery bags.

The following table estimates the global warming impacts just from the collection and disposal of the grocery bags.

As discussed previously, two scenarios will be considered for the kraft paper bags, the first is a worst-case scenario that follows the basic decomposition reaction for cellulose and the second scenario is one that estimates carbon sequestration for paper in MSW landfills.

The recyclable plastic bags will not degrade in the landfill; all the inherent feedstock energy and emissions will be sequestered. Therefore, there are no carbon dioxide emissions from recyclable plastic bags in landfills.

In the landfill, decomposition of biodegradable plastic bags made from a blend of Ecoflex and PLA is expected to degrade over time with the release primarily of carbon dioxide emissions and water.

Table 26A. Greenhouse gas emissions. 20-year carbon dioxide equivalents (in milligrams) resulting from the disposal of 1000 grocery bags.

Disposal process	Paper bag with "worst case scenario" of methane emissions	Paper bag with "sequestered scenario" of carbon dioxide emissions	Recyclable plastic bag	Degradable plastic bag With 100% aerobic decomposition in landfill	Degradable plastic bag with 50% aerobic & 50% anaerobic decomposition in landfill (using the same pathway as described for paper bags)
Recycling	21% recycled & burden is transferred	21% recycled & burden is transferred	5.2% recycled & burden is transferred	5.2% recycled to composting & burden is transferred	5.2% recycled to composting & burden is transferred
Incineration with energy recovery 13.6%	11,640,000	11,640,000	2,150,000	2,920,000	2,920,000
Landfill 65.4% paper, 81.2% plastic	412,000,000	41,300,000	0	17,400,000	129,400,000
Total disposal related emissions	423,640,000	52,940,000	2,150,000	20,320,000	132,320,000

Table 26A shows that after disposal, the recyclable plastic bag has the lowest greenhouse gas emissions. The paper bag with the "sequestered scenario" has more than 15 times the greenhouse gas emissions of the recyclable plastic bag. The paper bag with the "worst-case scenario" has more than 200 times the greenhouse gas emissions of the recyclable plastic bag. The degradable plastic bag has more than 9 times the greenhouse gas emissions of the recyclable plastic bag.

Table 26B. Greenhouse gas emissions. 20-year carbon dioxide equivalents (in milligrams) resulting from the disposal of 1000 kraft paper grocery bags and 1500 recyclable plastic and degradable plastic grocery bags.

Disposal process	Paper bag with "worst case scenario" of methane emissions	Paper bag with "sequestered scenario" of carbon dioxide emissions	Recyclable plastic bag	Degradable plastic bag With 100% aerobic decomposition in landfill	Degradable plastic bag with 50% aerobic & 50% anaerobic decomposition in landfill
Recycling	21% recycled & burden is transferred	21% recycled & burden is transferred	5.2% recycled & burden is transferred	5.2% recycled to composting & burden is transferred	5.2% recycled to composting & burden is transferred
Incineration with energy recovery 13.6%	11,640,000	11,640,000	3,230,000	4,380,000	4,380,000
Landfill 65.4% paper, 81.2% plastic	412,000,000	41,300,000	0	26,100,000	194,000,000
Total disposal -related emissions	423,640,000	52,940,000	3,230,000	30,500,000	198,000,000

Table 26B shows that even using 1.5 plastic bags to 1 paper bag, after disposal, the recyclable plastic bag has the lowest greenhouse gas emissions. The paper bag at a 1 to 1.5 use ratio, with the "sequestered scenario," has more than 10 times the greenhouse gas emissions of the recyclable plastic bag. The paper bag with the "worst-case scenario" has more than 130 times the greenhouse gas emissions of the recyclable plastic bag. The degradable plastic bag has more than 9 times the greenhouse gas emissions of the recyclable plastic bag with the 100% aerobic decomposition and more than 60 times the greenhouse gas emissions of the recyclable plastic bag with the 50% aerobic decomposition/50% anaerobic decomposition.

Table 27A. Carbon dioxide equivalents (in milligrams) resulting from all operations just prior to the disposal of 1000 grocery bags.

	Recyclable and Recycled Paper bag* (from Table 6B)	Recyclable plastic bag (from Table 14B)	Degradable plastic bag (from Table 22B)
20 year CO2 eq.	23,710,000 mg	19,200,000 mg	89,000,000 mg

*It should be noted that these emissions include the "credit" when carbon dioxide was absorbed during tree growing.

Table 27A shows that from all operations just prior to disposal, the resulting CO2 equivalents are more than 20% greater for the paper bag compared to the recyclable plastic bag. From all operations just prior to disposal, the resulting CO2 equivalents for the degradable plastic bag are the highest about 4 times greater than the recyclable plastic bag.

Table 27B Carbon dioxide equivalents (in milligrams) resulting from all operations just prior to the disposal of 1000 kraft paper grocery bags and 1500 recyclable plastic and degradable plastic grocery bags.

	Recyclable and Recycled Paper bag* (from Table 6B)	Recyclable plastic bag (from Table 14B)	Degradable plastic bag (from Table 22B)
20 year CO2 eq.	23,710,000 mg	28,800,000 mg	134,000,000 mg

*It should be noted that these emissions include the "credit" when carbon dioxide was absorbed during tree growing.

Table 27B shows that from all operations just prior to disposal, the resulting CO2 equivalents are more than 20% greater for the recyclable plastic bag compared to the paper bag. From all operations just prior to disposal, the resulting CO2 equivalents for the degradable plastic bag are the highest about 4 times greater than the recyclable plastic bag and 5 times greater than the paper bag.

Now, adding the greenhouse gas emissions from tables 26 and 27 the total LCA cradle-to-grave greenhouse gas emissions for the production, use, and disposal of 1000 grocery bags are given in Table 28.

Table 28A. Total LCA cradle-to-grave CO2 equivalents (in milligrams) for the production, use, and disposal of 1000 grocery bags:

	Paper bag with "worst-case scenario" of methane emissions	Paper bag with "sequestered scenario" of carbon dioxide emissions	Recyclable plastic bag	Degradable plastic bag With 100% aerobic decomposition in landfill	Degradable plastic bag with 50% aerobic & 50% anaerobic decomposition in landfill
20 year CO2 eq	447,350.000	76,650,000	21,350,000	109,300,000	221,300.000
100 year CO2 eq	202.200,000	65,490,000	18,850,000	99.300,000	134,800,000
500 year CO2 eq	90,410,000	60,910,000	17,850,000	87.320,000	92,100,000

Table 28A shows that the recyclable plastic bag has the lowest the total cradle-to-grave CO2 equivalents. The paper bag with the "sequestered scenario" has more than 3.5 times the total cradle-to-grave CO2 equivalents of the recyclable plastic bag. The paper bag with the "worst-case scenario" has more than 20 times the total cradle-to-grave CO2 equivalents of the recyclable plastic bag. The degradable plastic bag has more than 5 times the total cradle-to-grave CO2 equivalents of the recyclable plastic bag.

Table 28B. Total LCA cradle-to-grave CO2 equivalents (in milligrams) for the production, use, and disposal of 1000 kraft paper grocery bags and 1500 recyclable plastic and degradable plastic grocery bags.

	Paper bag with "worst-case scenario" of methane emissions	Paper bag with "sequestered scenario" of carbon dioxide emissions	Recyclable plastic bag	Degradable plastic bag With 100% aerobic decomposition in landfill	Degradable plastic bag with 50% aerobic & 50% anaerobic decomposition in landfill
20 year CO2 eq	447,350,000	76,650,000	32,030,000	164,000,000	332,000,000
100 year CO2 eq	202,200,000	65,490,000	28,300,000	149,000,000	202,000,000
500 year CO2 eq	90,410,000	60,910,000	26,800,000	131,000,000	138,000,000

Table 28B shows that even using 1.5 plastic bags to 1 paper bag, the recyclable plastic bag has the lowest the total cradle-to-grave CO2 equivalents. The paper bag, at a 1 to 1.5 use ratio, with the "sequestered scenario," has about 2.3 times more total cradle-to-grave CO2 equivalents of the recyclable plastic bag, depending upon the time horizon. The paper bag with the "worst-case scenario" has more than 20 times the total cradle-to-grave CO2 equivalents of the recyclable plastic bag. The degradable plastic bag has more than 5 times the total cradle-to-grave CO2 equivalents of the recyclable plastic bag.

STRATOSPHERIC OZONE DEPLETION

The stratospheric ozone layer occurs at an altitude of between 10-40 km. The maximum generation of ozone (O_3) occurs at the outer layer, where oxygen molecules (O_2) react with atomic oxygen. The presence of other compounds, particularly halogenated compounds, promotes the decomposition of this ozone in the presence of strong ultra-violet radiation.

In this study there were no identified ozone depleting chemicals associated with the bag systems studied, and therefore no contributions to stratospheric ozone depletion.

ACID RAIN

The production of acid rain in the northeastern United States is recognized as a regional problem. Acid rain results when sulfur and nitrogen oxides and their transformation products return from the atmosphere to the earth's surface. The major source of acid rain is the emission of these pollutants from coal powered electricity generating plants.

The following data were extracted from the results tables. There are no data available for SOX and NOX emissions after disposal.

Table 29A. Acid rain emissions (in milligrams of SO_2 and NO_2) resulting from all operations just prior to disposal 1000 grocery bags.

Acid rain emissions mg	Paper bag	Recyclable plastic bag	Degradable plastic bag
SOX	579,000 mg	50,500 mg	275,000 mg
NOX	264,000 mg	45,400 mg	304,000 mg

Table 29A shows that the recyclable plastic bag has the least SOX and NOX emissions. The paper bag has more than 10 times the SOX emissions compared with the recyclable plastic bag and more than 5 times the NOX emissions compared with the recyclable plastic bag. The degradable plastic bag has more than 5 times the SOX and NOX emissions compared with the recyclable plastic bag.

Table 29B. Acid rain emissions (in milligrams of SO_2 and NO_2) resulting from all operations just prior to disposal for 1500 recyclable plastic bags and degradable plastic grocery bags.

Acid rain emissions mg	Paper bag	Recyclable plastic bag	Degradable plastic bag
SOX	579,000 mg	75,800 mg	413,000 mg
NOX	264,000 mg	68,100 mg	456,000 mg

Table 29B shows that even using 1.5 plastic bags to 1 paper bag, the recyclable plastic bag has the least SOX and NOX emissions. The paper bag, at a 1 to 1.5 use ratio, has more than 7 times the SOX emissions compared with the recyclable plastic bag and almost 4 times the NOX emissions compared with the recyclable plastic bag. The degradable plastic bag has more than 5 times the SOX and NOX emissions compared with the recyclable plastic bag.

MUNICIPAL SOLID WASTE

Another widespread environmental issue concerns the generation and disposal of municipal solid waste. The mineral wastes from mining, the slags and ash wastes from oil and gas production and utility coal combustion, and regulated chemical wastes are generally managed by regulation and permits that exclude these wastes from the municipal solid waste stream. The type of wastes in mixed industrial wastes can contribute to the municipal solid waste problem. If, as in this study, there is an interest in focusing on the municipal solid waste problem, the results on mineral wastes, slags & ash, and regulated chemicals can be ignored. Selecting only the solid waste resulting from just the disposal of grocery bags in landfill, one can prepare the following table 30A considering disposal of 1000 grocery bags and table 30B considering disposal of 1000 kraft paper grocery bags and 1500 recyclable plastic and degradable plastic grocery bags. The table reflects the waste that is landfilled as 65.4% paper bags and 81.2% plastic bags.

Table 30A. The municipal solid waste (in mg) resulting from just the disposal of grocery bags in landfill. Based on 1000 grocery bags but only 65.4% of paper bags are landfilled and 81.2% of plastic bags are landfilled.

	Paper bag	Recyclable plastic bag	Degradable plastic bag
Municipal solid waste mg	33,900,000	4,690,000	12,800,000

Table 30A shows that the recyclable plastic bag has the least municipal solid waste. The paper bag has more than 7 times the municipal solid waste compared with the recyclable plastic bag. The degradable plastic bag has almost 3 times the municipal solid waste compared with the recyclable plastic bag.

Table 30B. The municipal solid waste (in mg) resulting from just the disposal of grocery bags in landfill. Based on 1000 kraft paper grocery bags but only 65.4% of paper bags are landfilled and 1500 plastic grocery bags of which 81.2% of plastic bags are landfilled.

	Paper bag	Recyclable plastic bag	Degradable plastic bag
Municipal solid waste mg	33,900,000	7,035,000	19,200,000

Table 30B shows that even using 1.5 plastic bags to 1 paper bag, the recyclable plastic bag has the least municipal solid waste. The paper bag, at a 1 to 1.5 use ratio, has almost 5 times the municipal solid waste compared with the recyclable plastic bag. The degradable plastic bag has almost 3 times the municipal solid waste compared with the recyclable plastic bag.

CONSERVATION OF FOSSIL FUELS

Conservation problems are concerned with the depletion and possible exhaustion of raw materials and fuels. With continued use, the finite supply of raw materials, and especially fossil fuels will one day be exhausted. The conservation of fossil fuels: coal, oil ,and natural gas is an important global environmental issue. It is therefore important to ensure that these resources are used with the maximum efficiency and the minimum of waste.

Table 31A. The gross fossil fuels and feedstocks, expressed as energy (MJ) required for the production, use, and disposal of 1000 grocery bags.

Energy in MJ	Paper bag	Recyclable plastic bag	Degradable plastic bag
Coal	324	65	161
Oil	207	206	353
Gas	391	186	705
Totals	922	457	1,219

Table 31A shows that the recyclable plastic bag uses the least fossil fuels and feedstocks. The paper bag uses more than 2 times the fossil fuels and feedstocks compared with the recyclable plastic bag. The degradable plastic bag used more than 2 1/2 times the fossil fuels and feedstocks compared with the recyclable plastic bag.

Table 31B. The gross fossil fuels and feedstocks, expressed as energy (MJ) required for the production, use, and disposal of 1000 kraft paper grocery bags and 1500 recyclable plastic and degradable plastic grocery bags.

Energy in MJ	Paper bag	Recyclable plastic bag	Degradable plastic bag
Coal	324	98	242
Oil	207	309	530
Gas	391	279	1,058
Totals	922	686	1,830

Table 31B shows that even using 1.5 plastic bags to 1 paper bag, the recyclable plastic bag uses the least fossil fuels and feedstocks. The paper bag, at a 1 to 1.5 use ratio, uses 34% more fossil fuels and feedstocks compared with the recyclable plastic bag. The degradable plastic bag used more than 2 1/2 times the fossil fuels and feedstocks compared with the recyclable plastic bag.

LOCAL & REGIONAL GRID ELECTRICITY USE

The US recently has experienced severe problems related to its local and regional grid electricity. Because of these recent "blackouts," "brownouts," and electricity interruptions, the need for appropriate conservation measures can be argued.

Table 32A. The electrical energy (MJ) required for the production, use, and disposal of 1000 grocery bags.

	Paper bag	Recyclable plastic bag	Degradable plastic bag
Electrical energy MJ	649	148	325

Table 32A shows that the recyclable plastic bag uses the least electrical energy. The paper bag uses more than 4 times the electrical energy compared to the recyclable plastic bag. The degradable plastic bag used more than 2 times the electrical energy compared with the recyclable plastic bag.

Table 32B. The electrical energy (MJ) required for the production, use, and disposal of 1000 kraft paper grocery bags and 1500 recyclable plastic and degradable plastic grocery bags.

	Paper bag	Recyclable plastic bag	Degradable plastic bag
Electrical energy MJ	649	222	488

Table 32B shows that even using 1.5 plastic bags to 1 paper bag, the recyclable plastic bag uses the least electrical energy. The paper bag, at a 1 to 1.5 use ratio, uses almost 3 times the electrical energy compared with the recyclable plastic bag. The degradable plastic bag used more than 2 times the electrical energy compared with the recyclable plastic bag.

WATER USE & PUBLIC SUPPLY

Parts of the US continue to be plagued by periodic drought conditions. During these times, laws and regulations concerning water conservation are enforced. Since public water supply issues have been identified as a problem, the following table has been prepared to compare public water supply used for the production, use, and disposal of 1000 grocery bags.

Table 33A. Public water supply (in mg) used for the production, use, and disposal of 1000 grocery bags.

	Paper bag	Recyclable plastic bag	Degradable plastic bag
Public water supply (in mg)	3,895,000,000	31,150,000	2,560,000,000

Table 33A shows that the recyclable plastic bag uses the least public water supply. The paper bag uses more than 125 times the public water supply compared with the recyclable plastic bag. The degradable plastic bag used more than 80 times the public water supply compared with the recyclable plastic bag.

Table 33B. Public water supply (in mg) used for the production, use, and disposal of 1000 kraft paper grocery bags and 1500 recyclable plastic and degradable plastic grocery bags.

	Paper bag	Recyclable plastic bag	Degradable plastic bag
Public water supply	3,895,000,000	46,700,000	3,840,000,000

(in mg)		

Table 33B shows that even using 1.5 plastic bags to 1 paper bag, the recyclable plastic bag uses the least public water supply. The paper bag, at a 1 to 1.5 use ratio, uses more than 80 times the public water supply compared with the recyclable plastic bag. The degradable plastic bag used more than 80 times the public water supply compared with the recyclable plastic bag.

SUMMARY AND CONCLUSIONS

Recent efforts by legislators to ban traditional plastic bags on the basis of environmental impact have reignited the debate surrounding single-use grocery bags, and whether there are any environmental trade-offs in switching from bags made with polyethylene to bags made from alternative materials.

This life cycle assessment was commissioned to examine the overall environmental impacts associated with the typical single-use polyethylene plastic grocery bag, compared with grocery bags made from compostable plastic resin and grocery bags made from 30% recycled paper.

Life cycle assessment is a useful analytical tool because it allows for the examination of an entire production system from cradle to grave, thus examining the full range (global, regional, and local impacts) of environmental issues at once rather than examining individual components of a system or individual products or processes. This broad picture analysis is important because environmental effects range from global (greenhouse gases), to regional (acid rain/solid waste) or local (toxic releases) impacts. And while there often is excellent information on local environmental effects, few complete data sets are available to understand the contributions production systems are making to global and regional environmental problems.

These study results confirm that the standard polyethylene grocery bag has significantly lower environmental impacts than a 30% recycled content paper bag. This supports conclusions drawn from a number of other studies looking at similar systems.[14, 15, 16] In addition, this report also shows that the typical polyethylene grocery bag has fewer environmental impacts than a compostable plastic grocery bag made from a blend of EcoFlex (BASF), polylactic acid, and calcium carbonate, when compared on a 1:1 basis, as well as when the number of bags is adjusted for carrying capacity so that the comparison is 1.5:1. Surprisingly, the trend is the same for most of the individual categories of environmental impacts. No one category showed environmental impacts lower for either the compostable plastic bag or the paper bag.

This study did not examine the impacts associated with reusable cloth bags, so no comparison was made between the cloth bags and single-use polyethylene plastic bags. In other studies, however, cloth bags were shown to reduce environmental impacts if consumers can be convinced to switch. The problem is that there are few examples where entire cities, counties, or countries have been successful in changing consumer behavior from the convenience of using bags provided by retail establishments to bringing their own bags to the store each time they shop. There is no question that a percentage of consumers do, and will use reusable cloth grocery bags, but the vast majority of consumers still appear to use the freely available bags provided by retail establishments. So, if consumer behaviors are not appearing to change, banning one type of single-use bag will simply mean that it is replaced by another type of single-use bag.

Given the above-stated assumption, it is clear that the replacement bags will either be compostable plastic bags or paper bags, as proposed legislation tends to stipulate these as the preferred alternatives. But can these alternative materials meet the legislative objectives, which often include: the reduction of litter, the need to reduce dependence on fossil fuels, and the need to reduce solid wastes? Taking the latter two objectives first, one can use the LCA results in this report to see if the above stated objectives are being met.

In the case of reducing dependence on overall energy, it is clear (see Table 34) that neither the life cycle of compostable bag nor paper bag provides a reduction in overall energy use. The standard polyethylene plastic grocery bag uses between 1.8 and 3.4 times less energy than the compostable and paper bag systems, respectively.

Table 34. Gross Energy by Activity (MJ)

	Fuel prod'n (total)	Fuel use (total)	Transport (total)	Feedstock (total)	Total
Paper Bag (1000 bags)	493	1105	34	991	2622
Compostable Plastic Bag (1000 bags)	265	659	38	418	1380
Compostable Plastic Bag (1500 bags)	398	988	57	627	2070
Polyethylene Plastic Bag (1000 bags)	106	114	11	279	509
Polyethylene Plastic Bag (1500 bags)	159	171	16	418	763

Table 35 demonstrates that in terms of fossil fuel use, including oil, the compostable plastic bag system does not provide any benefit. The compostable plastic bag system appears to use more oil than either of the other two bag systems, varying from 1.7 to 2.57 times more oil than either the plastic bag or paper bag systems, respectively. The paper bag system would appear to be able to provide a slight improvement, but only if the plastic bag system actually uses 1.5 bags for every 1 bag in the paper system. If this assumption cannot be supported, then the paper bag system would not provide even a slight advantage.

Table 35. Gross Fossil Fuel Use (kg)

	Paper Bag (1000 bags)	Compostable Plastic Bag (1000 bags)	Compostable Plastic Bag (1500 bags)	Polyethylene Plastic Bag (1000 bags)	Polyethylene Plastic Bag (1500 bags)
Coal	11.2	5.8	8.7	2.3	3.4
Oil	4.6	7.8	11.8	4.6	6.9
Gas	7.4	14.0	21.0	3.1	4.6

These results may appear to some to be counterintuitive, but both compostable plastic and paper bags require more material per bag in their manufacture. This results in greater use of fuels in the extraction and transport of raw materials for the manufacture of the bags, as well as greater energy in bag manufacturing and greater fuel use in the transport of the finished product from the manufacturer to retail establishments. Although standard polyethylene plastic bags are made from oil, the added requirements of manufacturing energy and transport for the compostable and paper bag systems far exceed the raw material use in the standard plastic bag system.

The results of this study also show that the standard polyethylene single-use plastic grocery bag's contribution to the solid waste stream is far lower than either the paper bag system or the compostable bag system. This is not surprising considering both the compostable bag and paper bag systems require more material per bag. The increase in solid wastes has become an important global issue as populations multiply and developing countries become wealthier, consuming more material goods. Currently, more land is being devoted to the disposing of solid wastes, and the lack of proper containment in solid waste facilities is causing problems in terms of soil contamination and water pollution.

Table 36. Municipal Solid Waste (kg)

Paper Bag (1000 bags)	Compostable Plastic Bag (1000 bags)	Compostable Plastic Bag (1500 bags)	Polyethylene Plastic Bag (1000 bags)	Polyethylene Plastic Bag (1500 bags)
33.9	12.8	19.2	4.7	7.0

This study was not designed to address the issue of litter, so no specific calculations were conducted on the effect of the various bag systems on litter. However, there are some interesting points that can be made with regard to meeting the objective of reducing litter by switching to alternative materials in the grocery bag system. The summary of results discussed above on energy use and solid waste already illustrate that reducing litter through a change in the grocery bag system will lead to greater use in energy and greater amounts of solid wastes. Those who believe that this is an acceptable trade-off must also understand that there are additional, and perhaps far more serious, environmental impacts that will result if plastic bags are supplanted by either compostable plastic bags or paper.

One of these serious environmental impacts is global warming. The study showed that switching from single-use polyethylene plastic grocery bags to either paper or compostable plastic grocery bags may increase the emission of greenhouse gases and therefore contribute to global warming (See Table 37). Based on these results, it appears that the trade-off for reducing litter is an increase in global warming, which if not curbed, is expected to cause problems for decades and to affect marine, freshwater, and terrestrial habitats, and species globally. If one of the major concerns about litter is its accumulation in marine habitats and its negative effect on sea life, it would hardly seem justified to address the effects of litter with a grocery bag system that can cause significant harm to not only the same habitats, but to all other habitats as well.

Table 37. Global Warming Potential (CO2 Equivalents in tons)

	Paper bag with "sequestered scenario" of carbon dioxide emissions (1000 bags)	Compostable plastic bag With 100% aerobic decomposition in landfill (1500 bags)	Compostable plastic bag with 50% aerobic & 50% anaerobic decomposition in landfill (1500 bags)	Polyethylene Plastic Bag (1500 bags)
Production	0.03	0.15	0.15	0.03
Disposal	0.05	0.03	0.22	0.00
Total	0.08	0.18	0.37	0.04

Another increasingly important issue is the protection of water sources around the globe. Concerns have been raised over the long-term availability of water to support the expanding population's need for drinking, manufacturing, and agriculture. Table 38 shows the use of freshwater resources for each of the grocery bag systems studied. The standard polyethylene plastic bag uses significantly less water, compared with the paper or compostable grocery bag systems. Paper grocery bags use approximately 1 gallon of water for every bag, compared with the plastic bag system, which uses only .008 gallons per bag or 1 gallon for every 116 bags. Compostable grocery bags do not appear to provide any improvement over paper bags, and use far more water than the standard polyethylene plastic bag. It appears, therefore, that in switching to a paper bag or compostable plastic bag system to combat a litter problem, consumers will have to accept another significant trade-off—the increase in use of valuable water resources.

Table 38. Gross Freshwater Resources (gallons)

	Paper Bag (1000 bags)	Compostable Plastic Bag (1000 bags)	Compostable Plastic Bag (1500 bags)	Polyethylene Plastic Bag (1000 bags)	Polyethylene Plastic Bag (1500 bags)
Public Supply	1000	660	1000	8	13
Other	4	12	17	32	45

Other environmental factors that show similar trends are the emission of acid rain gases and water pollutants. In both cases, paper bag and compostable bag systems show larger amounts of pollutants emitted into the environment than those emitted by the plastic grocery bag system. Similarly, there are other environmental matters that are important to consider when making a decision on which systems to implement. Paper bag systems use a completely different resource base—wood fiber—than the plastic bag system. If the wood fiber does not come from sustainably managed forest systems or from agricultural wastes, it may cause a trade-off that is unacceptable to consumers. Forests are important ecosystems that support a wide variety of life, and disrupting these ecosystems in the name of reducing litter is an effect that deserves further contemplation.

The study results support the conclusion that any decision to ban traditional polyethylene plastic grocery bags in favor of bags made from alternative materials (compostable plastic or recycled paper) will be counterproductive and result in a significant increase in environmental impacts across a number of categories from global warming effects to the use of precious potable water resources.

Addressing the issue of increasing litter with bans on plastic grocery bags may be counterproductive as this study has not considered many other mitigating circumstances that may lead to even greater differentials between plastic grocery bags and those made from either paper or compostable plastics.

Increased recycling rates for plastic bags, better bagging techniques at retail, and secondary uses of plastic grocery bags such as waste disposal could all further reduce the environmental impacts of plastic grocery bags. In addition, getting consumers to change their behavior so that plastic bags are kept out of the litter stream would appear to be more productive in reducing the overall environmental impact of plastic bags including litter.

This study supports the conclusion that the standard polyethylene grocery bag has significantly lower environmental impacts than a 30% recycled content paper bag and a compostable plastic bag. An LCA report and its findings can be used to demonstrate that an environmental impact analysis needs to take into account the entire picture, and when dealing with a product that is likely to be replaced by another, the trade-offs in the environmental impact of the replaced alternative should also be given a critical analysis.

LITERATURE REFERENCES

[1] Private communication between PBA member and Weyerhauser. June 2007.

[2] *Municipal Solid Waste in the USA: 2005 Facts & Figures.* USEPA, Office of Solid Waste, EPA530-R-06-011. October 2006.

[3] Boustead. I. *Eco-profiles of the European plastics industry: Report 3 – polyethylene and polypropylene.* A report for the European Centre for Plastics in the Environment (PWMI), Brussels, May 1993. Revised 1999.

[4] Private communications with BASF, Edwards, K. and Bradlee, C., May-July 2007.

[5] Vink, E. T. H., Rabago, K. R., Glassner, D. A., Gruber, P. R, *Applications of life cycle assessment to NatureWorks* TM *polylactide (PLA) production.* Polymer Degradation and Stability 80 (2003) Elsevier, The Netherlands.

[6] Stodolsky, F., and Mintz, M. .M, *Energy Life-Cycle Analysis of Newspaper,* Energy Systems Division Argonne National Laboratory, Argonne, IL , May 1993.

[7] Robinson, W. D., *The Solid Waste Handbook,* John Wiley & Sons, New York, 1986.

[8] Methane Emissions, Energy Information Administration/Emissions of Greenhouse Gases in the United States 2001.

[9] Rathje. W., *Excavating Landfills,* Presentation at GRCDA 13'th Annual Landfill Gas Symposium. Lincolnshire, IL, 1990.

[10] Barlaz. M. A. *Carbon storage during biodegradation of municipal solid waste components in laboratory scale landfills.* Global Biochem. Cycles. 12(2):373-380, 1998.

[11] *Evaluation of the Performance of Rigid Plastic Packaging Containers. Bags. and Food Service Packaging in Full-Scale Commercial Composting,* A report to the Integrated Waste Management Board, California Environmental Protection Agency. Sacramento. CA, March 2007

[12] Houghton. J. T., Meira Filho. L.G., Callander, B.A., Harris, N., Kattenberg. A. & Maskell, K. (eds). *Climate Change 1995 – Contribution of WGI to the Second Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge University Press, 1996.

[13] Evaluation of the Performance of Rigid Plastic Packaging Containers, Bags. and Food Service Packaging in Full Scale Commercial Composting. California State University, Chico Research Foundation. 2007. Prepared for the California Integrated Waste Management Board under Contract IWM-C2061.

[14] EPA of Polyethylene and Unbleached Paper Grocery Sacks. Prepared for the Solid Waste Council. Franklin Associates Report, June 1990.

[15] *Life Cycle Inventory of Packaging Options For Shipment of Retail Mail-order Soft Goods. Prepared For Oregon Dept. of Environmental Quality (DEQ) and* U.S. EPA Environmentally Preferable Purchasing Program. Franklin Associates, 2004.

[16] Evaluation des impacts environnementaux des sacs de caisse Carrefour. Analyse du cycle de vie de sacs decaisse en plastique, papier, et materriau biodegradable. Rapport prepare pour Carrefour. Fevrier 2004.

REFERENCES REGARDING THE BOUSTEAD MODEL

1. Boustead, I., *Boustead Model V5.0 Operating Manual,* Boustead Consulting Ltd., 2003.
2. Boustead, I., *Boustead Model V5.0 Code Book & Conversion Factors,*Boustead Consulting Ltd., 2003.
3. Boustead, I., *An Introduction to Life Cycle Assessment,*Boustead Consulting Ltd., 2003.
4. Boustead, I., *The Boustead Model Information Book, pages 1 – 500,* Boustead Consulting Ltd.

APPENDIX I – PEER REVIEW

Background

Dr. Overcash conducted the peer review and is a Professor of Chemical Engineering, as well as a Professor of Biological and Agricultural Engineering at North Carolina State University. Dr. Overcash has developed an in-depth national research program in life cycle research, developing the new areas for utilization of the life cycle tools. Dr. Overcash has led the effort in life cycle inventory techniques for manufacturing improvement and product change. Dr. Overcash has contributed to life cycle studies in energy production, electroplating, solvent selection, pharmaceutical processes, life cycle assessment comparisons, paper industry, and textiles. He has been active in European life cycle efforts and reviews of research in this field.

All of the suggestions and recommendations made by Dr. Overcash have been reviewed and incorporated in this report. Below is the Peer Review Report provided by Dr. Overcash.

Review of Draft Report
Life cycle assessment for three types of grocery bags – recyclable plastic; compostable, biodegradable plastic; and recycled, recyclable paper

By Dr. Michael Overcash
September 2, 2007

This report provides both a sound technical descriptions of the grocery bag products and the processes of life cycle use. The functional unit has a range to accommodate differences in customer use found to exist. These differences did not prove to change the resulting low environmental impact choice. The discussion of the limitations of the life cycle impact assessment is very important and the readers should use these observations. The following detailed review is divided into technical and editorial segments.

The conclusions regarding the relative environmental impact when using a life cycle view are consistent with previous studies and need to be reinforced in the policy arena. The policies to discourage plastic bags may have more to do with litter than the overall environment. Whatever the goals of the policy makers, these need to be far more explicit than general environmental improvement, since the life cycle story is consistent in favor of recyclable plastic bags. It is possible that the emphasis of another report might be that the full benefit of plastic bags is even higher when large recycling is in place.

Technical

1) p.3 last paragraph BBL is not defined
2) Table 3 at 5.78 kg functional unit this mass reflects the 50% water in wood. However this wood is lignin and cellulose and so only about 50% of the solid material ends up in paper bag, so this should be 274,000,000 mg

3) Table 5 These occur in all the raw material Tables
    a. Biomass is double counted as it appears also in Table 3 while wood does not appear both places
    b. Limestone is listed twice. here and as chalk
    c. N2 and O2 are listed twice as air and constituents of air
4) Table 7 This is an unusually high COD:BOD ratio. it might need to be checked
5) Table 9B Elec = 103 This did not change from Table 9A, while all the other values did change reflecting the differences in number of bags.
6) p.34 line 4 under Solid Waste This identifies steam or electricity as possible energy recovery mechanisms, but Table 25 is only electricity. Steam would have a much higher recovery value
7) p.41 2nd line From the data in Table 28A this ratio is more like 3.5 and not 2.5
8) p. 42 3rd line From the data in Table 28B it is hard to see any ratio as high as 13

Editorial

1) p1 2nd line world for governments
2) p4 last para, 3rd line represent
3) whole document the conventional style is that data are plural, but throughout this documents that is mostly not followed. A search for the word data and inserting the correct verb will fix this.

The ULS Report

REVIEW OF LIFE CYCLE DATA RELATING TO DISPOSABLE, COMPOSTABLE, BIODEGRADABLE, AND REUSABLE GROCERY BAGS

I. BACKGROUND

In March 2007, the Board of Supervisors of the City of San Francisco passed an ordinance effectively banning the use of plastic grocery bags at supermarkets and large pharmacies. The Board's objective was to stop environmental degradation and reduce litter, and its solution was to legislate the replacement of traditional plastic bags with reusable bags or bags made from paper or compostable plastic.

In an effort to gauge the impact of the Board's decision, both in terms of environmental impact and litter reduction, the Editors of *The ULS Report* have examined a number of credible third-party research reports, and used the findings to develop their own conclusions and recommendations.

Please note that this review was originally published in June, 2007 and has been revised as follows:

1. This review includes research performed by Boustead Consulting & Associates that was released after the previous version was published in June 2007.
2. Information from the EPA's web sites cited in the previous summary has been removed from this version, as it is no longer publicly available.
3. All results mentioned below have been made equivalent to reflect the different carrying capacity of paper vs. plastic bags. For reference, it is generally accepted that 1.5 plastic bags equal the capacity of 1 paper bag.

II. METHODOLOGY

An examination was made of four studies that compared the environmental impacts of various grocery bags, or provided data widely used to do so:

1. Carrefour Group, an international retail chain that was founded in France and is second only to Wal-Mart in terms of global retail revenues, commissioned a Life Cycle Assessment (LCA) Study by Price-Waterhouse-Coopers/EcoBalance *(Évaluation des impacts environnementaux des sacs de caisse, February 2004, #300940BE8)* that compared the environmental impact of four types of bags: plastic made from high density polyethylene (HDPE), paper, biodegradable plastic (50% corn starch and 50% polycaprolactone compostable plastic), and reusable plastic (flexible PE). The study evaluated environmental impacts from material production, through bag manufacturing and transport, to end of life management.

   The study was completed according to ISO standards 14040-14043, and peer reviewed by the French environmental institute, ADEME, the Agency for

Environment and Energy Management. The first review was by Henri Lecouls, an independent lifecycle analysis expert assisted by Laura Degallaix, representative of the Federal Consumers' Union, Que Choisir, and Dominique Royet, World Wildlife Federation (WWF) representative. A second review was made by related parties: APME (European Plastics Manufacturers Association; CEPI (Confederation of European Paper Industries); and Novamont, manufacturer of the biodegradable plastic assessed in the study.

2. *Life Cycle Inventories for Packagings,* Environmental Series No. 250/1, Swiss Agency for the Environment, Forests and Landscape (SAEFL), 1998. The study was critically reviewed by corporate and association members representing the paper, plastics, glass, aluminum and steel packaging industries.

3. *Eco-Profiles of the European Plastics Industry,* performed by I. Boustead for PlasticsEurope, 2005. This series was developed by LCA pioneer Boustead Consulting and conforms wherever possible to ISO standards 14040-14043. The data on polyethylene film are also referenced in the SAEFL study listed above.

4. *Life Cycle Assessment for Three Types of Grocery Bags - Recyclable Plastic; Compostable, Biodegradable Plastic; and Recycled, Recyclable Paper,* performed by Boustead Consulting & Associates Ltd. for the Progressive Bag Alliance, 2007. The study compared traditional grocery bags made from polyethylene, bags made from compostable plastics, and paper bags made using at least 30% recycled fibers. The life cycle assessment factored in every step of the manufacturing, distribution, and disposal stages of these bags.

   The study was peer reviewed by Dr. Michael Overcash, Professor of Chemical Engineering, as well as a Professor of Biological and Agricultural Engineering, at North Carolina State University.

III. STUDY LIMITATIONS

1. Findings, conclusions, and recommendations are based on data that have been obtained through publicly available channels or through the broad group of contacts that *The ULS Report* has developed. There may be other data available that refute, confirm, or extend the findings herein developed.

2. Results are based upon an analysis of quantitative data, especially in relation to materials consumption, energy and water usage, pollution, and greenhouse gas (GHG) production. Because of their qualitative and personal nature, issues that transcend a scientific approach, such as the social value of renewable vs. non-renewable resources and composting vs. landfilling, are best considered independently by the reader.

3. While the 2007 Boustead Consulting study was performed in the United States, the other studies originated in Europe. Because production processes are relatively similar globally, the data provide accurate assessments that can be used to draw valid conclusions in the United States. The similarity in results between the American and European studies further bears this out.

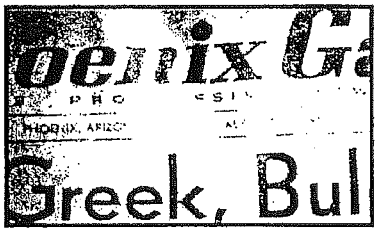
IV. FINDINGS

A. Biodgredation/Compostability

While paper and certain plastics may be biodegradable or compostable in specially designed industrial facilities, evidence indicates that this feature may be of little value in the effort to reduce waste:

1. Current research shows that in modern landfills, paper does not degrade or break down at a substantially faster rate than plastic does. Due to the lack of water, light, oxygen, and other important elements necessary for the degradation process to occur, nothing completely degrades in modern landfills.

   As evidence of this, here is a photo of a newspaper buried in an Arizona landfill and dug up after more than three decades. As can be clearly seen, paper does not degrade rapidly in landfills. *(Photo credit: Dr. William Rathje, Founder of The Garbage Project at The University of Arizona.)*

   oenix G

   Greek, Bul

   Compostable plastics, which are produced from plant-based feedstocks, do not degrade in landfills, either. According to Natureworks®, a producer of a corn-based plastic known as PLA, containers made from its material will last as long in landfills as containers made from traditional plastics.[1]

2. In order to breakdown as intended, compostable plastics must be sent to an industrial or food composting facility, rather than to backyard piles or municipal composting centers. Since there are apparently fewer than 100 of these facilities functioning in the entire United States, the economic and environmental costs of wide-scale plastics composting are prohibitive, significantly reducing the value of such an alternative.[2]

3. By definition, composting and biodegradation release carbon dioxide (CO_2), a greenhouse gas, into the atmosphere, increasing the potential for climate change. For example, composted paper produces approximately twice the CO_2 emissions produced by non-composted paper. (See Paragraph B.1. just below for specific details.)

B. Waste, Energy Consumption, Greenhouse Gas Emissions

The evidence does not support conventional wisdom that paper bags are a more environmentally sustainable alternative than plastic bags. While this is certainly counterintuitive for many people, relevant facts include the following:

1. Plastic bags generate 39% less greenhouse gas emissions than uncomposted paper bags, and 68% less greenhouse gas emissions than composted paper bags. The plastic bags generate 4,645 tons of CO_2 equivalents per 150 million bags; while uncomposted paper bags generate 7,621 tons, and composted paper bags generate 14,558 tons, per 100 million bags produced.[3]

2. Plastic bags consume less than 6% of the water needed to make paper bags. It takes 1004 gallons of water to produce 1000 paper bags and 58 gallons of water to produce 1500 plastic bags.[4]

3. Plastic grocery bags consume 71% less energy during production than paper bags.[5] Significantly, even though traditional disposable plastic bags are produced from fossil fuels, the total non-renewable energy consumed during their lifecycle is up to 36% less than the non-renewable energy consumed during the lifecycle of paper bags and up to 64% less than that consumed by biodegradable plastic bags.[6]

4. Using paper sacks generates almost five times more solid waste than using plastic bags.[7]

5. After four or more uses, reusable plastic bags are superior to all types of disposable bags --paper, polyethylene and compostable plastic -- across all significant environmental indicators.[8]

C. Litter

While the data appear to indicate that paper and compostable plastic bags may account for less litter, data also indicates that this finding is offset by the increased environmental impacts these bags produce versus traditional plastic bags:

1. The manufacture of paper bags consumes twice as much water and emits about 60% more greenhouse gases than the production of plastic bags.[9]

2. Compared to disposable plastic bags, biodegradable plastic bags generate higher levels of greenhouse gas emissions, atmospheric acidification and eutrophification (a process whereby bodies of water receive excess nutrients that stimulate excessive plant growth, such as algae blooms).[10]

V. CONCLUSIONS/INDICATED ACTIONS

The conclusion to be drawn about how to reduce the environmental impacts and litter associated with grocery bags is very much in line with both longstanding EPA guidelines and the *ULS Report* philosophy: the issue is not paper or plastic, but rather finding ways to reduce, reuse, and recycle both of them - *in that order*. By putting more items in fewer bags, avoiding double bagging, switching to durable tote bags, and reusing and recycling disposable bags, significant reductions in material and non-renewable energy consumption, pollution, solid waste, greenhouse gas emissions, and litter, will occur.

And, while recycling can help save resources, its real value lies in the reduction of greenhouse gas emissions, and the minimization of waste going to landfills. Also, recycling helps reduce litter, as bags are contained and stored. Containment reduces the potential for them to be left in open spaces, where they become eyesores.

VI. SUMMARY

Legislation designed to reduce environmental impacts and litter by outlawing grocery bags based on the material from which they are produced will not deliver the intended results. While some litter reduction might take place, it would be outweighed by the disadvantages that would subsequently occur (increased solid waste and greenhouse gas emissions). Ironically, reducing the use of traditional plastic bags would not even reduce the reliance on fossil fuels, as paper and biodegradable plastic bags consume at least as much non-renewable energy during their full lifecycle.

Further, an Internet scan of available government and non-profit information for the United States, United Kingdom, Canada and Australia indicates that chewing gum and cigarette butts account for up to 95% of the litter generated in the English-speaking world.[11] Thus, there would appear to be far better and potentially more effective legislative opportunities available if the objective is to significantly reduce litter.

Again, when it comes to reducing the environmental and litter impacts of grocery and merchandise bags, the solution lies in a.) Minimizing the materials used to produce all types of bags, regardless of their composition, and b.) Building public awareness and motivation to reduce, reuse and recycle these bags - in that order.

Robert Lilienfeld

Robert Lilienfeld, Editor

Footnotes

---

[1] *Corn Plastic to the Rescue*, by Elizabeth Royte, *Smithsonian*, August 2006 (www.smithsonianmag.com/issues/2006/august/pla.php?page=1).

[2] These figures were provided by a number of experts, but due to the fluctuating dynamics of the composting industry, no firm citation can be given. One article that mentioned the relative unavailability of industrial and food composting was *Composting that Plastic* by Eliza Barclay, *Metropolis Magazine*, March 1, 2004 (www. metropolismag.com/cda/story.php?artid=153). See also the *BioCycle* site www.findacomposter.com.

[3] *Life Cycle Inventories for Packagings*, Volume 1, SAEFL, 1998, Environmental Series 250/I and *Eco-Profiles of the European Plastics Industry*, developed by I. Boustead for PlasticsEurope, March 2005 (www.plasticseurope.org/content/Default.asp?PageID=404&IsNewWindow=True).

[4] Ibid and *Life Cycle Assessment for Three Types of Grocery Bags - Recyclable Plastic; Compostable, Biodegradable Plastic; and Recycled, Recyclable Paper*, performed by Boustead Consulting & Associates Ltd. for the Progressive Bag Alliance, 2007.

---

[5] *Life Cycle Assessment for Three Types of Grocery Bags - Recyclable Plastic; Compostable, Biodegradable Plastic; and Recycled, Recyclable Paper. Op cit.*

[6] Ibid and *Évaluation des impacts environnementaux des sacs de caisse Carrefour* (Evaluation of the Environmental Impact of Carrefour Merchandise Bags), prepared by Price- Waterhouse-Coopers/Ecobilan (EcoBalance), February 2004, #300940BE8. (www.ademe.fr/htdocs/actualite/rapport_carrefour_post_revue_critique_v4.pdf).

[7] *Life Cycle Assessment for Three Types of Grocery Bags - Recyclable Plastic; Compostable, Biodegradable Plastic; and Recycled, Recyclable Paper. . Op cit.*

[8] *Évaluation des impacts environnementaux des sacs de caisse Carrefour. Op cit.*

[9] Ibid.

[10] Ibid.

[11] See *Litter Composition Survey of England*, October 2004, produced by ENCAMS for INCPEN (www.incpen.org/pages/userdata/incp/LitterCompSurvey24Jan2005.pdf). Also see *Facts About Litter* from an Australian governmental site (www.environment.nsw.gov.au/litter/factsaboutlitter.htm), and equivalent government and non-profit sites in Canada and the United States, such as Keep America Beautiful.

3 Life cycle assessment of paper and plastic checkout carrier bags

3.1 Overview of the life cycle analysis approach and findings

This section has been approached by means of an introduction to life cycle analysis (LCA) followed by a description of a generic life cycle analysis methodology, a discussion of the limitations of LCA's, descriptions of the lifecycles of paper and plastic checkout carrier bags, a description of the research approach, a description of the limitations of the research, the presentation of the research found and a statement of conclusions.

The objective of this section was to present a summary of the findings of a literature review into studies previously undertaken of the life cycles of plastic (polyethylene), paper and cloth checkout carrier bags. The review found no data relating to cloth carrier bags. Two studies dealing with the comparison of, firstly, paper and plastic checkout grocery bags in the United States and, secondly, paper and plastic animal feed distribution sacks in Europe were found.

A comparison of the two studies indicates that the results are contradictory. Literature found suggests that the discipline of life cycle analysis is highly sensitive to internal variables including the project scope, methodology, objectives and environmental and geographic context in which the studies are undertaken. This therefore suggests that the studies are limited in both comparison to one another and interpretation in the South African context. It is therefore concluded that in order to generate an understanding of which product life cycle has the greater environmental impact (in South Africa) a South African LCA comparison must be completed.

3.2 Introduction to life cycle analysis

A life cycle analysis (LCA) provides a framework and methods for identifying and evaluating environmental burdens associated with the complete life cycles of products and services, i.e. from the product cradle to the grave.

3.3 What is Life Cycle Analysis?

The life cycle assessment (LCA) method deals with the complex interaction between the provision of a product or service, through all stages of its life cycle, and the environment. The LCA attempts to predict the overall environmental burdens associated with the provision of the product and identify particularly burdensome or wasteful processes therein.

The United States Environmental Protection Agency defines a Life Cycle assessment as 'an objective process used to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used and wastes released to the environment, and

...to evaluate and implement opportunities to affect environmental improvements"[3] The purpose of following the product life cycle from the cradle to the grave is to limit or eliminate impact displacement.

Typically a life cycle assessment would determine the energy and raw material utilisation and solid, liquid and gaseous emissions generated at each stage of the life cycle. Generally the second-generation impacts of the system are ignored (e.g. the energy used to fire the bricks that are used to build the kiln would typically not be included).

The basis of an LCA study is an inventory of all the inputs and outputs of industrial processes that occur during the life cycle of a product. The inventory process is simple, in principle. In practice, however, it is subject to a number of practical and methodological problems, as listed below:

- System boundaries
- Processes that generate more than one product
- Avoided impacts
- Geographical variations
- Data quality
- Choice of technology

3.4 Generic methodology

The life cycle of a product or service includes extraction of natural resources, production of raw materials, transport, production of the product, use, and waste management/recycling. In a life cycle assessment, the environmentally relevant input and output flows of the life cycle of the studied products, and the environmental impacts that these cause are calculated and evaluated.

Currently ISO 14040-43 defines a life cycle as comprising of four phases, namely:

Phase 1: Goal and scope assessment

The purpose of the study is described. This description includes the intended application and audience, and clearly states the reasons for carrying out the study. The scope of the study is described, which includes the limitations, the functions of the systems investigated, the functional unit, the systems investigated, the system boundaries, the allocation approaches, the data requirements, the key assumptions, the impact assessment method, the interpretation method and the type of reporting.

---

[3] Vignon B W, Tolle D A, Cornaby B W, Latham H C, Harrison C L, Boguski T L, Hunt R G and Sellers J D, 1993, 'Life-Cycle Assessment: Inventory Guidelines and Principles'. United States Environmental Protection Agency. Cincinnati, USA.

Phase 2: Inventory analysis

Data is collected and interpreted. calculations are made and the inventory results are calculated and presented. Mass flows and environmental input and output flows are calculated and presented.

Phase 3: Impact assessment

The production system is examined from an environmental perspective using category indicators. such as global warming, acidification and eutrophication.

Phase 4: Interpretation

Herein the results are analysed in relation to the goal of the study. Conclusions are drawn. limitations of the results are presented and recommendations are provided based on the findings of the preceding phases. The conclusions should be compatible with the goals and quality of the study.

Practical constraints of life cycle assessments

A continuing concern of LCA methodology development bodies is the time and cost required to complete LCAs. Some have questioned whether the LCA community has established a methodology that is beyond the reach the majority of potential users. Others have questioned the relevance of the LCA to the actual decisions that potential users must make.

Collection of Life Cycle Inventory (LCI) data can be extremely costly and time consuming and often results in LCA studies being abandoned or proving inadequate because of poor and inconsistent LCI data. Good LCA's demand sound LCI's that subsequently contribute to making good judgments about environmental matters. The build up of a LCI puts together a whole series of smaller process data sets, either for individual processes or collections of individual processes.

In an attempt to facilitate the completion of LCIs numerous industry segments have undertaken and made available 'cradle-to-gate' or 'gate-to-gate' LCI studies. These are prepared by many of the specific industry groupings for the connected processes that are under their control. Such 'block' collections of industry data are known as 'eco-profiles'. A collection of Eco-profiles can then be added together to form a complete LCI. This procedure serves to reduce costs. save time. provide reliable and accurate data and makes LCA studies easier to complete. be more widely applicable, and as a consequence. assists with sound decisions on environmental management by interested parties. The profiles are, however, highly dependent on the context in which they where developed and use in different contexts introduces risk of incompatibility.

There are a number of organizations marketing eco-profiles in the form of LCA databases however these have been found to vary considerably in[4]:

- Level of detail
- Flexibility of data manipulation
- Data quality
- Purchase costs

3.5 Limitations of LCAs

As with any scientific method the LCA methodology suffers from limitations that must be understood. Several basic principles and practicalities remain to be defined:

- Data details differ for each supplier. specific processes used, location, dominant methods of primary production
- Analysis of multi-product manufacturing systems provide complex allocation problems
- The impact assessment stages are not fully developed and cannot provide a full decision support system
- The impact assessment depends on environmental priorities of the industry segment and data provided
- Interpretation is subjective in its ranking of impacts

In this light LCAs have been shown to rarely produce clear winners and losers but rather serve to detail environmental implications and illustrate tradeoffs[5].

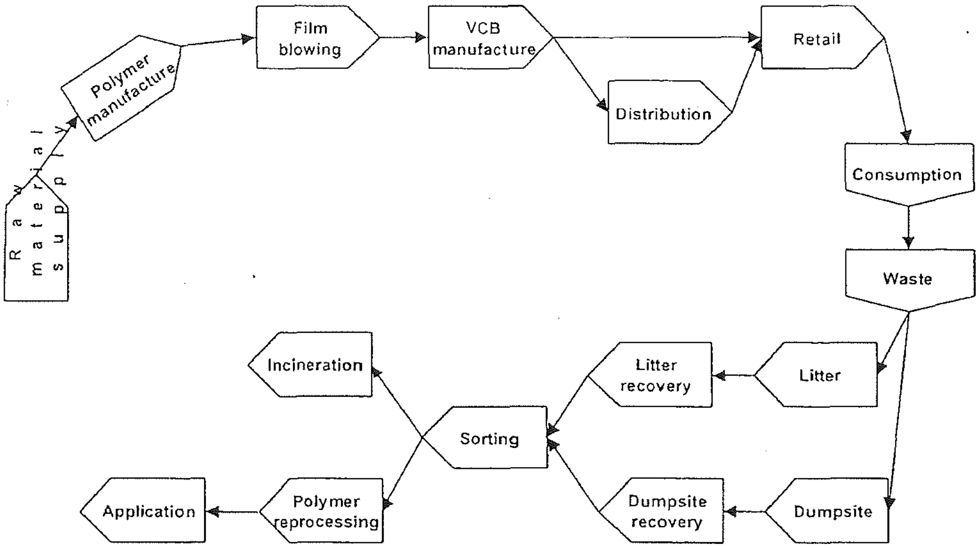
---

[4] LCA – Help or Headache?. Estelle Hook. http://www.co-design.co.uk/ehook.htm

[5] Use of Life Cycle Assessment (LCA) as a Policy Tool in the Field of Sustainable Packaging Waste Management. A EUROPEN Discussion Paper – September 1999. http://www.europen.be/issues/lca/lca_revised.html

3.6 Generic Life Cycle of Plastic Carrier Bags

The life cycle of plastic vest type carrier bags is illustrated in the diagram below.



Raw material supply and polymer production

Polymers used in the plastic resin and manmade fiber industries either occur naturally, such as cellulose, or are formed during polymerization when bond-forming reactions cause small repeating molecules to join together. Polymers are typically made from one type of simple chemical unit, or monomer.

Polymers are central to plastic resin manufacture. Many grades of different polymers are produced, each with different physical characteristics such as strength and ease of flow when melted. These different physical characteristics are achieved by changing operating parameters or by using different polymerization processes to change properties, such as polymer density or molecular weight. Polymers, which have been dried and formed into pellets, are called plastic resins. These resins are further processed at plastics processing facilities that create plastic products of different shapes, sizes and physical properties.

There are several steps that are important to polymerization. First, reactants are purified prior to polymerization. During polymerization, catalysts, heat, pressure and reaction time are all optimized to maximize polymer conversion and speed the reaction. Finally, the polymer is extruded and palletized for packaging and shipment. Various supporting steps are important to note because of their potential effect on the environment. These supporting steps include unloading and storage of chemicals and equipment cleaning.

Conversion of plastic film

Polymer resins are delivered to converters either in bulk tankers or in plastic sacks. Molten polymer is extruded as a continuous tube. As it leaves the extrusion die, the tube is inflated with air to form a bubble and when the bubble reaches the appropriate size it is cooled by air that changes it into a solid film. The region where the solidification occurs is known as the 'frost line', is the region where the required film thickness is reached. The tube is then guided by collapsing boards and gradually flattened and gusseted as it approaches the pinch rolls. When the film passes between them, the top of the bubble is effectively sealed.

The flat film is fed to the winding equipment via a pre-treatment and slitting unit. Slitting and trimming is a continuous operation. The flat film is then wound onto rolls.

Machinery for the extrusion of HDPE and LDPE differ significantly due to the different nature of the molten polymer. The differences prevail primarily in cooling, dye units and screws.

VCB manufacture

The gusseted wound film is unwound and passed through a series of rollers. Depending on the printing requirements the film may be passed under ultra violet lights to serve as preparation for printing and print curing. The film may then be printed.

Printed film is passed through rollers, sealed and cut at predetermined lengths. Lengths of film are then stacked and punched to form the handles of the vest type carrier bag. Bags are then bundled and baled for distribution.

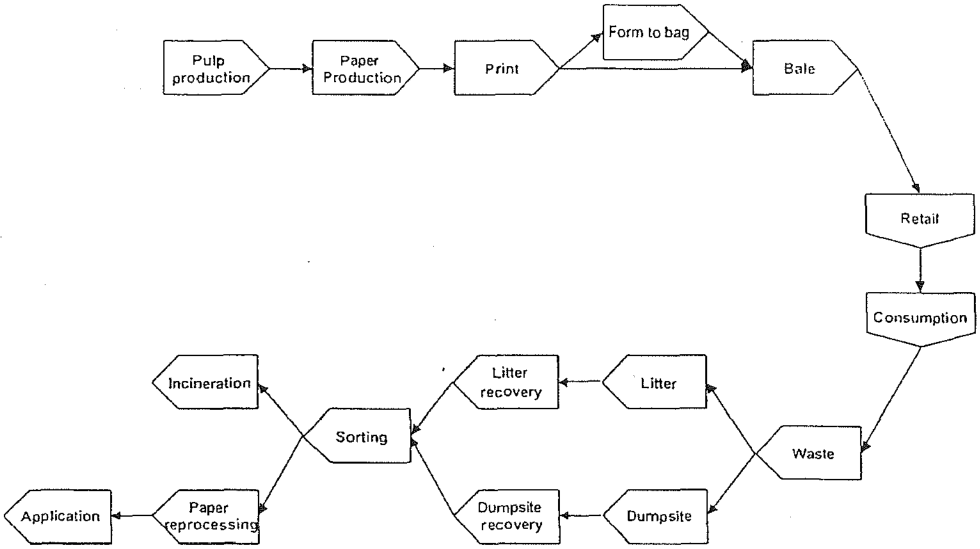
Distribution and consumption

Vest type carrier bags are distributed to formal and informal retailers though numerous mechanisms including hawkers, distributors and direct delivery. Carrier bags are used on checkout to hold purchased goods. On completion of use the carrier bag is thrown away or reused in numerous ways such as bin liners and carriers.

Waste management

The sources of materials for recyclers typically comprise in-house film that is collected and sorted by polymer grade. Collectors obtain materials from those not wishing to recycle their own materials and may also wish to obtain material from dumps by means of teams of pickers. Materials are then sorted and baled. Materials collected generally comprise post consumer waste and in process waste. Sorted and baled materials are passed through a granulator, agglomerator and then pelletised.

3.7 Generic Life Cycle of Paper Carrier Bags



Raw material production

Paper is manufactured by applying a watery suspension of cellulose fibres to a screen which allows the water to drain and leaves the fibrous particles behind in a sheet. Most modern paper products contain non-fibrous additives, but otherwise fall within this general definition. Only a few paper products for specialized uses are created without the use of water, via dry forming techniques. The watery fibrous substrate formed into paper is called pulp. The production of pulp is the major source of environmental impacts in the pulp and paper industry.

Processes in the manufacture of paper and paperboard can, in general terms, be split into three steps: pulp making, pulp processing, and paper/ paper board production. First, a stock pulp mixture is produced by digesting a material into its fibrous constituents via a chemical, mechanical, or a combination of chemical and mechanical means. In the case of wood, the most common pulping material, chemical pulping actions release cellulose fibres by selectively destroying the chemical bonds in the glue-like substance (lignin) that binds the fibres together. After the fibres are separated and impurities have been removed, the pulp may be bleached to improve brightness and processed to a from suitable for paper-making equipment. At the paper-making stage, the pulp can be combined with dyes, strength building resins, or texture adding filler materials, depending on its intended end product. Afterwards, the mixture is dewatered, leaving the fibrous constituents and pulp additives on a wire or wire-mesh conveyor. Additional additives may be applied after the sheet-making step. The fibers bond together as they are carried through a series of presses and heated rollers. The final paper product is then spooled on large rolls to be passed on to subsequent steps.

Conversion

Self opening bags are produced on S.O. bag machines. some of which have their own in line printing presses. These presses are used when the number of colours or type of design do not justify pre-printing. After printing. the plies pass trough slitters which pre-cut the bottom of the bag. and a cross pasting station where the plies are pasted together at regular intervals. A nozzle then applies adhesive to the longitudinal seam. The plies are then folded over one another and the pre-pasted seams allowed to adhere to the form a tube. This tube is immediately flattened, gussets being formed in the process. The tube now passes between a revolving knife and a stationary knife which cut with a scissor action. and separate the tube into individual lengths for converting into bags. The pre-slit bottom section of each length is opened up with the aid of suction cups and forming guides after which adhesive is applied. Bottom pasters ensure that adhesive is transferred to the required position on the bottom. The bottom is then closed by means of formers and rollers. The completed bags are compressed between a series of rollers before being counted, bundled and palletized.

Distribution and consumption

Paper checkout bags are distributed to retailers through numerous channels including distributors and direct supply. Paper checkout bags are primarily used by boutique stores and distributed free of charge to consumers at checkout. Currently paper bags make up approximately 9% of bags distributed by small retailers. However the percentage of grocery checkout carrier bags is significantly smaller than that (currently estimated at less than 1%).

Waste management

After use bags can enter the sorting phase by one of two mechanisms namely from litter or the dumpsite. After collection the waste is then sorted and depending on quality and condition is either disposed of by incineration or dumping or recycled.

3.8 Research approach for the life cycle assessment

Publicly available literature relating to LCAs of plastic. paper and cloth check out bags was sought from the following sources:

- ECOINVENT (Energy-materials-environment Group)
- BUWAL 250 (ETH Swiss Federal Institute of Technology)
- Eco-profile of the European plastics industry (APME)
- IVAM (IVAM Environmental Research)
- FEFCO
- STFI
- VITO (Flemish Institute for Technological Research)
- KCL ECODATA (The Finnish Pulp and Paper Research Institute)
- PEMS (Packaging Industry Research Association)

The review managed to identify numerous point sources of inventory data in the form of 'eco-profiles'. Lack of data continuity prevented the production of a Life Cycle Inventory, it was therefore necessary to resort to studies in which the complete life cycle for products had been analysed. Since the scope and objectives of LCAs greatly affect results, in order to provide comparisons between product types it was necessary to target comparative studies.

Review of the relevant literature revealed two studies that dealt with direct comparisons between paper and plastic sacks.

The first study, undertaken in the United States, is an LCA based comparison of LDPE and Paper "1/6 barrel grocery sacks" and was undertaken by Franklin Associates.

The second study undertaken in Europe dealt with the distribution of agricultural filling goods in different distribution systems, namely paper, plastic, semi-bulk and bulk. The distribution systems are 25 kg (capacity) sacks made of 140 micron Low Density Polyethylene and 70 g/m^2 two ply unbleached paper.

No data was found relating to the life cycle of biodegradable plastics. Industry experts however felt that biodegradable plastics offer no real life cycle benefit since production is on a smaller scale than polyethylene therefore production facilities are not as efficient per kilogram of polymer. In addition due to lack of local production facilities of biodegradable resins therefore require shipping thereby significantly affecting the life cycle profile. None of the alternative biodegradable polymers would have a density lower than polyethylene: therefore equivalent bags would require more resin thereby attracting a life cycle penalty[6].

No life cycle inventory data, or life cycle analyses were found for cloth bags this therefore has been left out of the report.

3.9 Limitations of the research approach

There are a number of issues affecting the comparison of the above studies both to the South African environment and to one another, for example:

- Geographies
    - Temperature
    - Availability of land
    - Annual rainfall
- Product life cycle
    - Raw material source (e.g. coal vs. oil)
    - Sources of energy (nuclear, coal, hydro electric power stations)
    - Production processes (Cracking and extrusion technologies, emission controls)
    - Conversion processes (Modern and antiquated technology)
    - Consumer processes (propensity for reuse, propensity to recycle, waste management, is the product used as a source of energy?)
    - Waste management processes
- Objectives and scope
    - Definition of system parameters
    - Definition of objectives
    - Data collection methodology

The issues listed above are indicative of the factors that may, or may not, cause significant differences in LCAs for similar products in different circumstances. These factors compromise the ability to use the above studies in the South African context. The two studies are, however, presented in the following section and conclusions drawn.

---

[6] Email communications with Tony Kingsbury, President of the International Biodegradable Products Institute, 27th August 2001.

3.10 Presentation of relevant literature

The functional unit

The functional unit of an LCA is the amount of product or material for which the environmental loadings are quantified. When comparisons are performed it is important that the products to be compared fulfil the same function, therefore the unit of comparison in both the following studies is 10.000 uses.

Study 1: Title: **"Resource and Environmental Profile Analysis of Polyethylene and Unbleached Paper Grocery Sacks,"** Franklin Associates, Ltd., 1990.

Franklin Associates, an independent Life Cycle Analysis and Solid Waste Management consultancy undertook the study.

Background

Packaging materials, in the United States, had come under the scrutiny of a wide range of interest groups as a result of decreasing landfill capacity, an inability to find new landfill sites and the large percentage by volume of packaging materials in landfills.

Objectives

The objective of this study is stated as the determination of energy and environmental discharges of polyethylene and paper grocery sacks.

Scope

Grocery bags examined in the study were the:

- 1/6 barrel polyethylene (HDPE and LLDPE) vest type grocery sacks; and
- 1/6 barrel 70 pound base weight single ply unbleached paper grocery sack.

Details of the sacks considered.

Bag type	Micron/ g/m^2	Dimensions (cm)	Similar to	Indicative pricing
1/6 Barrel Polyethylene	unknown	51 x 30.5 x 20	Maxi VCB	$ 45/ 1000
1/6 Barrel Paper	110	44 x 18 x 31	Shopper paper checkout bag	$ 70/ 1000

These sacks were regarded as being standard issue plastic and paper sacks used in grocery stores in the United States.

The utilisation ratio of polyethylene to paper sacks was identified as critical to the project. It was identified that there was no representative industry ratio indicating the number of uses of polyethylene grocery sacks that fill the same role as paper grocery sacks. The results of the analysis are presented at ratios of 1.5:1 and 2:1. i.e. 1.5 plastic sacks filling the same role as 1 paper sack. It is however recognized that the plastic sack has a greater reuse capability.

Methodology

A cradle to the grave approach was used to determine the energy and environmental discharges of the packages. this quantified energy consumption and environmental emissions at each stage of the product's life cycle beginning at the point of raw material extraction and proceeding through processing. manufacture. use and final disposal. or reuse.

Energy use was presented in the report in British Thermal Units but has been converted to Mega Joules for the purposes of this report.

Government documents as well as federal regulations, technical literature and confidential industry sources form the basis of the data.

Three broad environmental categories were considered, namely solid wastes, atmospheric emissions and waterborne wastes.

Both paper and polyethylene sacks were considered to participate in an "open loop" recycling system, in that recycled materials would replace virgin materials in the manufacture of other goods (e.g. in the case of polyethylene recycled material would go to the manufacture of pipes, etc.).

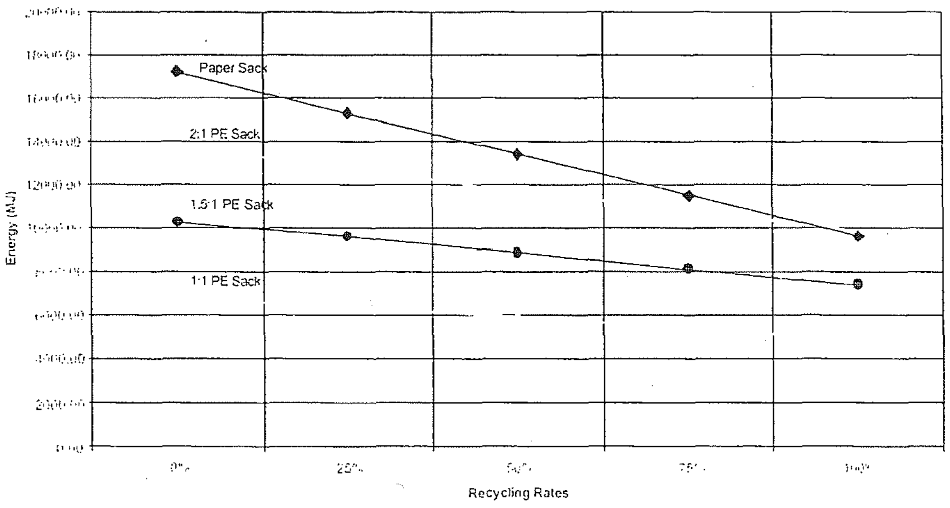
Findings of the study

Energy requirements

Energy requirements for 1/6 Barrel PE and Paper Grocery Sacks at Various Recycling Rates (MJ/10 000 bags)					
Sack type	Recycling rates				
	0%	25%	50%	75%	100%
1.0 PE to 1 Paper Sack Ratio					
Polyethylene	6822.70	6400.67	5908.31	5415.95	4923.59
Paper	17197.41	15298.31	13399.21	11500 11	9601 01
1.5 PE to 1 Paper Sack Ratio					
Polyethylene	10234.04	9601.01	8862.47	8123.93	7385 39
Paper	17197.41	15298.31	13399.21	11500.11	9601.01
2 PE to 1 Paper Sack Ratio					
Polyethylene	13715.73	12766.18	11711.12	10761.57	9812.02
Paper	17197.41	15298.31	13399.21	11500.11	9601.01

The energy requirements for the plastic polyethylene sacks were found to be 20 to 40% less than for paper sacks at zero percent recycling for both sacks. As recycling increases, the energy requirements became equivalent at approximately a 90% recycling rate (for a 2:1 ratio)

Energy requirements for Grocery Sacks

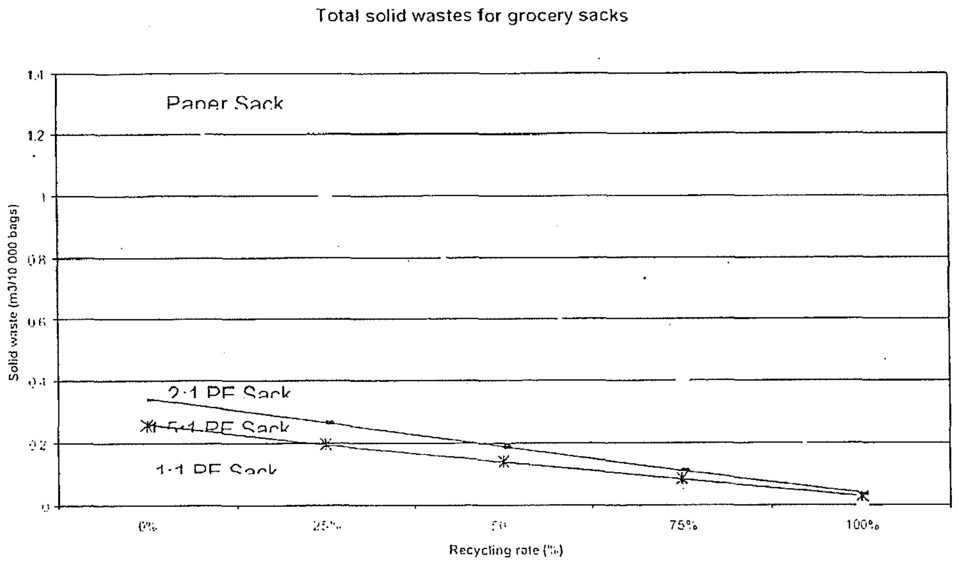


Environmental

Solid waste emissions

Solid waste emissions (m^3/ 10 000 bags)					
Sack Type	Recycling rates				
	0%	25%	50%	75%	100%
1 PE to 1 Paper Sack Ratio					
Polyethylene	0 17	0 13	0 09	0 05	0.02
Paper	1 30	1 00	0 70	0.40	0.10
1.5 PE to 1 Paper					
Polyethylene	0.26	0 19	0.14	0.082	0.025
Paper	1.30	1 00	0.70	0.40	0.10
2.0 PE to 1 Paper					
Polyethylene	0.34	0 27	0.19	0.11	0.03
Paper	1.30	1 00	0.70	0.40	0.10

For the purposes of this study solid wastes comprised ash from energy generation and incineration and post consumer solid wastes. Polyethylene sacks were found to contribute 74 to 80 percent less solid waste than paper sacks at zero percent recycling. Polyethylene sacks continued to contribute less solid waste than paper sacks at all recycling rates.



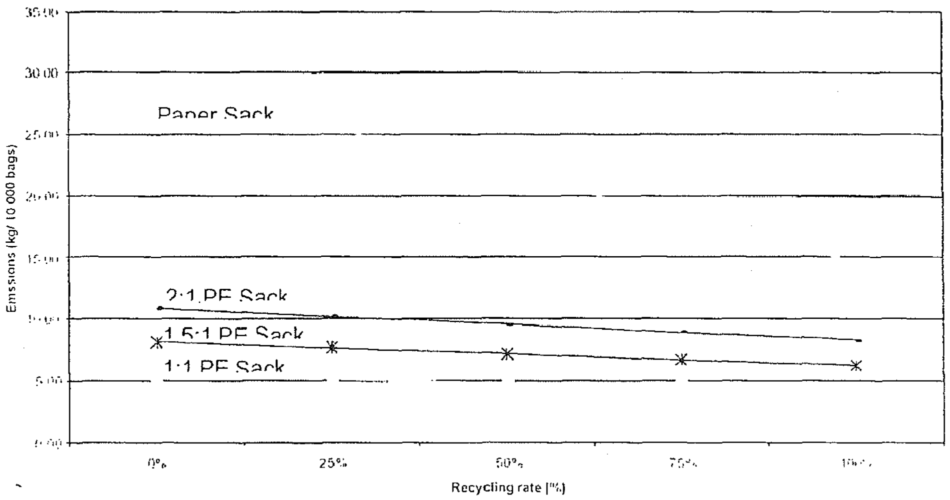
Atmospheric emissions

Atmospheric emissions (kg/ 10 000 bags)					
Sack Type	Recycling rates				
	0%	25%	50%	75%	100%
1 PE to 1 Paper Sack Ratio					
Polyethylene	5.41	5.11	4.78	4.48	4.14
Paper	29.12	25.49	21.86	18.23	14.61
1.5 PE to 1 Paper					
Polyethylene	8.12	7.67	7.17	6.71	6.21
Paper	29.12	25.49	21.86	18.23	14.61
2.0 PE to 1 Paper					
Polyethylene	10.84	10.21	9.57	8.94	8.30
Paper	29.12	25.49	21.86	18.23	14.61

Six components were analysed in combination in this category, namely particulates, nitrogen oxides (NO_x), Hydrocarbons, sulphur oxides (SO_x), carbon monoxide and odorous sulphur.

Atmospheric emissions for the polyethylene sack were found to range from 63 to 73 percent less than for paper sack at zero percent recycling. These lower impacts for polyethylene sack continued throughout all recycling rates.

Atmospheric emissions of grocery sacks



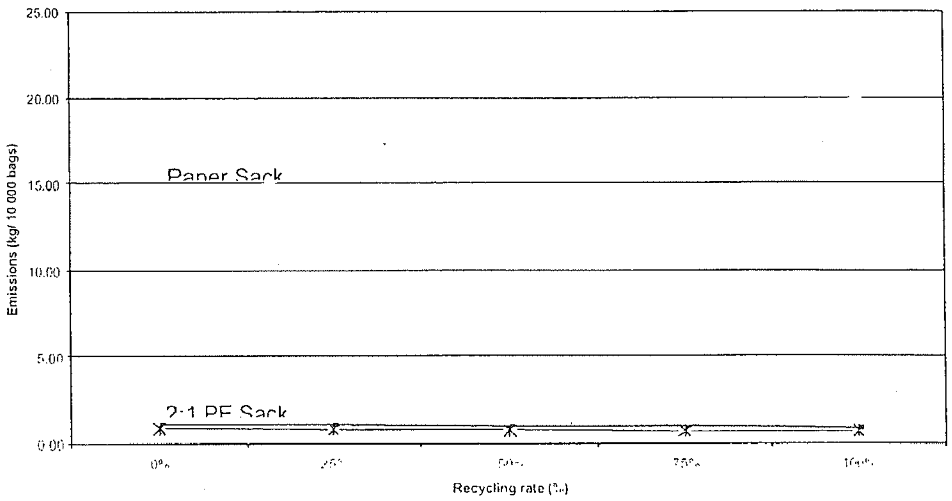
Waterborne wastes

Waterborne emissions (kg/ 10 000 bags)					
Sack Type	Recycling rates				
	0%	25%	50%	75%	100%
1 PE to 1 Paper Sack Ratio					
Polyethylene	0 54	0 51	0 48	0 45	0 45
Paper	14 15	15 56	17 06	18.46	19.91
1.5 PE to 1 Paper					
Polyethylene	0 82	0 77	0 73	0.68	0.68
Paper	14 15	15 56	17.06	18.46	19.91
2.0 PE to 1 Paper					
Polyethylene	1.09	1 04	1.00	0.91	0.86
Paper	14.15	15.56	17.06	18.46	19.91

Four components were analysed in combination in this category. namely dissolved solids, biological oxygen demand (BOD), suspended solids and acids.

At zero percent recycling rate the polyethylene sack contributed over 90 percent less waterborne wastes than the paper sack. As the rates of recycling increased the difference was found to increase as the recycling of paper contributes more to waterborne wastes than paper made from virgin material.

Waterborne wastes for grocery sacks



Recyclability

Both polyethylene and paper sacks were found to be recyclable. Manufacturing and scrap trim from the fabrication of the sacks were typically recycled. Post consumer recycling for both sacks was not found to be significant. In the case of paper sacks. recycling efforts relied on the collection of old newspapers as a support. For Polyethylene sacks. efforts were found to focus on industrial film scrap.

Combustion

Polyethylene releases 2.75 times more energy upon incineration than unbleached paper. However on an unequal basis, paper grocery sacks weigh 4 to 5 times more than plastic grocery sacks. Therefore the paper sack was noted as having the greater potential for energy release from incineration than the polyethylene sack.

Landfill impacts

The landfill volume occupied by the polyethylene sack is 70 to 80 percent less than the volume occupied by paper sacks given equivalent uses. It was noted that little data exists regarding the rate of degradation for both polyethylene and paper. It was therefore argued that the rate of decomposition could not be estimated and so no estimates regarding the potential impact on landfill leachate or methane gas production were included.

Discussion

The products under consideration are clearly are directly relevant to the South African study. In terms of comparison to a South African situation the factors discussed earlier may alter the results significantly. Unfortunately the only access to the study was in the form of the final report. It was not possible to get better access to the study results.

Study 2: Title: "**Distribution in Paper Sacks.**" CIT Ekologik. Chalmers Industriteknik. 2000.

The study was undertaken by CIT Ekologik. an independent Swedish environmental consultancy. on behalf of Eurosac and CEPI Eurokraft.

Goal

To compare the environmental performance of distribution in 25kg paper sacks with alternative distribution systems. The alternatives include bulk distribution. 25kg Plastic sacks and 1000kg 'big bags'. It is noted that the products analysed in this study are fundamentally different products to check out carrier bags – they are bigger bags.

Objectives

The primary objective of the study was to compare the environmental impacts of distribution in paper sacks with those of distribution in other systems for filling goods in Europe.

Scope

All of the systems studied include extraction of natural resources, production of raw materials, production of sacks/big bags/silos, after use treatment and all associated transport.

On the comparison of the distribution systems, it became clear that the distribution systém transport itself gave the highest impact of the studied systems. This was due to the assumed distribution of 1000kg of filling goods over a distance of 300km. It was also noted that the environmental effects were of the same size regardless of the packaging system and were therefore removed from the presentation of the study results.

The paper and plastics sacks are described as follows:

Bag type	Micron/ g/m^2	Dimensions (cm)
LDPE	140	37 x 72 x 13
Paper	2 x 110	50 x 70 x 13

The lifecycle phases covered in this report are explained in the table below

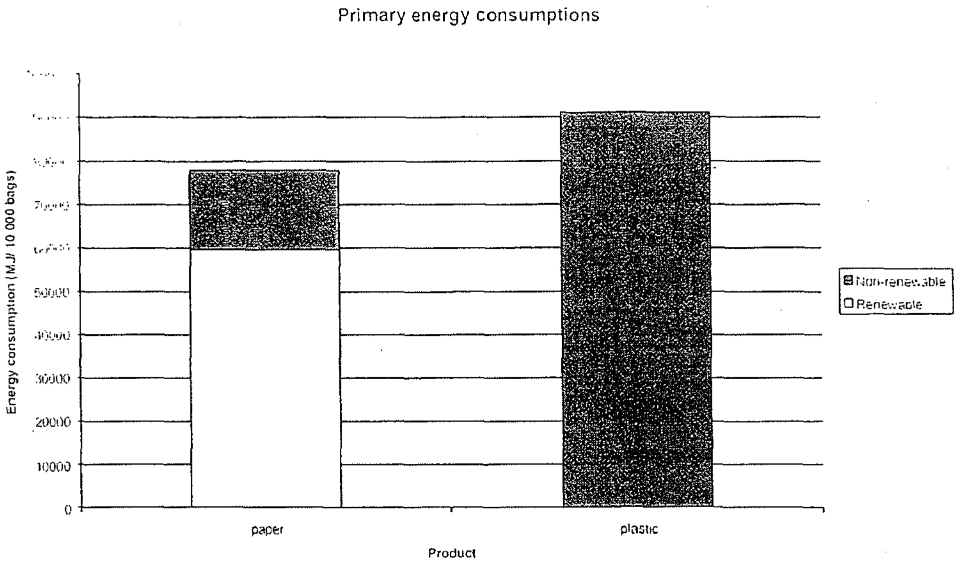
Life cycle stage	Explanation
Raw material production	Production of paper and LDPE from original source
Conversion	The conversion of paper and resin into Sacks
Waste management	Waste management. incineration. land filling or composting were considered as separate scenarios. The recycling scenario has assumed 100% recycling for both paper and plastic. Note for ease of comparison only reflected the recycling waste management scenarios have been reflected. however where relevant reference is made to other scenarios
System expansion	The systems are expanded to include parts of other life cycles that are affected by the compared systems. The purpose of this system expansion is to avoid allocation problems that arise at waste incineration or at open loop recycling of material from one life cycle to another. The systems are expanded to include parts of other systems that are affected by the recycling of major materials after use in the distribution system.

This life cycle analysis considered environmental impacts under the following headings:

Impact category	Unit
Primary energy consumption	MJ/ 10 000 bags
Abiotic resource depletion	Kg/ year/ 10 000 bags
Global warming	Kg CO_2 equivalents/ 10 000 bags
Acidification	Kg SO_2 equivalents/ 10 000 bags
Nutrient enrichment	Kg NO. equivalents / 10 000 bags
Photochemical ozone formation	Kg C_2H_2 equivalents/ 10 000 bags
Aquatic ecotoxicity (water emissions)	M^3 polluted water
Air emissions	Kg contaminated body weight
Water emissions	Kg contaminated bodyweight

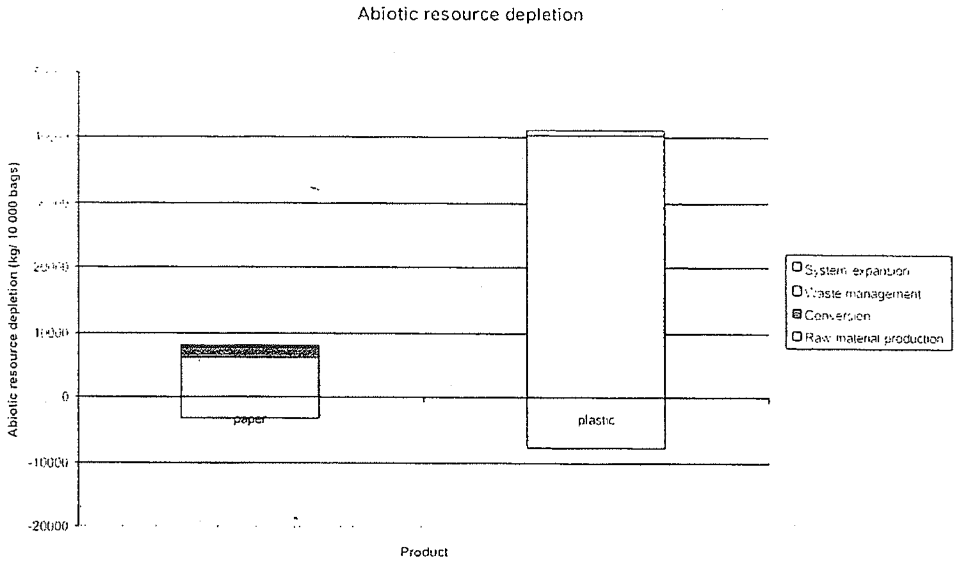
The findings of the analysis are presented in the following sections.

Primary energy consumption



Primary energy consumption was calculated including energy utilization in the production of the raw material (i.e. crude oil and wood). The LDPE sacks were found to give a higher contribution to the depletion of non-renewable resources than paper. This is due to the use of fossil raw material and energy in the production of LDPE.

Abiotic resource depletion

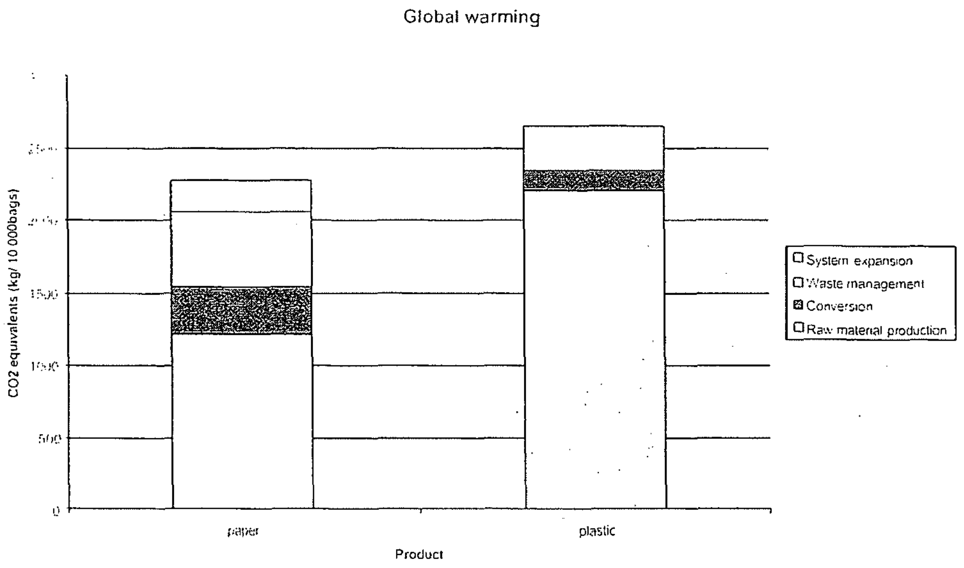


The depletion of abiotic resources such as metal ores and fossil fuels is problematic since it results in a situation where future generations will be required to resort to use other resources. It is important to note in this respect that, in Europe, forests grow faster than they are depleted and this was therefore not included as resource depletion.

The LDPE sack was found to give the highest contribution to abiotic resource depletion. This was dependant on the fact that, in the study geography, LDPE is made from crude oil and natural gas. The characterization factor associated to extraction of natural gas and oil is large due to the assumption that annual extraction is large when compared to reserves.

In addition the recycling scenarios gave higher contributions than the corresponding incineration scenarios since the energy produced on incineration was assumed to replace heat and electricity from other sources. Heat energy has been assumed to be a mix of 60% light fuel oil and 40% natural gas, and electrical energy was based on European averages.

Global warming



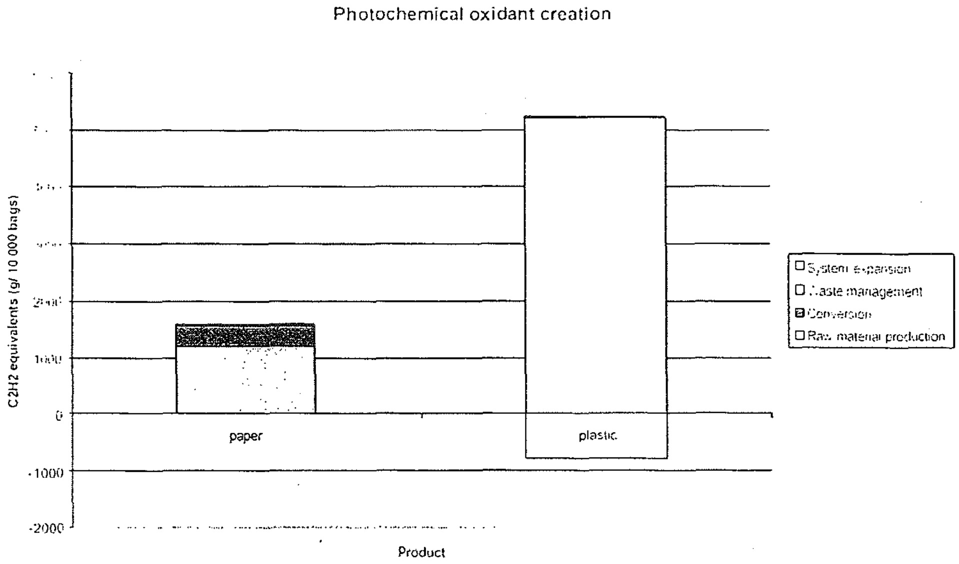
Global warming is caused by increases in the atmospheric concentration of chemical substances that absorb infrared radiation. Global warming is measured in CO_2 equivalents.

It was found that the LDPE sacks gave the highest potential contribution to global warming. It was also found that the contribution to global warming from paper sacks on incineration was low because the carbon dioxide at incineration of paper was deemed to be biological thereby eliminating a net contribution to global warming. In addition the heat generated during incineration has been assumed to replace heat produced from a mix of 60% light fuel oil and 40% natural gas.

The contribution from the LDPE sack. incineration scenario was found to be higher than the incineration scenarios for the paper sacks. This was due to the characterization of carbon dioxide emissions from incineration of LDPE as fossil. as opposed to biological. LDPE was found to have a higher 'heat value' than paper thereby allowing greater recovery of energy.

The contribution to global warming from the paper sacks. recycling scenario was found to be high. This was as a result of system expansion as the recycled sacks were assumed to replace virgin paper from other products that were assumed to end up in landfills thereby causing methane gas emissions.

Photo chemical oxidant creation



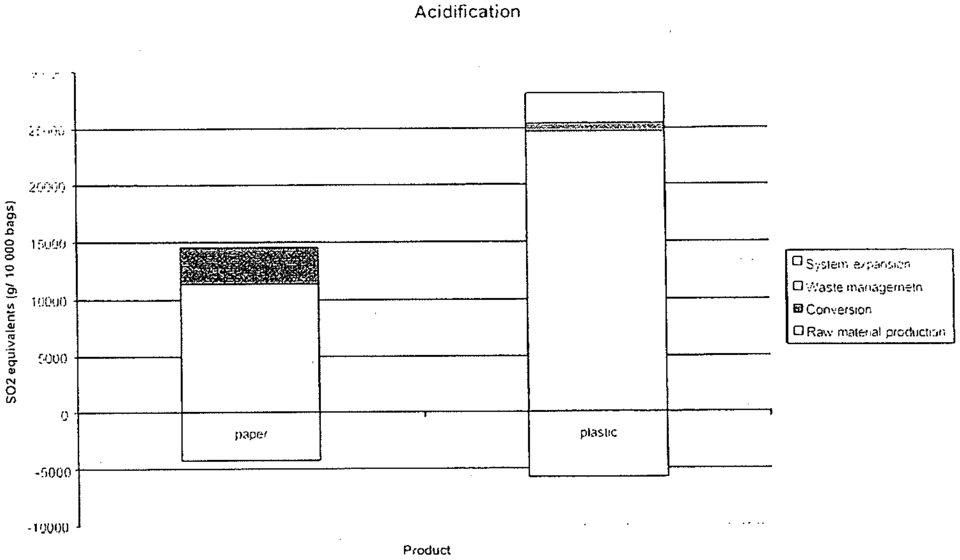
This impact category reflects the creation of oxidizing compounds through photochemical reactions in the air. The most important oxidant, in this context, is ozone.

The LDPE sack gave the highest contribution to photochemical oxidant creation. This was as a result of the emission of hydrocarbons from the production of LDPE.

The landfill scenarios for the paper sacks gave the higher contributions than the other scenarios for the paper sacks due to the formation of methane during decomposition.

An additional difference between photo oxidant creation was found to be a gap in data provided by STFI (i.e. lack of detail).

Acidification



Acidification is the reduction of the pH value in terrestrial and water systems. This is problematic since it causes substances, including nutrients, in the soil to dissolve and be carried away by water systems.

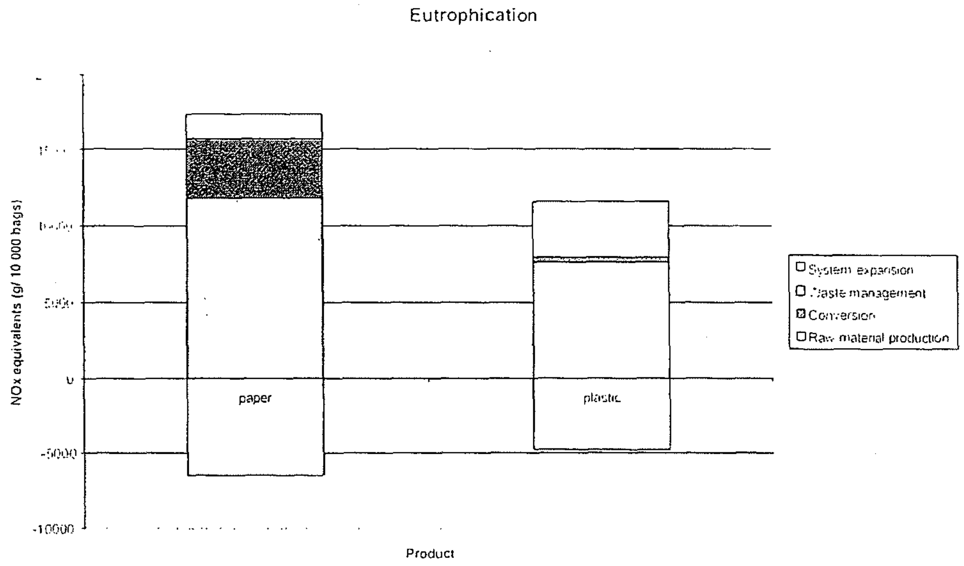
The LDPE sack gave the highest contribution to acidification due to emissions of NO_x and SO_2 associated with the use of fossil fuels.

During the incineration of LDPE, NO_x, is created, contributing to acidification.

The positive contribution to acidification from the recycling of LDPE comes from creation of NO_x and SO_2 at electricity generation. The negative contribution from the system expansion at the recycling of LDPE is mainly from the avoided LDPE production, the avoided LDPE recycling and from the alternative energy production.

The difference between the LDPE sack and the paper sack is however rather high, which primarily depends on the fact that at recycling, the LDPE has been assumed to replace only 17% virgin material while the paper replaces 44% virgin material.

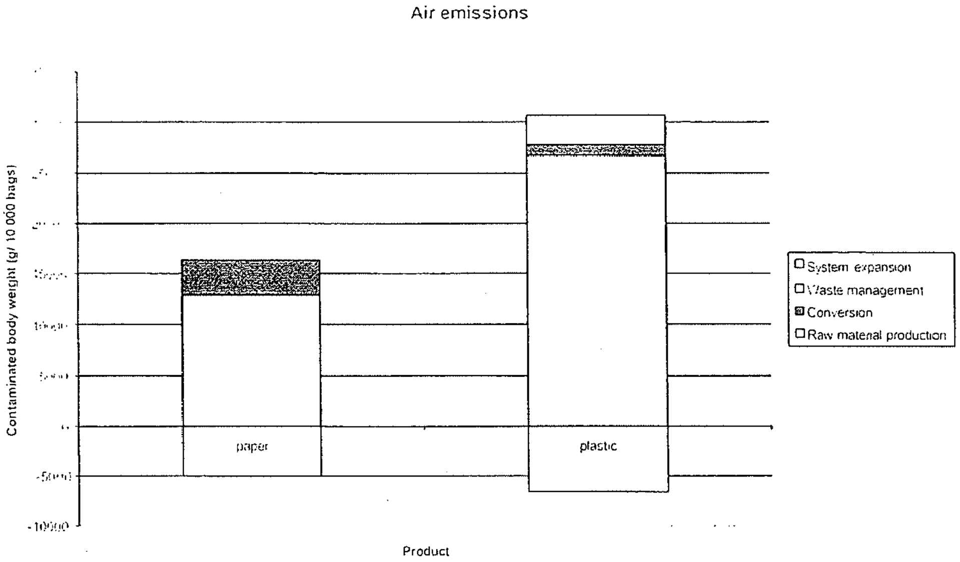
Eutrophication



Eutrophication is the disturbance of the nutritional balance in the soil. In aquatic systems this leads to increased production of biomass, which may lead to oxygen deficiency on decomposition.

The paper sack gave the highest contribution to eutrophication due to the high levels of COD from sack paper production.

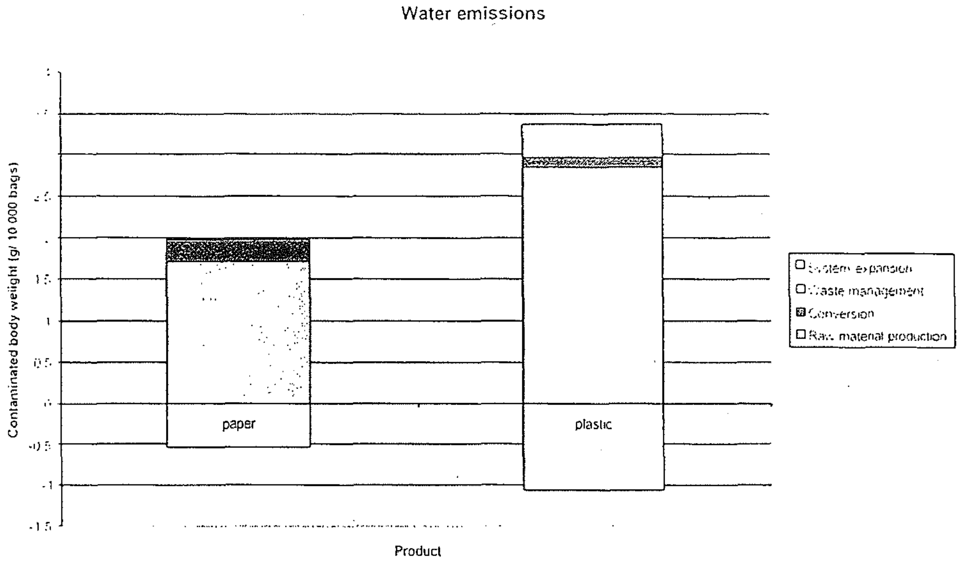
Air emissions



For human toxicity caused by air emission, it is the LDPE sack that gives the highest contribution. The emissions of NO_x and SO_2 associated with the use of fossil fuels at the production of LDPE were found to dominate thereby giving the LDPE sack a greater contribution to air emissions.

The positive contribution from the recycling of LDPE arises due to the creation of NO_x and SO_2 at electricity generation. The negative contribution from the system expansion at the recycling of LDPE is mainly from the avoided LDPE production, the avoided LDPE recycling and from the alternative energy production.

Water emissions

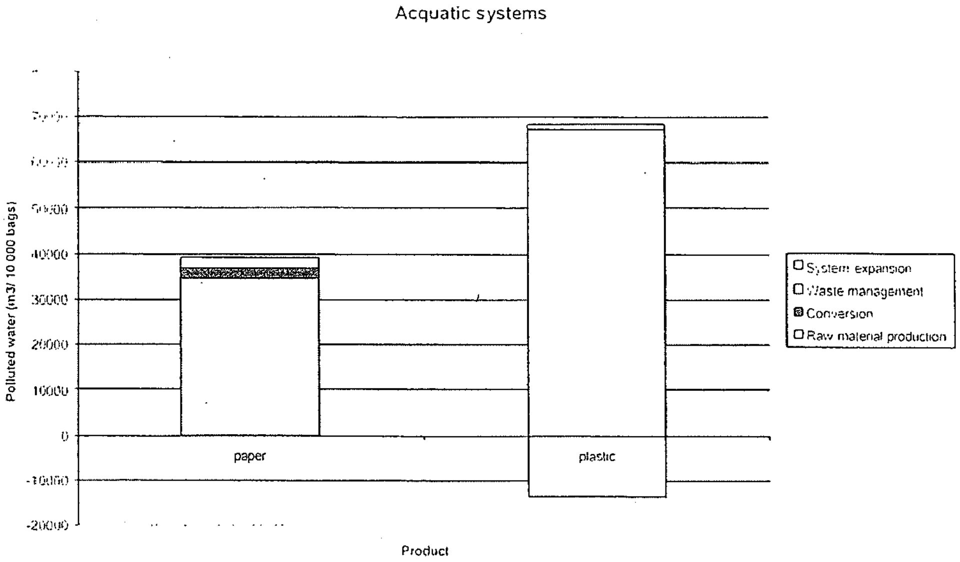


For human toxicity caused by water emissions, it is the bleached paper sack, landfill scenario that gives the highest contribution.

The negative contributions from the system expansions for recycling were found to be higher for the LDPE sacks than for the paper sacks. The recycling of LDPE was assumed to replace 83% recycled material from other products and 17% virgin material. The recycling of paper was assumed to replace 56% recycled material from other products and 44% virgin material.

The slight negative contribution from the recycling of paper is due to the production of electricity. This is a negative contribution due to the lack of emissions of iron (Fe) to water from European average electricity production.

Pollution of aquatic systems



The contribution to the pollution of aquatic systems from the production of LDPE was found to be higher than the contribution from paper production.

The negative contributions from system expansions for recycling are higher for the LDPE sacks than for the paper sacks.

3.10.1 Conclusion

The objective of this section was to prepare a comparison of the environmental life cycle effects of both plastic and paper checkout carrier bags. It was found however that due to the sensitivity of the results of LCA to factors such as scope. objective. geography. climate. energy sources including others that LCA's are limited in their comparison. firstly. between studies and. secondly. between environments (e.g. Europe and South Africa).

Life cycle studies analysing relevant products were found. the findings of which are listed for each of the impact categories in the table below:

Impact category	**Study 1** **1/6 barrel grocery sacks**	**Study 2** **25 kg (capacity) distribution sacks**
	Paper versus Plastic	**Paper versus Plastic**
Primary energy	Plastic life cycle uses 23.08% less	Paper life cycle uses 80.00% less
Solid waste	Plastic life cycle produces 75.68% less	Category not considered
Abiotic resource depletion	Category not considered	Paper life cycle depletes 85.00% less
Global warming	Category not considered	Paper life cycle contributes 95.69% less
Acidification	Category not considered	Paper lifecycle contributes 53.79% less
Nutrient enrichment	Category not considered	Plastic life cycle 55.36% less
Photochemical ozone formation	Category not considered	Paper life cycle contributes 64.04% less
Aquatic ecotoxicity	Category not considered	Paper life cycle contributes 37.04% less
Air emissions	Plastic life cycle contributes 57.45% less	Paper life cycle contributes 52.23% less
Water emissions	Plastic life cycle has 96.58% fewer	Paper life cycle contributes 28.79% less

Clearly the results presented in the table above are contradictory. This serves as an illustration as to the possible effect of project scope, system limitations, objectives and assumptions and possible geographic factors on the LCA results. Furthermore. close examination of the exact by-products examined as emissions in each LCA may reveal differences which identify why the results are contradictory (the consultants are not privy to these details). Greater access to studies may have shed light on sources of differences unfortunately however access was limited to the final reports of the projects. This however would shed no light on the possible geographic and environmental differences between study locations and South Africa. Furthermore. any LCA can be constructed to carry a specific message by carefully selecting the appropriate impacts to examine.

It is therefore concluded that in order to formulate an accurate assessment of which life cycle is the more environmentally friendly in the South African context a streamlined LCA should be commissioned.

CITY OF MANHATTAN BEACH
PROPOSED NEGATIVE DECLARATION

In accordance with the California Environmental Quality Act of 1970, as amended, and the City of Manhattan Beach CEQA Guidelines, the Community Development Department after conducting an Initial Study found that the following project would not have a significant effect on the environment and has instructed that this Negative Declaration be prepared.

1. **Project Title:**	Municipal Code Amendment to Prohibit Single-Use Plastic Carry-Out Bags at Commercial Establishments
2. **Project Location:**	Citywide
3. **Project Description:**	Prohibit Issuance of Plastic Bags with Purchased Merchandise at all Manhattan Beach Commercial Establshments.
4. **Support Findings:**	Based upon the Initial Study, which is attached hereto and made a part hereof, it is the finding of the Community Development Department that the above mentioned project is not an action involving any significant environmental effects.

Prepared by the Community Development Department on June 11, 2008

Richard Thompson, Director of Community Development