



PE AMERICAS

A joint venture of Five Winds and PE



PE INTERNATIONAL

Final Report

Comparative Life Cycle Assessment Ingeo™ biopolymer, PET, and PP Drinking Cups

for
Starbucks Coffee Company
Seattle, WA
&
NatureWorks LLC

by
PE Americas
Boston, MA

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ACRONYMS

ACC	American Chemistry Council
AP	Acidification Potential
CO ₂	Carbon Dioxide
EoL	End of Life
EP	Eutrophication Potential
GaBi	Ganzheitlichen Bilanzierung (German for holistic balancing)
GHG	Green house gas emissions
GWP	Global Warming Potential
EPA	Environmental Protection Agency
HIPS	High impact polystyrene
IFEU	Institute for Energy and Environmental Research
IP	Intellectual Property
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standards Organization
kg	Kilogram
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MJ	Mega Joule
NO _x	Nitrogen Oxides
OPS	Oriented polystyrene
OVAM	Public Waste Agency for the Flemish Region
oz	Ounce
PE	Polyethylene
PEA	PE Americas
PET	Polyethylene terephthalate
PLA	Polylactic Acid
PP	Polypropylene
TRACI	Tool for Reduction and Assessment of Chemical and Other Environmental Impacts
WNC	West North Central



1 INTRODUCTION

Life Cycle Assessment (LCA) is a standardized scientific method for systematic analysis of any kind of flows (e.g. mass and energy) associated with the life cycle of a specified product or with technological or service or manufacturing process systems (ISO, 2006a). The approach in principle aims at a holistic and comprehensive analysis of the above items including raw materials acquisition, manufacturing, as well as use and End of Life (EoL) management. According to the International Organization for Standardization (ISO), 14040/44 standards, an LCA study consists of four phases: (1) goal and scope (framework and objective of the study); (2) life cycle inventory (input/output analysis of mass and energy flows from operations along the products value chain); (3) Life Cycle Impact Assessment (evaluation of environmental relevance, e.g. Global Warming Potential); and (4) interpretation (e.g. optimization potential) (ISO, 2006a; ISO, 2006b).

The goal and scope stage outlines among others the rationale of the study, the anticipated use of the results of the study, the boundary conditions, the data requirements and the assumptions to analyze the product system under consideration. The goal of the study is based upon the specific questions which need to be answered, the target audience and the stakeholders involved and the intended application. The scope of the study defines the systems boundary in terms of technological, geographical, and temporal coverage of the study, attributes of the product system, and the level of detail and the complexity addressed by the study.

The Life Cycle Inventory (LCI) stage qualitatively and quantitatively documents the materials and energy used (input) as well as the products and by-products generated and the environmental releases to the environmental compartments and the wastes streams (output) for the product system being studied. The LCI data can be used on its own to: understand total emissions, wastes and resource use associated with the material or product being studied; to improve production or product performance; or it can be further analyzed and interpreted to provide insights into the potential environmental impacts from the system (Life Cycle Impact Assessment (LCIA) and interpretation).

Starbucks Coffee Company (Starbucks) is interested in integrating sustainable packaging materials into its cold beverage cup designs. In order to do so, Starbucks is exploring alternative materials for its current polyethylene terephthalate (PET) cold cups and flat lids, seeking better environmental performance characteristics when examined from a life cycle perspective. NatureWorks LLC (NatureWorks), manufacturer of Ingeo™¹ biopolymer (polylactide acid, PLA), could potentially supply this material, an alternative to PET, to Starbucks' drinking cup manufacturer (Solo). To support this effort, Starbucks and NatureWorks have partnered to analyze the environmental performance of Ingeo with respect to the total life cycle of select options of bio-based materials and plastics. Polypropylene (PP) as an alternative to the current PET cup was also considered. The

¹ Ingeo™ is the trade name of the polylactide biopolymers produced by Natureworks LLC.



results as given in the underlying report are only valid for Ingeo™ biopolymer, a polylactide polymer produced by Natureworks LLC. The results are not valid for PLA in general.



2 GOALS OF THE STUDY

Starbucks Coffee Company (Starbucks) is interested in

- Continually improving its environmental sustainability performance;
- Analyzing sustainable material alternatives for use in its products;
- Exploring alternative material options for use in its 16 ounce cold cup and flat lid system; and
- Comparing viable alternatives (e.g. Ingeo, PP) to its current use of polyethylene terephthalate (PET) in these drinking cup systems.

The goals of this study are:

- Analyze and compare the environmental performance of PET, Ingeo and PP;
- Support the material selection decisions within Starbucks by determining which material (PET, Ingeo, PP) is currently the most suitable, from an environmental perspective for the purpose defined.

The intended audience of this study is Starbucks and NatureWorks, for internal applications and decision-making. In addition to this internal usage and audience, the results of this study may be made available to the public in the future, at the discretion of Starbucks and NatureWorks. A third party critical review panel has been engaged to meet the ISO standards for comparative assertion studies.

This LCA is an original ISO 14040-series compliant study comparing 16-ounce cold beverage drinking cups and flat lids comprising of virgin PET, virgin PLA (Ingeo), and virgin PP.

The life cycle phases of the beverage cup and lid product systems that were studied include:

- Cradle-to-polymer factory gate pellet production for PET, Ingeo, and PP,
- Pellet transportation to converter,
- Conversion of pellet into cups and lids,
- Transport of cups and lids to Starbucks shops,
- Waste disposal in landfill

3 SCOPE OF THE STUDY

The following section describes the general scope of the project to achieve the stated goals. This includes the identification of specific products to be assessed, the supporting product systems, boundary of the study, allocation procedures, and cut-off criteria.

3.1 SYSTEM DESCRIPTION OVERVIEW

This study assessed the cradle-to-grave life cycle of a cold beverage cup and lid, from raw material acquisition through to End of Life options, excluding the use phase. Figure 1 shows the general life cycle of the cold drinking cup that was analyzed in this study.

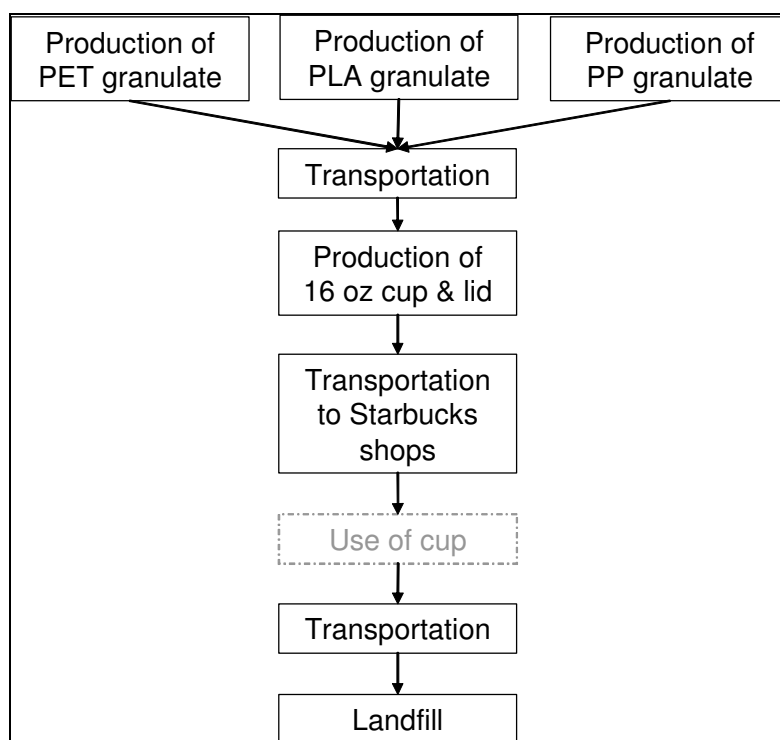


Figure 1: General Flow Diagram for Systems Analyzed

Three material alternatives (PET, Ingeo, PP) were considered for the manufacturing of the beverage cups and lids. Landfill is the only End of Life fate considered in this main study. The three scenarios that were considered include:

1. Virgin PET 16 ounce cup and flat lid – waste disposal in landfill
2. Virgin Ingeo 16 ounce cup and flat lid – waste disposal in landfill
3. Virgin PP 16 ounce cup and flat lid – waste disposal in landfill



Managed composting is discussed as a possible End of Life fate for Ingeo in Appendix C as an additional scenario.

Recycling of used cups as an End of Life fate has not been addressed in this study as there is no established infrastructure throughout the US to manage recycling of PET, PLA, and PP cups and lids².

3.2 FUNCTIONAL UNIT

The functional unit quantifies the performance of a product system and provides a reference unit for the completed LCA. The functional unit for this study is one 16-ounce single use cold beverage plastic cup with flat lid. It is assumed that all plastics used meet the quality requirements as defined by Starbucks.³

The reference flows are:

1. 16-ounce single use cold beverage PET cup with flat PET lid
2. 16-ounce single use cold beverage Ingeo cup with flat Ingeo lid
3. 16-ounce single use cold beverage PP cup with flat PP lid

Results for 1 billion pieces of 16-ounce single use cold beverage plastic cup with flat lid are shown in Appendix C.

3.3 STUDY BOUNDARIES

The study included the cradle-to-gate analysis for raw and processed materials, energies and fuels required in the manufacturing, and transportation and a gate-to-grave analysis for the disposal of the 16-ounce cup and flat lids for Starbucks' cold drinks. The transportation of raw materials to manufacturing, the transportation of finished product to Starbucks shops, and the transportation of product to End of Life disposal were all included. The use of the cup and lid was assumed to be identical and therefore not included in this study.

Table 1 summarizes what was included and excluded in this study, while the system boundaries diagram is shown in Figure 2.

² The authors of this study are aware of the fact that PET, PLA, and PP can theoretically be separated from waste streams and recycled. As this is currently not common practice this scenario is not analyzed in this effort. However it is recommended to include this in an update of this study.

³ Please note that the different materials show different technical characteristics, e.g. wall strength. As it is assumed that all materials are meeting Starbucks specifications, performance characteristics are not further discussed in this assessment.

Table 1: System Boundaries

Included	Excluded
<ul style="list-style-type: none"> • Raw materials production • Processing of materials • Internal recycling loops of plastics during product manufacturing • Energy production • Transportation of raw and processed materials • Transportation of finished product • Product disposal 	<ul style="list-style-type: none"> • Capital equipment and maintenance • Overhead (heating, lighting) of manufacturing facilities when easily differentiated • Human labor • Transportation of materials within a facility • Use of product

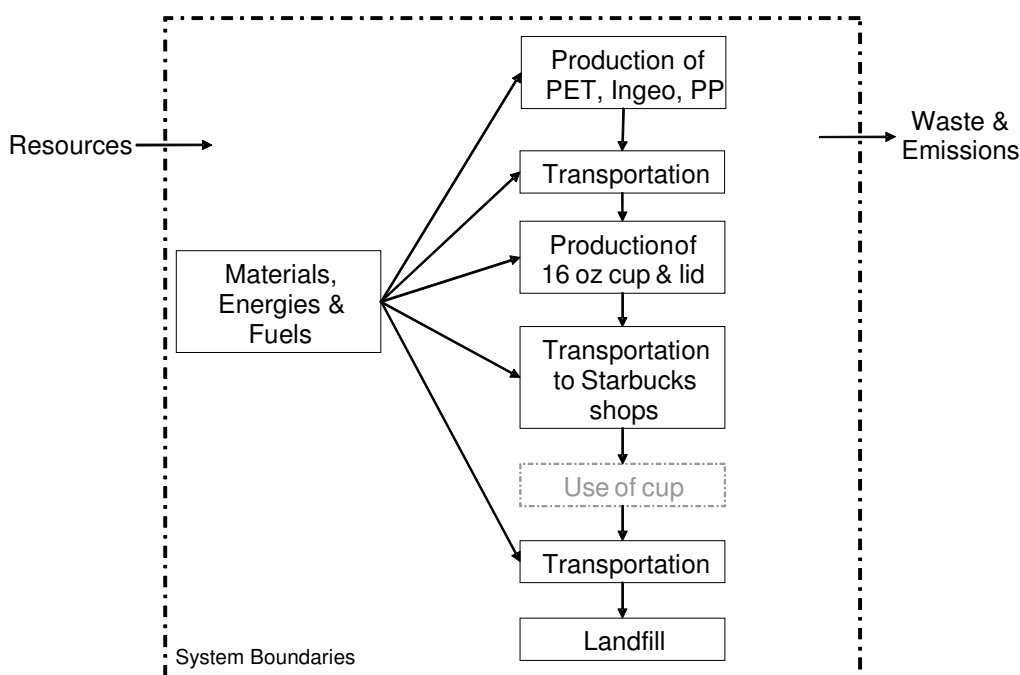


Figure 2: System Boundaries Diagram

3.3.1 TECHNOLOGY COVERAGE

In this study, site-specific data representative of current cup manufacturing technology were collected and analyzed. Primary data were collected for currently used technology on the production of PP and PET cups. Ingeo production was modeled according to unit process information as provided by Ingeo™ for their operation in Blair, Nebraska⁴.

The Polypropylene (PP) and Polyethyleneterephthalate (PET) models represent to US situation and are based on proprietary information as well as internal knowledge at PE

⁴ More information can be found on NatureWorks® web site: <http://www.natureworksilc.com/our-values-and-views/life-cycle-assessment.aspx>



International. Please see chapter 3.5.2.1 and 3.5.2.3 for information on main material and energy input of PP and PET production.

When no primary data were available, either estimations provided by the involved companies or publicly available secondary data were used and documented as such. For other ancillary or process materials, such as the production of chemical stock, fuels and power, average industry or country mix, profiles from the GaBi databases 2006 (GaBi 4 Software system for Life Cycle Engineering database) were utilized.

For any required material-, energy-, and utility-production the “state of the art” technology was used.

3.3.2 GEOGRAPHIC COVERAGE

The geographical coverage of this study was 16-ounce cold beverage cups and lids produced for Starbucks in the United States (U.S.) for use in the United States (U.S.) The Life Cycle Inventory (LCI) data on the production of PET and PP are representative of U.S. production only and do not include potential imports from China, Mexico, or other countries. Ingeo was modeled according to information provided by Ingeo™ on their operations in Blair, Nebraska.

3.3.3 TIME COVERAGE

Polymer and background data (i.e., raw materials, intermediates, fuels, electricity) were obtained from the GaBi 4 database and are representative of the years 2000-2005.

Ingeo data provided by NatureWorks, LLC are representative of 2009 (Ingeo 2009).

Data for the conversion of polymer pellet to the cup is representative of the current situation (2008).

3.4 SELECTION OF IMPACT ASSESSMENT CATEGORIES

A comprehensive set of environmental impact categories were investigated. Within the standard state-of-the-practice of life cycle impact assessment this includes the following inventory flows and environmental categories: primary energy demand (Non Renewable Resources)⁵, climate change (Global Warming Potential), smog formation (Photochemical Ozone Creation Potential), Acidification Potential, and Eutrophication Potential. This report presents results according to the CML methodology (Centre for Milieukunde Leiden). The Tools for Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI, developed by the US EPA) impacts are provided for one cup in Appendix F.

⁵ Primary Energy Demand is not an impact but is included in this section as it is also a sum value indicating the total amount of energy extracted from earth or based on renewable resources.



Primary Energy Demand, as a measure of consumption of non renewable resources and Global Warming Potential, as a measure of radiative forcing (heat absorption) relative to carbon dioxide (CO₂) are internationally accepted (respectively by the International Energy Agency (IEA) and the Intergovernmental Panel on Climate Change (IPCC)). As such, these measures of impact are considered relatively the most robust among the life cycle impact assessment categories currently available to life cycle assessment practitioners. This is explained in further detail in Appendix A.

Primary Energy Demand and **Global Warming Potential** are included in the study because of their growing importance to the global environmental and political/economic realm. Acidification, Eutrophication, Photochemical Ozone Creation Potential/ Smog Air are included because they reflect the environmental impacts of regulated and additional emissions of interest by industry and the public, e.g. SO₂, NO_X, CO, and hydrocarbons. Acidification and Eutrophication impacts are directly related to the agricultural context (farming).

In 2004 a group of environmental leaders released a report, the Apeldoorn Declaration⁶, describing the shortcomings of toxicity and hazard characterization within LCA. As per this declaration, it is the position of this study that “even though LCIA can use models and methodologies developed for Risk Assessment, LCA is designed to compare different products and systems and not to predict the maximal risks associated with single substances.” Human and eco-toxicology results are best suited for case- and site-specific studies that accurately model dispersion pathways, rates, and receptor conditions.

The topic of **water consumption** has become more relevant in recent years. Therefore it has been included in the assessment knowing that it is not a typical impact category. In agricultural contexts, the quantities of water needed may outweigh the impacts of a different material especially in areas which may be experiencing drought conditions in recent years. This study considers the net water consumption. This means any water which is used for cooling and then returned to an outside source is not counted. Only the water which is consumed and integrated into the project is counted.

3.5 DATA COLLECTION

Data collection was coordinated by PE Americas. The following primary data were collected or estimated:

- IngeoTM production: The following data were provided on the unit process level
 - Material input
 - Energy consumed
 - Process emissions

⁶ Apeldoorn [2006] - http://www.leidenuniv.nl/cml/ssp/projects/declaration_of_apeldoorn.pdf



- Water consumption
- Transportation:
 - Inbound transportation of raw materials: distance and mode provided by the manufacturing companies
 - Transportation of cups to distribution center: information provided by Starbucks
 - Transportation distribution center to Starbucks shops: average distance and mode estimated by PE Americas after consultation with Starbucks
- Manufacturing of cup
 - Weight of cup and lid
 - PET: actual weight of current cup
 - Ingeo: weight based on test runs
 - PP: weight based on test runs
 - Material efficiency
 - Electricity consumption

All other data were from the GaBi databases or public data sources.

3.5.1 LIMITATIONS OF DATA

The results of this study are only applicable to the defined scenarios. Any adjustment of the study boundaries or processes may change the results.

3.5.2 PRODUCTION PHASE

3.5.2.1 PET Granulate

The LCI inventory dataset for PET Granulate (Polyethylene terephthalate) production was modeled using data from the GaBi databases 2006 and represents the U.S. situation. The following two figures show the main energy and material input flows for the different routes by either lower heating value or mass. The final model represents a combination of the two main production routes used in the U.S.:

- PET produced via terephthalic acid (85%)
- PET produced via dimethyl terephthalate (15%)

US: Polyethylenterephthalat Granulat (PET) via DMT

GaBi 4-Prozesskette: Energie (Carboner Neutralität) [10]

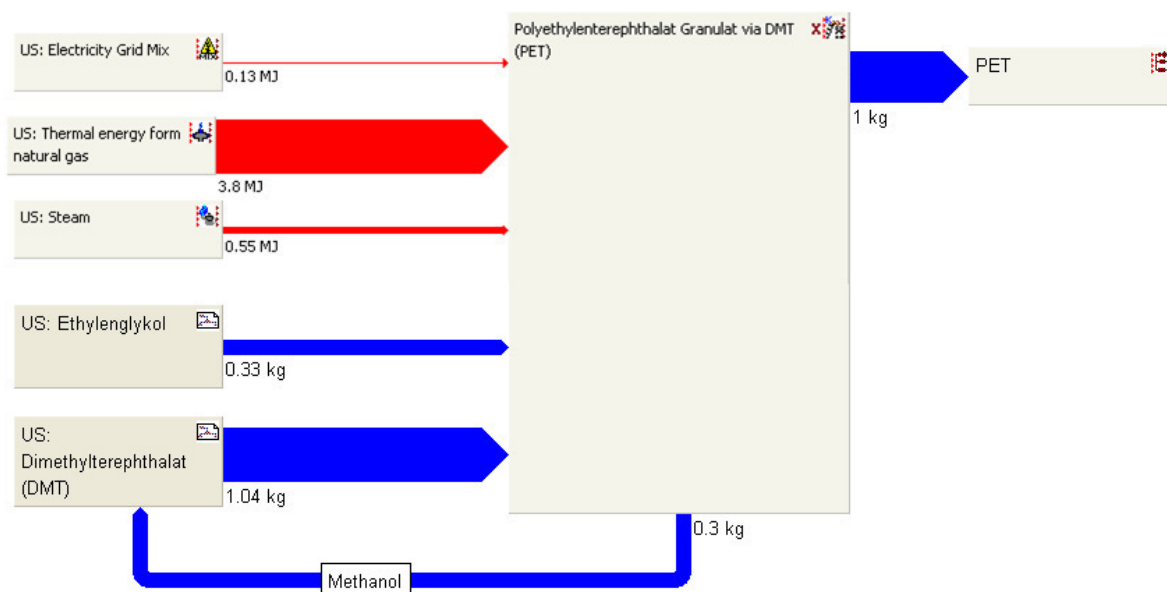


Figure 3: PET via DMT production model

US: Polyethylenterephthalat Granulat (PET) via TS und EG

GaBi 4-Prozesskette: Energie [10]

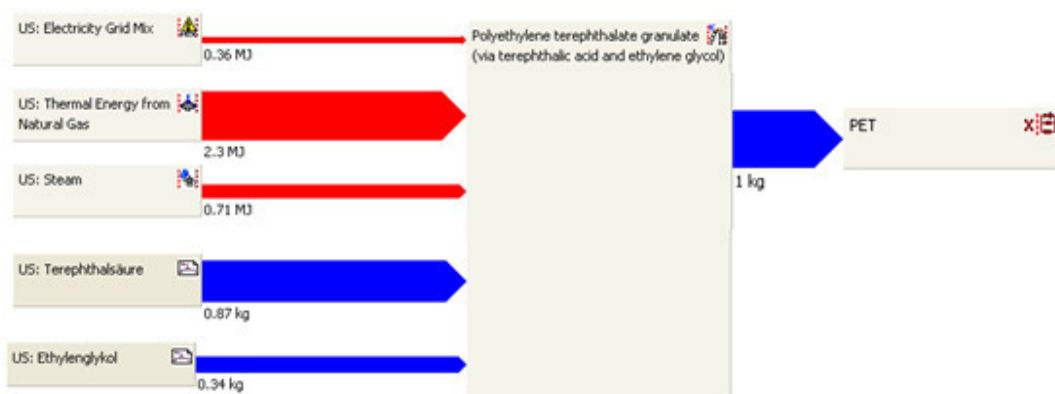


Figure 4: PET via terephthalic acid and ethylene glycol production model

The background datasets for energy and fuels (including steam) are also representative of U.S. boundary conditions and are taken from the GaBi databases 2006. Additional materials needed to run the process are considered but not shown due to confidentiality and intellectual property reasons in the screenshot. In sum they contribute less than 5% to the considered impact categories

3.5.2.2 Ingeo Granulate

Polyacide (PLA/Ingeo) is a thermoplastic polymer derived from bio-based materials such as corn. Data used in this study were provided by Ingeo™ in a disaggregated way, and represented the energies and auxiliaries/process materials needed for the Ingeo production in addition to the process emissions related to the production process.

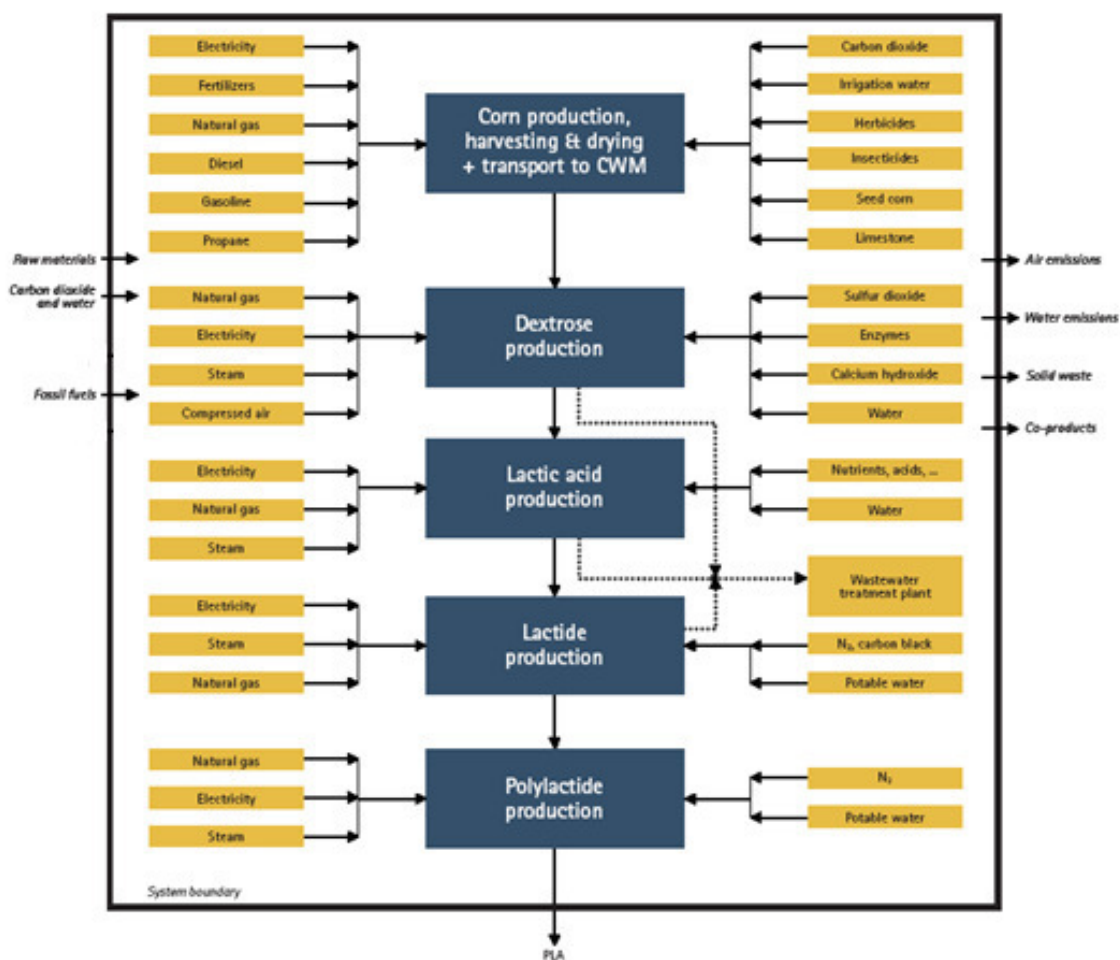


Figure 5: Process Flow Diagram for Manufacturing of NatureWorks Ingeo Resin⁷

⁷ Figure 1 from Erwin T.H. Vink, David A. Glassner, Jeffrey J. Kolstad, Robert J. Wooley, Ryan P. O'Connor "The eco-profiles for current and near-future NatureWorks® polylactide (PLA) production" (Spring 2007). More information can be found on NatureWorks® web site: <http://www.natureworkslc.com/our-values-and-views/life-cycle-assessment.aspx>

In Figure 5, the general process flow diagram for Ingeo™ biopolymer is shown. Unit process data provided include production of:

- Corn (harvesting, drying and transport),
- Dextrose,
- Lactic acid,
- Lactide, and
- Polylactide

Ingeo biopolymer has been modeled based on the unit process information as provided by NatureWorks® and environmental profiles from the GaBi databases 2006 for energy and background materials for US boundary conditions. This approach was chosen to ensure that consistent energy and background materials profiles were used for all materials assessed in this study.

3.5.2.3 PP Granulate

The LCI data set for PP granulate was modeled using data from the GaBi databases 2006 and represents the U.S. situation. In Figure 6 and Figure 7, the input flows into the process are shown either as lower heating value or mass. Additional materials like nitrogen, hydrogen, sodium hydroxide as well as the catalysts which are needed to run the process are considered but not shown due to confidentiality and intellectual property reasons in the screenshot. In sum they contribute less than 5% to the considered impact categories.

US: Polypropylen Granulat (PP) (2005, Starbucks)

GaBi 4 - Prozeßplan: Plast (kg)

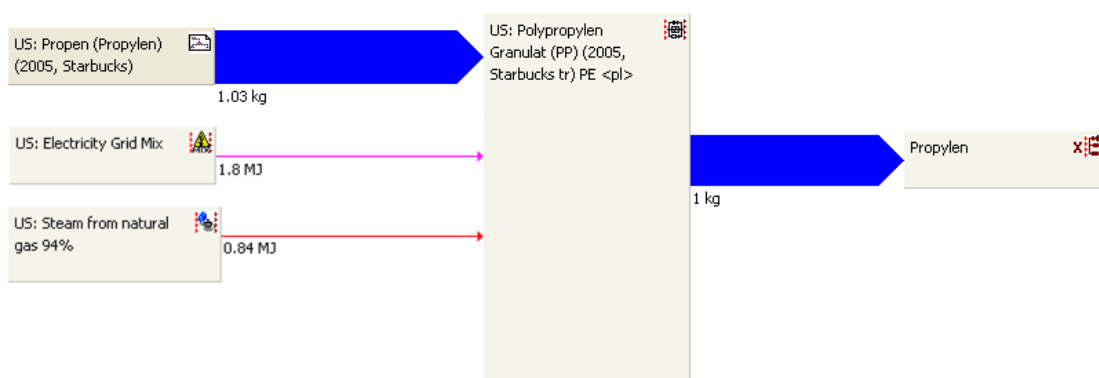


Figure 6: Polypropylene Granulate Production Model

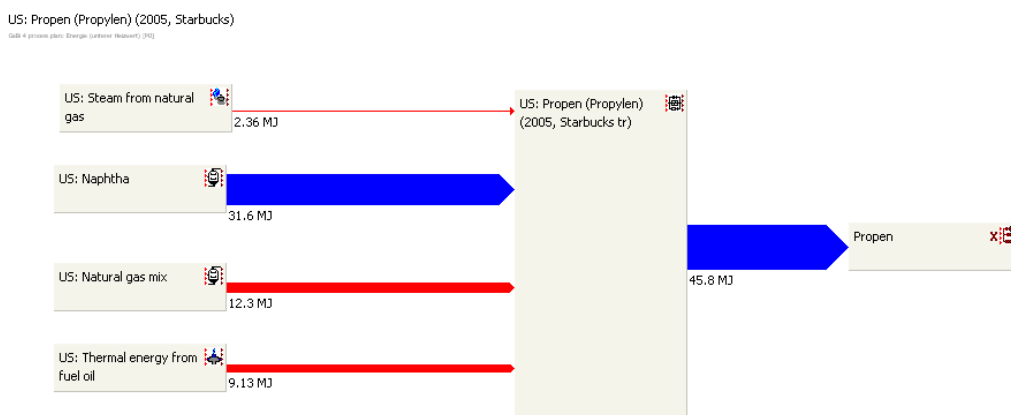


Figure 7: Propylene Production Model

The background datasets for energy and fuels (including steam) are also representative of U.S. boundary conditions and taken from the GaBi databases 2006.

3.5.2.4 Cup & Lid Manufacturing

Cup and lid production data were collected from Starbucks suppliers of cold cups and lids. Data on weights of the different material options are based on primary data as provided by Solo (primary supplier of PET cups) for PET and prototypes for PP and Ingeo.

Energy consumption for the cup and lid manufacturing process has been provided by the different manufacturers.

As no primary data on the production of Ingeo cups could be obtained during the project, it has been modeled based on the information as provided for PP cups as well as for PET cups. Based on discussion with the cup manufacturer, no significant difference in energy consumption for Ingeo is expected. In Table 2, the considered weights of the cups and lids assumptions are shown. Different weight scenarios for the PP and Ingeo options were modeled since only prototype data were available, see Table 2.

Table 2: Cup and Lid Specifications

	PET	PP Scenario 1	PP Scenario 2	Ingeo Scenario 1	Ingeo Scenario 2
Weight per unit (grams)					
Cup	15.5	12.73	13.18	13.6	14.4
Lid	2.5	2.05	2.12	2.19	2.32



3.5.2.5 Transportation

The specific transportation distances as shown in Table 3 have been included in this study. The distance of the incoming polymers to the cup manufacturer was provided by the specific cup manufacturer and the distance to the distribution center is based on information provided by Starbucks, while the distance for final transport to the Starbucks shops is an estimation based on information provided by Starbucks.

Table 3: Transportation

	PET	PP Scenario 1	PP Scenario 2	Ingeo Scenario 1	Ingeo Scenario 2
Transport					
pellets to manufacturer [mode]	1000 miles [train]	865 miles [train]		650 miles [train]	
manufacturer to distribution center [mode]	1250 miles (average) [train]	1200 miles (average) [train]		1250 miles (average) [train]	
distribution center - Starbucks shops [mode]	75 miles [truck]	75 miles [truck]		75 miles [truck]	

3.5.3 END OF LIFE PHASE

The End of Life for all scenarios is for the cups and lids to be landfilled. Data on the implications of disposing of PET, Ingeo, and PP cold beverage cups and lids as part of municipal landfill were taken from the GaBi databases 2006.

All three materials are assumed to have inert behavior and therefore no landfill gas or emissions are related to their deposition in a landfill. Therefore, the environmental impact of these materials going to a landfill is related only to the operation of the landfill.

The following list describes the GaBi landfill model and the main parameter settings:

- Municipal waste landfill with surface and basic sealing
- Site include: landfill gas treatment, leachate treatment and sludge treatment and deposition
- Landfill height 30 m, landfill area 40,000 sqm; 100 years deposit
- The effort for sealing materials (clay, mineral coating, PE film) and diesel for the compactor is included in the data set
- Landfill gas production and distribution of landfill gas is calculated. As a base scenario the parameters on landfill gas distribution are set to: 22% flare, 28% used, 50% emissions
- The “used” landfill gas is handled by a power plant producing electricity
- Precipitation data from (666 mm/a)



- A rate of 60% transpiration/run off is assumed. Landfill leachate: exponential solubility of fluids is assumed
- Solubility factors are used for different solubility calculations
- Leachate and landfill body are assumed to be homogeneous
- Landfill body is saturated
- No circulation of leachate
- Basic sealing effectively for leachate: 70%. Leachate treatment includes active carbon and flocculation/precipitation processing
- Sludge treatment and deposition is included

3.5.4 FUELS AND ENERGY AND BACKGROUND MATERIALS

Energy sources including electricity, natural gas, and steam were obtained from U.S. average profiles available in the GaBi databases 2006. The majority of the background data used is publicly available and public documentation exists⁸. The GaBi LCI datasets originate from the years 2002 – 2007.

3.5.5 CO-PRODUCT ALLOCATION

Life Cycle Inventory Analysis relies on being able to link unit processes within a product system using simple material or energy flows. In practice, few industrial processes yield a single output or are based on a linearity of raw material inputs and outputs. In fact, most industrial processes yield more than one product, and they recycle intermediate or discarded products as raw materials. Therefore, the materials and energy flows as well as associated environmental releases are allocated to the different products according to clearly stated procedures, see ISO 14040/ 44. The relevant allocation procedures in the analyzed life cycles are described below.

For **all systems**, refinery products such as diesel, naphtha, fuel oil and lubrication oil are allocated by mass in relation to the refinery emissions and energy demands are allocated by energy content in relation to the crude oil consumption.

For **polymer production** allocation based on energy content is performed on the steam cracker products. Propylene as monomers for the polypropylene production are allocated with by products such as butadiene, pyrolysis gases, hydrogen, and heating gas.

No allocation was necessary for the manufacturing of **cups and lids** assessed in this study.

3.5.6 EMISSIONS TO AIR, WATER AND SOIL

No direct emissions have been reported for the cup manufacturing process.

⁸ Documentation can be found at: <http://documentation.gabi-software.com/>



Direct process emissions data associated with Ingeo production were determined by primary technical contacts familiar with the specific operations.

Data for all upstream materials and electricity and energy carriers were obtained from the GaBi 4 Software databases.

Downstream emissions associated with distribution of the finished product were determined by capturing the logistical operations.

No emissions during the use phase of the cup were anticipated and therefore this life cycle phase was not assessed in this study.

End of Life emissions were determined by municipal waste operations data associated with landfill for inert materials.

3.5.7 CUT-OFF CRITERIA

The cut-off criteria for the study include or exclude materials, energy and emissions flows as follows:

- Mass – If a flow is less than 2% of the cumulative mass of the model it may be excluded, providing its environmental relevance is not a concern.
- Energy – If a flow is less than 2% of the cumulative energy of the model it may be excluded, providing its environmental relevance is not a concern.
- Environmental relevance – If a flow meets the above criteria for exclusion, yet is thought to potentially have a significant environmental impact, it will be included. All material flows which leave the system (emissions) and whose environmental impact is over 2% of the whole impact of an impact category that has been considered in the assessment, must be covered.

The sum of the excluded material flows must not exceed 5% of mass, energy or environmental relevance.

3.5.8 DATA QUALITY

Overall the data quality is considered good. Data quality is judged by its precision (measured, calculated or estimated), completeness (e.g. are there unreported emissions?), consistency (degree of uniformity of the methodology applied on a study serving as a data source) and representativeness (geographical, time period, technology). To cover these requirements and to ensure reliable results, first-hand industry data in combination with consistent, background LCA information from the GaBi LCI database. This background information from the GaBi LCI database is widely distributed and used with the GaBi 4 Software throughout numerous industries, research institutions, universities, etc. The data sets have been used in LCA-models worldwide for several years in industrial and scientific applications for internal as well as critically reviewed studies. In the process of providing these datasets, they have been cross-checked with other databases and experience values from industry and science.



Precision and completeness

- **Precision:** Manufacture of the cups and lids is based on information provided by different cup manufacturers and PLA is modeled based on primary information provided by the owner of the technology (NatureWorks LLC). No better precision is attainable in this project. PP, PET as well as all upstream data is consistently derived from the GaBi professional data base with the documented precision to ensure consistency of boundary conditions.
- **Completeness:** All relevant, specific processes for the different options are considered and modeled to represent each specific situation. Any background processes are taken from the GaBi databases (see GaBi 4 documentation).

Consistency and reproducibility

- **Consistency:** To ensure consistency, only primary data of the same level of detail and background data from the GaBi databases 2006 are used. While building the model, cross-checks concerning the plausibility of mass and energy flows are continuously conducted. The primary data provided by the technology representatives was checked and recalculated by PE several times. No inconsistencies were found.
- **Reproducibility:** The reproducibility is given for internal use since the owners of the technology provided the data and the models are stored and available in the GaBi database. Sub-systems are modeled by 'state of art' technology using data from publicly available and internationally used databases. Full reproducibility will not be available for external audiences due to confidentiality agreements.

Representativeness

- **Time related coverage:**
 - Cup and lid manufacturing: actual production data for 2007
 - PLA: 2005 and 2009
 - PP, PET and upstream data: 2002 to 2007
- **Geographical coverage:**
 - United States of America
- **Technological coverage:**
 - The PET and PP models represent the US situation of PP and PET production in the United States
 - PLA represents the specific technology used by NatureWorks LLC.
 - Manufacturing of cups and lids is based on primary information provided by suppliers. It is representative for cup and lid manufacturing. The information has been cross checked and averaged with literature data. It has to be noted that the efficiency and



energy consumption may differ from literature and between suppliers. The manufacturing models for the different materials are mainly based on information provided by the same suppliers to ensure that the same efficiency is considered.

3.6 SOFTWARE AND DATABASES

This LCA used the internationally recognized software system GaBi 4 for life cycle engineering for simulations and calculations. GaBi 4 was jointly developed by LBP (former IKP), University of Stuttgart, and PE International.

GaBi 4 is a tool for analyzing the environmental impacts of the operations as well as to calculate mass and energy balances. GaBi 4 is also used to create emission profiles of the operations, namely:

- to identify the process in the chain with the highest environmental impact
- for visualizing energy and mass flows by using Sankey diagrams
- for calculating Life Cycle Inventories (LCI) of the products
- for characterizing the LCI into environmental impacts

The GaBi 4 software includes an extensive database of upstream environmental data regarding the production of materials, transports and energy supply.

The databases of GaBi 4 contain over 150 person years of data collection and compiling. LCA data of over 1,000 different chemical process chains are available within GaBi.

Quality - Consistency – Relevancy – Continuity have been the main drivers in the GaBi 4 database. Close cooperation with many different industries across the life-cycle is the essential element that guarantees usability and coverage, including: energy supply chains and resources (such as oil, gas, coal, etc.) according to the country specific situation; in any important resource mining area as well as end-energy supply processes (such as power plants and refineries) in their country specific operation modes (adapted to new standards); and all major and many other specialty production processes in the fields of chemistry, plastics, metals, non-ferrous metals and precious metals (adapted to current technology standards).

3.7 QUALITY ASSURANCE

An internal assurance review was performed by PEA staff members who were not involved in conducting the work contained within this study.



3.8 CRITICAL REVIEW

According to the ISO 14040 series standards that define the LCA methodology, a comparative assertion study requires a third-party critical review. The critical review panel for this study consisted of both technical and non-technical (peer review) members who were agreed upon by Starbucks, Ingeo™ and PEA.

3.8.1 PANEL

The technical panel included:

- **Panel Chair:** Dr. Joyce Cooper – Associate Professor, Department of Mechanical Engineering, Design for Environment Laboratory, University of Washington;
- Dr. Rob Anex – Associate Professor, Department of Agriculture and Biosystems Engineering, Iowa State University;
- Bryan Lembke – Director of Sustainability, several subsidiary brands of PepsiCo Beverages and Foods, Executive Committee Member of Sustainable Packaging Coalition.

The peer review panel included:

- Martha Stevenson – Project Manager, GreenBlue;
- Eric Brody – Principal, Shift Advantage, www.shiftadvantage.com



4 DESCRIPTION OF SCENARIOS

Within this chapter the different scenarios analyzed are described. This chapter combines the technical parameters as described in earlier chapters.

As shown in Table 4, for Ingeo and PP two different weight scenarios have been modeled and analyzed for each material. In addition to the different weight scenarios for Ingeo, four different cup production scenarios for Ingeo have been assessed during this study. The polymer production was based on technologies for 2009 using a regional electricity mix at the plant (West North Central).

Table 4: Technical Parameters of Scenarios

	PET	PP		Ingeo	
		Scenario 1	Scenario 2	Scenario 1	Scenario 2
weight per unit (grams)					
cup	15.5	12.73	13.18	13.6	14.4
lid	2.5	2.05	2.12	2.19	2.32
Transport (miles)					
pellets to manufacturer [mode]	1000 miles [train]	865 miles [train]		650 miles [train]	
manufacturer to distribution center [mode]	1250 miles (average) [train]	1200 miles (average) [train]		1250 miles (average) [train]	
distribution center - Starbucks shops [mode]	75 miles [truck]	75 miles [truck]		75 miles [truck]	
Manufacturing					
energy consumption	consumption provided by manufacturer	consumption provided by manufacturer		2 scenarios: PET: per unit (PET numbers) PP: per mass with consumption per kg as provided by PP cup provider	
material data source	GaBi LCI database (US)	GaBi LCI database (US)		Ingeo 2005, Ingeo 2009, Ingeo Target: NatureWorks specific and GaBi 4 LCI background information (energies/chemicals)	
End of Life					
Landfill	inert	inert		inert	



5 ENVIRONMENTAL RESULTS

The following chapter shows the comparative results as well as the relevance of the different life cycle stages. The results are analyzed and discussed.

Please note that all PLA numbers are based on NatureWorks LLC information and are only valid for Ingeo™ PLA.

5.1 SCENARIO DESCRIPTIONS

These scenarios examine the different material options and weights. A total of 7 different scenarios were considered and assessed in the main sections of the report.

Please note that the different scenarios are described according to the following logic:

“material” (“cup weight”/ “lid weight) **“production technology”**

Material:

PET, Ingeo 2009, PP

Production technology:

In case of PET and PP, specific information on the energy consumption was available. For Ingeo, no specific data has been available and, therefore, Ingeo has been modeled based on the information as provided for PP and PET.

prod PP = energy consumption for PP

prod PET = energy consumption for PET

As no information on the production of Ingeo cups and lids has been available, two manufacturing scenarios have been modeled for Ingeo.

1. prod PET

This scenario is based on the information as provided for PET.

2. prod PP

This scenario is based on the information as provided for PP.

Additional scenarios for Ingeo 2005 and Ingeo Target are presented in Appendix B. Please note that Ingeo 2009 is an improved version of Ingeo 2005 while Ingeo Target represents the efficiencies NatureWorks® expects to reach in the future.



5.2 LIFE CYCLE IMPACT ASSESSMENT RESULTS

5.2.1 PRIMARY ENERGY DEMAND - NON RENEWABLE RESSOURCES

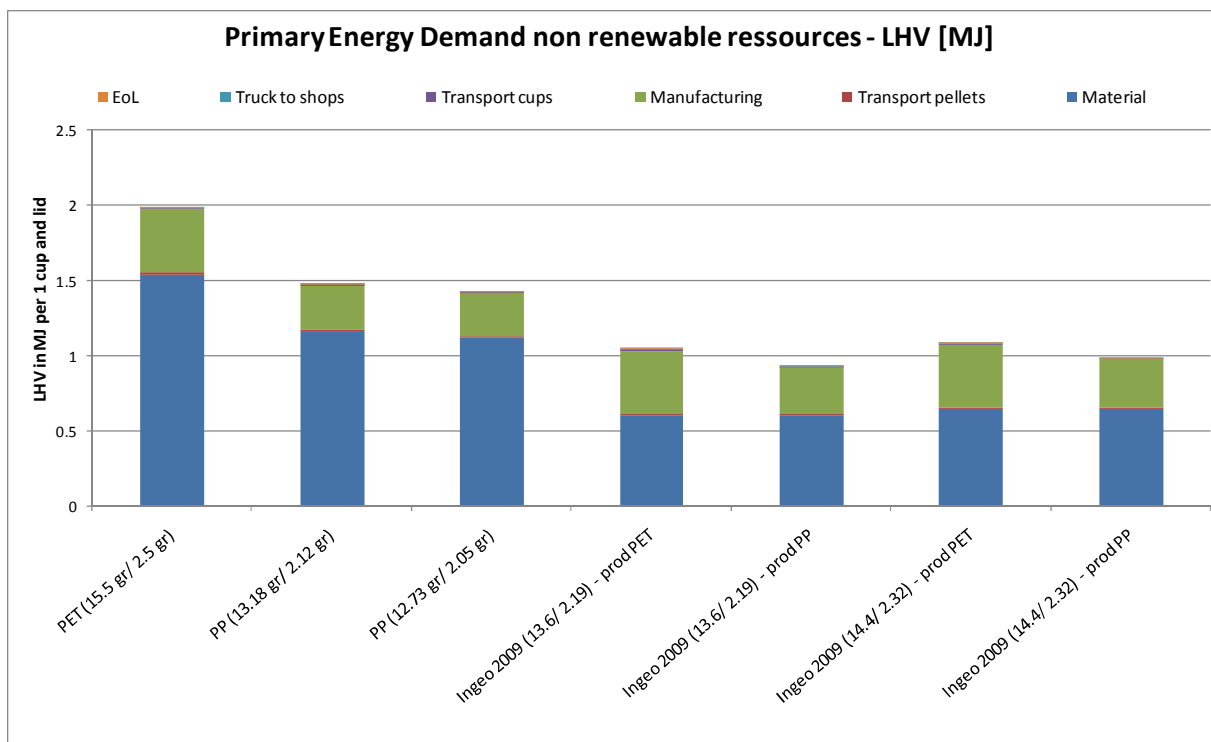


Figure 8: Primary Energy Demand

Figure 8 shows that the Primary Energy Demand from non renewable resources (fossil energy) is dominated by the production of the various polymers and the manufacturing of cups and lids. In addition, the different scenarios for cup weight for Ingeo and PP shows a slight influence on the material share of these scenarios. Figure 8 also indicates that the PET has the largest primary energy demands – non renewable resources. While the PP cups have a lower primary energy demand than the PET, the Ingeo scenarios have the lowest primary energy demands of all the scenarios.

5.2.2 GLOBAL WARMING POTENTIAL

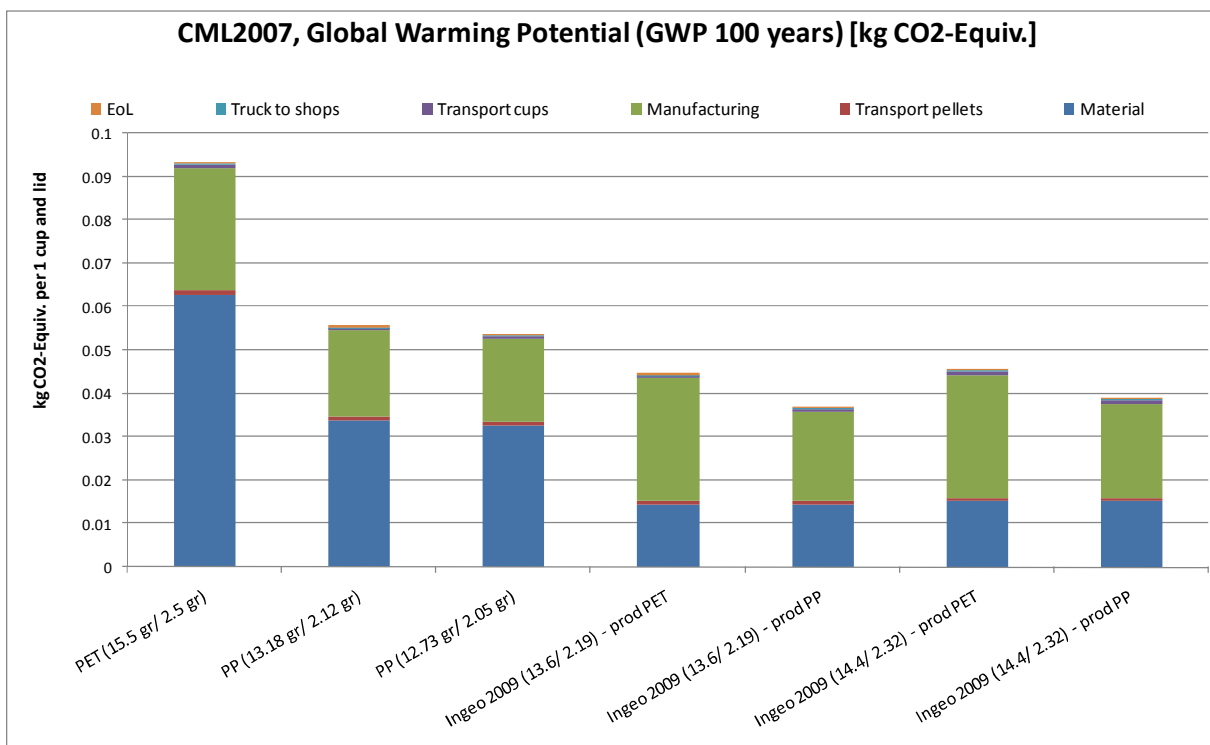


Figure 9: Global Warming Potential

Figure 9 clearly shows that the Ingeo scenarios have significantly lower impacts on global warming potential than either the PP or PET scenarios. PET, which is currently used, has the highest carbon footprint of all scenarios. The materials are the largest source of emissions for the PP and PET scenarios, while the manufacturing stage generates the most emissions for the Ingeo scenarios.

5.2.3 ACIDIFICATION POTENTIAL

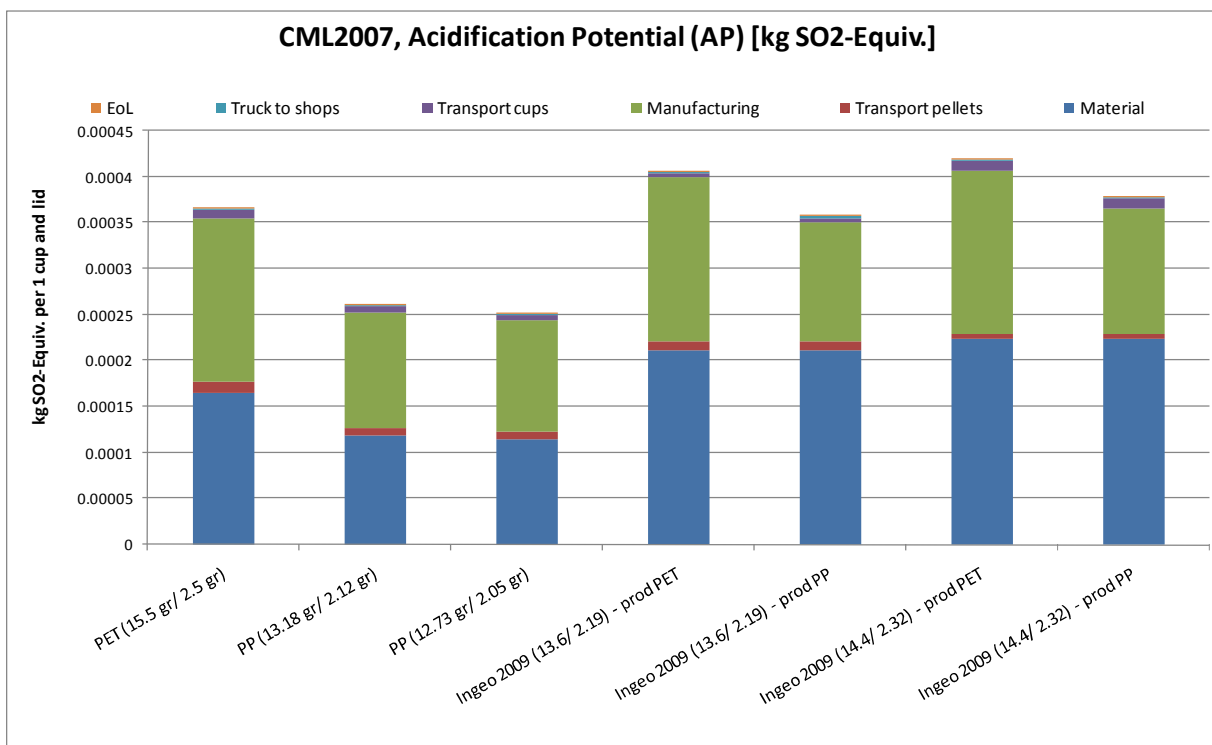


Figure 10: Acidification Potential

In Figure 10, the Acidification Potential (AP) is shown. PP cups have the lowest impacts for acidification. For the Ingeo scenarios, roughly half of the material contribution is coming from the growing of corn while the other half comes from electricity production.



5.2.4 EUTROPHICATION POTENTIAL

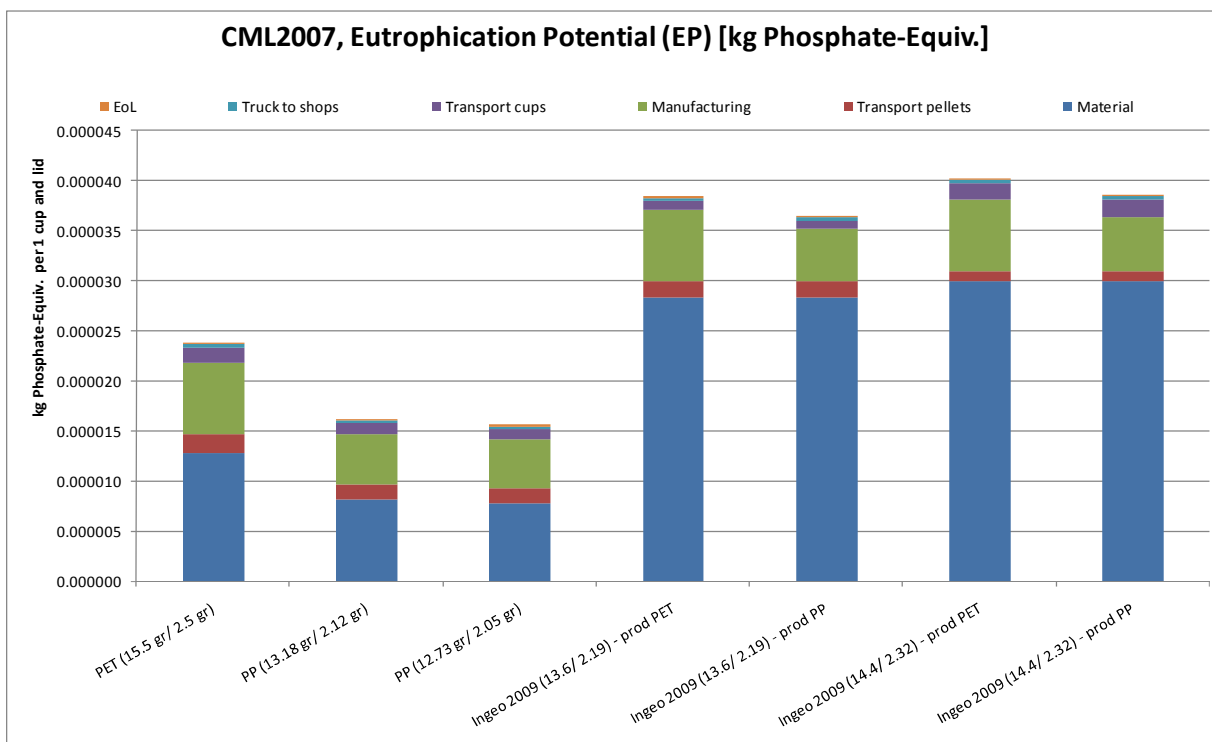


Figure 11: Eutrophication Potential

The relative high numbers for Eutrophication Potential for all Ingeo scenarios is driven by the agricultural portion of the Ingeo production chain. As shown in Figure 11, by switching from PET to PP, the Eutrophication Potential would be reduced.



5.2.5 SUMMER SMOG (POCP)

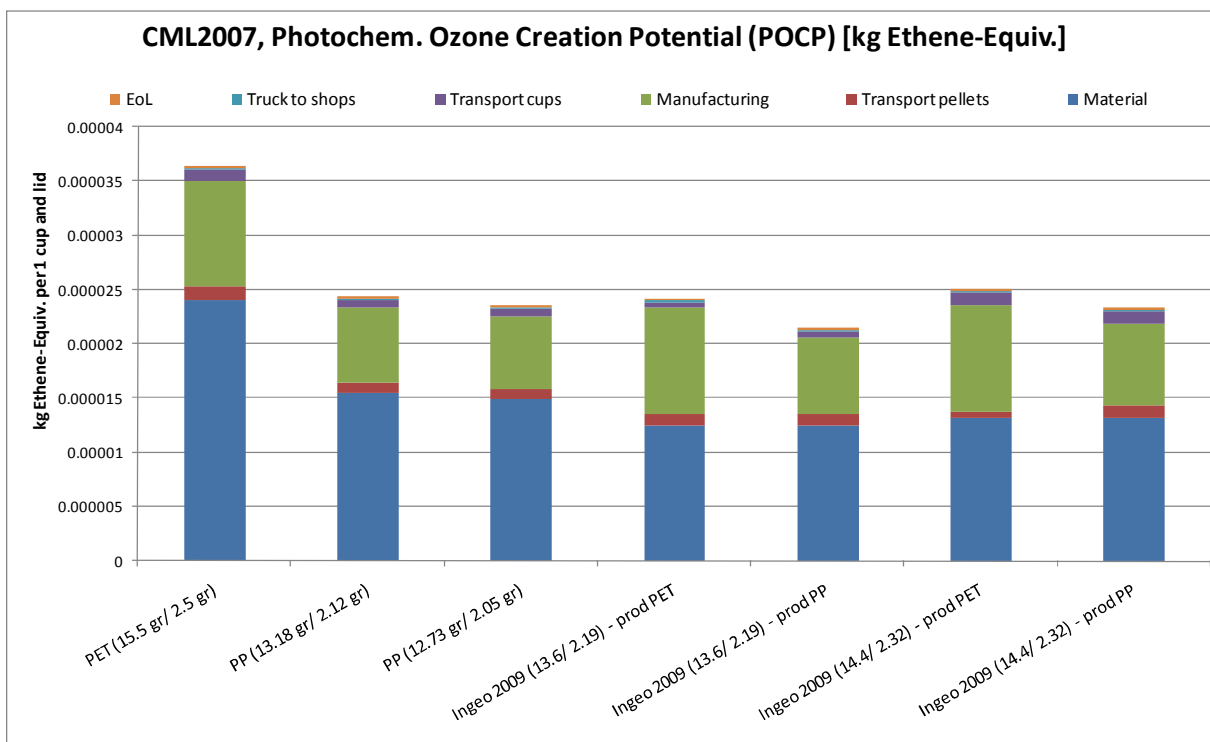


Figure 12: Summer Smog (POCP)

The current PET cups have the highest smog potential as shown in Figure 12. Ingeo cups provide a reduction from the PET. The reduction varies by the weight of the cup. The PP cups currently would provide a significant reduction from the current PET cups and is about equivalent to the Ingeo alternatives. The materials play a larger role in the smog creation for the PET cups than for the PP and Ingeo. The manufacturing impacts are similar for all scenarios.

5.2.6 WATER CONSUMPTION

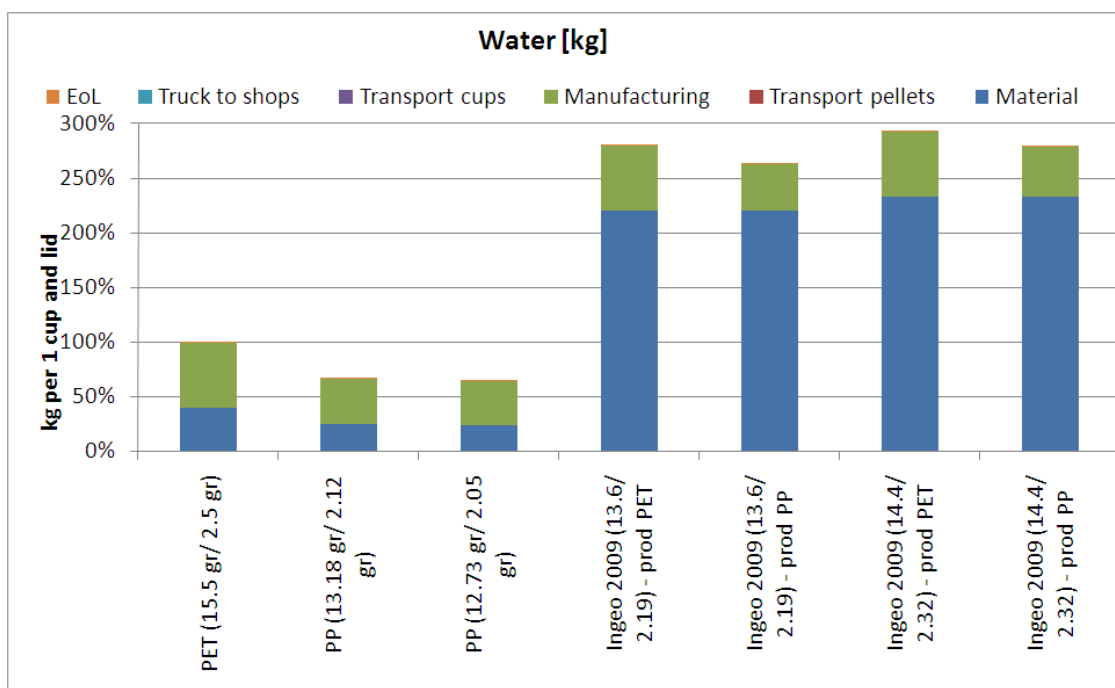


Figure 13: Water Consumption

The water consumption for the various scenarios are shown in Figure 13. The Ingeo scenarios require the most water due to the fact that it involves agricultural processes as corn is the basis for the plastic. The water consumption shown for Ingeo mainly takes place at the location where the corn is grown and the Ingeo manufacturing facilities are located. In this study both locations are considered to be in Nebraska. The current PET scenario requires one-third of the water which would be needed for the Ingeo scenarios. The PP requires about two-thirds of the water that the PET does.

5.2.7 RELEVANCE OF DIFFERENT PHASES

The following three figures clearly indicate that manufacturing and material choice dominates all impact categories. Transportation is not a large contributor to any impact category, due mainly to the transportation mode being by train. Transportation of the polymer material by rail to the cup producer and transportation to the distribution points only has an influence on impact categories which are influenced by NO_x (EP and AP) or CO (POCP). The transportation by truck to the final shop is not significant.

Figure 14 provides an overview of the relative importance of the different sub-systems based on the scenario for the PET cup, Figure 15 for PLA 2009 and Figure 16 for PP.

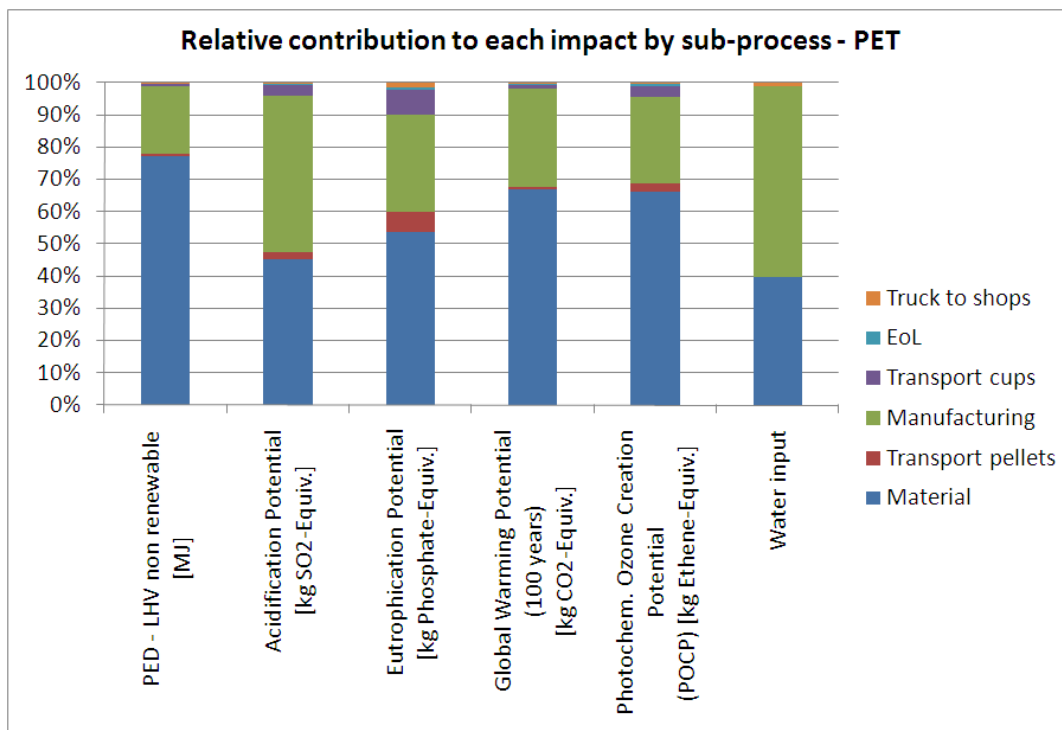


Figure 14: Relative contribution to each impact by sub-process – PET

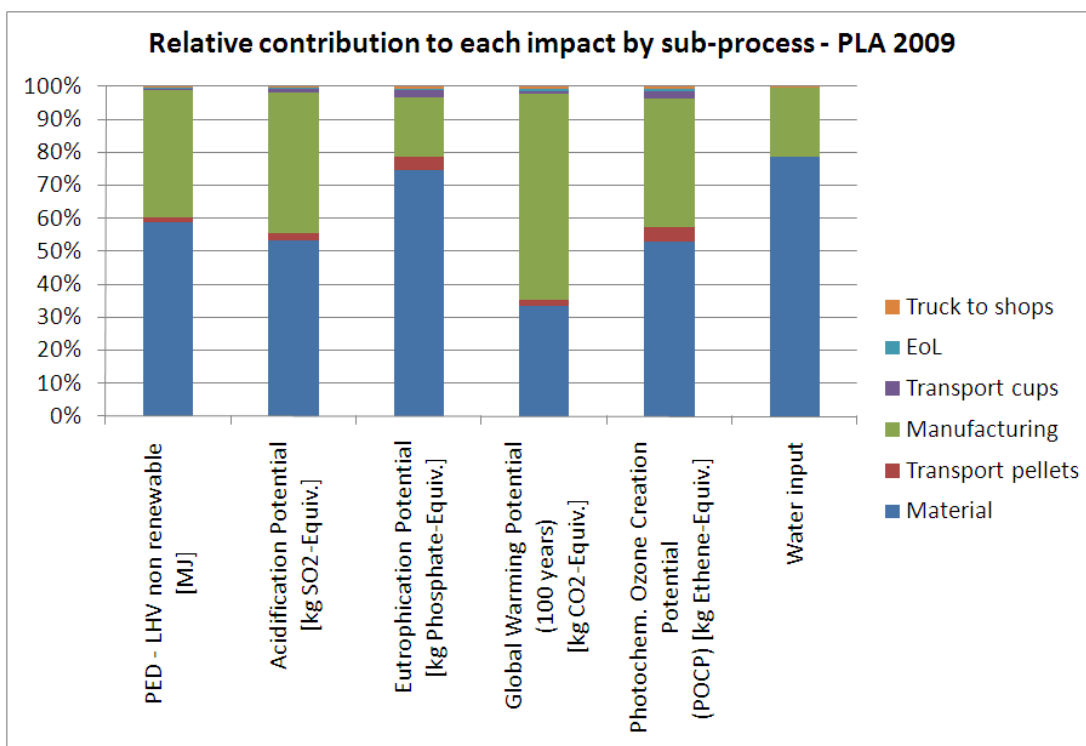


Figure 15: Relative contribution to each impact by sub-process – PLA 2009

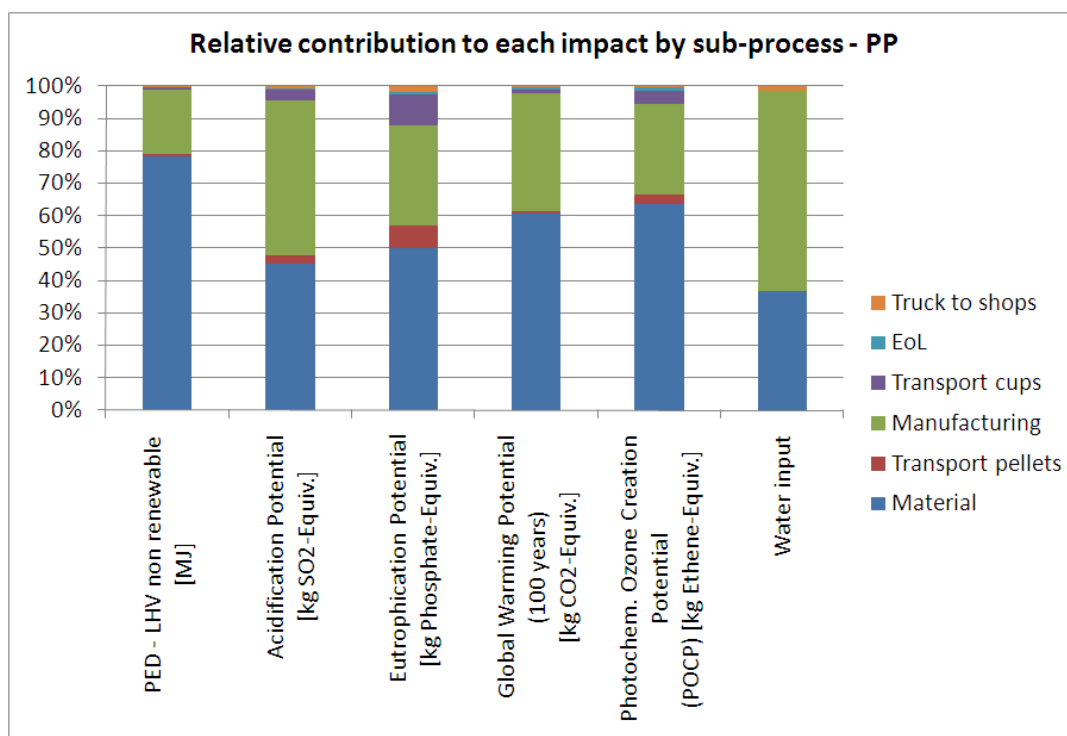


Figure 16: Relative contribution to each impact by sub-process – PLA 2009

5.2.8 OVERALL FINDINGS

The environmental performance of the current Starbucks 16-ounce cold drinking cup and lid made from PET and potential alternative material options, Ingeo and PP, have been assessed.

The conclusions are based on the data and results shown in the previous chapters.

It has to be stated that the Ingeo numbers are based on NatureWorks LLC information and are only valid for Ingeo™ PLA. The results may vary for other PLA production technologies.

The assessment of the different scenarios resulted in the following findings:

- ⇒ The different weight scenarios for cup and lid weight for PP and Ingeo considered in the study show
 - small influence on the environmental footprint related to the material share of Ingeo respective PP scenarios, and
 - the influence on transportation by train is negligible.
- ⇒ Manufacturing show significant contribution for all scenarios.
- ⇒ Ingeo 2009 shows large improvement on all impact scenarios considered due to improvements and more efficient production process of Ingeo, but not a large difference between the two types of scenarios



-
- ⇒ PP shows better environmental performance than PET for all considered categories of interest
 - ⇒ Ingeo and PP show lower numbers for all scenarios for primary energy demand (PED) from non renewable resources, GWP and POCP than PET
 - ⇒ Final weight of cups and lids are an influential parameter. The contribution of the environmental impact of the cup is mainly influenced by the material of choice and weight as the efforts for manufacturing are within the same ballpark for all three materials and transportation via train is not important.
 - ⇒ Transportation via train, polymer pellets and cup/lids to distribution center, is not significant and not influential for the material selection.
 - ⇒ Transportation via truck to shops is not significant
 - ⇒ The impacts associated with landfill can be neglected. All three materials are considered to be inert in landfill operations. It is assumed that all three materials do not degrade in conventional landfill operations.



6 CONCLUSIONS & RECOMMENDATIONS

Starbucks should consider the environmental performance results based on the analysis of this study when choosing between the alternatives. The decision must consider the study boundary conditions and assumptions, including the assumptions that transportation is mainly done by train and that all materials have inert behavior should they be disposed in a landfill operation. Differences in product performance assumptions should also be taken into consideration when formulating a conclusion.

When focusing on GWP (consumption of fossil energy sources and summer smog), both of the alternative material options considered in this study (Ingeo and PP) show significant potential to reduce the environmental impact of cold drinking cups over the current use of PET.

Switching to Ingeo 2009 as a material of choice would reduce PED, GWP, and in most cases the Smog Potential when compared to switching to PP in the considered boundary conditions.

Transportation via train does not contribute significantly to the environmental performance. Therefore a focus on transport via train over transport via truck should be made for future considerations when expanding the market.

Recommendations:

As it is expected that the infrastructure for recycling used polymer drinking cups will mature in the future, recycling of used cups should be added as a scenario to determine the potentials and risks associated with closed loop recycling.



Appendix A. LIFE CYCLE IMPACT ASSESSMENT CATEGORIES

Primary energy consumption

Primary Energy Demand is often difficult to determine due to the various types of energy sources. Primary Energy Demand is the quantity of energy directly withdrawn from the hydrosphere, atmosphere or geosphere or energy source without any anthropogenic change. For fossil fuels and uranium, this would be the amount of resource withdrawn expressed in its energy equivalent (i.e. the energy content of the raw material). For renewable resources, the energy-characterized amount of biomass consumed would be described. For hydropower, it would be based on the amount of energy that is gained from the change in the potential energy of the water (i.e. from the height difference). As aggregated values, the following primary energies are designated:

The total “**Primary energy consumption non renewable**”, given in MJ, essentially characterizes the gain from the energy sources natural gas, crude oil, lignite, coal and uranium. Natural gas and crude oil will be used both for energy production and as material constituents e.g. in plastics. Coal will primarily be used for energy production. Uranium will only be used for electricity production in nuclear power stations.

The total “**Primary energy consumption renewable**”, given in MJ, is generally accounted separately and comprises hydropower, wind power, solar energy and biomass.

It is important that the end energy (e.g. 1 kWh of electricity) and the primary energy used are not miscalculated with each other; otherwise the efficiency for production or supply of the end energy will not be accounted for.

The energy content of the manufactured products will be considered as feedstock energy content. It will be characterized by the net calorific value of the product. It represents the still usable energy content.

Global Warming Potential (GWP)

The mechanism of the greenhouse effect can be observed on a small scale, as the name suggests, in a greenhouse. These effects are also occurring on a global scale. The short-wave radiation from the sun comes into contact with the earth’s surface and is partly absorbed (leading to direct warming) and partly reflected as infrared radiation. The reflected part is absorbed by so-called greenhouse gases in the troposphere and is re-radiated in all directions, including back to earth. This results in a warming effect at the earth’s surface.

In addition to the natural mechanism, the greenhouse effect is enhanced by human activities. Greenhouse gases that are considered to be caused, or increased, anthropogenically are, for example, carbon dioxide, methane and CFCs. Figure 17 shows the main processes of the anthropogenic greenhouse effect. An analysis of the greenhouse effect should consider the possible long term global effects.

The global warming potential is calculated in carbon dioxide equivalents (CO₂-Eq.). This means that the greenhouse potential of an emission is given in relation to CO₂. Since the residence time of the gases in the atmosphere is incorporated into the calculation, a time range for the assessment must also be specified. A period of 100 years is customary.

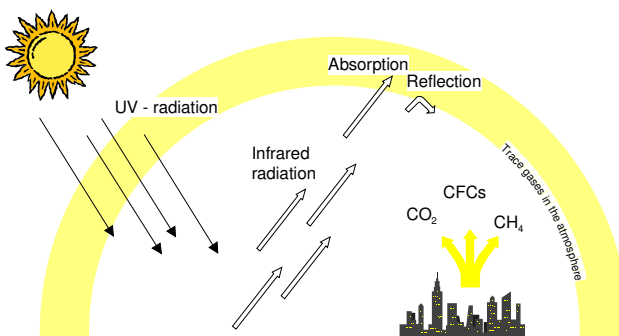


Figure 17. Greenhouse Effect

Acidification Potential (AP)

The acidification of soils and waters occurs predominantly through the transformation of air pollutants into acids. This leads to a decrease in the pH-value of rainwater and fog from 5.6 to 4 and below. Sulphur dioxide and nitrogen oxide and their respective acids (H₂SO₄ und HNO₃) produce relevant contributions. This damages ecosystems, whereby forest dieback is the most well-known impact.

Acidification has direct and indirect damaging effects (such as nutrients being washed out of soils or an increased solubility of metals into soils). But even buildings and building materials can be damaged. Examples include metals and natural stones which are corroded or disintegrated at an increased rate.

When analyzing acidification, it should be considered that although it is a global problem, the regional effects of acidification can vary. Figure 18: displays the primary impact pathways of acidification.

The Acidification Potential is given in sulphur dioxide equivalents (SO₂-Eq.). The acidification potential is described as the ability of certain substances to build and release H⁺ - ions. Certain emissions can also be considered to have an acidification potential, if the given S-, N- and halogen atoms are set in proportion to the molecular mass of the emission. The reference substance is sulphur dioxide.

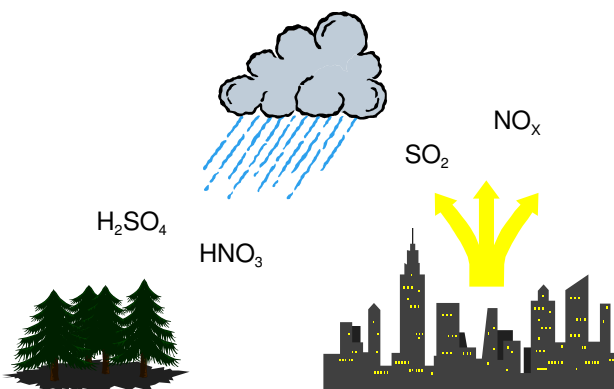


Figure 18: Acidification Potential

Eutrophication Potential (EP)

Eutrophication is the enrichment of nutrients in a certain place. Eutrophication can be aquatic or terrestrial. Air pollutants, waste water and fertilizer in agriculture all contribute to eutrophication.

The result in water is an accelerated algae growth, which in turn, prevents sunlight from reaching the lower depths. This leads to a decrease in photosynthesis and less oxygen production. In addition, oxygen is needed for the decomposition of dead algae. Both effects cause a decreased oxygen concentration in the water, which can eventually lead to fish dying and to anaerobic decomposition (decomposition without the presence of oxygen). Hydrogen sulphide and methane are thereby produced. This can lead, among others, to the destruction of the eco-system.

On eutrophicated soils, an increased susceptibility of plants to diseases and pests is often observed, as is a degradation of plant stability. If the eutrophication level exceeds the amounts of nitrogen necessary for a maximum harvest, it can lead to an enrichment of nitrate. This can cause, by means of leaching, increased nitrate content in groundwater. Nitrate also ends up in drinking water.

Nitrate at low levels is harmless from a toxicological point of view. However, nitrite, a reaction product of nitrate, is toxic to humans. The causes of eutrophication are displayed in Figure 19. The Eutrophication Potential is calculated in phosphate equivalents ($\text{PO}_4\text{-Eq}$). As with acidification potential, it's important to remember that the effects of eutrophication potential differ regionally.

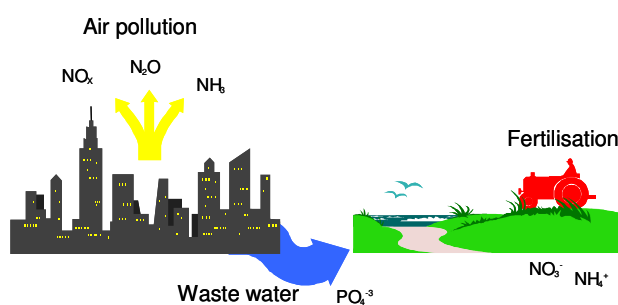


Figure 19: Eutrophication Potential

Photochemical Ozone Creation Potential (POCP)

Despite playing a protective role in the stratosphere, at ground-level ozone is classified as a damaging trace gas. Photochemical ozone production in the troposphere, also known as **summer smog**, is suspected to damage vegetation and material. High concentrations of ozone are toxic to humans.

Radiation from the sun and the presence of nitrogen oxides and hydrocarbons incur complex chemical reactions, producing aggressive reaction products, one of which is ozone. Nitrogen oxides alone do not cause high ozone concentration levels.

Hydrocarbon emissions occur from incomplete combustion, in conjunction with petrol (storage, turnover, refueling etc.) or from solvents. High concentrations of ozone arise when the temperature is high, humidity is low, when air is relatively static and when there are high concentrations of hydrocarbons. Today it is assumed that the existence of NO and CO reduces the accumulated ozone to NO_2 , CO_2 and O_2 . This means, that high

concentrations of ozone do not often occur near hydrocarbon emission sources. Higher ozone concentrations more commonly arise in areas of clean air, such as forests, where there is less NO and CO (Figure 20).

In Life Cycle Assessments, Photochemical Ozone Creation Potential (POCP) is referred to in ethylene-equivalents (C₂H₄-Eq.). When analyzing, it's important to remember that the actual ozone concentration is strongly influenced by the weather and by the characteristics of the local conditions.

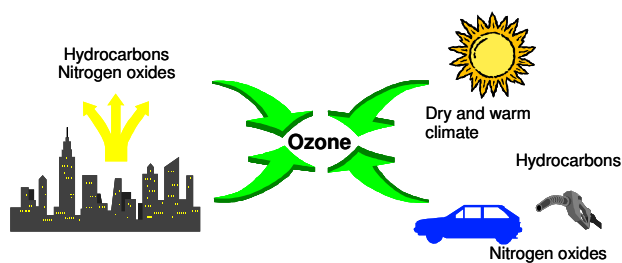


Figure 20: Photochemical Ozone Creation Potential



Appendix B. LIFE CYCLE IMPACT ASSESSMENT RESULTS COMPARISON OF INGEO 2005, 2009, AND TARGET SCENARIOS

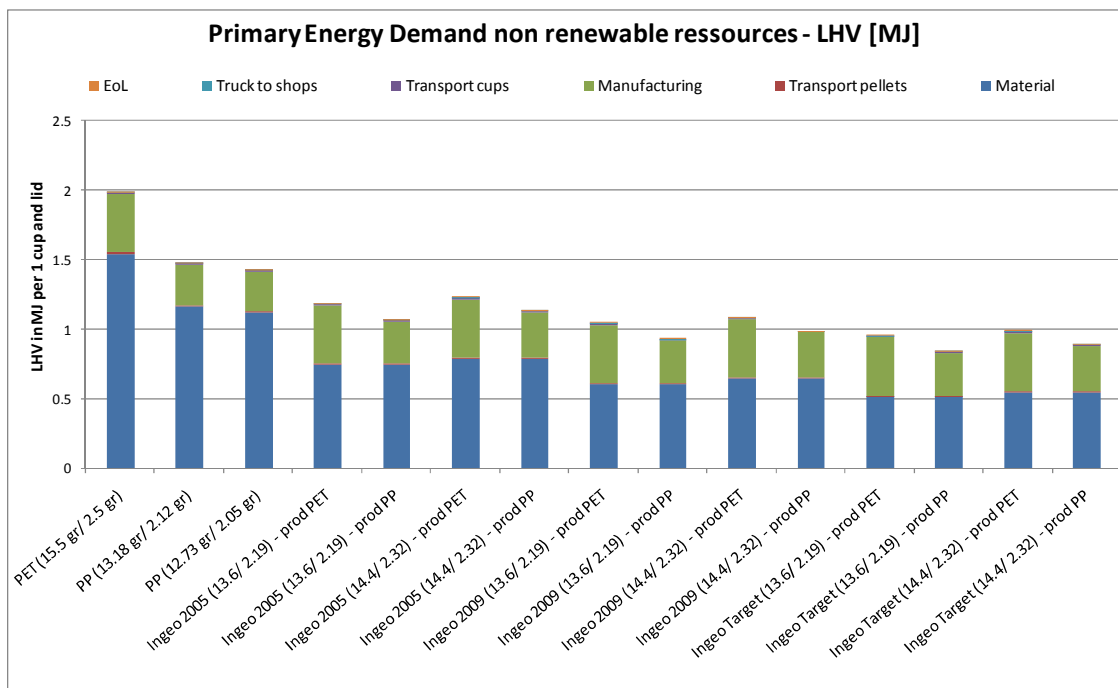


Figure 21. Primary Energy Demand-Non Renewable Resources, Comparison

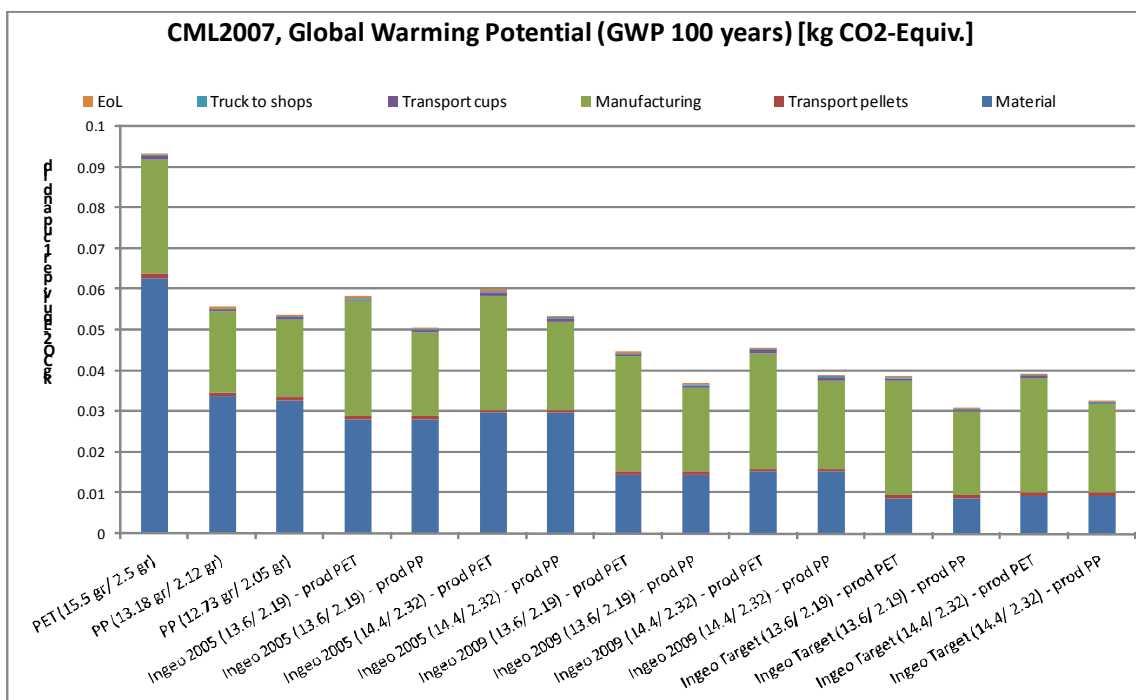


Figure 22. Global Warming Potential, Comparison

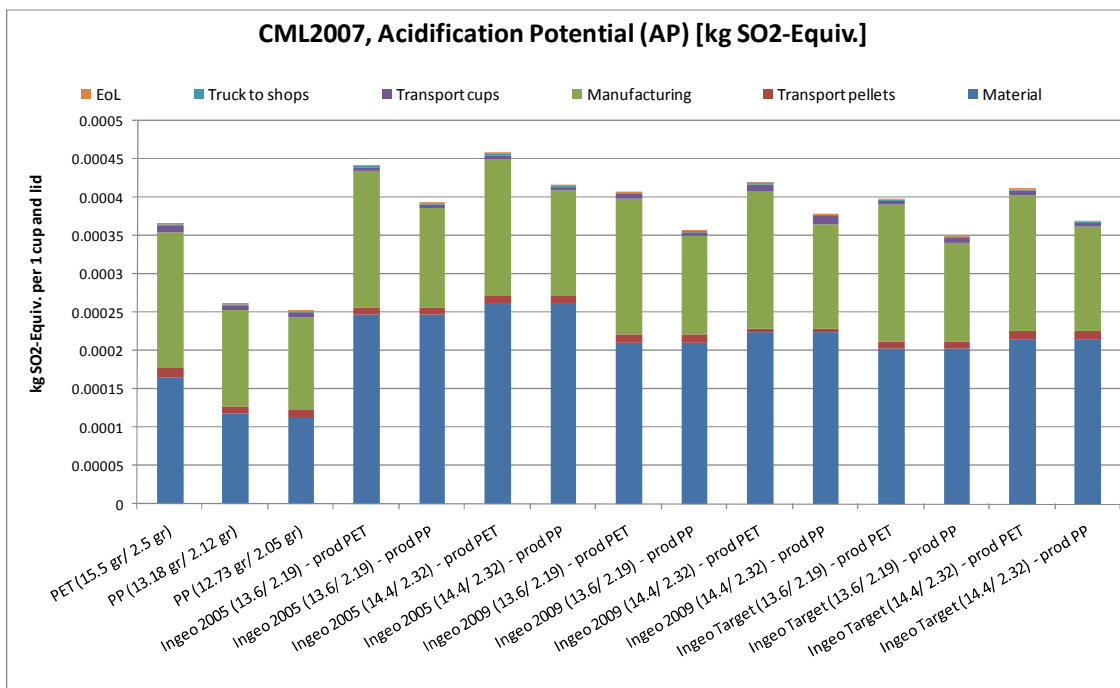


Figure 23. Acidification Potential, Comparison

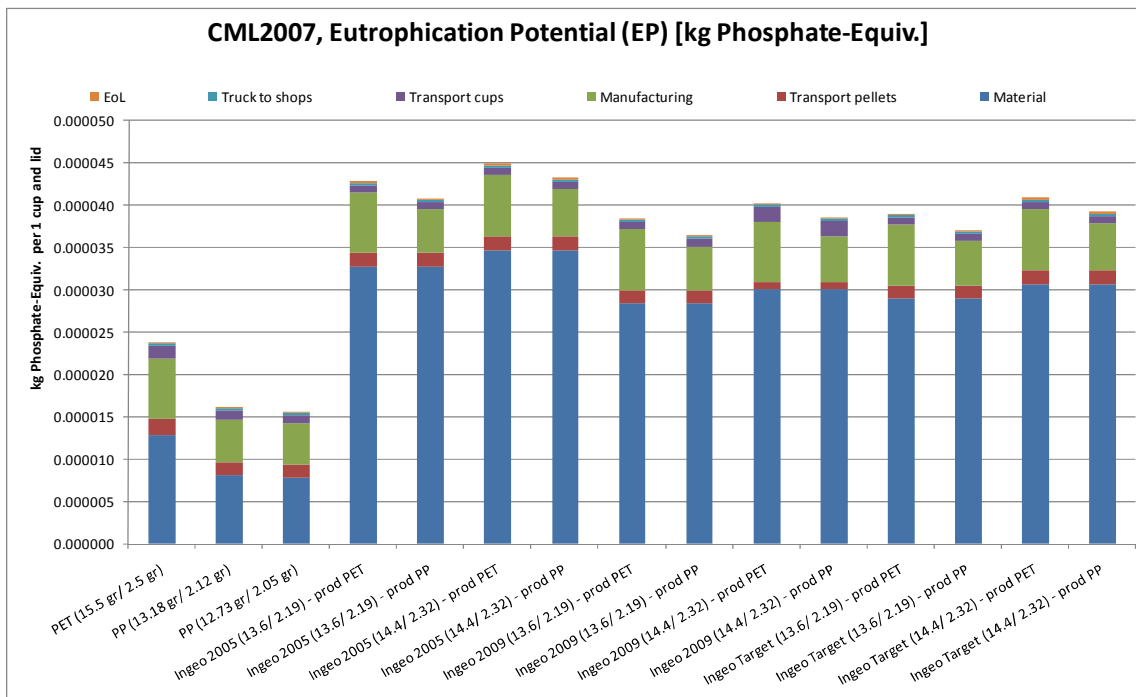


Figure 24. Eutrophication Potential, Comparison

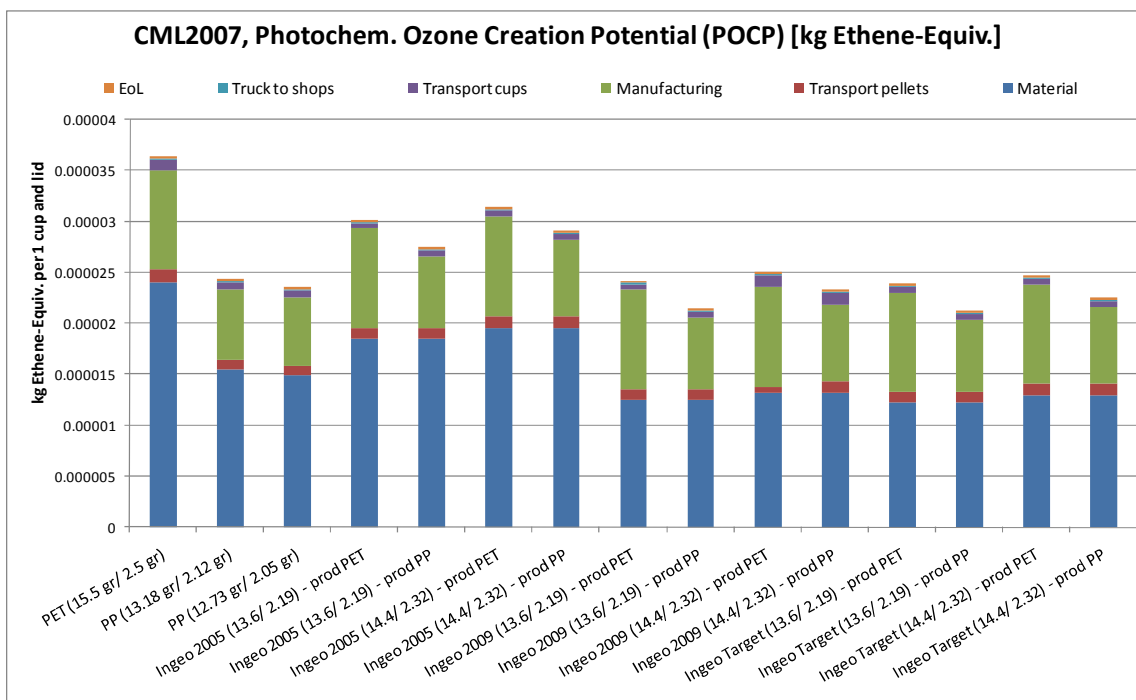


Figure 25. Summer Smog, Comparison

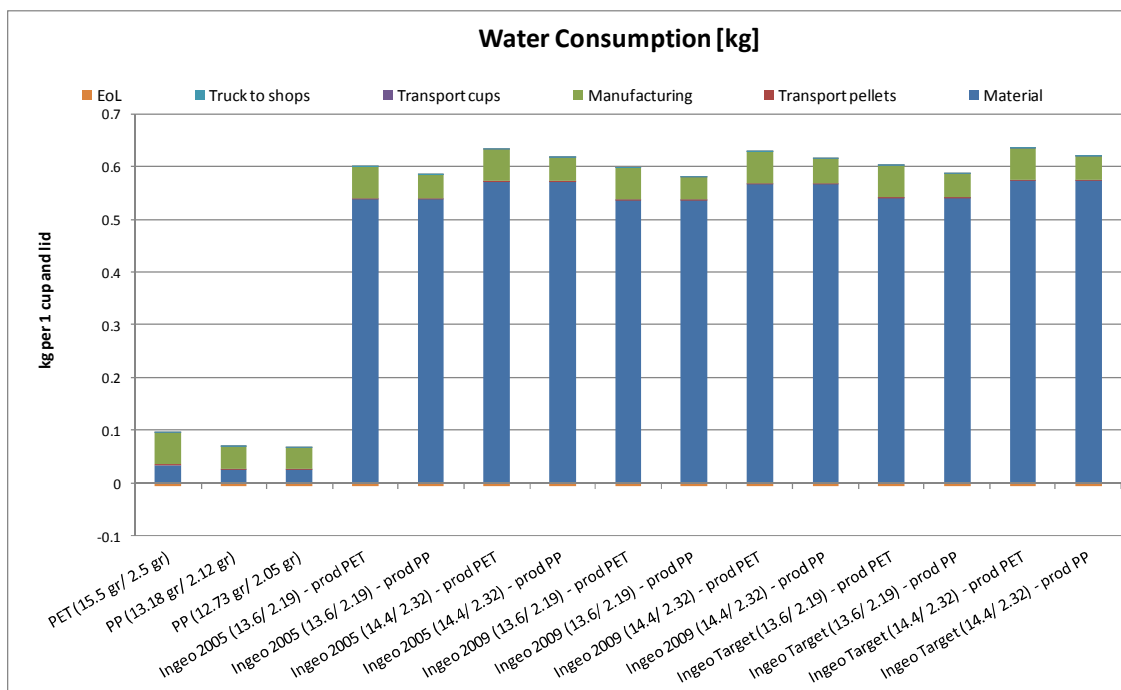


Figure 26. Water Consumption, Comparison



Appendix C. SCENARIOS FOR 1 BILLION CUPS

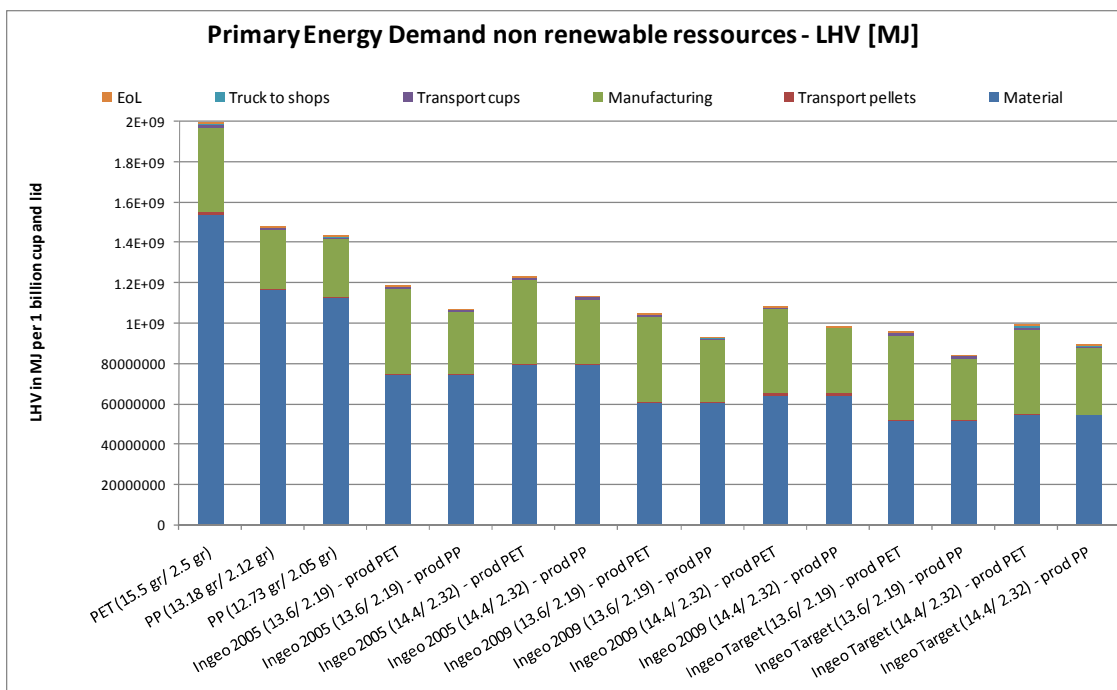


Figure 27. Primary Energy Demand, Non-Renewable Resources (billion cups)

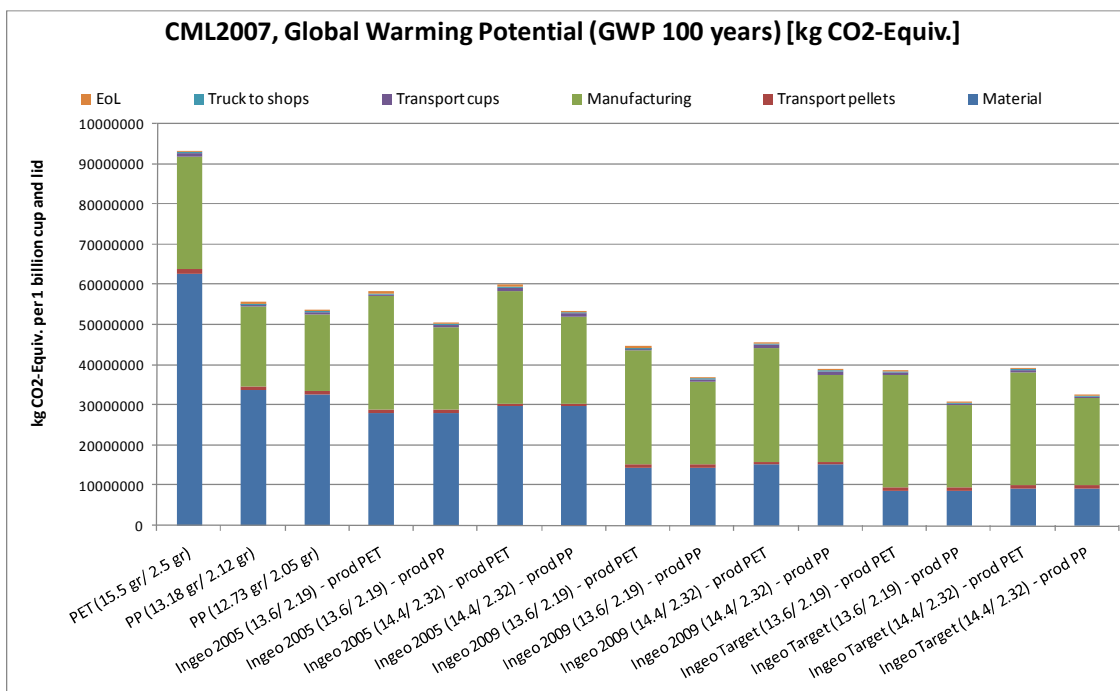


Figure 28. Global Warming Potential (billion cups)

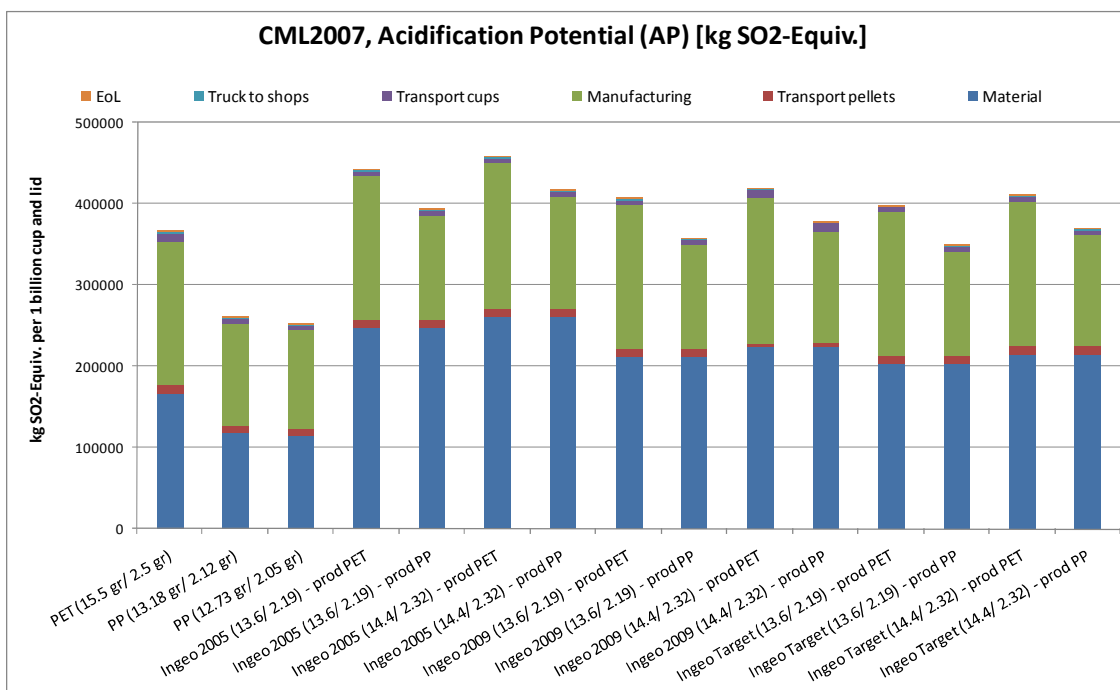


Figure 29. Acidification Potential (billion cups)



Eutrophication Potential

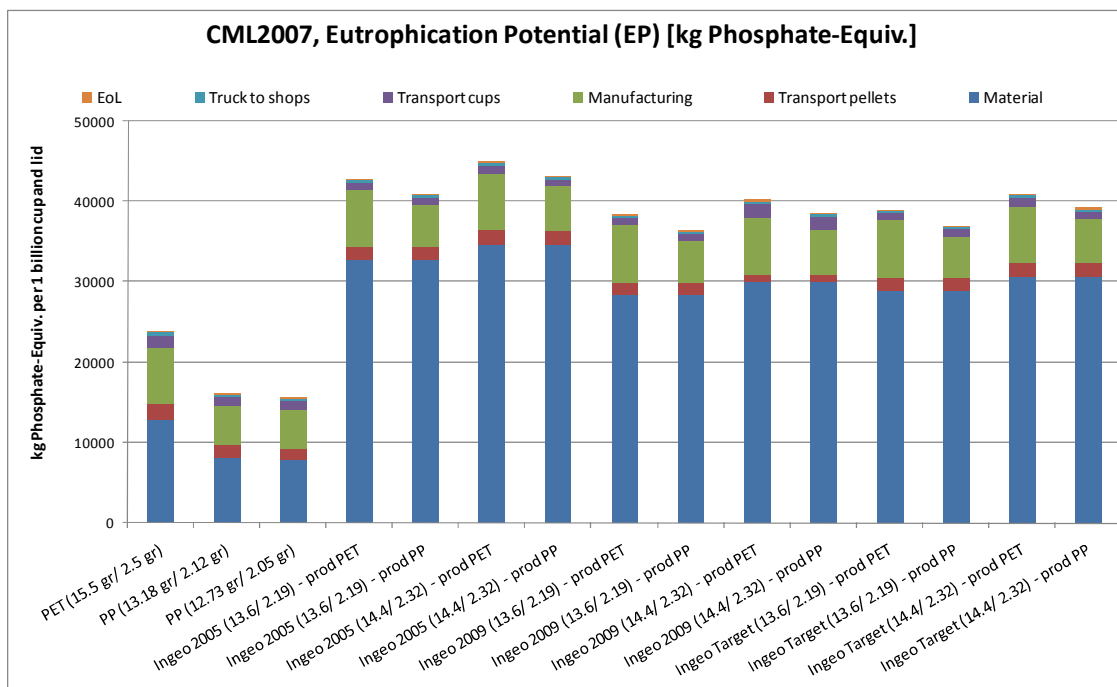


Figure 30. Eutrophication Potential (billion cups)

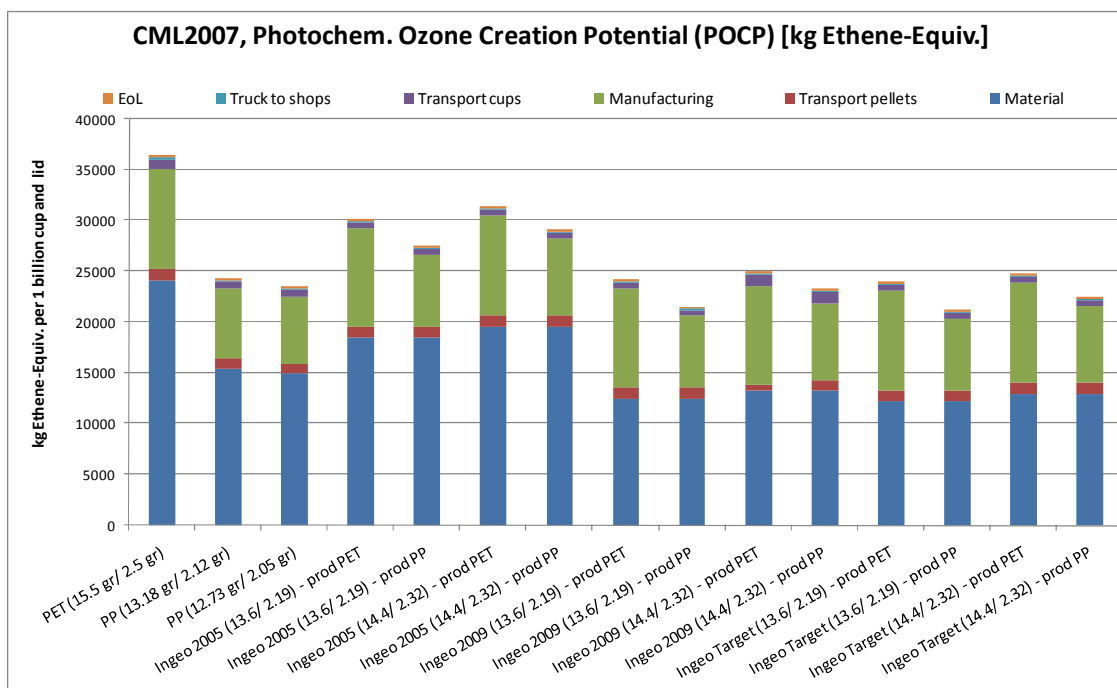


Figure 31. Ozone Creation Potential (billion cups)



Appendix D. COMPOSTING

The current study has been specific to the performance PET, PP, and Ingeo cup & lids systems with a landfill end-of-life. Because Ingeo™ cups are compostable in an industrial compost facility; it is of separate interest to understand how a composting end of life treatment compares with those characterized by LCA in the current study. This appendix provides a general discussion of the type considerations that should be made in future LCA work in this area.

From a conceptual or qualitative perspective, if the system boundaries are defined as the cup in isolation, as in the current work, then for the industrially compostable Ingeo cup, an increase in the indicator global warming potential is only to be expected. This is because the industrial composting of an Ingeo cups involves the aerobic degradation of polylactide to form CO₂ and H₂O, while such an option is not possible for PET or PP cups.

This is clearly confirmed below from a quantitative perspective (Figure 33), in which the PET/PP/Ingeo products of the current study are compared with the current system boundary as defined limited to the cup & lid unit.

A pitfall in drawing conclusions from such an approach is that such a system boundary cannot recognize a primary aim of industrial composting, which is to divert compostable waste stream (garden, horticultural, food, etc.) away from landfill and to reduce the total volume in an environmental and economic efficient way. Industrial composting provides an alternative to putting the compostable waste in landfill, with the related landfill methane generation which results from the subsequent anaerobic degradation process. In an industrial composting facility all the carbon in the waste is converted aerobically in a controlled way into carbon dioxide. The final product of industrial composting is the compost product itself that can be used in a wide range of applications.

Industrially compostable bioplastics foster the diversion of compostable waste from a landfill. For example, for a food waste stream normally contaminated for example, with PET or PP foodservice items, industrial composting requires source separation of the non-compostable packaging from the food waste, which can be impractical). Food waste streams containing industrially compostable plastics however, can readily be composted in their entirety. Such a treatment would be expected to have a significant impact on increasing diversion of food waste from landfill to industrial composting, but it is not possible to visualize this without expanding the boundaries of the total LCA system studied.

Expansion of the LCA system boundaries to quantify impacts on composting rates due to packaging composition is a rich area for future LCA work, and the points below capture some initial consideration on the subject as a starting point for further work.

- For example systems A and B could be defined.



- System A consisting of PET/PP clamshell packaging mixed with food waste which go to landfill. The food waste part is easily degradable and can generate methane, its fate depending on landfill design and operation.
 - System B consists of industrially compostable clamshell packaging mixed with the same food waste which go to composting. Now the industrial compostable cups and the food waste are both converted into CO₂ and compost.
- Under the assumption that System B would increase diversion of food wastes from landfill to industrial composting, the system boundary should be such that there is a rigorous accounting of any environmental impacts associated with the application of finished compost. These could include for example:
 - Maintenance of soil fertility by increasing the soil carbon content and improving the soil structure
 - Reduced soil erosion and runoff emissions
 - Weed suppression and reduces herbicide requirements
 - Reduced irrigation requirement via compost use in landscaping (bicycle paths and parks, etc)
 - Improved water infiltration and water retention resulting in a better and longer accessibility of plants to nutrients (potentially increased fertilizer effectiveness and reduced fertilizer need)
 - In some markets, an alternative for compost is peat, and therefore a credit could be given for the avoided peat production.

Quantitative treatment with system boundary limited to the cup & lid:

As an illustration of the considerations above, the influence of industrially composting Ingeo on the environmental performance of 16-ounce cold drinking cups and lids made from Ingeo has been quantified based on the system boundary of the current study.

Industrial composting is included based on a study commissioned by NatureWorks on composting systems as applied in Germany, see process flow diagram Figure 32.

Information on the following unit processes will be provided for composting:

- Processing/ conditioning (mainly crushing),
- Industrial composting and
- After industrial composting (the final process in the composting).



As indicated in Figure 33 switching to industrial composting from landfilling has little effect on the life cycle environmental impacts of AP, EP and POCP, but as expected, has a significant impact on the life cycle GWP impacts. The impact on GWP is based on the following effects:

- No GHG relevant emissions occur related to Ingeo in landfill as all polymers are considered to be inert material. Therefore the carbon content of the polymers can be considered as sequestered.
- During industrial composting 95% of Ingeo is degraded. 97% of the degraded C is converted into CO₂, 1% into methane and the remaining 2% into TOC. 5% of the carbon stays in the final compost.⁹
- In this analysis, the final product (compost) has not considered of value as a fertilizer and therefore no credits for avoided fertilizer production have been modeled.

⁹ 1% methane value provided by B. de Wilde, Organic waste systems, Belgium, personal communication, September 9 2009.



Appendix E. COMPARISON OF INGEO 2009 SCENARIOS WITH COMPOSTING TO PET AND PP

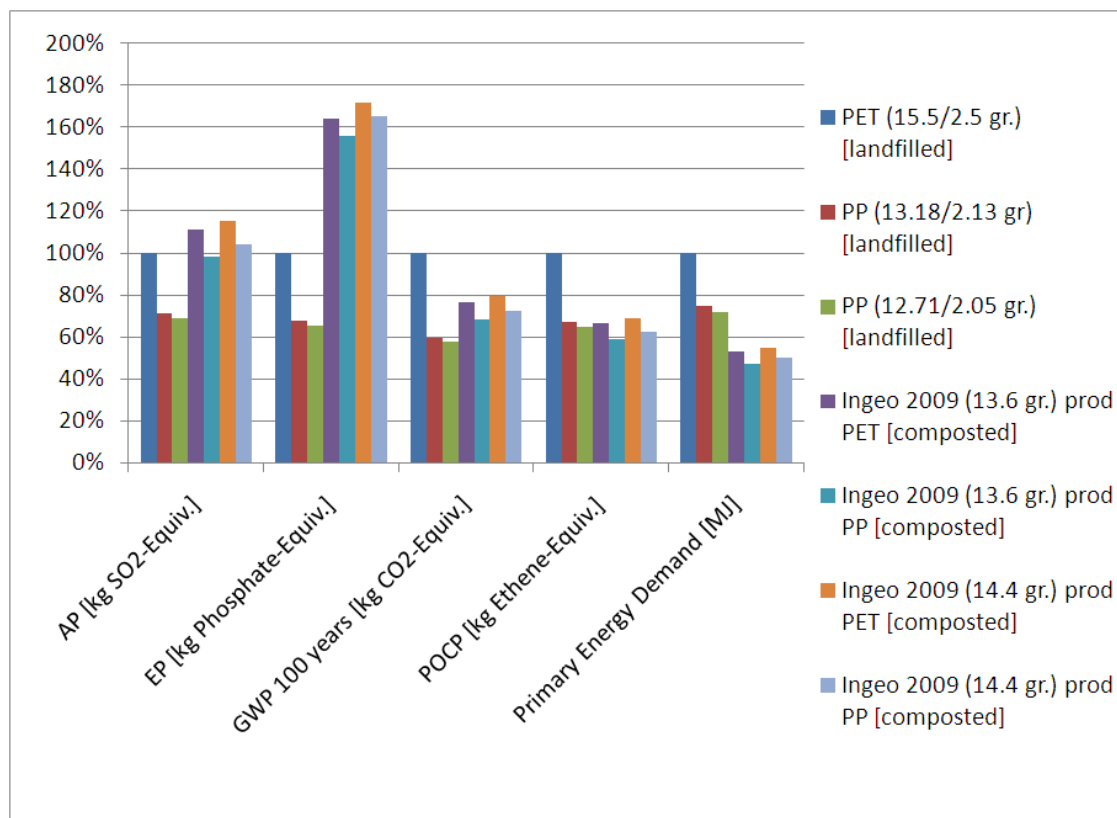


Figure 34: Comparison of Life Cycles across Impacts

Figure 34 shows the relative comparison of the impacts when focusing in the Ingeo 2009, PET and PP scenarios. The current scenario of the use of PET is set to 100% and all other scenarios are being compared to it. The PET and PP scenarios are assumed to be landfilled; the Ingeo 2009 scenarios are assumed to be industrially composted with assumptions around TOC, CH₄ etc., as described above.

As seen in the figure, Ingeo 2009 with industrial composting has lower impacts than PET for Global Warming Potential, Smog Creation, and Primary Non Renewable Energy Demand. The reduction in Global Warming Potential is caused by the lower Primary Non Renewable Energy Demand and the take up of carbon dioxide during corn growing which is finally harnessed into the Ingeo polymer backbone.

Compared to PET, Ingeo 2009 has equivalent emissions for Acidification Potential and much higher releases for Eutrophication Potential.



PP has lower impacts than the PET for all categories except for the Primary Energy Demand. The Global Warming Potential is lower than that of the Ingeo even though the Primary Energy Demand is higher due to the fact that the PP is assumed to be in an inert landfill while the Ingeo is industrially composted and therefore releasing its carbon content.



Appendix F. SCENARIOS FOR TRACI IMPACT ASSESSMENT METHODOLOGY

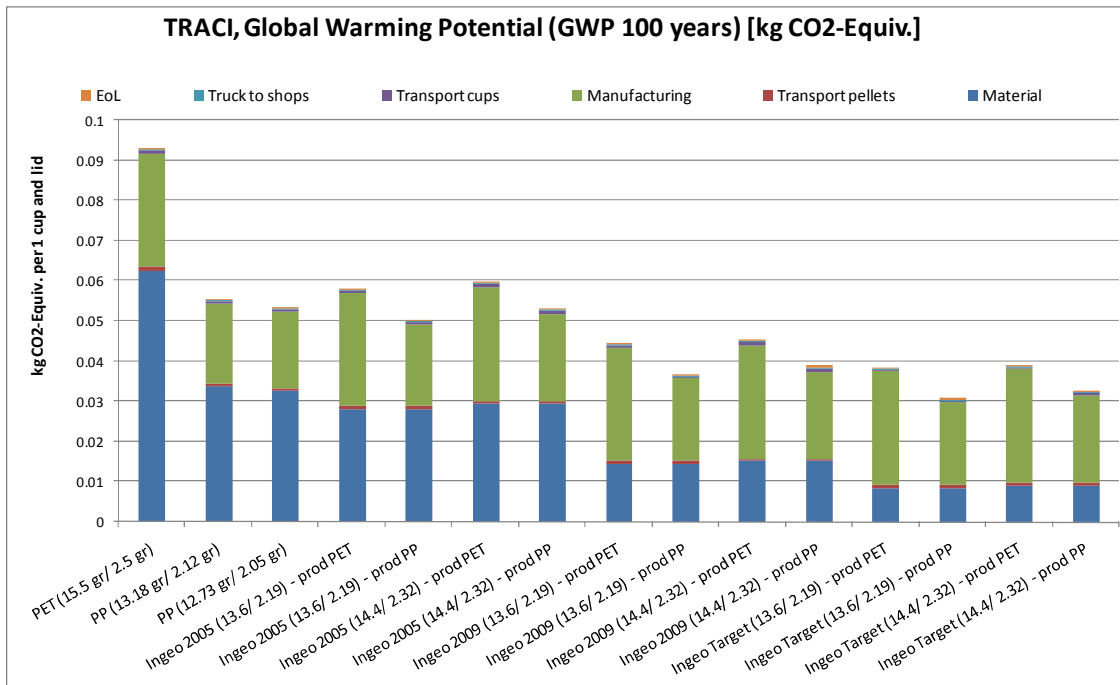


Figure 35. Global Warming Potential (TRACI)

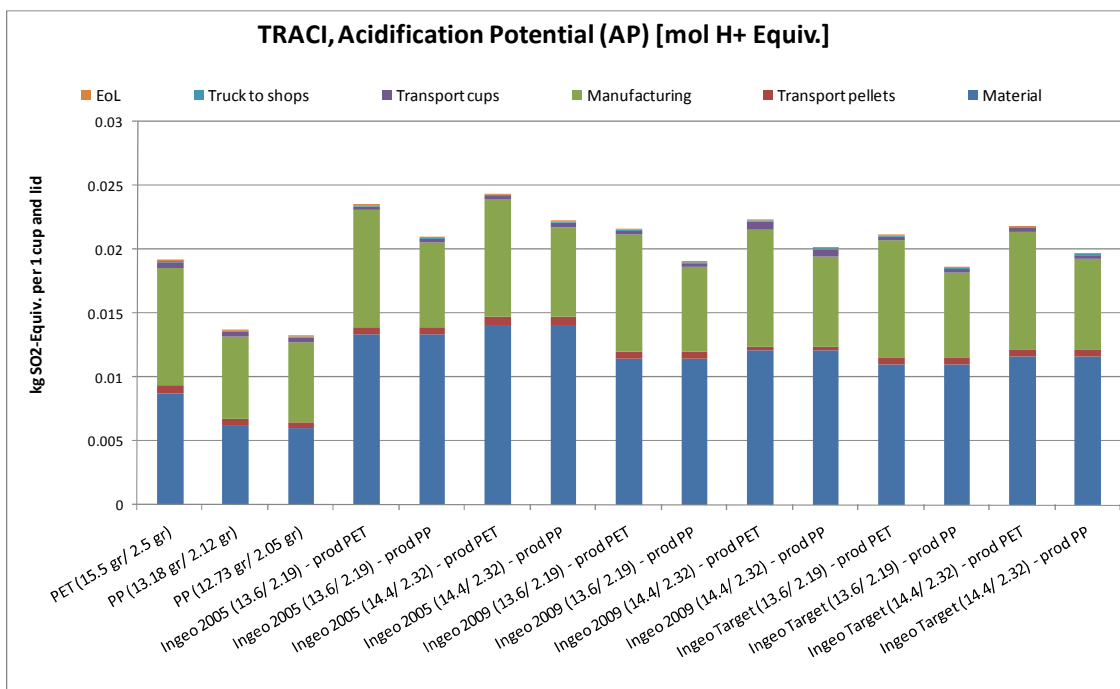


Figure 36. Acidification Potential (TRACI)

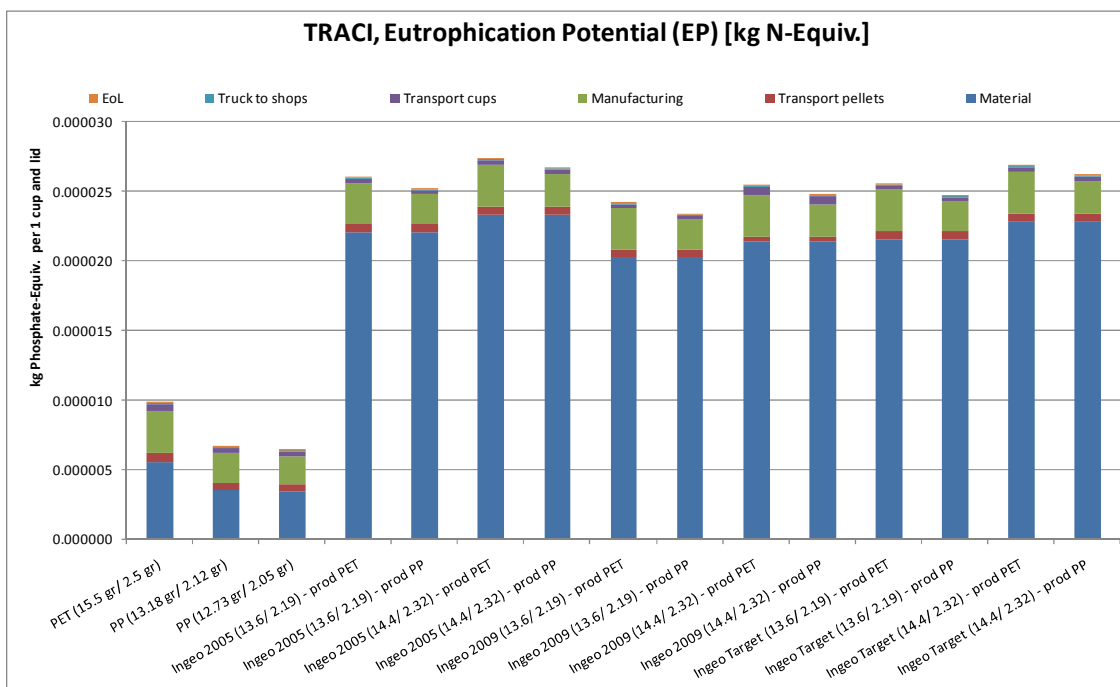


Figure 37. Eutrophication Potential (TRACI)

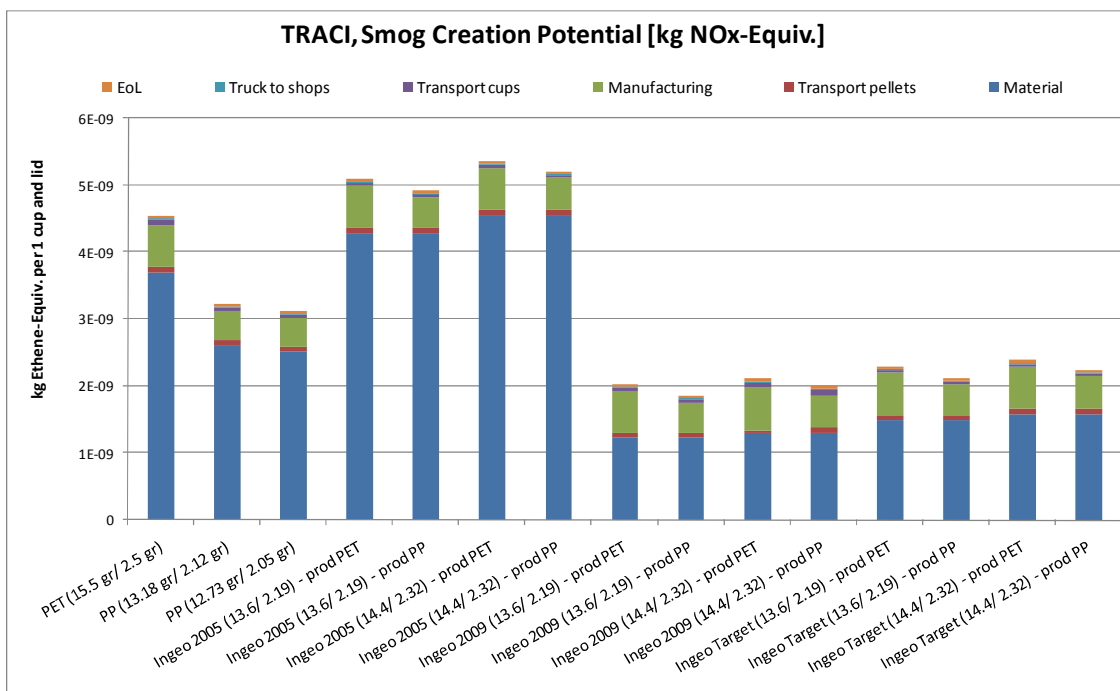


Figure 38. Smog Creation Potential (TRACI)



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CRITICAL REVIEW STATEMENT

Review Team: Comparative LCA of Ingeo™ biopolymer, PET, and PP Drinking Cups

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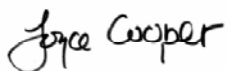
March 8, 2010

RE: Review of *Comparative Life Cycle Assessment Ingeo™ biopolymer, PET, and PP Drinking Cups* for Starbucks Coffee Company (Seattle, WA) & NatureWorks LLC by PE Americas (Boston, MA)

Having reviewed *Comparative Life Cycle Assessment Ingeo™ biopolymer, PET, and PP Drinking Cups* prepared for the Starbucks Coffee Company and NatureWorks by PE Americas, we find that the methodology, the documentation, and the process used are in accordance with the ISO 14040 requirements and provide results ready for public dissemination. This conclusion is the result of a review process which began in August 2008. The review process was iterative, in which the review team was provided preliminary documentation for comment, the review team met (by conference call) with PE Americas staff to discuss the methodology and underlying data, and PE Americas staff in turn responded, resulting in the final LCA documentation. Issues resolved included an update of the PLA production technology data, the consideration and treatment of offsets, and the use of PP as a comparative system.

Please feel free to contact our team with any questions.

Best Regards,



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