Sustainability Opportunities and Challenges of Bioplastics

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2008

Thesis submitted for completion of Master of Strategic Leadership towards Sustainability, Blekinge Institute of Technology, Karlskrona, Sweden.

Abstract: Bioplastics (BPs) can be defined as plastics made of biomass such as corn and sugarcane. These substances have been increasingly spotlighted as means to saving fossil fuels, reducing CO2 emission and plastic wastes. Biodegradability of BPs has been widely publicized in society and the demand for packaging is rapidly increasing among retailers and the food industry at large. However, there is little consensus on actual impacts of BPs production. This thesis therefore aims to identify current strengths and weaknesses and future threats and opportunities and leverage points for the bioplastics industry in a move towards sustainability?"

The Strategic Life Cycle Management (SLCM) and Templates for Sustainable Product Development (TSPD) approaches were used to reveal current ecological and social impacts in relation to Sustainability Principles from the Framework for Strategic Sustainable Development.

Various sustainability challenges and opportunities were identified. Most threats were in agricultural production and in the disposal of products. Compelling measures for the BP industry include: having a consensus in BPs applications based on strategic sustainable development, universal labelling and recycling systems for BPs, government strategic policies to encourage research into new technologies in improving biodegradability and energy efficiency in manufacturing.

Keywords: bioplastics, polylactic acid, life cycle assessment, strategic sustainable development.

Statements of Contribution

This thesis was a fruit of contributions from three of us. Our thesis topic was developed from our interests and groups who were interested in collaborating a thesis with BTH.

During the literature review, we divided the work from based on key member's each background. Eri made a structure of thesis and conducted the main part of the dialogue with Rohm and Haas as she has Chemistry background. As Yan Ye has knowledge in civil engineering and Xiaoxuan has knowledge in marketing, three different backgrounds helped to develop brainstorming to seek the sustainability issues around bioplastics.

Chapter 3 (Results) was written by three of us after the brainstorming. Yan Ye edited from Chapter 1 to 2 and wrote a part of conclusions. Eri wrote most discussion parts and edited from Chapter 3 to 5. Xiaoxuan formatted figures and tables in a whole document. After the final submission, Yan ye and Eri carried out the final edition with the feedback from Henrik.

Karlskrona, June 2008

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Acknowledgements

This project was carried out at the Department of Mechanical Engineering at Blekinge Institute of Technology in Karlskrona, Sweden. Our deepest gratitude goes to our primary advisor Henrik Ny and secondary advisor Fiona Wright, for their constant guidance and valuable support during the whole process of our thesis project.

We would like to express our heartfelt appreciation to the professor Karl-Henrik Robért and Pong Leung, who instructed us by their constructive suggestions and guidance.

This study was conducted by the cooperation with Rohm and Haas. We could like to express our heartfelt gratitude to stakeholders from Rohm and Haas, Muriel Hebrard and Bahar Azimipour, for their contribution during the dialogue process in guiding our project in the right direction.

We would like to thank our shadow group and our peer groups, for their constructive suggestions and guidance. We would also like to share our gratitude with our classmates who help with our thesis edit.

Finally we would like to thank our families, for their support and encouragement.

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Executive Summary

Introduction

Today's world is almost unimaginable without plastics, but most of these materials have historically been derived from oil and face potential problems with increasing fossil fuel costs, potential scarcity and customer demands for alternatives. These concerns have helped generate new research and development of alternative raw materials for use in Bioplastics (BPs).

Bioplastics are plastics that are derived from renewable biomass sources of carbon such as hemp and soy bean oil, corn and potato starch. Sometimes the term BPs also refer to plastic polymers produced by microbes or plastics which are likely to be biodegradable. There are three major ways to synthesis bioplastics, one is "Use of natural polymer", another is "Use of Bacterial Polyester Fermentation", and the last one is "Chemical polymerization"

This thesis focuses on biodegradable plastics, which are plastics that can decompose into carbon dioxide, methane, water, inorganic compounds, or biomass via microbial assimilation (the enzymatic action of microorganisms). Not all BPs are biodegradable and not all biodegradable plastics are BPs. Nevertheless, a number of fossil fuel-based polymers are certified biodegradable and compostable.

Movement towards sustainability of BPs is still slow since there are limits to the applicability of biodegradable plastics. Currently, the production of raw materials for BPs is much smaller than ordinary plastics due to technical issues and very low demand in the marketplace. The raw materials for BPs may come from crop biomass that can face competition pressures from agricultural and biofuels interests. Also, the use of genetically modified bacteria and plants in the production of crops for BPs is controversial, as some believe they may lead to systematic degradation of biodiversity in ecosystems in the future. These considerations make it difficult to claim that BPs are 'truly' sustainable products.

There are a couple of barriers that must be overcome to make the lifecycles of BPs more sustainable.

To strike a balance between the interests of Rohm and Haas and Blekinge Institute of Technology, this project aims to identify current strengths and barriers and potential responses in terms of regulatory, market and technological considerations from a strategic sustainable development point of view. This led to the following research questions:

Research Questions

What are some current strengths and weaknesses, future threats and opportunities and leverage points for the bioplastics industry in a move towards sustainability?

This overarching question is informed by answering the following sub-questions:

Primarily, what are some current bioplastics market, regulation and technology strengths and weaknesses in relation to sustainability?

Secondarily, what could bioplastics look like in a future sustainable society?

And thirdly, what are some leverage points that could help move the bioplastics industry towards sustainability?

Methods

The main methods used to answer the research questions are Strategic Life Cycle Management and Templates for Sustainable Product Development. These methods are based on a Framework for Strategic Sustainable Development (FSSD) and ABCD planning.

The FSSD is a structure that facilitates effective planning in complex systems and ABCD planning is a step by step application of the FSSD using backcasting from sustainability principles, which assists in dealing with problems strategically rather than one by one as they appear. Backcasting is the approach where a successful outcome is imagined first and only thereafter followed by a plan of action of how to get there from today.

Four sustainability principles are defined by The FSSD as:

In a sustainable society, nature is *not* subject to systematically increasing…

1 …concentrations of substances extracted from the Earth's crust, (e.g. Use of fossil fuels for production and transportation)

2 …concentrations of substances produced by society, (e.g. Use of chemicals as additives)

3 …degradation by physical means, (e.g. the previously mentioned degradation of biodiversity through GMO cultivation)

and, in that society. . .

4 … people are *not* subject to conditions that systematically undermine their capacity to meet their needs. (E.g. Potential occupational health and safety issues)

In our selection of research methods we also explored the combination of traditional and non-traditional scientific approaches. Traditional Life Cycle Assessment (LCA) is a tool that evaluates impacts of a product throughout its life cycle, from product design to end use, or "cradle to grave."

Strategic Life Cycle Management is based on LCA, however has incorporated FSSD by including backcasting from sustainability principles. This allows for an analysis of the industry from a bird's eye perspective, capturing broadly the industry's sustainability opportunities and challenges for each main step of its life-cycle. Establishing this initial broad perspective provided a sustainability direction at the outset, from which a traditional LCA can later proceed.

The approach called Templates for Sustainable Product Development (TSPD) is designed to generate a faster and more complete overview of the major sustainability challenges and potential solutions. It is initiated by experts, giving a quick overview of the sustainability performance of a given product category to top management and product development teams to support their decision making. The template approach was first introduced to a case study of Matsushita electronics group (Ny et al 2008). However, it can be readily applied to other product categories since the context of templates are based on generally applicable sustainability principles. Thereby, TSPD can suggest how organizations can plan and act to make society sustainable.

Results

The thesis research questions were answered by looking at the current state of the BPs industry through the lense of the four sustainability principles. The research identified both strengths and gaps in relation to sustainability:

Sustainability Principles 1

Gaps: Large inputs of fossil fuels throughout the lifecycle of BPs are employed by the industry, which is the main activity contributing to increasing concentrations of substances extracted from the earth's crust, which also contributes to greenhouse gas emissions.

Strengths: The potential "carbon neutral" feature of BPs products that could help to conserve the depleting oil reserves.

Sustainability Principles 2

Gaps: Persistent pesticides and other agrochemicals are routinely dispersed into the ecosphere during feedstock production. Genetically modified organisms (GMOs) may also increase concentrations of substances produced by society. While they are still of major concern, some feedstock production practices have already been undertaken to reduce or eliminate GMOs. This includes the use of biological control of pests and insects.

Strengths: BPs waste helps control the amount of carbon dioxide emissions, and it has great potential as a material with low environmental burden for contributing to the prevention of global warming

Sustainability Principles 3

Gaps: Poor agricultural practices, and other degradation to nature by physical means. These activities, and the resulting concern for decreasing biodiversity and local water quality, characterize the industry.

Strengths: Bioplastics can be composted locally into the soil amendment and can be fully biodegradable (capable of being utilized by living matter).

Sustainability Principles 4

Gaps: Child labour and inadequate employment and farm incomes within the industry have undermined people's ability to meet their basic human needs. In the future this could also include the competition of land for food versus energy production, as human populations increase.

Strengths: Bioplastics products can contribute to healthier rural economies and create new job opportunities.

This broad overview, as seen through the four system conditions, provides the main sustainability challenges of the industry today. The overwhelming impact of BP production for both countries was found in feedstock production, or manufacturing processes.

It is important to ensure safe and stable renewable feedstock as a foundation of BP production. To move towards sustainable BP, four leverage points were suggested below.

- Introduction to new technologies in use of biomass alternative
- Development of additives to improve biodegradability
- Design for minimum number of different material types
- Design for handling by small scale, locally managed composting and recycling systems

Conclusions and Further Work

The research conducted by the authors indicates a potential for BPs to be more sustainable in the future by implementing sustainability strategies. For example, improving technology to extend the life span of BP products and creating new additives to make BPs degrade completely. Before undertaking these measurements, the BP industry needs to have a consensus of sustainability based on backcasting from the sustainable principles. By doing so, the BP industry will be able to identify suitable approaches to ensure that the new products are sustainable and meets market needs.

List of Acronyms

BP	BioPlastics
CA	Cellulose Acetate
No	Nobelium
SPs	Sustainability Principles
PLA	Polylactic acid
PGA	Polyglycolic acid
PET	polyethylene terephthalate
PHA	Polyhydroxyalkanoate
PHB	Polyhydroxybutyrate
PBS	Polybutylenexacinate
PCB	Polychlorinated Biphenyls
BTH	Blekinge Tekniska Högskola (Blekinge Institute of Technology)
FAO	Food and Agriculture Organization
TNS	The Natural Step
GHG	Green House Gases
PVC	Polyvinyl Chloride
CRP	Conservation Reserve Program
LCA	Life cycle Assessment
LCM	Life Cycle Management
R & H	Rohm and Haas
ICI	Imperial Chemical Industries
ISO	International Organization for Standardization
SLCM	Strategic Life Cycle Management
TSPD	Templates for Sustainable Product Development

FSSD Framework for Strategic Sustainability Development

SLCA Sustainability Life Cycle Assessment

JORA Japan Organic Recycling Association

SWOT Strengths, Weaknesses, Opportunities and Threats

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1 Introduction

The industrialization in the late 18th Century changed people's lives dramatically. Countless new technologies requiring fossil fuels made it possible to create new transportations, new industries and a large scale food production. It caused rapid increase in global population and wealth but negatively impacted on the ecosystems. We are now facing serious environmental issues such as global warming, pollutions and a shortage of natural resources as a result of this industrialization.

Today's world is almost unimaginable without plastics, but most of these materials have historically been derived from oil and face potential problems with increasing fossil fuel costs, potential scarcity and customer demands for alternatives. These concerns have helped generate new research and development of alternative raw materials for use in bioplastics (BP).

1.1 Description of Bioplastics

1.1.1 Bioplastics

Bioplastics normally refer to two categories of plastics. The first category is plastics derived from renewable biomass sources of carbon (as opposed to fossil fuels), such as hemp and soy bean oil, corn and potato starch, cellulose or molecules produced by microbes. Second, biodegradable plastics made of biomass or fossil fuels (European bioplastics 2007). These BPs are produced in three major ways. An overview of bioplastics and biodegradable plastics is given below (Table 1.1).

1.1.2 Biodegradable plastics

Biodegradable plastics are plastics that can decompose into carbon dioxide, methane, water, inorganic compounds, or biomass via microbial assimilation (the enzymatic action of microorganisms) in a compost facility. Polylacticacid (PLA) plastics have been successfully commercialized and applied most in many different fields.

Not all biodegradable plastics are made of biomass. A number of fossil fuel-based polymers such as Polybutylenexacinate (PBS) and Polyglycolic acid (PGA) are certified biodegradable and compostable (Bioplastics supply chains 2004).

Table 1.1 The types of bioplastic by production process. Bioplastics in the bold enclosure show biomass plastics. Others are made of petroleum but biodegradable.

Type of polymer production	Name of bioplastics
Use of natural polymer	Cellulose Acetate (CA), Starch polymer
Use of Bacterial Polyester Fermentation	Polyhydroxyalkanoate(PHA) Polyhydroxybutyrate (PHB)
Chemical polymerization	Polylacticacid (PLA)
	Polybutylene succinate (PBS) Aliphatic polymers e.g. Polyglycolic acid(PGA) Aliphatic-aromatic-copolymers e.g. Polycaprolactone (PCL)

1.1.3 Traditional (conventional) plastics

Traditional (conventional) plastics are derived from fossil fuels or non-renewable carbon. About 4% of annual consumption of oil and gas in the world are used to produce plastics (Plastics Europe 2008). Although fossil fuels have their origin in ancient biomass, they are not considered biomass by the generally accepted definition because they contain carbon that has been "out" of the carbon cycle for a very long time. Therefore their combustion therefore disturbs the carbon dioxide content in the atmosphere.

1.1.4 Bioplastics compared to conventional plastics

Biomass materials are derived from recently living organisms. This includes plants, animals and their by-products. Manure, garden waste and crop residues are all sources of biomass. The use of biomass fuels can therefore contribute to waste management as well as fuel security and help to prevent climate change, though alone they are not a comprehensive solution to these problems.

Bioplastics differ from traditional plastics. Bioplastics carbon is derived 100% from renewable biomass material resources. However, manufacturing of bioplastic materials is often still reliant upon petroleum as an energy and materials source (Sustainable Biomaterials Collaborative 2007).

1.2 Advantages of Bioplastics

Introduction of BPs has been promoted among developed countries for the following three major reasons:

- Waste management benefits of biodegradable bioplastics

Bioplastics packaging has been successfully introduced by supermarket chains, in food service sectors and in the agricultural industry in an effort to reduce the amount of plastic wastes produced by society. Biodegradable plastics make organic waste management easier. For example, catering companies, which produce large amount of waste including the disposal of plastic tableware, have started to use biodegradable cutlery. This has led to greater composting rates and a decrease in the amount of trash that is collected and sent to a landfill (Innocenti et al. 2007). Landfills are generally sealed with clay which means little biodegradation occurs below the surface, so what is thrown away may not degrade for a long time. However, it is still environmentally better than ordinary plastics, as eventually the BPs will still biodegrade. Also, emissions from the incineration of ordinary plastics (under poor conditions or non-optimized incineration process) have a high risk of containing substances such as dioxin or trace metals (Sato et al 2005).

- Carbon neutrality of bioplastics

Bioplastics have increasingly come into the limelight as a solution to help reduce society's overall carbon dioxide (CO_2) emissions, as global warming has become a serious concern. While the production of ordinary plastics requires a net introduction of carbon into the ecosphere, the CO2 released by BPs originally come from biomass, and is therefore potentially carbon neutral in its lifecycle. Bioplastics processing might still run on fossil fuels even though the BPs feedstock might be carbon-neutral.

- Less energy consumption (less petroleum dependence)

Potential petroleum shortages have become a serious concern. Bioplastics production requires less fossil fuel consumption than that of ordinary plastics. Life Cycle Assessment of Polylactic Acid multilayer films showed that its environment impact was almost half that of petroleum-based films (Garrain et al. 2007).

1.3 Sustainability and sustainable development

Sustainability could be defined as a future state when society is no longer systematically destroying the ecological and social structures it is dependent upon for its long term survival. Sustainable development would then involve such development processes that take society closer to sustainability.

The Natural Step is an international non-governmental organization based in Stockholm, Sweden, that promotes the pursuits of sustainable development in a society through the use of a Framework for Strategic Sustainable Develeopment (FSSD) (e.g. Holmberg and Robert 2000, Robèrt 2000, Robèrt et al 2002) (see section 2.1). This framework is built around a planning process with backcasting from four sustainability principles.

1.4 Sustainability and chemical industry

Conventional plastic is one of the most resource-efficient materials around (Plastics Europe 2008). It has been applied in many different products and services to add convenience to your daily lives. The chemical industry, however, has often become a target to be criticized by environment conservation organizations since their activities have negative impacts on ecosystems in the forms of excess waste, and production and potential release of hazardous substances (e.g. dioxin) and green house gases (GHG) in combustion.

The chemical industry needs a strategy to address the environmental issues related to their products and manufacturing processes. For example, Hydro Polymers, a UK based manufacturer of polyvinyl chloride (PVC) was the first chemical company to work closely with The Natural Step (TNS) to move systematically towards sustainability. As a result, Hydro Polymers took an initiative to also start dialogues with its suppliers, customers and the industry at large on how to make PVC and chemicals in general more sustainable (Leadbitter 2002). After the successful start by Hydro Polymers, Imperial Chemical Industries (ICI) has also started to assess the sustainability performance of their products, using a Sustainability Life Cycle Assessment (SLCA) tool (ICI 2007). This tool is based on Strategic Life Cycle Management theory (Ny et al 2006) and the FSSD.

1.5 Global market situation of bioplastics

Even though 245 million tones of conventional plastics was globally produced in 2006 (Plastic Europe 2008), Bioplastics markets are very small (see figure 1.1). The BPs market was less than 1% in Europe and 0.1% in Japan of the entire plastics markets (EBA 2006: Ogawa 2006). Bioplastics is still a very promising innovation for both industry and the economy. According to a survey conducted by European Bioplastics Association (2006), their member industries experienced an increase in demand for BPs in Europe that ranged from a few percent to 20% when compared to the previous year. Major retailers and supermarket chain stores in Europe such as Delhaize and Auchan have introduced bioplastic packaging products for their products. Moreover, since the price of petroleum has rapidly increased lately, there is an expected 20% minimum increase in the world market in 2008 (Helmut Kaiser Consultancy 2008).

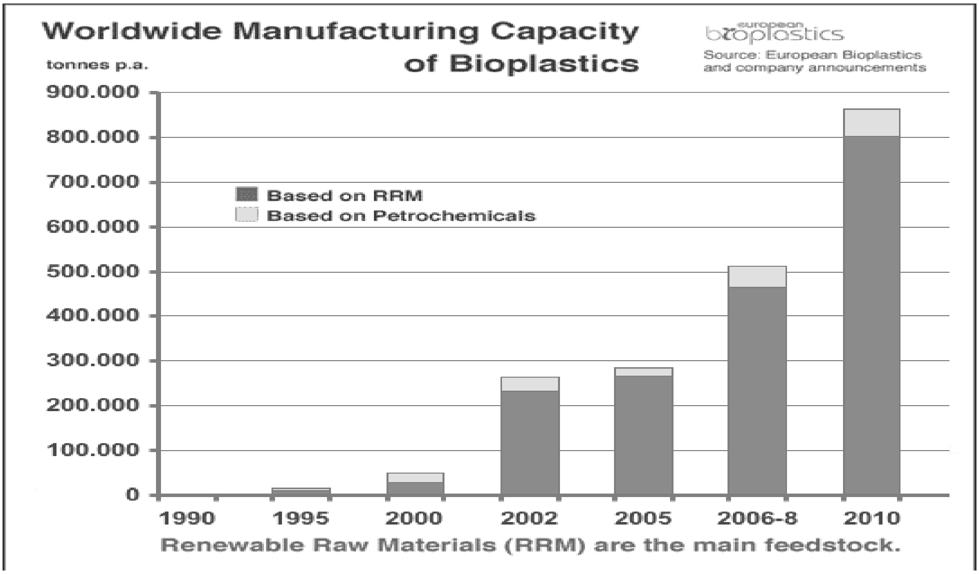

Figure1.1: Global production capacity of biodegradable bioplastics

(Source: European Bioplastics 2007)

To protect consumers from false and misleading advertising of BP products, the standards or requirements for BP have been promoted through BP labelling systems created by industrial associations and governments. However, consumers still have low awareness of BP and often do not understand its role in society (Green Consumer Tokyo network 2003). Therefore there is an urgent need of sustainability assessments for BP.

1.6 Research Background, Aim and Questions

1.6.1 Research background

As a leader in the worldwide chemical industry, Rohm and Haas is internationally recognized for their commitment to developing innovative, sustainable technologies for use across a wide range of industries. For example, they have already used the previously mentioned "Sustainability Life Cycle Assessment" (SLCA) to assess the sustainability of some their products. Hydro Polymers and Rohm and Haas have used this tool to study life-cycle activities in their supply chains. Rohm and Haas is interested in making more sustainable additives for BPs in the future. They are particularly interested in understanding sustainability issues around BPs related to the BPs market and product development of BPs additives.

1.6.2 Aim and questions

To strike a balance between the interests of Rohm and Haas and Blekinge Institute of Technology, this project aims to identify current strengths and barriers and potential responses to the following questions in term of regulatory, market and technological considerations from a strategic sustainable development point of view. To understand current situation, the following questions have been prepared:

What are the current strengths and weaknesses and future threats, opportunities and leverage points for the bioplastics industry in a move towards sustainability?

This question is informed by answering the following sub-questions:

1) What are some current BP market, regulation and technology strengths and weakness in relation to sustainability?

2) What could bioplastics look like in a future sustainable society?

3) What are some leverage points that could help move the BPs industry towards sustainability?

This information will help inform the steps that Rohm and Haas can implement to help ensure that the new product is sustainable and meets the future market needs. In addition, this study will hopefully help to give some ideas about sustainability issues related to BP production.

1.7 Limitations of study

Each type of plastic has unique properties and goes through different manufacturing processes. Products types also vary and the required additives and sub materials that are needed in the production process. Despite PLA is the most successful and commercialized plastic among BPs, its demand is still increasing in the growing BP market. Rohm and Haas is also interested in developing PLA additives. Therefore this study particularly focused on PLA plastics production process and assessed its sustainability performance.

2 Methods

The main methods used to answer the research questions are Strategic Life Cycle Management and Templates for Sustainable Product Development. These methods are based on the Framework for Strategic Sustainable Development (FSSD), its sustainability principles and ABCD planning process. This process is also called backcasting from sustainability principles (Robèrt et al 2002).

In the first stage of the research, Strategic life cycle management (SLCM) integrates an overview life cycle assessment of BPs with the sustainability principles of the FSSD. During the second period of the research, data and information collected by FSSD are presented to Rohm and Haas through templates which mainly focus on B-step and C-step of ABCD planning for BPs.

2.1 Backcasting from sustainability principles

Backcasting from sustainability principles is a systematic approach where a successful outcome is imagined followed by the question “what shall we do today to get there?" It is a normative view of strategic planning that acknowledges and embraces the inclusion of values in the creation of desirable future vision, within the basic constraints of the four sustainability Principles (Robèrt 2000; Robèrt et al. 2002).

The international non-governmental organization, The Natural Step (TNS), developed and tested this approach to help organizations incorporate SSD into their operations.

Box 2.1 The Natural Step Sustainability Principles:

Basic Principles for Sustainability
In a sustainable society, nature is not subject to systematically increasing…   1 …concentrations of substances extracted from the Earth's crust,   2 …concentrations of substances produced by society,   3 …degradation by physical means, and, in that society. . .   4 …people are not subject to conditions that systematically undermine their capacity to meet their needs.

The four sustainability principles were designed to fit a set of strict criteria including that they should (Holmberg and Robèrt 2000):

(a) Be based on a scientific world view,
(b) Describe what is necessary to achieve sustainability,
(c) Be sufficient to cover all relevant aspects of sustainability
(d) Be generally applicable in different organisations and planning contexts
(e) Not overlap to allow comprehension and develop indicators for the monitoring of transitions and
(f) Be concrete enough to guide problem analysis and decision making.

2.1.1 Framework for Strategic Sustainable Development (FSSD)

The framework (table 2.1) for strategic sustainable development has been built around backcasting from sustainability principles .The purpose of applying the Five Level Framework for sustainable development (FSSD) is to bring clarity, rigor and insight to planning and decision-making towards the sustainable goal. Two key elements include: the establishment of basic principles (or 'system conditions') for sustainable society in the biosphere (which provides a principle-level definition of 'success') and the development of strategic guidelines to guide efforts towards success by informing the selection of various actions and tools. This framework also helps how organizations can plan and drive a society towards that future goal while avoiding financial risk related with unsustainable practices and seeking new business opportunities.

Table 2.1 "Framework for Strategic Sustainable Development" (Robèrt 2000 and Robèrt et al 2002)

Framework for Strategic Sustainable Development	
System Level	Organization or activity within society within biosphere
Success Level	(i) Meeting organizational vision or activity-specific goals in a way that (ii) Eliminates organizational contribution to violations of Sustainability Principles.
Strategy Level	- Backcasting from (i) within constraints of (ii), (listed above). - 3 prioritization questions for sustainability: Does this measure proceed in the right direction with respect to all principles of sustainability? Does this measure provide a stepping-stone for future improvement? Is this measure likely to provide a sufficient return on investment to future catalyze the process? - Other guidelines or strategic principles to achieve organizational or activity specific goals.
Actions Level	The actions that help move the Topic (e.g. organization) towards compliance with success AND global sustainability
Tools Level	The tools that help move the organization or activity towards compliance with stated goals AND global sustainability

2.1.2 The ABCD Planning Process

The ABCD process is a strategic tool for backcasting from basic principles for sustainability designed to trigger creativity and to act as a checklist for the planning process. The four-step ABCD process helps an organization to draw its own conclusions from SPs as regards problems, solutions and goals. Thus, it can serve as a tool for learning, analyses, creation of vision, design of programs, and leadership (Holmberg and Robert 2000).

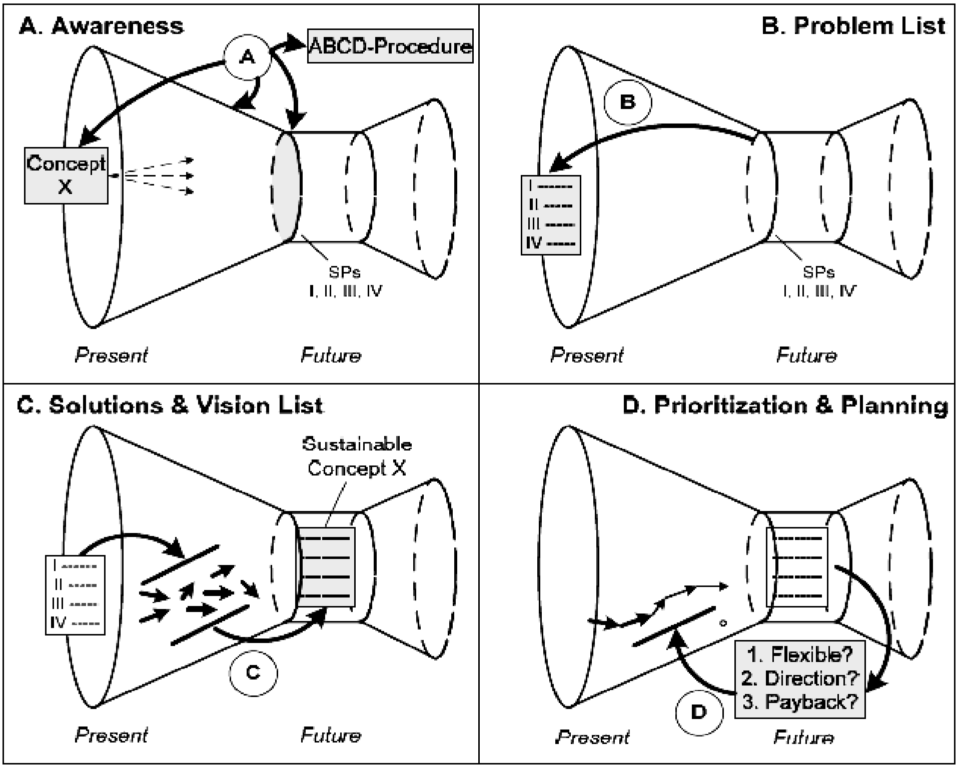

Figure 2.1 The ABCD Procedure of Backcasting from Sustainability Principles (reproduced from Ny et al 2006)

A – Awareness: Sharing a common understanding of sustainability and determining its the 'whole-systems' context.
B - Baseline Mapping: What does society or organization look like today? Understanding current reality of the major flows and impacts of the organization related to sustainability.
C - Creating a Vision: What does your organization look like in a sustainable society? Working together to create a compelling long-term vision for a sustainable enterprise.
D - Down to Action: Supporting the execution of specific initiatives by providing appropriate training, techniques, and tools for implementation (Ny et al 2006).

2.1.3 The SWOT assessment

Strengths, Weakness, Opportunities and Threats (SWOT) assessment was undertaken to analyze the current reality (B step). This is a way to identify the most important considerations for both exterior world and interior (operational) world to achieve the vision. This analysis of current reality gives a summary of the organization's most important threats and opportunities (external world) and the strengths and weaknesses within the organization (internal world).

2.2 Strategic Life Cycle Management

2.2.1 Overview of SLCM

Strategic life cycle management (SLCM) is an approach which integrates an overview life cycle assessment with the sustainability principles of the FSSD. SLCM aims to identify the main potential sustainability-related problems throughout a product life-cycle of value-chain (Ny et al 2006). It is a more systematically integrated way to view the life-cycle of a product including supply-chain, manufacturing, use and reuse, recycling or disposal (Byggeth et al 2007). The SLCA uses the SLCM approach and revolves around a sustainability performance matrix that scrutinizes violations of each of the four sustainability principles for each activity in the life-cycle and the supply chains (Ny et al. 2008).

The summary of SLCM is presented with 5 grey scales to show the degree of ecological and social impacts. The 5 scales evaluation is made by the sum of 6 questions. These questions are based on each sustainable principle and followed by the evaluation of the sustainability aspects (Robert et al. 2007)

2.2.2 Procedure of SLCM

Strategic Life Cycle Management is based on sustainability principles to develop systematic strategies and guidelines for how to approach societal compliance with these principles with the respective organisation's specific life-cycle value chains (Ny et al. 2006). The procedures of SLCM are the following four aspects:

1. Goal and scope definition: SLCM starts with setting up the goal and scope related to BPs production. As SLCM focus on providing an overview of the environmental and social impact of a product, four main stages of the Life cycle of PLA bioplastics are selected (Figure 2.2). This life-cycle model is chosen from the PLA production in NatureWorks LLC - the largest PLA manufacturer in the world (NatureWorks 2007).

2. Identification of process maps: Detailed process and activity maps are created to identify the fields we will focus on. For example, in the Agriculture process, corn production in the United States was used since corn is a major ingredient of PLA in NatureWorks (NatureWorks 2007).

3. Process Analysis: Each activity and processes are compared with SPs to identify current strengths and challenges.

4. Solutions: Solutions for sustainable BPs are identified and discussed.

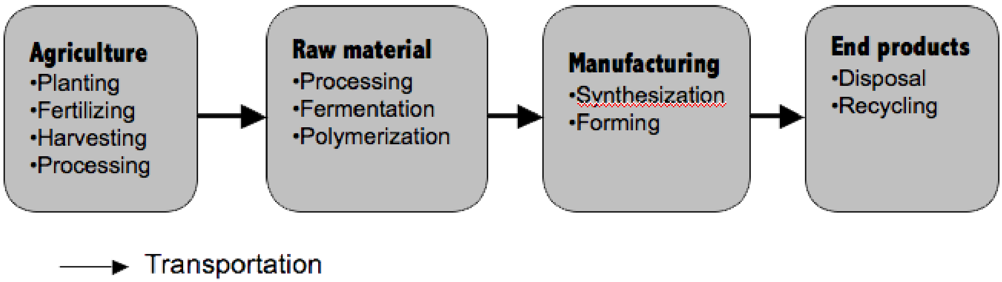

Figure 2.2: Main Life-cycle activities of PLA production

2.3 Templates for Sustainable Product Development (TSPD)

The data and information gathered by the SLCM method are used to develop "templates" for BPs.

2.3.1 Overview of the templates approach

The approach called Templates for Sustainable Product Development (TSPD) is designed to generate a faster and more complete overview of the major sustainability challenges and potential solutions. It is initiated by sustainability experts, giving a quick overview of the sustainability performance of a given product category to top management and product development teams to support their decision making. The template approach was first introduced to a case study of Matsushita electronics group (Ny et al 2008), however, it can be readily applied to other product categories since the context of templates are based on generally applicable sustainability principles. Thereby, TSPD can suggest how organizations can plan and act to make society sustainable.

The purpose of the template approach is to trigger creativity and function as input for later detailed priorities. The templates serve as benchmarks for the analysis of existing products' sustainability performance. There are three templates which include the current situation (B) and possible future solutions and visions (C):

Template 1: Covering Market Desired/ Needs - asks what types of products the company wants to provide and what markets should focus on.

Template 2: Covering Product Concepts - gives early indications of negative impacts on ecological and social systems that product concepts might cause throughout their life-cycles.

Template 3: Covering "Extended Enterprise" - to complete this marketing planning by creative actions around possibilities for the company to influence customers and other stakeholders' preferences as well as market conditions including legislation, taxes and subsidies. The basics of templates 1, 2 and 3 are described briefly in Table 2.3.

Table 2.3: Master Template Matrix (reproduced from Ny et al 2008).

Time	**Templates 2.3.1**		
	I. Market Desires /Needs	**II. Concepts**	**III. Extended Enterprise**
B (current situation)	Current market desires addressed: What *current* market desires is the product/service intended to meet? What are some *current* overall sustainability problems related to these market desires? How do these market desires relate to basic human needs?	Conceptual design of today's product: What *current* flows and management routines from the life cycle of the chosen product/service concept are critical from a full sustainability perspective? In other words, what *critical violations* of the sustainability principles could be identified for the following general lifecycle phases? • resource extraction, supply chain & manufacturing • distribution and use • final disposal or reuse/recycling/ land filling	Current stakeholder communication/cooperation: What *current* preferences and conditions of *societal stakeholders* are opposing the introduction of more sustainable product/service concepts? Is the company trying, through external communication and actions, to change these preferences and conditions? If so, how? What *current product/service value-chain* cooperation is agreed upon and what gaps can be identified that prevents responsible handling of sustainability problems throughout the lifecycle?

Time	Templates 2.3.2		
	I. Market Desires /Needs	**II. Concepts**	**III. Extended Enterprise**
C (future solutions/visions)	Likely future market desires to address: What *new* market desires are likely to evolve in the future as responses to the sustainability challenges? What *new* market desires, related to your core business, could improve the chances of fulfilling basic human needs? Are there any market trends that point in this direction?	Likely conceptual design of future product: Could the physical flows, management routines, etc, related to the *current* life-cycle of the product concept be developed to reduce the risk of societal violation of the basic sustainability principles? In other words, what *solutions* to product-related sustainability problems could be identified for the following general lifecycle phases? • resource extraction, supply chain & manufacturing • distribution and use • final disposal or reuse/recycling/land filling Could *new* product/service concepts be developed that meet the current and/or future market desires while reducing the risk of societal violation of the basic sustainability principles?	Likely future stakeholder communication/cooperation: What *future societal stakeholder* preferences and conditions would be particularly favourable for the development of more sustainable product/service concepts, and how could the company interact with external stakeholders to facilitate such change? What *future strategic product/service value-chain cooperation* would be particularly favourable for responsible handling of sustainability problems throughout the lifecycle? How could the company develop such cooperation?

2.3.2 Procedure of the template approach

The templates are used to create a learning dialogue between the sustainability expert and the company.

The stages of the process are as follows:

1) The expert gives statements regarding to current situation (B) and future solutions and visions (C) for BPs.

2) Top management and product developers respond to these general statements and provide specific information regarding to the products.

3) The experts return with feedback on their responses. This dialogue gives the company a critical point of view on sustainability and will be repeated until both have agreed on the results of the discussion.

2.3.3 Dialogues with Rohm and Haas

The authors used the above described template procedure to initiate dialogues with Rohm and Haas. Interviews were carried out with representatives from Rohm and Haas. Oral interviews were conducted with Mrs. Muriel Hebrard (European Laboratories- Plastics Additives, France) and exchange of questionnaires via email with Mrs. Bahar Azimipour (Plastics additives R&D, located at Spring House, PA, and USA).

3 Results

The review of current situation of PLA plastics was analyzed using SLCM. The overview of the results of SLCM is presented below. Detailed results of analysis are shown in tables following the overview. In the following section, the sustainability opportunities and challenges of the industry are presented along with outlined solutions. This chapter is concluded with the results of the TSPD.

3.1 Current "Sustainability Gaps" of PLA Plastic Production

The overview of ecological (SPs 1-3) and social impacts (SP 4) throughout the life cycle of PLA production is presented with gray scales in Table 3.1. This chart was made by answering questions related to each SP. The criteria's questionnaires are listed in Appendix 1. A couple of sustainability challenges were identified at each life cycle stage by literature reviews and an interview with Rohm and Haas. The result showed that the greatest sustainable challenges are in agriculture process. The detailed results of assessments in each life cycle stage of PLA production are described in the following sections.

Table3.1: Overview of Sustainability impacts along the PLA Life cycle

		Four Sustainable principles			
Life Cycle stages		**SP1:** Materials from the earth's crust	**SP2:** Man-made materials	**SP3:** Physical Degradation of ecosystems	**SP4:** Undermining capacity to meet human needs
	Agriculture				
	Raw material production				
	Manufacturing				
	Distribution, Use and End of life				

←Low Impact				High Impact →

3.1.1 Agriculture (corn production)

The SLCM analysis starts with the agricultural stage. Table 3.2 below shows the results. Bioplastics and agriculture are closely related to each other since agricultural feedstock ("renewable resources") plays an important role in BPs manufacturing processes. Composting BPs and using the compost in agriculture makes 'closes the loop' of the lifecycle – mimicking to the natural system.

About 50 million hectares in Europe (EU 25) are not currently needed for food production. These hectares are referrred to as a "set aside area" (European Bioplastics 2007). Therefore income alternatives for farmers and the non-food sector is becoming more important today. The US, the world's largest exporter of corn, experiences a similar situation. Bioplastic production opened new application areas in agriculture.

Corn production is typical of the agricultural stage. Currently, PLA is produced mostly from dent corn, a variety of corn processed into cornstarch including Genetically Modified (GM) species since the US, the largest supplier of corn heavily relies on GM corn in feedstock production. The selection of safe crops is fundamental to produce sustainable BP. Since dent corn, which is has been mainly used to produce PLA, there is a concern that it would have a negative impact on food production due to over harvesting and conversion of farmland as result of increasing demands (Braumn 2007; Searchinger et al 2008). The industries stated that the demands would not cause a food crisis (NatureWorks 2007; JBPA 2007), however, IFPRI (2007) pointed out that increasing demands on dent corn will increase the price of corn on the market and causes land use conflicts with food production. As a result, an increasing use of dent com will create more poverty and food crisis in the future. Since 485 million people in the developing world live on less than one dollar per day and cannot afford to buy basic foods (Braumn 2007), appropriate selection of feedstocks need to be considered. It could also reduce a risk in fluctuation in the price of corn by natural disasters.

Table 3.2: Results of PLA agricultural production, as analyzed using the four sustainability principles (SPs)

AGRICULTURAL PRODUCTION				
PROCESS: selection of crops, planting, harvesting, transporting, processing, crop (oil, starch, fiber), agricultural waste management.				
INPUT: oil, mineral coal, gas, agrochemicals, metals, and labour.				
	SP 1	**SP 2**	**SP 3**	**SP 4**
Benefits				-New job opportunity
Challenges	-Use petroleum for machinery	-Use hazardous chemicals into land. -Releases carbon dioxide during this process.	-Mono-cultivation. -Use of GM crop. -Eutrophication due to over use of fertilizer -Correct simultaneously the problems of salinity and soil acidification and general problems of depletion.	-Competition in land use (e.g. for energy source, food) . -Change of land Use for local community. -Unemployment due to mechanization. -Use the work of "child labour"

3.1.2 Raw material (starch—PLA)

According to Nature Works (2007), which is the largest provider of raw material (PLA pellets), 2.5 kg of corn grain is needed to manufacture 1.00 kg of PLA.

Other agricultural raw materials, such as rice, sugar beet, sugar cane, wheat and sweet potatoes, can also serve as sources for the starch or sugars used to make PLA (Engineer Live 2006) though, PLA production from corn is preferred as more profitable in the price and availability.

This stage included the process from raw materials starch, to PLA produced by raw material manufacturers.

Table 3.3 Results of raw material production (starch—PLA), as analyzed using the four sustainability principles (SPs)

RAW MATERIAL				
PROCESS: transportation, hydrolysis, fermentation, electrodialysis, liquid extraction, ion exchanges, distillation and polymerization				
INPUT: oil, minerals, metals, chemicals and labour.				
	SP 1	**SP 2**	**SP 3**	**SP 4**
Benefits				-New job opportunity
Challenges	-Use petroleum for machinery .	-Releases carbon dioxide during raw materials production process (e.g. machinery) manufacturing	-Degradation of water quality and resources from washing processes.	-Chronic and acute health impacts caused by exposure to heat of machinery operations. -Accidents and toxic spills caused by use of chemicals and poor workplace safety practices.

3.1.3 Manufacturing process

This stage included the process to make plastic products from PLA polymers produced by raw material manufacturers and additives made by additives manufacturers to the end products. As a plastic product is made of polymers and additives (OOTAHIRO 2007), the relation between additives and the Sustainability Principles was also described.

Table 3.4 Results of manufacturing process, as analyzed using the four sustainability principles (SPs)

MANUFACTURING PROCESS				
PROCESS: transportation to the plant, polymerization, addition of additives, form processing (extrusion and moulding)				
INPUT: oil, metals, chemicals and labour				
	SP 1	**SP 2**	**SP 3**	**SP4**
Benefits	-High reduction of use of petroleum in ingredients.	-Some BP additives are safer than additives for conventional plastics		-New job opportunity
Challenges	-Use of additives containing trace metals. -Use of fossil fuel for machinery.	-Use of chemicals as additives.	-Degradation of water resource due to water consumption in processing.	-Potential occupational health and safety issues.

Within today's energy system there are still needs of fossil fuels for energy generation to operate plants and machinery. However, the production of PLA requires 65% less fossil fuel than other hydrocarbon polymers since about one third of energy required in PLA production come from renewable sources (NatureWorks 2007). PLA production by NatureWorks does not require a solvent to remove lactic acid from the fermentation process while other competitors use a solvent in the process (Henton 2005). Therefore, it is more sustainable to produce PLA.

Most plastics contain additives to add benefits in processing (e.g. lubricants and surfactants) and in properties such as impact resistance and heat resistance. More than 34 million organic and inorganic substances have been registered in Chemical Abstract Service and thousands of them are used for polymers (CAS 2008). While a few million chemical substances are newly registered every year, only a few percent of them have authorized information with Material Safety Data Sheet (3E Company 2008). There are several categories of chemical substances used for plastics additives as showed in Table 3.5 and many of them are normally combined for the purpose of processing. There is concern that some additives may leach out from the end product and behave as environmental hormones (RSBS 2006). Moreover, no safety test is required for substances in composting processes (Green Consumer Tokyo network 2005). It means there are great unknown factors that these substances would impact on ecosystems and human health for the long term. Therefore, also potential occupational health issues could emerge.

Table3.5 Example of additives used in plastic

Categories of plastics additives	
Antistatics	Mineral fertilizers
Blowing agents	Modifiers
Catalysts	Plasticizers
Colorants	Reinforcements
Fillers	Stabilizers
Flame retardants	Surfactants
Lubricants	

3.1.4 Distribution, use and end of life

During the distribution process, wholesalers and retailers market the product while the end user purchases, uses and maintains it. At the product's end of life, the user discards it and it is then reused, recycled, composted, incinerated or landfilled.

- Polylactic acid is a versatile polymer that has many potential uses and many applications for different BPs. Bioplastic products have been used in the industries of food and packaging industry, medical equipment, toys, and textile in recent years. Bioplastics are transported by different ordinary ways to customers. Transportation by rail is used to accommodate the enormous quantities of bioplastic raw materials and finished goods. (Donnerstag, 2007).

- New BPs are suitable for the variety of plastic goods in customers' daily life, increasing progress towards sustainability while improving the quality of life. Bioplastics' market share is rapidly expanding at a rate of more than 8-10% per year（ Helmut Kaiser Consultancy, 2008 ）.

- Materials for most BPs do not require carbon from fossil fuels as a building block, rather; they 'cycle' carbon from the atmosphere captured by plants during the growing process. The general ways of disposing of BP products at their end of life are landfill, incinerator, compost and recycle.

  Landfills pose a problem in that they occupy valuable space and result in the generation of greenhouse gases and contaminants. This creation of pollutants, whether in landfills or incinerators (including those used for energy generation), is to be avoided (Sustainable Bioplasitc Guideline 2007). Direct land filling of untreated waste containing organic carbon will be prohibited in the European Community, in the near future (Council directive 1999/31/EC).

  Recycling BPs in a closed loop primary recycling system represents a high value end use, reclaiming more of the energy and resources embodied in the product. Properties of recycled polymers are often seriously inferior to virgin polymers and labelling of biodegradable products and collecting facilities are prerequisites for an efficient waste stream handling for recycling (Davis and Song 2006).

Bioplastic products available today are certified as compostable in commercial facilities and can help the functioning of food composting. One benefit of promoting compost operations is that they tend to be locally based, accepting organic matter, selling products within, and serving to strengthen local economies.

Table 3.6 Sustainability analysis for the process of distribution, use and end use of PLA products

Distribution, use and end use of PLA				
PROCESS: Application and Formation of PLA for BPs, Distribution of Products to Customers, Use of BPs products and Disposition of Waste.				
INPUT: oil, metals, chemicals and labour				
	SP 1	**SP 2**	**SP 3**	**SP 4**
Benefits	-The "carbon neutral" feature of PLA products that help to conserve the depleting oil reserves.	-PLA waste helps control the amount of carbon dioxide emissions, and it has great potential as a material with low environmental burden for contributing to the prevention of global warming.	-PLA can be composted locally into the soil improver and can be fully biodegradable (capable of being utilized by living matter).	-PLA products can contribute to healthier rural economies
Challenges	-Use of fossil fuels for production and transportation	-Use of chemicals as additives -Creation of air pollution from production and transportation	-Use of land resources for PLA disposal -Lack of a recycling system for PLA products -Soil contamination as a result of landfilling -Requirement of composting facility to compost (not biodegradable in natural condition)	-Over consumption of products -Products are not available for everyone -Limitation in products application -Lack of the protection of worker health and provision of fair compensation

3.2 Current strengths and weaknesses for BP market and product design

To understand the current reality of BP production, two templates - Market Needs and Product Concept and Design were completed by the BTH Bioplastic Thesis group. The templates were then used to have a dialogue with Rohm and Haas to meet consensus on how PLA production could begin moving towards sustainability. The templates are attached as Appendix 2. This section presents the overview of current sustainability issues for BP market and product design.

3.2.1 Current BP Market Needs

Bioplastics have a rapidly growing market share, expanding at a rate of more than 8-10% per year. Currently, it covers approximately 10-15% of the total plastics market and is expected to increase its market share to 25-30% by 2020. The market itself is growing, and it reached over $1billion US in 2007 and will be over $10billion US by 2020. Increasing numbers of companies are entering and investing in this market, as new applications and innovations in the Automotive and Electronics Industries are creating a market boom. Over 500 BPs processing companies are already available; more than 5,000 are expected by 2020.

Less than 3 percent of all waste plastic worldwide gets recycled, compared with recycling rates of 30 percent for paper, 35 percent for metals and 18 percent for glass (Helmut Kaiser Consultancy 2006).

The currently available BPs cover approximately 10-15% of the plastics market and is expected to grow between 8-10% annually. Due to the limited amount of crude oil reserves, Europe is considered one of the most important markets. In recent years, bioplastics have been used in the food and packaging industry, medical, toys and textile industries. With new innovations expected in the near future, there will be many more and more applications for BPs, especially in areas such as the automobile and electronics industries, where plastics play a major role. Within the automobile industry, companies know that cars incorporating plastic parts made from plants will appeal to environmentally conscious customers.

Bioplastics production companies currently produce relatively small quantities and are still in the early stages of their development of these products. With new developments in the future, the production will surely increase in efficiency, opening up applications, and new opportunities.

3.2.2 Current Product Development and Design

The SLCM assessment revealed current sustainability challenges along the life cycle of PLA products. Various industries have been interested in introducing BP to appeal public to show their illustrating their responsibilities to the environment. In fact, PLA can be applied for many different uses; however, to meet strict properties demands from consumers, PLA processing technologies require additives and materials to improve properties identical to conventional plastics. As a result, it would use more energy and cost more. Therefore the industry needs to consider which application of BP should be prioritised.

Another issue is that the biodegradability of BP requires a composting facility for rapid degradation. Fragments of BP products remain for long periods when degraded in natural conditions (non composted). Since composting facilities require heat to compos BP, developments of BP with better biodegradability in natural conditions need to be considered.

3.3 Extended enterprise

Extended enterprise means stakeholders in the exterior world of the BP industry. It includes many different kinds of groups such as customers, competitors, public authorities, politicians, universities, NGOs, suppliers and media. As an example of extended enterprise, current regulation systems of BP by the industrial authorities were compared to show the gaps among the labelling systems since the industrial authorities have a stronger influence to other stakeholders such as suppliers, competitors and customers.

3.3.1 Current regulation and the gaps related to sustainability

Since EU, Japan and US have taken the initiative in developing BP, industrial associations have made certain criteria for BP and labelled BP products in each region. However, consumers have low recognition of BP labelling systems. For example, only 30% of Japanese consumers were aware of BP and many of them still misunderstootod biodegradability (MAFF 2007).

Each labelling system has its own testing systems following ISO standards in biodegradability and constituents.

However, current labelling systems allow BP to use inorganic materials including petroleum-based polymers, which creates the concern that a part of BP would remain in soil without decomposing. There have been few studies to show how it affects an ecosystem in the long term (Green Consumer Tokyo network 2005).

Table4.1: Comparison of criteria of BP labelling systems (Sources: European Bioplastics 2007; JBPA 2007; US Composting Council 2007; BMG 2007)

Label Name (Country)	**Label Design**	**Criteria**
Compostable bioplastic (Germany, Switzerland, the Netherland, Poland and the United Kingdom): authorized safety and biodegradability by EN13432 testing standard		- Disclosure of all material properties - Biodegradability; at least 90% of the organic material must be converted into CO2 within 6 months - Disintegration; no more than 10% residue may remain, as compared to the original mass - Practical test of compostability - No negative influence on the composting process - Compost application (agronomic test and ecotoxicity test)
Biomass plastic (Japan)		- Use of Biomass plastic listed on the Positive List - The volume of biomass plastic is greater than 25.0wt% - No use of hazardous substances listed by JBPA

Green plastic (Biodegradable plastic, Japan): plastics authorized safety and biodegradability by JIS K6950, 6951, 6953 or 6955 or MITI testing standards, which are equivalent to ISO14851,14852 and 14855	グリーンプラ	-Disclosure of all constituents - The amount of biodegradable plastic and natural organic materials is greater than 50wt% in total volume - Limitation in use of heavy metals (Cd, Pb, Cr, As, Hg, Cu, Se, Ni, Zn, Mo and F) - All ingredients are used from the positive list by JBPA - Biodegradability is equivalent to organic
COMPOSTABLE Certificate by International Biodegradable Products Institute and U.S. Composting Council (USCC)	COMPOSTABLE Biodegradable Products Institute | US Composting Council	Products with this symbol are designed to compost quickly, completely and safely, without leaving any plastic residues.
BMG: Biodegradable Materials Group (China)	BMG	The intention of BMG is to develop standards of BDP (biodegradable polymers), to supply a correct surrounding to BDP, then it can conduct BDP be produced, applied, disposing, etc healthily and widely in China.

3.4 Future visions - What will BP look like in the future sustainable society?

If BP is to be commonly used in a sustainable society, it should be designed to benefit society without negative impacts on biosphere. From a Sustainability Principle's point of view, a vision of sustainable BP production was implied followed by each SP.

SP1: Not contribute to increasing concentrations in nature of substances from the Earth's crust

- No petroleum-based energy and raw materials to produce BP

- No use of unusual or rare metals as lead, cadmium, mercury, copper and chromium

SP2: Not contribute to increasing concentrations in man-made substances from society

- Replace artificial pesticides and fertilizers by biological pest control and organic fertilizers in feedstock production

- No genetically modified crops in feedstock production

- No hazardous substances which accumulate into soil or effect human health to be added in manufacturing

SP3: Not contribute to systematic physical degradation of ecosystems

- Biodegradable under natural conditions or with lower temperature in composting facility

- No negative impacts on ecosystems and human society when disposed of

- Not misuse renewable raw materials from forests, fields and underground water in the life-cycle operations

- No purchases of land for manufacturing sites in fragile environments, productive green land or fertile agricultural soils.

SP4: Not contribute to conditions that systematically undermine people's capacity to meet their needs

- Not obstruct supplier needs and employee's needs e.g. healthy working environment, protected human rights, financial terms and business relations

- Not obstruct customer needs e.g. only products that does not constitute a health risk

- Not obstruct the needs of the general public and future generations e.g. does not monopolize land use for feed stocks

The overall goal for the distribution, use and end use of PLA is that products be healthy and safe for humans and the environment during use and end use of products, not overburden the world's farmland and other resources. Manufacturers are responsible for designing products that meet healthy exposure goals. Users are responsible to move to use reusable goods, reduce their usage of disposables and be efficient in use. Manufacturers, retailers, users and public and private waste management entities must all work together to create and use the most efficient possible end of life management systems for products.

To confirm the future vision of sustainability in BP products, the sustainability analysis of BPs helps to reduce the direct impacts of wastes on the environment and limit the toxicity risks for terrestrial and aquatic organisms. The analysis covers two key points:

1) Ensure safe and rapid biodegradation: Ensure that products are certified compostable in timescale that works with municipal and other commercial composting systems and leaves no toxic residue of heavy metals or organic chemicals when degraded.

2) Design product for recycling or composting: Design for handling by small scale, locally managed composting and recycling systems and design products and labelling that facilitates easy identification and sorting by the consumer.

3.5 Leverage Points to bring the Bioplastics Industry towards Sustainability

Following the analysis of the current situation in BP production and imagination of future BP in a sustainable society, a series of leverage points were identified to increase the sustainability of the BP industry, primarily in feedstock production and manufacturing stages. The following section outlines other supplemental actions to accelerate a change of the industry.

3.5.1 Prioritized actions regarding new technologies and systems moving towards sustainable Bioplastics

For sustainable production of BP, there is a need to ensure stable and safe renewable sources as a foundation of BP production. The industry needs to ensure the safety of all ingredients in the product development stage. Since agriculture and manufacturing stages had higher impacts on sustainability, leverage points related in these stages were prioritized. These actions could also be solutions for increasing demands of BP in the short-term. Four key recommendations to the BPs industry are listed below:

1) Introduction to new technologies in use of biomass alternative

Lactic acid can be produced from dextrose. Corn, potato, sugar beet and sugarcane which can easily saccharify are often used to produce PLA (Henton et al 2005). The use of starch is an efficient way to produce lactic acid. However, production of PLA is technically possible to produce any materials which can produce sugar extracts. Agricultural and food processing residues can be good alternative low-cost biomass sources.

For example, about 142 billion tonnes of agricultural production residues were produced in the United States in 2003 (Stokke 2005). The use of such residues has benefits as a resource for saccharification and to reduce a cost of waste management in the agricultural industry. As PLA is mostly produced from corn and sugarcane, the use of agricultural processing waste would have an opportunity to make PLA more sustainable.

Similarly, Shirai (2000) has developed a biomass recycling model to use food waste from the food industry for PLA production. It can produce 5kg of PLA from 100kg of organic waste and save 97% of the energy to be used for incineration. It has a benefit for both municipalities and the industry to reduce a cost for waste management and create new business opportunities in a local area.

2) Development of additives to improve biodegradability

Considered as a sustainable alternative to petrochemical-derived products, polylacticacid (PLA) is derived from the fermentation of agricultural products. Bio-based and biodegradable, PLA has held strong appeal among the packaging industry for select industrial applications, which consider the significant benefits and consumer demand of offering environmentally friendly packaging. PLA's attractiveness as a sustainable alternative is enhanced by the capability of the material to be composted in industrial facilities. However, despite its strong attributes and allure, packaging and industrial products made of PLA have been hindered by performance deficiencies that include brittleness and decreased durability when compared to the competing petroleum derived plastics.

Nowadays, more new additives are becoming available to boost PLA's process ability and performance. Some chemical companies have already started to produce environmentally friendly additives for BPs to meet society's need (PolyOne 2007: Clariant Masterbatches 2007).

3) Design for minimum number of different material types

Label material content to disclose all materials utilized in the product, including percentage of bio-based content. For multi-component products, design for quick disassembly and positive identification of component materials for recycling or composting. Avoid barrier materials such as trace metals that interfere with composting or recycling.

Some consumers such as parents with small children are concerned the impacts on the human body by plastic additives (JBPA 2007). Particularly, food packaging materials are of concern due to a direct contact with foods. Therefore, CO-OP Japan (2007) has developed packaging films without additives since 1998 and used 85 tonnes in 2006. It is a possible way to eliminate the risk of additives and in disturbance of composting in some BP products.

However, most BP products cannot avoid use of additives to have certain required properties such as heat resistance and form processing. In that case, to make sure the safety, biodegradable plastic in Japan can only use additives listed in the Positive list authorized by the Japan Bioplastic Association (JBPA 2007).

4) Design for handling by small scale, locally managed composting and recycling systems

Design and product and labelling that facilitate easy identification and sorting by the consumer is important to reduce the contamination of post consumer recycled plastic streams. Bottle applications should be designed and labelled to facilitate easy sorting at materials recovery facilities.

Since there are many different kinds of conventional plastics in a society, it is difficult for consumers to separate in the right way. Although some conventional plastic products such as polyethylene terephthalate (PET) bottles and polystyrene (PS) trays have been targetted through recycling systems in developed countries, most are still either landfilled or incinerated after use. PLA plastics could have a high potential to become an excellent source of material recycling (Nishida 2007). Recycled PLA materials could be important to secure raw ingredients for bioplastic production if feedstock production became to compete with biofuel production in the future (METI 2007). Currently, there is no guideline for PLA recycling systems. As a result, it is mixed with conventional plastic, loosing an opportunity to be recycled as a high quality raw material.

With the condition that uses of PLA products could increase more than100, 000 tones per year, manufacturing PLA products from recycled PLA can save the cost and required energy to make a product again by comparison with manufacturing from virgin materials (Kondo 2007). Since the consumption of PLA products is very small still compared to conventional plastics in current plastic market, it makes it difficult to commercialize a larege and successful chemical recycling business. To overcome this issue, Shirai (2000) suggested that the establishment of a central PLA recycling center to make a waste recycling system commercialized by collecting wastes from regional small consumptions of PLA products.

3.5.2 Supplemental actions to accelerate sustainable PLA Feed Stocks

The research of the most sustainable raw materials selection for PLA depends on different facts, local plant species harvesting area, cultivation technology and also price. The crop selection process could reduce its impact by:

1) Promote biological diversity: Utilize local plant species instead of imported plant species for PLA. Use selection of plant species and varieties adapted to site-specific conditions and/or biological pest control methods, including development of habitat for natural enemies; Avoid monoculture planting. Develop feed stocks raised in poly culture and perennial-based agricultural systems serving multiple purposes; Do not convert existing forest, wildlife refuge or parkland or other important habitat to plantations or crop-land. Conservation Reserve Program (CRP) lands can be used only with crops and farm plans compatible with the CRP purpose (Sustainable Biomaterials Collaborative 2007).

2) Reduce transportation impacts: Establish local processing facilities to reduce transportation distances and maximize energy efficiency of process.

3.5.3 Behavioural changes to move towards sustainability

1) Reduce quantity used

i) Increase efficiency in use of all products. Evaluate needs and change use patterns to reduce product demand.

~~i)~~ii) Use reusable instead of single-use products whenever possible. For example, efforts to reduce the impacts of retail bags should focus on providing incentives for the use of cloth reusable bags, rather than single-use bags, biodegradable or not. Likewise, food services should evaluate the feasibility of moving to reusable food service ware instead of single use products - bioplastic or otherwise - especially when composting or recycling are not possible.

2) Create opportunities for sustainability education

i) Use branding and marketing opportunities to support education on sustainability.

ii) Use school/community/business partnerships to develop increased awareness and education of potential benefits of sustainable BPs.

3) Extended Producer Responsibility

Polymer manufacturer and converters can assist in increasing the sustainability of the BPs industry by:

i) Maximizing use of post consumer content.

ii) Setting restrictions to eliminate use of hazardous additives by converters.

iii) Working with the recycling community to find solutions for challenges of mixed waste streams containing similar products made of fossil fuel plastic and of bioplastic.

iv) Participating with recycling industry in developing and enforcing agreements on clear and consistent labelling/coding for easy separation and education for composting or recycling.

v) Working with retailers to take responsibility to assist development of end of life infrastructure for products, including development of automated sort technology. Manufacturer take back will be necessary for products as long as hazardous ingredients necessitating special handling remain in the product formulation.

vi) Avoiding products that are particularly disruptive of existing recycling systems, such as bottle applications, without first establishing economically viable commodity recycling systems. Direct manufacturer or retailer take back should only be as a bridge to development of economically viable independent systems. (Note that composting bottles is not currently economically viable due to sorting costs and fees charged by compost operations.)

3.6 A dialogue with Rohm and Haas

After sending the templates for sustainable BP with comments of BTH BPs thesis group (Appendix 2 and 3), a teleconference was set up in the mid April 2008. The discussion was supposed to be carried out according to the method described in section 2.3.2. However, it was not completed as expected due to a limitation of time and misunderstanding the purpose of the templates. Ultimately, we were able to obtain comments regarding the templates from a manufacturer's point of view.

A summary of those comments is presented below.

Current problems of BP related to sustainability

-PLA does not biodegrade in landfill conditions, and it needs a controlled humidity/temperature environment to biodegrade.

-The lack of composting facilities in nature reduces the importance of the lower polluting factor of PLA.

- Lack of recycling streams for PLA is another limiting factor. E.g. it creates issues in existing recycling systems such as PET by combining of PET and PLA products.

- No environmentally friendly additives are available commercially with good performance due to current technology limitation.

Demands for future BP

-Review the whole life cycle stages of PLA including LCA of BP additives

- Impacts linked to the synthesis of the PLA may need to be checked, as well as during the processing of PLA to produce articles

- Safe Disposal: high biodegradability in natural conditions without negative impacts on an ecosystem

- Material Recycling: setting up a new recycling system for PLA

-Environmentally friendly additives, e.g. improvement of biodegradability and the lifespan of products.

4 Discussion

A broad picture of the ecological and social challenges within the life cycle of PLA plastic was reviewed by SWOT analysis and through our result of Strategic Life Cycle Management (SLCM). The results of the SLCM then fed into the Templates for Sustainable Product Development. Economic challenges and opportunities and product concepts towards sustainability were identified through the dialogue with Rohm and Haas about the Template for Sustainable Product Development (TSPD) for bioplastics. In this chapter thesis questions are reviewed from the results of SLCM and TSPD and literature in and research validity is discussed.

4.1 Moving towards Sustainability: Where does the BP Industry stand and where could it go?

From the result of SLCM, a number of gaps towards sustainability were identified. As a couple of different manufacturers are involved in the life-cycle of PLA production, there are overarching gaps, threats and opportunities linked to each manufacturer.

1) Current strengths and weaknesses

BP have been promoted to be an alternative in the future sustainable society because of the expected shortage of oil and as a method to reduce GHG emissions by using biomass as raw materials. Additionally it gives agricultural sectors and the chemical industry new business and employment opportunities.

However, since its biodegradability is not completed yet under natural conditions, waste management sectors need composting facilities that require energy in operation. This could off-set the advantages of using BP. In some countries like Japan, society is not yet prepared to accept regular use of BP since there are no waste management composting systems used by municipalities (JORA 2007). Recognition of BP is still low and consumers do not have a good understanding of BP and how to dispose of it. Since the use of BP products has been very low in the plastic market, there is no large promotion in appropriate disposal. However, it would be worthless to introduce BP without a sustainable product design through all life cycle stages.

2) Future sustainability threats

The industrial authorities and manufacturers claims that BPs have an advantage by utilizing a carbon neutral manufacturing process and end use due to the use of biomass. However, this can apply the case in current feed stock production within existing crop field. In the case of extension of farmlands due to competition with bio fuel production, it could violate ecosystems by land conversion and would also loose carbon absorption sources such as forests and glass land.

For example, changes in land use for the purpose of corn production in the US nearly doubled the amount of GHG emissions over 30 years due to forest conversion (Butler 2008). A large scale mono-culture requires irrigation and a large amount of pesticides and fertilizers. It weakens soil fertility in a long term can cause salinization.

Moreover, the competition with other uses of feed stocks has increased the price of those feed stocks and it would affect small scale farming and local food production. As a result it could contribute to food crises and increase water stress in the future. Therefore, system boundaries for fair crop use and application of BP will be needed.

The current certification system of BP does not cover the safety of residuals from BP when disposed of since BP technology is relatively new and there is little study about it. As BP is not 100% biodegradable, there are small amounts of BP compounds remaining after composting. It would have negative impacts on wildlife that swallow the BP fragments at landfill sites. Crop yields would also affect in a long term due to accumulation of BP remaining micro-substances in soil. Additionally, when BP degrades without oxygen, it releases methane, a greenhouse gas 23 times more powerful than carbon dioxide (Vidal 2008), which can create a green house gas impact worse than using conventional plastics. Therefore a system to monitor impact on soil for future regulation updates is necessary.

Misunderstanding biodegradability of BP disturbs current existing waste management system for plastics (Vidal 2008). Easy replacement for BP would also encourage disposal and over-consumption of BP in a society.

3) Leverage points- future sustainability opportunities

Five leverage points were primary suggested in the Results chapter. Research in developing additives to make BP biodegradable in natural condition could be accelerated to promote use of BP as a prioritized action. From the dialogue the authors had with Rohm and Haas (see section 3.5), it seems possible to invent biodegradable additives with technological development. Since manufacturing of additives is not clear in their products' components and unknown in the impacts on ecosystems for some additives made of inorganic substances, they need a system to check the safety by authorities or the third organization.

The dialog with the authors and Rohm and Haas has recognized the current weakness of BP and that the company needs to find a way to be more sustainable in their products. As Rohm and Haas has been seeking new business opportunities in sustainability, creating sustainable additives would be motive and appealing points to extent their business in the BP market. From the literature review, the authors were also able to see proactive actions to make environmentally-friendly products by manufacturers and suppliers (Nature Works 2007: PolyOne 2007: Rohm and Haas 2007).

There are many challenges for the industry to make BP truly sustainable. Since there is a lack of consensus in sustainability among stakeholders, each company develops PLA products using their own criteria. Although there is high environmental awareness in the BP industry itself, it is important for the industry to share the same visions moving towards sustainability and in finding creative solutions. It is helpful to see that much research has been carried out in use of alternative biomass such as organic wastes from the food industry and agricultural sectors. A large quantity of organic wastes is produced in processing and requires a high cost to dispose it. Therefore, reuse of agricultural wastes for PLA production would solve the both problems with availability of crops and agricultural waste management.

PLA is considered a high quality recycled material source since it is relatively easy to separate from other substances in plastics (Kondo 2007). If PLA recycling plants could be commercialized in the future, PLA production will put less pressure on agriculture with PLA production from organic waste streams.

4.2 Research Validity

4.2.1 Research questions

In establishing a solid foundation for the sustainable development of industry and BP specific guidance, some opportunities and threats, as they exist today, have been identified. Therefore, the main research question "What are the current strengths and weaknesses and future threats and opportunities and leverage points for the BP industry in a move towards sustainability?" was valid to analyze current issues related to sustainability from backcasting. The three sub-questions systematically supported to answer the main question and magnified sustainability issues around BP by comparison with the future vision. The research questions were mostly answered by literature review. The overall research would have been more valuable with further input from the manufacturers, however, this wasn't possible. The literature review covered different sustainability issues around BP from various stakeholders' point of view. It helped to answer the research questions.

4.2.2 Strength and weakness of research methods

Strengths

We have successfully used SLCA approach based on SPs to identify how well it supports each life cycle stage. It used tables to clearly relate current sustainability issues to SPs. SLCA also helped to make criteria to brainstorm the vision of future sustainable BP.

TSPD helped to give a complete overview of the industry by summarizing sustainability issues from SLCA. Particularly the B- and C-step analysis of the industry, are prompted by template development in our research. TSPD approach helped us to systematically collect literature for BP since there are great number of publications and documents regarding to BP.

The feedback and input on both of these steps validated our own findings, and offered additional ideas from key people. Therefore, the analysis undertaken was suitable and appropriate.

Weaknesses

There is a difficulty understanding and developing SLCA for BP since application of life cycle assessment was new to us. We were not clear how to make a boundary of inventory for each life cycle stage. Another factor in the difficulty encountered in drawing conclusions was the need for much more conclusive data in BP research since Rohm and Haas gave us almost no data as they had just started developing new sustainable additives. With rapid research and development in this broad field continuously occurring, much of the data can become obsolete very quickly. There will always be the need for further data review.

Since there are few papers in TSPD available from previous years, there were difficulties in reviewing already tested templates and in customizing new ones for BP production. The TSPD approach is supposed to help the development of consensus in sustainability though dialogue. However, in this case the application of TSPD was not o valuable because we failed to communicate the approach with Rohm and Haas due to time limitations. In the case of Matsushita, the TSPD was developed through dialogue over a period of two years (Ny 2008). However, in this study, Rohm and Haas spent too little time to be able to understand the template approach compared with the Matsushita case study.

We attached guidelines to assist in answering the templates with explanation of FSSD because we had an idea they have already understood some basics of sustainability as the company has been formally working with TNS since December 2007. Nevertheless, representatives from Rohm and Haas had difficulty understanding the purpose of TSPD due to lack of information relating to sustainability. We felt that we needed to provide more basic information in FSSD before the templates were given to them for a successful application of TSPD. Another possibility that can have reduced our success in communicating the TSPD approach was that the guideline for TSPD we wrote might not be clear to them because none of us were native English speakers.

Most communications to the company were made by emails. This made it difficult to know how much they understood the purpose of this project, which may have been reflected by a lack of response to our communications. We think there was too little communication about this project between BTH and the company despite the preliminary discussion with the program stuff. As a result, there was little time for dialogue to provide the level of research and analysis we would have liked to have undertaken to assist Rohm and Haas. BTH BP thesis group was, however, able to present current reality to the company, although we were not able to reach an agreement of the future of sustainable BP with the company. In order to improve the TSPD and address the global scope of BP development, a broader stakeholder group is needed. For better communications, a stakeholder engagement process needs improvements. This could be done by using a more refined process for communicating information to stakeholders, and providing more guidance.

5 Conclusions and Future research

5.1 Conclusions

This project identified current strengths and barriers in term of regulatory, market and technology from the sustainability point of view for BP. Bioplastics seems to be biodegradable and advantageous to our environment, however, movement towards sustainability is still slow since there are limitations in BP manufacturing technology and in application of biodegradability under natural conditions. The risk in lower food availability by increasing price of basic grains as a result of competition with bio energy sectors for feedstock also needs be considered for the future generation.

Our research has identified a potential for BP to be more sustainable in the future by using sustainability strategies, for example, improving technology to extend the lifespan of BP products and creating new additives to make BPs completely compostable. These strategies based on backcasting and system thinking will also inform Rohm and Haas as to the most sustainable approaches to be implemented to ensure that the new product is sustainable and meets market needs.

5.2 Future research

The TSPD requires further research to approach stakeholders; however, we feel that it provides a good starting point for improvement. Building a dialogue guideline for TSPD would be helpful for future application into other products. If the guideline covers a flow chart to assist communication with stakeholders and templates to build effective questions for sustainability, it would also be useful to improve stakeholder engagement and to understand required time line to apply TSPD into an organization. In addition, it would help to increase applications of TSPD by NGOs or the environment support agencies in assisting with the integration of sustainability within in an organization.

Further research in feedstock production and distribution is primary recommended in order to address biodiversity issues and food security concerns. Building a consensus in biomass application based on FSSD supports more sustainable foundation of BP application for increasing BP demands.

The performance of a biodegradable polymers used for food packaging needs to be improved by new additives, its manufacturer claims (Ahmed ElAmin 2007). Improvement of performance should be compatible with the safety of additives. To ensure this, the safety certificate system for additives also needs to be developed by manufacturers and authorities.

It is also necessary to develop high environmental standards that can apply to facilities in which biological treatment takes place. This will be achieved through the upcoming review of the Directive on Integrated Pollution Prevention and Control (96/61/EC) under which national authorities issue permits for major industrial and agricultural installations based on the concept of Best Available Techniques (BAT) (Environment Agency 2008).

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Appendices

Appendix 1: Check list for SLCM

To measure sustainability of the life cycle stages of BP production, twenty-four questions were created to check if there are violations of SPs. Six questions were prepared to fit each SP. The questions were answered by selecting one out of four grades; 0: No 1: Yes, little bit 2: Yes, moderate 3: Yes, very much.

Questions to check violations of SPs	**Agriculture**	**Raw materials**	**Manufacturing**	**End of life**
1. Does it use petroleum for materials?	2	1	1	1
2. Does it use metals (Al and Fe)?	2	2	2	2
3. Does it use minerals (Cu, Ni, Zn and Sn)?	1	1	1	0
4. Does it use trace metals (Cd, Pb, Cr, As, Hg, Mo and F)?	0	0	1	0
5. Does it use noble metals (Au, Ag and Pt)?	0	0	0	0
6. Energy generation from fossil fuels (coal and natural gas)?	2	2	2	2
SP1 sum	7	6	7	5
7. CO2?	1	2	1	0
8. Green House Gases (CH4, CFC and HCFC)?	0	2	1	2
9. Photochemical oxidant (NO, SO and VOC)?	1	1	2	1
10. Chemicals (pesticide, chemical fertilizer and hazardous substances)?	3	3	3	0
11. Genetically modified plants & microbes?	3	3	0	0
12. Dioxins and PCB?	0	0	0	1
SP2 sum	8	11	7	4
13. Contributing air pollution?	1	2	2	2
14. Ozone depletion?	0	0	0	1
15. Contributing water pollution?	3	1	1	2
16. Contributing soil pollution?	3	0	0	2
17. Contributing loss of biodiversity?	3	0	0	0
18. Degradation of natural resources (forest and underground water)?	3	2	2	0
SP3 sum	13	5	5	7
19. Contributing poor work environment (health and safety)?	1	2	2	1
20. Illegal laboring?	1	0	0	0
21. Contributing to unfair crops/products distributions?	3	1	1	2
22. Contributing to unfair natural resource use for future generations?	2	1	1	0
23. Contributing to excess use of fossil fuels and materials?	0	0	2	2
24. Contributing to unhealthy ecosystems for the future generations?	3	1	1	2
SP4 sum	10	5	7	7

Appendix 2: Instructions to answer “Templates for Sustainable Product Development (TSPD) for Bioplastics” Questionnaires

Instructions Provided to Template Users

Directions for filling out the template questions

The templates are organized according to the following format:

Guidance to answer
Questions for the Bioplastics (BP) market and product concept
Response to each question from BTH Bioplastics Thesis Group
Feedback from Rohm and Haas

1. There are six questions in the templates. Read through the entire text and all questions before answering.

2. Use the following assumptions in reviewing this template:

- The Sustainability Principles (SPs) as system conditions for sustainability in Appendix I.
- Bioplastics are plastics derived from renewable biomass sources, such as hemp and soy bean oil, corn and potato starch, cellulose or microbes that are biodegradable and easy to compost (European Bioplastics 2007). For answering the templates, your answers limit to **PLA plastic.**
- Correct or modify any general statements in the templates that you find flawed or incomplete into the columns “Response from Rohm and Haas”.
- For industry representatives: Reflect on your typical organizational

perspective on the templates asking: 'how is your organization currently dealing with this issue in comparison to the respective templates, and how are you planning to deal with it either in the long term, or near future?'

- Critical to the sustainability analysis are areas where no data are available, or where the answer lies outside your domain. Unknown relevant aspects of sustainability are as important to identify as aspects that have concrete, detailed or quantitative answers. Therefore, such unknown and relevant aspects should be specifically noted.
- In a strategic sustainability analysis (based on Strategic Life Cycle Management (SLCM)), it is critical to present the overall picture so that important aspects are not overlooked amongst other information that may be less important. Please note that a more in-depth Life-Cycle Analysis may be completed later.

Context & Guiding Principles

Based on the ongoing Sustainable Product Development (SPD) research being conducted at Blekinge Institute of Technology (BTH), we aim to help ensure that the new product is sustainable and meets the future market needs. In addition, our research helps to develop a sustainability standard for the global production of BPs.

The tool, the 'Templates for Sustainable Product Development' (TSPD) for bioplastics, which has been originally developed for the case study of Matsushita Electric Group by Ny (2006), is meant to provide a simple and manageable tool to industry for social, ecological, and strategic sustainability throughout the life cycle production of BPs.

The foundation of the methodology for these templates is "backcasting from basic principles for sustainability," as developed by The Natural Step (TNS[1]) in its approach to Strategic Sustainable Development (SSD).

[1]TNS is an international non-profit NGO, advising enterprises and other organizations on strategic sustainable development.

Backcasting

How can these sustainability principles (SPs) be applied to an organization's everyday operations? TNS has developed and tested an approach to help organizations incorporate sustainability into their business strategies. The A-B-C-D Analytical Approach includes four elements, which are repeated as the organization progresses along various pathways towards sustainability.

A-B-C-D Analytical Approach

A=Awareness

The first phase involves aligning your organization around a common understanding of sustainability and the 'whole-systems' context for their organization.

B = Baseline Mapping (Current reality)

What does your organization look like today? This phase consists of conducting a Sustainability Gap Analysis of the major flows and impacts of the organization, using the SPs, to see how their activities are running counter to SPs.

C = Creating a Vision and Solutions

What would your organization look like in a sustainable society? Imagine what your operations will look like in a sustainable society based upon the four sustainability principles. In this phase, key decision-makers and stakeholders work together to create a compelling long-term vision for a sustainable enterprise.

D = Down to Action

Companies set their priorities for improvement, based on the vision they have created.

Backcasting is used on an ongoing basis as a method for continually assessing decisions and actions in terms of whether or not they move the organization towards the desired future outcome identified in Step C[2] (The Natural Step New Zealand 2008).

You will note in reviewing these templates that they include only questions on the "B" and "C" elements of the backcasting approach. Elements "A" and "D" are not included and can be completed by the BPs producer, with assistance from a sustainability expert if needed.

[2] The Natural Step New Zealand 2008.The Nature Step Framework for Sustainability. http://www.naturalstep.org.nz/tns-f-implementation.asp

Appendix 3: Templates for Sustainable Product Development for Bioplastics Questionnaires

Template 1: Market needs

Guidance to answer

All products are developed for particular functions and utilities. When thinking of current and future market needs, consider what values consumers are willing to pay for. For current market need, consider why PLA plastic has been applied for particular fields. For the future market, consider the potential of different markets and applications.

1B: Current situation

Question 1B-1: What are the current markets for PLA plastic and what advantages do PLA plastics have?
BTH Bioplastic Thesis Group response to B1-1: PLA is a major material in the biodegradable plastics market. PLA is a hard plastic and excellent in transparency and elasticity. PLA has been applied in many fields due to its flexibility in processing, including; film products such as bags, packaging materials and agricultural mulch film. In addition, PLA has been used for office supplies and disposable table wares which can be mixed with general waste for compost. Current markets include: • Packaging industry • Retail chains • IT hardware (mobile handset, laptop computer and cables) • Office supplies (stationary) • Food industry • Agriculture and fishery industry • Construction industry • Medical and Pharmaceutical industry • Automotive industry • Household sectors • Textile industry The demand for biodegradable plastic has developed due to environmental concerns and the future shortage of fossil fuels. If made from a renewable source then PLA could be considered to be potentially carbon neutral. Its bio-degradability can also help reduce the amount of plastic wastes generated when compared to traditional alternatives. The following advantages include: • Saving energy use and petroleum use in BP production • New and improved packaging properties (e.g. breathable film) • Reduced disposal costs by users (e.g. agricultural sector) • Reduced costs for waste separation (e.g. waste management sector) • Easier waste management of health & sanitary materials • Raised consumer's awareness in environmentally friendly products • Responds to government strategy to shifts towards sustainable society As a result, the use of BP has benefits for a whole society in a long term.
Response from Rohm & Haas:

Question 1B-2: What are the sustainability problems linked to those increasing demands?

BTH Bioplastic Thesis Group response to 1B-2:

With an increase in environmental awareness, demand in BP has increased over the last decade. However, PLA production is limited in scale because of technical plant size and competing demands for bio-feedstock. Key potential sustainability problems include:

- The price of biomass highly relies on the climate in particular region. It would affect a stable feedstock supply.
- High demands in BP would affect land use for food production in local community and could undermine people's need in feedstock in the future.
- PLA is relatively cheaper among BP materials. However, it is still more expensive than conventional plastics. It is mainly available in developed countries where most demands for BP come from.
- BP market is only 1-10% of the current plastic market in developed countries. There is low recognition of BP among consumers and limited promotions for the right use of BP.

BP production requires many different kinds of additives to overcome technical issues such as heat resistance and endurance. Use of additives in a PLA product is very little in volume (less than 5% in total). However, the safety information is not clear in a long term since BP is relatively a new technology.

Response from Rohm & Haas:

1C: Future Vision and Solutions

Question 1C-1: What would the future demand of BP in the sustainable society?
BTH Bioplastic Thesis Group response to 1C-1: BP is needed to reduce dependency on use of fossil fuels and to reduce net CO2 emissions. However, it has to have a balance between food production and renewable energy use. In sustainable society, BP's should: - Be safe to dispose and no have negative impacts on ecosystems - Increase the rate of material recycling to save energy in manufacturing - Enhance life spans of BP products - Incorporate environmentally friendly additives into BP
Response from R & H:
Question 1C-2: How could we change the system to increase the use of BP in the future market without violating Sustainable Principles (SPs)?
BTH Bioplastic Thesis Group response to 1C-2: Since PLA is a major BP which can commercialize in many fields, new technologies in PLA production (e.g. PLA production from alternative biomass such as agricultural residues and organic wastes, less energy consumption in operation and PLA material recycling) will be available in the future. For the future common use of PLA plastic in the sustainable society, the BP industry needs to work together with governments and industrial associations to increase recognition of BP and build new systems to recycle materials such as: - A Universal labelling system for BP - New recycling and plastic waste management systems for BP in society - Global legal restrictions in recycling in the industry - Stable supply chain in renewable biomass (crops)
Response from R & H

2.2 Template 2. Product Concept and Design

<u>Guidance to answer</u>

When considering a product flow for this template, it is not necessary to describe detailed stages to become a product, as the purpose of the template is to give a company an overview of relation between a product and sustainability. Identify the major stages of production that could have highly impacts on sustainability. Focus on how each stage relates to the sustainable principles. For the future concept, consider the product design with reference to using backcasting: how would sustainable bioplastic look like in the sustainable society?

2B. Current situation

Question 2B: For each sustainable principle (SP), what sustainability benefits and challenges does the BP industry have from the current life cycle of PLA plastic production (1. Agriculture, 2. Raw Material Processing, 3. Manufacturing, 4. Distribution and End Use)?

BTH Bioplastic Thesis Group response to 2B-1:

Currently, PLA plastics are mostly produced from corn. Four Life Cycle stages (LCs) of PLA plastic production are identified to review sustainability: LC1. Agriculture (corn production to starch processing); LC2. Raw material processing (starch to PLA pellets); LC3. Manufacturing (PLA pellets to end products); LC4. Distribution, Use and End of life.

From Sustainability Principles' point of view, the following benefits and challenges were identified in each LCs.

Sustainable Principle 1

(Not systematically increasing concentrations of substances extracted from the Earth's crust)

<u>Benefits</u>

- High reduction of petroleum use in ingredients (100% renewable biomass to produce PLA) (LC3)

<u>Challenges</u>

- Use of fossil fuel in machinery and plant operation (LC1, 2 and 3)

Sustainable Principle 2

(Not systematically increasing concentrations of substances produced by society)

Benefits

- PLA products can recycle as a raw material and save virgin ingredients (LC4)

- CO_2 emissions in bacterial fermentation but carbon neutral (LC3)

- CO_2 emissions in combustion but carbon neutral (LC4)

Challenges

- Use of a large amount of fertilizer and pesticides (LC1)

- Major ingredient of PLA is corn produced in the US including GM corn (LC1)

- Manufacturing process highly uses biotechnology (LC2)

- Use of trace metals and petroleum in some additives (LC3)

Sustainable Principle 3

(Not systematically increasing degradation by physical means, and, in that society)

Benefits

- Reduce plastic waste in land fill sites due to biodegradability (LC4)

- Improve soil by PLA compost (LC4)

Challenges

- Decrease soil fertility due to mono-culture and loss of biodiversity (LC1)

- Degradation of water quality and resources (LC1, 2 and 3)

- Competition with food production and bioenergy source for land use (LC1)

- Contamination of landfill sites when decomposed due to petroleum based additives

and incomplete waste management to separate BP from conventional plastics (LC4)

Sustainable Principle 4 (Not systematically undermining people's capacity to meet their needs worldwide) <u>Benefit</u> - Creation of new business opportunities in a local community (LC1, 2 and 3) - Give consumers a better choice to live with sustainable manner (LC4) <u>Challenges</u> - Use of workers with poor labour standards from developing countries (LC1) - Fair crop trading for not conflict with the future food production (LC1) - Potential occupational health and safety issues (LC1, 2 and 3) - Over consumption of BP (Not encourage of disposal society) (LC4)
Response from R&H

2C: Future vision and solution

Question 2C: How could the life cycle of BP comply with SPs to measure actions?
BTH Bioplastic Thesis Group If BP is to be commonly used in a sustainable society, it should be designed to benefit society without negative impacts on biosphere. Sustainable BP design should comply with the following SPs: **SP1**: BP production should minimum amounts of fossil fuels and trace metals in operation and ingredients. **SP2**: Minimum use of artificial pesticides and fertilizers in feedstock production. BP should generate less CO2 when compared with disposal of traditional plastic waste and no hazardous substances should be emitted during combustion. **SP3**: BP has no negative impacts on ecosystems and human society when disposed of. **SP4**: BP production supports fair natural resource use (not competing with food production) and healthier biosphere to meet future human needs. For sustainable production of BP, there is a need to ensure a stable renewable source. The industry needs to ensure the safety of all ingredients in the product development stage. This could be possible by: - Using biomass alternatives by recycling agriculture production residues or organic waste from industries and households - Increasing material recycling of PLA - Using environmentally friendly additives or less use of conventional additives - Developing additives to increase the life span of products when it is required - Using renewable energy in production operations - Identifying priorities for use by society - Establishing global standards for safety of use in food packaging - Providing accurate information for use of BP by consumers
Response from R&H