Success factors for the adoption of bio-based packaging in EU food industry

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Abstract

This paper is written as a contribution towards a sustainable society in the context of bio-based packaging. A few decades back, the world was looking for processes that were efficient in terms of output and quality, but now the situation has changed. The world is looking for solutions which are not only effective and efficient but also are sustainable and positive for not just economics but also for the society. This paper is also an effort to elaborate the potential of bio-based packaging. However, this thesis covers the aspects presented by different key players along the value chain which increases the contribution of this thesis towards the real world.

Other motive of this paper is to give attention to the plastic waste accumulation in the seas. This paper will make use of Geels’s Multi Level Perspective theory along with Roger’s adoption theory to enlighten the key factors for adoption of bio-based packaging. Geels’s theory will introduce the concepts of evolution of a niche level product into a main stream market product. The evolution does not only depend upon the attributes of the product, it depends on many macro elements like landscape pressure or sudden change in the outside environment.

Different hypothesis or proposals are presented in this paper on the basis of Geels’s Multilevel Perspective (MLP) theory to demonstrate the possible situation for bio-based packaging product to be either accepted or rejected by the key players in the current regime. The most influential factors discovered during the research process are price, supplier strength and technological feasibility of bio-based packaging with the status quo.

The dilemma for the key players in this economically unstable situation is investment associated with the new packaging schemes and the incentives or business logic in bio-based packaging materials. Currently, the concentration of key players in this business arena is more on cost saving by making the process more efficient and product differentiation which somehow makes the road to success for bio-based packaging much narrower.

Nevertheless, bio-based packaging has shown great potential in terms of technological feasibility and improvement in price. If bio-based packaging opt economies of scale, price can effectively improve and make bio-based packaging competent. Bio-based packaging seems the legitimate solution for the thousands of tons of plastic waste accumulating in the seas of the world which is already having severe effects on sea life which will indirectly affect human health.

A few decades back, the manufacturing practices focused entirely on improving the ways that could help in achieving more quantities by optimizing the processing parameters. Today, the world has changed critical concerns like sustainability in context of environment and society has triggered the need of manufacturing practices that are not economically beneficial but also beneficial in context of environment and society. In the world of plastic, bio-based packaging products are considered to solve the issues mentioned above. This paper will highlight and discuss critical parameters that bio-based packaging has to counter in order to incorporate itself into mainstream market.
It was always a dream for me to get higher education from top universities in Europe. I thank to God for fulfilling my wish to do so. This master thesis is the last piece of the puzzle to accomplish my dream. There were ups and downs during the whole journey and I would like to offer gratitude to my family and friends for always supporting and encouraging me.

I would like to thanks INNVENTIA for offering me the opportunity to perform a market research. It could never be completed without supervision of Tom Lindström, Magnus Gimåker and Michael Novotony.

Never-the-less, I would like to thank the very kind staff of the whole IMIM consortium for supporting me throughout the Masters course.

Thank you all!

Shahzad Tariq

Stockholm, 05, 2013
NOMENCLATURE

Abbreviations

BAU- Business As Usual
BDG- Biodegradable
BP- Bio Polymer
CFC- Chlorofluorocarbons
EFSA- European Food Safety Authority
FDA- Food and Drug Authority
FMCG- Fast Moving Consumer Goods
FPIRC- Forest Products Industry Research College
GDP- Gross and Domestic Product
GHG- Green House Gases
GPPS- General Purpose Poly styrene
GPE- Green Polyethylene
GRAS- Generally Recognized As Safe
HIPS- High intensity Polyethylene
LCA- Life Cycle Analysis
HCFC- Hydro Chlorofluorocarbons
MFC- Microfibrillar Cellulose
NBDG- Non Biodegradable
PA- Polyamide
PCL- Polycraptolactone
PDO- Propanediol
PE- Polyethylene
PE-LD- Polyethylene Low Density
PE-HD- Polyethylene High Density
PET- Poly ethylene tetraphtl late
PEST- Political, Economic, Social, Technological
PLA- Poly lactic acid
PHA- Polyhydroxyalkanoates
PP- Poly propylene
PVC- Poly vinyl chloride
PVOH- PolyVinyl Alcohol
RCP- Resource Chain Product
RM- Raw Material
SME- Small and Medium Enterprises
SML- Specific migration Limit
SWOT- Strengths, Weakness, Opportunities, threats
TT- Technological Transition
VOC- Volatile Organic Compound
WEEE- Waste Electrical and Electron Equipment
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Climate change
"Too many leaders seem content to keep climate change at arm’s length, and in its policy silo. Too few grasp the need to bring the threat to the center of global security, economic and financial management. It is time to move beyond spending enormous sums addressing the damage and to make the investments that will repay themselves many times over”.

UN Secretary-General Ban Ki-moon
Remarks at the Council on Foreign Relations (February 2013)

Energy security
“The country that can make renewable energy sources price competitive with traditional fossil fuels will become the economic superpower of the future.”
US President Barack Obama
Energy Security Speech (Feb 2009)

Public interest in Sustainability
“Sustainable development means that the needs of the present generation should be met without compromising the ability of future generations to meet their own needs”
United Nations
Earth Summit (2012)

Sustainable Strategy
“Humanity has the ability to make development sustainable – to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs.”
World Commission on Environment and Development, 1987
The Packaging industry, today, relies strongly on the petroleum derived plastics which pose concerns to future in relevance with both economy and environment. Also, the scarcity of raw materials, pose a threat to the availability, cost of raw materials and there bio-degradability (Magnus et al. 2011). The EU market for packaging has a value of about 127 billion US dollars Euros and has about 40% of the global packaging market. The European packaging materials can be broken down as contribution from Glass with 8%, Metal 14%, Paper 42% and Plastic 36% (Global Packaging Alliance 2013).

It is important to remember that the role of packaging now revolves about around three concepts i.e. Environmental, Economic and Social, covering the aspects of sustainability. The recent trends in EU packaging market show an interest of moving towards, what is called ‘green’ packaging i.e. using recyclable materials, recycled materials, reduced material usage and polymers extracted from bio-mass. The accomplishment has been driven by EU directives for the evolution of eco-friendly packaging solutions in EU. Some of the few worth mentioning research groups that have an insight in packaging from renewable materials are Food Biopack project, SustainPack, SustainComp, SUNPAP, FlexPakRenew, RenerFunccBarr and VTT (Johanson et al. 2012)

Packaging has always been under discussion, criticism and apparently a “Quiet Revolution”. There is always a debate to redesign and discover new packaging materials, but the process on the whole is very complex. It involves the alignment of four key players i.e. Packaging Manufacturers, Fast Moving Consuming Goods (FMCG) Companies, Retailers and Government and Trade Bodies. The ultimate potential in this sector is not realized since the uncertainty faced by investors, due to legitimacy and legislation issues, is high in these turbulent and volatile economic situations. (Staffan Jacobson, 2008)

1.1 Background

Before starting the discussion on technological transition of emerging packaging technology, it is important to know about conventional packaging materials. They include monolayer PVC, perforated thin LDPE, LDPE/HDPE with EVA, Kraft paper, LDPE, HDPE, White pigmented PVC or PP, expanded PS, LLDPE, Shrinkable film, Regular net stocking or expanded plastic netting, PET, Molded paper pulp with a thermo fold plastic liner and sleeve packs (Clause 2009)

In order to counter conventional plastics, utilization of wood biomass as an effective raw material for a variety of products is an emerging field of research these days. Major components of fibers are cellulose, hemicelluloses and lignin. Pectins, pigments and extractives can be found in small quantities as well. Wood is treated under variety of conditions to separate and convert these components into various useable forms. Cellulose and hemicelluloses undergoes a number of physical, chemical and structural changes under such conditions (Eva Ålander 2013). Nano materials, which are derived from woods and plants, are not just easily accessible but also renewable does not have any direct effect of petro-chemicals on their functionality. Paper, is one of the most key packaging products derived from wood. Major constituents of paper are cellulose fibers obtained from wood by pulping processes. The packaging properties of paper i.e. physiochemical and mechanical, depends upon the process under which the fibers are being pulped. Some key applications of paper based packaging are rigid paper board containers, folding paper board cartons, composite paper board cans and corrugated fiber board case trays. Nano Paper produced from
nano fibrillated cellulose, is of great interest for the innovators because of its high effectiveness as an oxygen barrier (Eva Ålander 2013).

Recent studies have also shown the superiority of paper board over plastic or glass packaging for liquids (Food packaging Vol. 11). Keeping in mind the importance of sustainable packaging, the idea is to continue research in process technology with emphasis on new markets for packaging in Europe. The positive results have encouraged the research to be done on broader scale for countering conventional polymer based plastic packaging. (Patel et al. 2005)

“One very big challenge facing us towards 2020 is regulation for materials intended for food contact, which can be a problem for innovation, as it gets more complicated to get new chemicals used in materials and articles approved”- Kristina Salmen, legal expert of trade and industry group Normpack at Innventia

1.2 Purpose

An issue of particular concern is that giant masses of plastic waste which have been discovered in the North Atlantic and Pacific Oceans, the full environment impacts of which are not yet fully understood but which cause carbon storage reduction of the oceans as well as severe damage to seabirds, marine mammals and fish. Therefore, the development of biodegradable packaging has been extensively debated. A major impediment to biodegradable packaging is the lack of composting infrastructure (Jonathan et al. 2011)

Europe has always been a key player in driving the technology, to keep this culture alive, Swedish research and development firms and some forest based industries have started research and technological solutions for the demands of future. The focus has emerged on bio-materials, which when combined with the new technologies can contribute to the green environment and can result in sustainable solutions to the problems relevant to CO2 foot print or percentage of Aluminum in packaging as well. The following figure shows the evolution of plastic production in terms of volume per year. The comparison is made between Europe and rest of the world plastic producers.

Reference: Jonathan et al. 2011
The main concern of this Master thesis is related to the core concept of sustainability with reference to technology in packaging and its perception to the actors in the Value Chain, how they respond to it and explore the niches/potential markets for bio-based packaging, since the key players in the value chain have been under influence by the voice of customers. The major share of packaging lies in food and drinks industries which is a stable and non-cyclical market growing steadily and they mainly rely on metal and plastic compound materials. The following graph shows the major share of food packaging in plastic industry which motivates the purpose to do a research on this topic.

Reference: Global Packaging Alliance 2013

Sustainable development is becoming the core commitment to create shared value by increasing worlds access to the best quality available in food and beverages while focusing on staying being eco-friendly. The project is led by a Swedish firm, Innventia, a partly government industrial research company, with the aim to explore the niche in bio-based/eco-friendly packaging materials. Food packaging requires protection, tampering resistance and special physical, chemical or biological needs and is a large and complex market. Most, if not all of this, can be handled by bio-based materials. Focusing alone on the sustainable development of the packaging material is not enough and is short sighted. That is why the industry has increased the communication efforts to realize the pros and cons on the whole chain i.e. raw materials to processing to whole sale and retail to use and finally to disposal.

The project seeks information related to retailers, suppliers and the packaging industry perceptions about emerging bio-based packaging solutions. The current statistics of waste in oceans also indicates that all food handling industries will face a necessity to change their packaging routines due to sustainability reasons but also due to other mechanisms. We may here identify incremental as well as radical shifts, new functionalities, new roles for packaging etc. The thoughts of sustainable products do exist, but they are countered by long development times, uncertainty in the market and social acceptance.

**Research Question:** This paper will elaborate the information based on articulation of market with reference to evolution of a niche into a main stream market product by exploring the extent of articulation of market with reference to technology maturity, bio mass potential, waste management system and key factors e.g. price, life cycle assessment and application barriers. Hence, the research questions developed are

1) What are the factors that motivate the adoption of bio-based packaging?
2) What are the factors that demotivate the adoption of bio-based packaging?
1.3 Classification of packaging materials

Basically there are four types of packaging materials i.e. Primary packaging which is in direct contact with the food, secondary packaging which aims to attract customer’s attention, Tertiary packaging which includes corrugated boards and quaternary packaging which are containers. The project is limited to primary packaging (in direct contact with food) and secondary (conferring rigidity/advertising, info) packaging excluding liquid packaging and linerboard materials (tertiary packaging).

For the packaging materials, the key concerns or attributes they must possess to guard the material being packaged are microbiology, color, oxidation, structure, flavor, enzymatic degradation, photo oxidation and chemical changes e.g. hydrolysis, protein etc. (Innventia, Bifrost, Food packaging)

Schematic presentation of bio-based polymers on their origin.
Reference: Clause 2009
The concept of sustainability is very broad. In the literature the sustainability is referred to be mainly in economic, environmental and social terms. This project understands sustainability as meeting our needs for our present without compromising the future generation to meet their own i.e. reducing the environmental impact and being well to society while keeping Prosperity (Magnus et al. 2011)

At present the major resources powering the world’s economy are of nonrenewable origin, there will be a need to find and exploit new resources at some point in time (PlasticsEurope, 2011a). Even before this point rising prices for the limited resources and CO₂ emissions will draw attention to other alternatives, such as renewable materials (Oberstein et al. 2001; van Aalst, 2006). The replacement of non-renewable resources by renewable bio-resources is the basic idea behind the bio-economy, which is gaining popularity in the developed world at present (Stevens, 2001; Mohanty et al., 2002). From management and strategic perspective, a sustainable material is the one that is abundant in the nature, whose availability can be assured which does not jeopardize the material availability for future needs. A material which under goes cost efficient processes while making sure that the carbon foot print is not disturbed and a material which when subjected to waste treatment undergoes various recycling techniques to get the energy recovered from it or convert it to be used in some other applications again. Bio-degradability is an ideal aspect for a sustainable material to keep the loop of ‘Cradle to Grave’ closed for plastics used (Shen et al., 2009; Natureworks, 2009; Weiss et al., 2007)

It is very easy to define a sustainable material on a piece of paper. But it accounts for an extremely exquisite infra-structure mainly relying on technological strength, knowledge management and legislation. Research has proven the potential of bio-based or sustainable material. Never-the-less, there is a debate on Biodegradables’ sustainability claims (Stevens, 2001; Mohanty et al., 2002). From a sustainability perspective, a material should have a combination of degradability and renewability. Since, the resources of earth are not infinite.

Currently, all the manufacturing processes are almost completely aligned with the oil based economy. In order to inject the concept of sustainable material, it needs strong legislation policies, infrastructure relying on bio-based materials and the belief of customers in such materials. A material will not be able to survive in the market if it is unable to meet the needs/demands of consumers. Literature review suggests that there are two types of sustainability i.e. weak and strong. A weak sustainability based on apparently less sustainable material cannot eliminate the tradeoffs between social, economic and environment dimensions and they offset each other. The opposite case, strong sustainability bases on completely sustainable resources maximizes the benefits on each dimension and there are no silos between them (Magnus et al, 2011)

A sustainable material’s performance is measured in terms of its effect on ecology of the system. It must not provide any harm to the environment from the point it is extracted until it is disposed (post and pre-consumer waste) (Stevens 2002). In order to sustain, great investments in term of knowledge transfer is required. An economy based on sustainable material is actually a knowledge based economy. A sustainable material must be able to cope with the following challenges (Leadbitter, 2002).

1) Dependency on oil based resources
2) The total energy consumption
3) Carbon foot print/environmental concerns
4) Food supply security
5) Contamination caused upon disposal
Bio mass is considered to be a renewable and biodegradable (not every bio-based material is biodegradable), since it receives energy from sun, but only as long as the nutrients used for growth are returned back to the land (Shen, Worrell & Patel, 2009).

1.4 Delimitations

The scope of bio-based packaging products is huge and the nature of bio-based packaging products in terms of food packaging is diverse. This thesis will cover the adoption and rejection perspectives for bio-based biodegradable packaging materials. As, bio-based packaging materials are confused to biodegradable and compostable, this thesis will also help in distinguishing different categories of bio-based packaging materials and will focus entirely on biodegradable packaging materials. This thesis will elaborate the market perspectives for the adoption of packaging materials. There are many key factors besides the ones mentioned in this paper. They are not presented in detail, although they are mentioned in order to make the reader familiar with those factors e.g. customers perception about bio-based packaging, complementary technologies. The thesis is more focused towards economic and environment milestones in context of sustainability. The author is unable to mention key information regarding price and technological maturity from brand owners and suppliers due to the high it confidentiality, which made the author use secondary sources to pursue research. From a geographic point of view, this thesis is limited to European industry only. The results may or may not apply to other markets. Only key players in the industry are interviewed due to limitation of time.

1.4 Method

This section defines the structure and methodology to investigate the content of this master thesis. The research paradigm will be identified and argued upon. The aim will be to elaborate research question and methods adopted to achieve the goal. INNVENTIA has started a project to understand the perception of emerging new packaging solutions made by bio-based resources. The resources include agricultural and forest based raw materials. The rising plastic waste in oceans has forced the global community to think about a sustainable solution. INNVENTIA as a research institute has come up with various technologies that have the potential to replace conventional bio-based packaging materials. The thesis focuses on understanding the influential factors for adoption or rejection of bio-based (biodegradable) packaging. So, the project revolves around technology push by research institutes and understanding the pull on key players in the industry.

Currently, there has been no proper method adopted to understand the market demand at INNVENTIA. So, the method used for understanding the influential parameters for bio-based packaging is SWOT analysis obtained on the basis of surveys and interviews. The data for the thesis is collected from various sources i.e. scientific journals, books, INNVENTIA AB database and other relevant sources including Google Scholar, Wikipedia and library database from KTH and Stockholm universities. The research question formulated is completely in the interest of INNVENTIA’s for the field in which they opt to operate.

The choice of adopting this thesis is linked with the the author’s background in chemical engineering which focused on finding some unique, undeveloped and potential issue that is the next big thing in the coming times. The market analysis of bio-based packaging is fairly undeveloped. Most of the papers talk about the potential in the bio-based packaging. There are very few papers which discuss the market projection and current demand of bio-based packaging. INNVENTIA has developed potential products to replace bio-based packaging but lacks the understanding of market demand as already mentioned that there are very few
papers discussing about the market projection. This thesis however will be considered as a starting point to understand the market pull. In literature there are no specific theories to boost typical packaging products which may be considered as a risk. However, a blend of Geels multilevel perspective theory and Roger’s adoption theory is used. The contribution of both theories can be seen in the chapter of theoretical framework.

One of the conclusions in context of vision and scope of thesis is, it is like a balloon and it can be filled with as much air as one can wish. The scope of research for bio-based packaging is too vast. However, an effort is made to cover important aspects related to bio-based packaging in the design of problem formulation.

Bio-based packaging is an emerging product that is successful to grab attention of key players in the packaging industry. They are successful in pushing the technology but are facing problem in understanding the market pull. This thesis will also help other companies to understand the rhythm of market in packaging industry. A course on ‘Renewable materials and Green polymers’ (FPIRC) offered by INNVENTIA, has also helped the author in understanding the phenomenon deeply.

The research design opted by the author has the infra-structure in following order:

**Problem formulation**

The first step towards exploring the research question is pre-studying the context of need of bio-based packaging. The initial phase took more than 4-5 weeks. This has been the most crucial time of the thesis as it included the understanding of work ethics, the packaging terminologies and certification obtained at INNVENTIA. The course included lectures from professors belonging to different universities across Europe including some industrial experts. During the course seminars, the author had the opportunity to extract key information from important players. The pre-study period helped the author to structure, organize and prepare initial reflections about the problem. The unit of analysis covers both industrial and academic perspectives.

The aim of this investigation is to cover the perspectives favoring the incubation of such bio-based sustainable packaging materials in the value chain i.e. brand owners, FMCG, Suppliers and related institutions. Furthermore, considerable efforts will be given to judge how articulate is the framework when it comes to bio-based packaging with reference to Technological and design specifications, government policies, cultural and psychological factors, production network, market, environment, societal factors, Maintenance network and infrastructure. This thesis will also help in analyzing Innventia’s technical expertise and its competence to impact potential packaging markets and finding partners to co-evolve in such developments.
The problem formation has been completed with the help of both academic and company supervisors. The initial phase helped in understanding the underlying problems, review of some theories and finally after revising few times a final draft was made. The initial phase has been more of abductive approach i.e. using the existing knowledge to search for further facts. This included unstructured interviews with company representatives at INNVENTIA and a literature review. The literature review revealed some potential theories which may be related to the evolution of niche product like bio-based packaging. The selection of the theory was difficult but on the basis of naïve nature of bio-based packaging as niche product, a blend of Geels and Rogers is used.

Maximum contribution in this phase, from industrial point of view is the unstructured interviews done with INNVENTIA experts and literature review.

**Surveys and Interviews**

Surveys and Interviews (structured and semi-structured) have been the best option for the author to explore the present scenario for bio-based packaging and can be considered as a valuable contribution to the literature for bio-based packaging. More of the surveys and interviews were done after the first 4-5 weeks. The surveys have helped not only to elaborate the current situation but also to narrow down the problem. Surveys and interviews yielded many surprising facts which moved the adductive approach to deductive. It must be noted that literature review and surveys moved parallel to each other. The process of doing surveys and interviews was continued until the end of the master thesis in order to extract maximum information. All of the interviews were done in the presence of company supervisors Magnus and Tom.

In the initial phase in context with informal observation in the retail markets for packaging products, shoppers and containers, the semi structured interviews helped in envisioning the broader picture in packaging dynamics. The survey was sent to many companies in EU division (about 50 companies) which included both SME and corporate level companies. The questionnaire was designed in relevance with agreement from company supervisors to grab maximum useful information from the right market segment. The questionnaire comprised of both open and closed ended questions with a section where they can freely write their opinion.

Although the surveys were designed to extract information in order to formulate the questions for interviews more accurately but the response rate of surveys was very low i.e. 15%. The lack of respondents was mainly due to unavailability, busy schedule, reluctance reply and less or no knowledge about the bio-based packaging. The author relied more on the willingness of the respondents and did not pressurize or forced them to reply. On the other hand, the questions can be perceived to be in wrong direction due to probably not stating the question in the right way. The ill formatted questions can be misleading and result in decreasing the accuracy of the information required. On the basis of results obtained by surveys, empirical analysis was made using secondary resources. The key elements obtained from surveys are

1) Price
2) Technological maturity
3) Raw material supply
4) Application barriers
5) Complementary technologies
6) Legislation
All of the structured formal interviews were conducted along with a well-designed presentation (under the supervision of company supervisors). The interviews were mainly held in Sweden due to geographic edge. The presentation was designed to enlighten the audience with the background and motives of the project and then take their feedback on issues. It must be noted that the questionnaire formulated after semi structure interviews and survey results was not completely used in meeting company officials in person. The formal interviews were conducted more in a way that what key players are looking for and how bio-based packaging is beneficial or useless for them. The interviews were of qualitative nature with the author’s knowledge more relying on literature review and knowledge provided by INNVENTIA. Other structured interviews were conducted on telephone due to time shortage or visa issues.

**Case Studies**

Case studies have been a major contribution to this thesis too especially, in drawing the results for life cycle analysis. This methodology has helped the author in understanding the evolution of niches in different industries. The understanding of most important elements for a niche to take over regime was also developed by case studies e.g. the watch industry, ship industry, sewerage system in France etc. This qualitative approach helps in empirical inquiry that investigates a contemporary phenomenon with its real life context, when the boundaries between phenomenon and context are not clearly evident and in which multiple sources of evidence are used (Yin, 1984).

The case studies have helped in context of determining and defining the research questions, selecting the relevant cases and determining data gathering and analysis techniques, preparing to collect the qualitative data and analyze the data to prepare the final reflection from case studies.

**Reliability and Validity**

Reliability is the measure of the extent to which the same results can be achieved by repeating the same procedure adopted to obtain results earlier (Collin and Hussey, 2009). This is a complicated issue as; the author received different responses for the same question from different respondents. So, there is a high probability that if the interviews are extended further with more interviewees the response may vary altering the reliability of the thesis. The interview process included interaction with people at different managerial posts, so it can be assumed that company representatives in the same professional category may have similar opinions.

The validity is the measure of the alignment of the empirical results with the problem formulation and research question (Collin and Hussey, 2009). The validity of this paper can be assured by different chapters written which are linked with each other for exploring reader’s knowledge about bio-based packaging.

**Implementation**

In order to extract the valuable information necessary for this project, the strategy adopted by the author in correspondence with the academic and company supervisors was to conduct extensive surveys based on an exclusive questionnaire mentioned in appendix A. After the conduction of surveys, structured and semi structured interviews were conducted with different key players in the value chain. The interviews were conducted with different players in order to understand different perspectives from different sources along the value chain. The companies interviewed are mentioned in appendix B.
In terms of food packaging companies, the list in huge. The strategy adopted was to interview key players with major market shares in market as they are the trend setters and SME’s follow them. The general framework for implementation of strategy opted can be seen below.

The framework adopted for the implementation is completely aligned with the research framework chosen. For the adoption of niche level product like bio-based packaging, key players involved in the current regime are mentioned in the value chain mentioned above. It is of sheer importance to understand the current dynamics of packaging materials and attributes associated with packaging. SWOT analysis is conducted, based on the interviews and surveys conducted, which clarifies the two most important aspects for this thesis i.e. raw material supply and brand owners.

To improve the quality of the results in this thesis, case studies which show the healing of niche level products into strength have played a major role. The contribution of case studies is already mentioned in the research methodology part. The list of the companies interviewed is given in Appendix C. The results obtained are mentioned in the chapter results. It was intended to use analytical tools to assess the key factors contributing to adoption of bio-based packaging. Due to two reasons, the idea was dropped and the qualitative analysis was focused on i.e. low sample size for statistical analysis.
This section links the theoretical explanations in the literature with the problem associated with this thesis. This section will explain different concepts in innovation and then narrow down on the core issue.

In the literature, there are many theories which explain the mechanisms of technological transitions. Few of the most important names are Kemp, Dosi, Jacobson and Geels, especially Dosi, who is the guru in explaining the technological regime shifts and their trajectories. This paper will try to relate the concepts discussed by different authors in reference with technological transitions. Concepts like technological system, technological innovation system, demand pull, technology push and the influence of key players and their impact on the process of transition in terms of supporting or resisting the transition process.

The discussion will begin by Dosi, who writes, "A technological paradigm has a powerful exclusion effect: the efforts and the technological imagination of engineers and of the organizations they are in are focused in rather precise directions. While they are, so to speak, 'blind' with respect to other technological possibilities" (Dosi 1982)

There are two possible reasons for the exclusion effect i.e. the engineering beliefs and the ex-ante “before the event” selection, but also the process of coupling the variations and selection processes are insufficiently developed. The few barriers faced by new technology are:

- Technologically, a proto-type or a new sustainable product may require complementary technology to be used, which may be expensive to use. Further, the new technology may not fit in the currently used technology. It will need to be further developed, optimized and re-designed. The unforeseen design specifications sometimes end up ruling the new idea out (Kemp 2007)

- It is important for the government to make technology policy based on a clear view of the future to guide technology developers, planners and investors towards sustainable development. The existing regulatory framework may actually form a barrier to the development of new technologies which derives uncertainty in the minds of manufactures about the market and hence negates investment (Geels 2002)

- The perceived image of the product is of sheer importance. How the consumers perceive the product will tell their willingness to pay, preferences, aversions and demands. New products are often expensive because they don’t undergo dynamic economies of scale for which it needs a commendable customer base. The unwillingness of customer to pay for the new product is one of the biggest barriers (Abdul Muhmin 2007)

- The risks associated with the cumbersome process of developing a proto-type to mass product that consumer may not be interested in buying it, negates the manufacturer’s attention. A new market might be created but the incentive is too low to be considered. In these economically turbulent times no company is trying to ruin their core competencies superfluous. It’s not just about the investment in the product; it’s about the whole production factors which include many other actors (PWC 2012)

The normal practices adopted by the companies are:
1. Cost leader-ship: offering the products at the most competing prices
2. Product differentiation: Offering exclusive products, enchanting the brand
3. Niche markets: Exploring new small segments in markets and serving the limited group of customers. (Kemp 2007)

According to the interviews with the key figures in Plastic industry, the reasons offered not to switch to bio-plastics or new sustainable products are insufficient capital, lack of economies of scale, lack of co-operation in the network as it has become more about the market competition, lack of technology and regulations. A very common and simple barrier to think is the lack of infrastructure, as the new technology will require strong maintenance infrastructure. The point to ponder is who will be responsible for the development of whole infrastructure; will it be the government or the coalition itself? Next question being, how the costs will be covered?

The following model is based on the philosophy of Geels’s proposal of evolution of a niche level product into a mainstream market product. The folding/unfolding refers to the idea of incorporating the product (in this case bio-based packaging) with crucial parameters like price and quality to make the bio-based packaging competitive with petroleum based packaging.

The Green circles represent the voids left by the current technology which acts as “Incubators” or “Protected Spaces” for the new technology where it can be breed. The dotted lines represent the complex network of Technology, User practices, Market domains, Perception of technology, Infrastructure, Industry Structure, Regulations and Techno-Scientific Knowledge. The red lines emerging from green circles present the possible mechanism of development of Niche. It can be divided in three steps. (Schot et al., 1997)

1) Technology creation
2) Technology forcing
3) Technological maturity

The interplay between the controlled and uncontrolled variables in the process can be perceived as quasi-evolution in which one has no control over the allocation of the treatment or other factors being studied. Schmookler relates it as “High correlations between two variables are often the result of their joint dependence on a third variable. The size of industry may be the third variable in this case, Thus it may be argued that investment and invention will tend to vary directly with the size of industry” (Schmookler et al., 1989). The R&D and production policies are highly influenced by the innovator organizations and hence turning the external environment selection in their favor to control and promote a particular technology. The technological regime for the bio-plastics needs to encompass both the
paradigmatic framework of the engineers and the external selection environment for technology (Kemp 2007)

Technological Transitions (TT) are not only about technological changes but also changes in the complete infrastructure i.e. consumer practices, policies, Industrial network and perception of technology. It is a “seamless web” embedded with physical artifacts, natural resources, scientific elements, organizations and legislative artifacts to achieve functionalities. The configuration for a radically new technology will only work if the heterogeneous mixture of elements is aligned and linked together (Geels 2001)

Radical innovations often include technological transitions that are based on either constructive innovation or destructive innovation. Managing such innovations from the point of incubation to actually enhance them commercially requires some technological model for change (Tushman and Anderson 1997). There are several gurus who have mentioned in their theories about technological transitions e.g. Dosi explaining the technological paradigms, Geels talks about technological transitions in terms of elements from socio-technical configuration, Abernathy/Utterback model for managing innovation through cycles of technological change and Roger’s diffusion of innovation theory for investigating factors hampering or resisting the adoption of a certain innovation.

Frank W. Geels presents the discovery process of a niche as a multilevel perspective i.e. technological niches, socio-technical regimes and socio-technical landscape, in which he states that TT occurs as result of linkage between progress at multi-level and thus the tension between these levels create to what is termed as “windows of opportunity” for niches. These windows of opportunities are protected spaces insulated from the market and act as incubation rooms where the technology can foster. Elements at the regime level stabilize as the bond gets stronger. The bond is tightened by different actors involved in co-ordination and alignment. (Geels 2007, Schot 1998).

With reference to the bio-plastics and the technological regime, both of the technological evolution theories must be embedded with the strategies chosen by the strategic actors (suppliers, government, manufacturers and consumers) to impose a socio-technical change. If the socio-technical thought for technological change is narrowed by embedding existing technology in a technical system, production techniques, consumer behaviors/patterns and engineering values, it will create economic and cognitive barriers for a new technology. This embedment and regime optimization rather than regime transformation is one of the main reasons that many even useful creations stay in the shelf which actually asks for change in both sides i.e. the supply and demand.

According to Rosenberg and Fransman (1990), “firms have a restricted technological horizon and a bounded vision, which serve to focus their exploratory activities upon problems posed by the existing product”

For obvious reasons, firms in packaging industry will try to re-optimize and re-formulate their existing products rather than risking investing into radically something new. (Rosenberg, 1976)

Radical Innovations often emphasize on a certain specific element of a technology originating from the sociology of the technology (Geels 2001). Technologies with such disruptive/destructive innovations are ‘powerless’ and several artefactual factors e.g. legislation, research and development facilities must combine together to reach a specific goal. Geels relates the transition of radically new technologies as a change from one configuration to other. The reconfiguration process is not easy as the configuration alignment
of status quo is strongly linked (Geels 2001). Radical/discontinuous innovations are that break through innovations which advance by on order of magnitude the technological state of art which characterizes and industry and they are competence destroying (Michael and Philip, 1997). This relates to the fact that new technologies have technical limits inherently higher than the previously dominant technology. It will not be unusual if bio-based packaging methodology faces some resistance as radically new innovations have to face strong resistance against the already underlying infrastructure, legislations and user practices (Freeman and Perez, 1988).

In order to understand the inertia of the evolution of technology, there are two views. The first view based on Nelson and Winter’s concepts defines the evolution as process of variation, selection and retention (Geels 2001). The second idea is based on Schumpeter’s view of evolution as a process of unfolding and creating new combinations (Schumpeter. 1934).

Multilevel perspective (MLP) theory interprets the concept of technological transition in terms of alignment between multiple levels as a result of development between several different artifacts e.g. legislation, research, user practices etc. (Geels 2007). Geels has explained MLP on basis of three heuristic analytical concepts i.e. nice innovation, socio-technical regimes and socio-technical landscape.(Geels 2002)

As, this paper focuses on regime shift from status quo plastic industry to new bio-based biodegradable packaging, the focus will stay on the regime level and important factors that may influence interaction with other two levels.

The socio-technical regime by Geels is actually an extended version of concept presented by Nelson and Winter’s (1982) technological regime which presented the idea of shared experimental, subconscious and subjective routines in technical world and enlightened the development of technological trajectories. The major reason for adopting Geels’s MLP theory to elaborate transition phenomenon for bio-based packaging is that it takes in account not only the scientists, policy makers and users but also special interest groups that contribute to alignment of technological development e.g. social groups and their influence on the alignment of landscape. In terms of socio-technical regime and in context of cognitive routines, bio-based plastics suffer resistance as technical aspects are major barrier. They are blinded by the existing trajectories (Nelson and Winters 1982) in terms of regulations and standards, policies, adopting the life style in technological developments, stuck with the dominant technology and there competencies (Tushman and Anderson 1986).

Niche innovations such as bio-based packaging suffer not just weak structuration but also in terms of cognitive routines which are not well defined. The reason behind is probable arrival and departure of actors continuously from the regime and debate on the specification of the dominant design depending on policy and measures which will ultimately alter user practices. The main responsibility is on the shoulders of key actors in the regime to strengthen the niche. (Kemp et al., 1988)

However, on the socio-technical regime level, the structure is well articulated and completely aligned as the infrastructure in terms of policies, supply chain, market domains, maintenance and customers are well developed. Cognitive aspects are stable unlike niche innovation as the dominant design is already developed and agreed upon by all key actors in value chain.

Niches or discontinuities like biodegradable packaging products emerge from micro level which literature refer as a point from where radical novelties emerge. Being novel, initially the green packaging scheme will suffer unstable structure with performances very low as compares to status quo. The niches act as insulated breeding chambers allowing them to grow
against main stream market. It must be noted that niches have to grow in the same frame work i.e. the frame work of petro based plastics (Schot 1988).

MLP argues the transition comes by interaction between processes at three levels

1) Niche innovation builds up internally. They grow stronger in terms of most influential factors to be adopted e.g. price, functionalities. The strength comes from learning process and knowledge management. The support of powerful groups is also very important.

2) Any change at the landscape level will influence the activities at regime level i.e. positive or negative depending upon the pressure received.

3) Any disruption at the current regime level will create an opportunity for radically new product at niche level (Geels 2002, 2007)

If these processes are aligned, the novelties can intercept the status quo products in main stream market i.e. in this case the petro based packaging products for food and the can compete with the existing products. Actually the current socio-technical landscape has created an external environment which the niche product cannot influence directly. The change will how ever take time to come. Most influential impact can be created by legislative actions and macro-political developments.

However, MLP theory can be criticized on two general points. First criticism concerns the empirical and analytical level. It is unclear that how it may be applied empirically as socio-technical regime has several empirical levels. In bio-based packaging, on system as whole there are multiple levels e.g. production, distribution, and energy consumption. So, a regime shift at one level might appear to be an incremental change in the context of input to other regime levels (Berkhout et al., 2004)

The second criticism being is the limited tendency of MLP to integrate agencies. MLP is over functionalistic (Smith et al. 2005). It relates to the fact that MLP can be treated on a much broader perspective involving more rational actors forming a more colossal process over all. MLP is also accused of being too descriptive and structural which leaves a space for analysis for other influential factors too. In bio-based packaging system, MLP apparently may not count for the complementary technologies e.g. distribution channels, brand image, lead time of the technology to the market.

According to Smith’s regime theory the regime shift occurs as a result of internal or external pressures which causes a ‘downward to upward’ movement of a bubble. The apparent conceptualization of this theory is the same as MLP. So, bio-based regime shift scenario will undergo two steps.

1) Internal resources: Making the regime strong inherently by removing the pressure from the critical selection pressures like taxes, regulations and competition.

2) External resources: Optimizing the coordination of internal and external resources of the unit in order to get the maximum strength to counter the pressures.
The above matrix clearly states the functional achievements in different quadrants. ‘Endogenous renewal’ occurs when regime actors put highly planned and coordinated efforts by utilizing the internal resources like tangible, intangible assets and organization’s internal capabilities, when received pressure. The ‘purposive transition’ takes place, when processes occurring in exogenous environment are coordinated efficiently. Reorientation of trajectories is the result of regime undergoing extremely unprecedented situation/shock followed by low response of involved actors in regime in context of internal resources. Emergent transformation occurs when high selective pressures results in uncoordinated actors by regime actors (Geels 2007)

It is true that if bio-based packaging on the whole as a system is considered, it may be nested in to several levels e.g. production, packaging material classification, energy utilization, carbon dioxide footprint, total energy utilization or total shelf life. But, empirical levels like these are not similar to analytical levels of MLP. Actually there are different institutional theories offering different explanations to functionalize the organizations which make the total picture complicated e.g. individual, organizational sub system, organizations, organizational population, organizational field, society, world system. The complication can be solved by first delimiting the scope of the phenomenon to be analyzed on empirical level. The advantage of analyzing in this way is, it will not only direct the focus on status quo, there infrastructure and alignment but also the total picture of the relevant actors (DiMaggio and Powell 1983).

For the second point i.e. the bottom up bubble, it is considered to be biased towards novelty and its journey in the ‘innovation’. The criticism points on the strategic niche management which can bring about the technological transitions if niche innovations are well developed within the framework of SNM. To counter this perspective of MLP, it is worth mentioning that “More explicit attention needs to be paid to ongoing processes at the regime and landscape level” (Geels 2002). Also, MLP divides the total regime shift into different levels where the interactions can be studied much properly unlike Smith’s ‘selection pressure’ in which all processes are included.

Reference: Berkout et al. 2004
Above is a classic framework for MLP proposed by Geels and the problem using this picture can be in terms of not mentioning some important actors. The diagram is an explicit representation of a typical technological transition over a time period. As mentioned earlier, the technological niches have to emerge and grow in the same framework as the socio-technical regime did. Both, niche and status quo regimes have their own, what is referred to as ‘organizational fields’. The stability in the organizational fields is measures in terms of strength in coordination, articulation of infrastructure and the rules. The infrastructure also includes the rules and especially the user practices. For the status quo the organizational fields are much more established and strong. For the niche innovation, the fields are unstable and ‘under construction’.

Following the Geels’s MLP theory of technological transition, the rules defined for the organizational fields can be divided into three categories i.e. Regulative, which refers to the standard regulations and policies. Normative rules counts for the establishment of relationships, norms and values. Cognitive rules refer to logical, cerebral, subjective and intellectual beliefs.

Reference: Geels 2002

Emergence and Breakthrough of regimes

Reference: George Papachristos 2011
Under the conceptualization of MLP (Geels 2002, 2007), the important points to be noticed are:

1) Actors tend to be involved in their own interests and tend to act ‘strategically’ in a way in which they can calculate the best possible ways to achieve their targets.

2) Cognitive attributes for niche innovations play a vital role in establishing relationships with other actors in the whole regime.

3) Rules are actually defined by the actions and reactions of the actors in the value chain.

4) Niche innovations can grow into a socio-technical landscape not before they create strong social networks and becoming more stable in terms of infrastructure.

5) Niche innovations create an impact on landscape through sociological structuration. The impact indicates actions in terms economic and technical progression i.e. strategies that attract investment funds for R&F and overcoming technological barriers.

6) The actors are constrained in a ‘boundary’ by the rules i.e. cognitive, normative and regulative.

7) Even though the game is structures, still a turbulent can be created within the frame as the ‘game’ includes entailment of huge resources of a firm.

So far the internal dynamics of the niche innovation and socio technical regime are discussed that can create a favorable landscape for bio-based food packaging. The endogenous factors i.e. the external environment cannot be neglected. The whole regime shift is analogous to a ‘biotope’ environment comparable to soil, trees, mountain ranges and rivers. The ‘biological evolution’ will not come as far as the local conditions are static. As soon as the external dynamics i.e. the temperature, rainfall patterns or storms change their patterns, the socio technical landscape will be affected.

However, the factors that create help the external factors to create an impact on landscape are categorized as:

1) Factors that remain static and do not change or the time consumed by them is too long.
2) Factors that create a rapid change followed by panic in the environment
3) Factors that create a long term change. (Van Driel and Schot 2005)

The external changes that impact the landscape and create windows of opportunities for the niche innovations to evolve are classified in terms of frequency, amplitude, speed and scope

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Amplitude</th>
<th>Speed</th>
<th>Scope</th>
<th>Environment change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Regular</td>
</tr>
<tr>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>Hyper turbulence</td>
</tr>
<tr>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Specific shock</td>
</tr>
<tr>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Disruptive</td>
</tr>
<tr>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Avalanche</td>
</tr>
</tbody>
</table>

Reference: Geels 2007

Frequency: it refers to the changes in the environment per unit of time
Amplitude: Deviation from the origin due the change in the environment
Speed: Acceleration of change in the environment
Scope: Measures the number of elements disturbed due to the change in the environment.

The above table indicates various types of external environmental changes. The regular change which is low in all aspects of critical factors is an indicator of a moderate and progressive change. It also indicates a stable market followed by small incremental changes.
unless experienced by a radical entry. Hyper turbulence is caused by high frequency and speed. It happens when a radical innovation starts to create an impact on the regular market stream or when under the influence of severe competition. Specific shock refers to high speed and amplitude. This change is very rare. It may or may not let the dimension affected to come back to its base line/origin. Disruptive change how ever happens sporadically and slowly. It shifts the direction of a ‘specific’ dimension completely. Avalanche change, which is very scarce in its nature, creates a huge impact in terms of amplitude, speed and scope. The changes needed to inject bio-based food packaging may be triggered by avalanche change.

2.1 Timing of the Interaction

After discussing the internal and external dynamics for the regime shift under MLP theory, now this paper will address the critical timing of interaction of landscape and regime in context of niche development. Under the influence of external changes, the landscape may create an opening for niche innovation as the regime will be interrupted. The critical factor here is the timing when the landscape creates ‘pressure’ on the regime. At that specific time, the niche may or may not be stable or fully developed. Depending upon the situation of niche growth, the transition will take different path ways. However, it is very subjective discussion whether the niche is fully developed or not at the time of interaction. Different actors involved in niche innovation have different perceptions in this regards. The indicators set to measure the development of niche are (Tushman and Anderson 1996)

1) A dominant design has emerged i.e. learning process is fully developed
2) Involvement of influential actors to strengthen the cast of coalition
3) The desired functionalities are achieved
4) The market adopts the niche product i.e. 5-20% of market share will create a self-sustaining diffusion process. (Rogers 1996)

According to Rosenberg and Fransman, “firms have a restricted technological horizon and a bounded vision, which serve to focus their exploratory activities upon problems posed by the existing product”. This indirectly refers to the situation when niches are in there ‘embryotic’ state, a stage where they are novel in their nature and pose no pressure on the regime. The external pressure on landscape may create an opening for niches, if the niches are not structured enough to take advantage of the opening the regime actors will take actions to close it.

2.2 Types of Interaction

This section will try to elaborate if in the process or producing a favorable landscape for bio-based packaging, the relationship between niche level and landscape either helps or distorts the building up process. This section will try to assess the obstreperous or strengthening nature of the interaction and develop four propositions.

Note: The below hypothesis is drawn on the basis of Geels MLP theory.
Proposition 1: If the landscape experiences no external pressure, then the regime will remain effectively stable.

Explanation: Niche innovations although exist in a competing mode with the current regime, but it needs an opportunity to break through. It is not possible if the regime remains dynamically stable. Even if there is a problem incurred with in the regime, it has enough potential to counter the problem and stabilize the regime again. The stability of the regime
does not mean that it undergoes zero dynamics e.g. internal competition within the existing industry (Porter 2008), join ventures, alliances, investment in a new product development, etc. The differentiating factor with the changes in existing regimes is that all processes takes place in already ‘defined’ set of rules and boundaries. The end results can be predicted to a great extent. Besides, the incremental changes also enhance the performances of the products existing in current regime. (Rosenberg 1982). This type of pressure may be referred to as ‘regular change’

Regular change  
(Symbolic representation of regular change)

**Proposition 2:** If there is an abstinent pressure experienced by the landscape, at the moment when niches are not fully developed, the regime actors will adapt strategies to transform dimensions of development and innovation.

**Explanation:** Unlike proposition one, this case refers to moderate pressure exerted on landscape. This pressure forces regimes actors to devise strategies to avoid deviation of the main stream market from their interests. This case refers mainly to disruptive changes. External pressures received on landscape may be neglected by the regime actors but thanks to ‘outsiders’ such NGO’s and social groups working for environmental sustainability (specifically for our case), may force the regime actors to think about the disruption/irregularity considerably. These ‘outsiders’ may also include scientific and engineering experts that may confront technological abilities of current regime. This pressure will activate regime actors to find reasonable alternatives to the problem and the consequent actions may change the course of innovation (Smith 2005).

Disruptive Change

However, the changes at regime level under the influence of external pressure and criticism do not come by easily. It involves difference in opinions, combats in terms of better ideas or influence of power to maneuver the situation. Regime actors may or may not, depending upon the situation, will ‘intake’ knowledge existing in selection environment that created pressure as competency-add-on factor. The add-o factor may reinforce the path of regime to grow into new ways making the older ways expired. Never-the-less, the basic edifice remains the same.

**Proposition 3:** If the landscape experiences a sudden external change of large amplitude, the value chain will be de-aligned. The niche innovations will only find a chance to be substitute, if they are ready otherwise multiple niche innovations will compete and finally a dominant design will emerge.

**Explanation:** This is a special case for which external change is referred to as ‘avalanche change’. The landscape is under great pressure which has potential to destroy the alignment of value chain. Ultimately, regime actors may lose their belief in core architecture and model of the regime. This will leave the regime weaker and create an opportunity for the niches to incorporate the vacuum. This ‘hollowness’ will create an uncertainty about which dimension the innovation should proceed to. Probably different directions to proceed will be e.g. technical abilities, user preferences, process optimization etc. Departure of the regime actors will leave the regime defenseless and exhausted. In this situation, regime will go bankrupt as R&D investments will be declining.

From the niche innovations perspective, the actors can act as opportunist and take advantage of this situation only if the niches are developed to substitute the products in main stream market. Otherwise, the absence of a viable alternative will lead to emergence of multiple
incipient niches. The formation of a new socio technical regime is a prolonged process followed by coexistence of many niches. The niches will compete on basis of superiority in technology, design, sustainability, market share etc. (Tushman and Anderson 1996). The change in regime dynamics followed by avalanche change faces many challenges. Few of the most important challenges that will be discussed in the later part of the thesis are

1) Price
2) Raw material availability
3) Technical feasibility
4) Lead time to market
5) Agricultural -Forest Industry/management
6) Complementary technologies
7) Innovative designs
8) Customer’s attitude

Proposition 4: If the niches are fully developed and the landscape experiences strong pressure, niche innovation will overtake the existing regime.

Explanation: This proposition is valid under the assumption that in the way of transition, niches have fully developed and have the potential to replace the existing regime. The possible reasons of niche’s failure to overtake might be ‘locked’ surface of the existing regime or the regime may be dynamically stable. The absence of landscape pressure enables the regime to reproduce itself by means of incrementing innovations in mainstream market.

Avalanche or specific shock creates enough pressure on socio technical landscape to create an opening for the niches to incorporate in the mainstream market and completely replace the dynamics. The regime actors in this case will try to sustain their position by investing more in the existing regime and try to block ways for niches. Niches will diffuse through the ‘perforations’ created in regime due to the landscape pressure in accumulated form. The actors in niche innovation will try to influence mainstream market by pushing the technology against regime actors that will still be trying to create demands. The discussion on technology push against demand pull is in the later chapter. The existing regime will disappear de-align and re-align with niche innovations.

2.3 Technology Push vs. Demand Pull

For every inventive activity there has been always a “prime mover” for the innovation. As noted by Rosenberg and Mowery, the prime mover is the supposed recognition of needs. The emergence of need is completely related to the invention, first comes invention then comes the need. The proper innovative process begins when consumers reveal their needs either based on anthropological or general terms for a special product, the manufacturers realize the utility function and bring in improves innovated products and yet again monitoring the consumer behavior. (Dosi 1982)

Never-the-less, government led policies play a vital role in the complex interplay of Demand Pull and Technology Push conundrum. The Technology Push explicitly defines the advancement in science and technology as core of determining the rate and direction of innovation which envisions innovation as incubation of knowledge from basic science to applied research to product development and finally to commercial products (Bush 1945a, b). This gives the notion that in order to push a technology, the firm must invest in scientific knowledge in order to arm themselves with knowledge and explore the emerging opportunities from the conventional state of art model (Rosenberg, 1982, Cohen and
In order to encourage Technology Push scenarios, such policies should be designed which reduce the cost of firms producing innovations, government funds for R&D, Tax incentives for companies to invest in R&D, Improved Knowledge management, Supporting training and funds for demonstration projects (Jones and William 1998).

In short, the government can induce innovation by two ways (Nemet 2009):

1) Alter the economic incentives infra-structure. So, the investors gets pay-off well (demand pull)
2) Providing financial support, hence reducing the cost of producing Innovation (technology push)

On the contrary the technology push lacks consideration of prices and economic volatility. A major critic is the misalignment of unidirectional progression of innovation, which is incompatible with the subsequent work which emphasizes problems, interactions and networks. (Kline and Rosenberg, 1986, Freeman 1994, Freeman and Louca 2001)

On the other hand, the Demand pull theory relates innovation completely with the demand which steers the Innovation (Rosenberg 1982). Factors like prices (Geels 2002), Latent demand (Schmookler 1989) and potential new markets (Nemet 2009), all play a key role in successful pay off of an investment. In order to induce the demand pull policy, the policy must be equipped to make sure that it triggers demand for a technology, increased demand in future and higher pays off to improve technology (Nemet 2009). However, the critics have been hard of demand pull theory on the basis of three points:

1) The dominance of a specific technology and convergence of market to that special technology, which limits the scope of innovation
2) The longevity of the dominant technology at ‘that’ time limited the innovation since it will take years to pay off the investment made in it.
3) Lack of interest in R&D funding and weak presidential engagement.

Neither Demand pull nor Technology push alone can foster a technology; both must co-exist in order to make a technology survive (Nemet 2009). Since technology push fails to account for market opportunities and misalignment with the current technology and demand pull ignored technological capabilities, so the process of innovation cannot be totally reduced to two causal factors.

3.0 Rogers Theory

For a technological discontinuous break though like bio-based (biodegradable) packaging product, Geels theory for technological transition and Rogers diffusion of innovation theories are the most appropriate to be defined as framework. Frank Geels theory motivates the factors to be addressed in terms of socio-technical configuration. Rogers’s theory motivates “the technology as a design for instrumental action that reduces the uncertainty in the cause-effect relationships involved in achieving a desired outcome” (Rogers 2003). Both theories complement each other in context that different niches are competing to emerge as a dominant product to capture the socio-technical regime. Rogers’s adoption theory complements and notifies the important attributes that must be owned by niche product to owe in order to conquer the battle. Rogers’s theory is more explanatory towards the demand side which can be a negative point for using this theory solely for the explanation of adoption of bio-based packaging. To counter this problem, a blend of Geels’s MLP theory and Roger’s adoption theory is used.
### 3.1 Relative Advantage

Relative Advantage accounts for factors that will actually elevate adoption of certain specific technology and add more value over the competing technology. According to literature, the relative advantage is the degree to which an innovation is better than its precursor (Moore and Benbasat, 1991). The ultimate effect of relative advantage could possibly end in either financial benefits or non-financial benefits e.g. brand image. Creating financial advantages are directly related to the end consumer, if they are willing and are convinced enough to pay extra premium for the bio-based products (Autio et al., 2009; Abdul-Muhmin, 2007; Diamantopoulos et al., 2003; Laroche et al., 2001). For a product that undergoes a radical innovation, the first challenge it faces is that it has to disrupt the subconscious purchasing pattern of the consumer (Abdul-Muhmin, 2007). A commodity product like packaging will not threaten the core business model of a company; such innovations often are entangled with ignorance (Gilbert 2005)

Consumers are mainly concerned with the products content inside the packaging and they do not normally care if the packaging is environmentally friendly. Still, according to Innventia 2020 projections and some literature, there is willingness in consumers to pay premium over current prices and ecological concerns may become an influential factor for purchasing decision (Rhör et al., 2005; Grunert, 2005)

However, the complex dynamics of major distributors and brand owners of key concern. In the start phase of an innovation trajectory, the benefits seems to be overwhelmed and uncertainties and risks are often underestimated (Alkemade & Suurs, 2012) e.g. Wal Mart’s complete unwillingness to pay more for bio-based products over conventional plastics (Wal-Mart, 2007), brings to attention the Porter’s strong bargaining power over suppliers (Konefal et al., 2007; Fuchs et al., 2009; NY Times, 2006). In contrast, Coca Cola’s proactive approach to launch bio-based plastics (Coca-Cola, 2011) show there strategic approach of not using their strong brand power over the distributors.

The non-financial benefits are however related to legislative benefits, as discussed earlier in the demand pull section. But the role of legislation so far has not been very effective (Wydra, 2012; Hermann et al., 2011; Gillespie et al., 2011). According to Innventia experts, one such non-financial advantage for switching to bio-based products could possibly be the title of leading innovator in the market i.e. related to brand image. If the market later on switches to bio-based packaging products, the companies who have already made investments in bio-based packaging or working with bio technology would not suffer the lag in the lead time to reach the market.

### 3.2 Compatibility

The second most influential factor is described as “the degree to which an innovation is perceived as being consistent with the existing values, needs, and past experiences of potential adopters” (Moore & Benbasat, 1991). The key concerns are related to process technology for switching to bio-based from petroleum products. The compatibility issue seems to impose a negative effect on the adoption of 100% bio-based packaging facility because the inherent material needs to have competence of petro plastic it will compete with (Shen et al., 2009). For brand owners like Coca Cola with 20-30% bio-based packaging, the compatibility issue of the two processes seems to be of little issue.
3.3 Complexity

It is related to as ‘degree to which an adoption is perceived stringent’ (Moore & Benbasat, 1991). One of the key issues with bio-based plastics is the confusion of the concept created with the term in it. Initially, the challenge faced in the complexity dimension is the clear understanding of different categories of bio-based materials i.e. 100% compostable, renewable, biodegradable and Oxo-degradable or partially owing the mentioned properties. Even with compostability, there are two dimensions, industrial and home processing. So, to inject the bio-based packaging in the value chain, the key players must be educated to understand the different categories of bio-based materials (Oku, 2005).

If bio-based packaging products take over market share, it will come with a very obvious additional cost i.e. increased organizational complexity. The only remedy that appears to lessen the complexity is the involvement of brand owners to make the supply chain more mature.

3.4 Trial ability

Trial ability is defined as “the degree to which an innovation may be experimented with before adoption” (Moore & Benbasat, 1991). It is related to foundation of market dynamics i.e. Technology Push and Demand Pull. The brand owners are tied to trial ability in a way that they need to experiment the innovation not just from technological perspective but also to analyze the attractiveness for the product in market.

From the producer perspective, they need to push the bio-based packaging products in the market with different techniques like labeling to enhance communication with customer via packaging. From the market point of view, the results are always surprising. There is no single answer to consumer’s attitude of buying (Diamantopoulos et al., 2003). The debate is still ongoing if customers are willing to pay for eco-friendly products (Autio et al., 2009; Abdul-Muhmin, 2007; Diamantopoulos et al., 2003; Laroche et al., 2001).

3.5 Observe ability

Observe ability is defined as “the degree to which the results of an innovation are observable to others” (Moore & Benbasat, 1991). According to Rogers 1995, there is a direct relationship between the Observability and adoption of a certain innovative product. It can also be mentioned here that the adoption of biomass to be utilized as bio fuel for transportation in Linkoping city of Sweden. Observer ability is actually about branding the image of a product, since branding is one of the most convincing ways to communicate the qualities of product (Smith, 2003; Zadek, 2004; Hagel et al., 2012), based on either competitor’s decision to adopt a certain innovative product or analyzing the perceived image of the adoption. If a big player in value chain adopts a certain innovation, he sends signals to the market about the strategic importance of adoption in future. The perceived benefits may not be very viable and visible in short terms but in long terms they will reap considerable advantages i.e. market leader in innovation.

If a single key brand owner switches to bio-based packaging, rationale being differentiated point of sale or operational efficiency probably, it can ultimately result in causing a threat for the rivals to motivate and step up to the competition (Porter, 1996; Gilbert, 2005). The recent most examples are Pepsi Co., who in response to Coca Cola has switched to bio-based packaging (Plastics News 2011). The conclusion is that being those who adopt the innovation
in an initial phase, those that react now are likely to be the fast-followers, whose aim it is to establish a stronger appropriability regime than the leading innovators, allowing them to obtain a larger profit from the innovation (Teece 1986).
4 Literature Review

This chapter uses secondary resources to elaborate the concepts of bio-based materials and market projections about bio-based packaging materials.

This thesis is mainly focused on niche products for packaging materials i.e. bio-based biodegradable plastics. In order to understand the difference, bio-based plastics are actually extracted from renewable resources such as starch, vegetable oil, sugar or from wood pulp. The difference between bio-based plastics and biodegradable plastics must be clearly understood in order to avoid the confusion between the two. Bio-based plastics do not necessarily mean that they are biodegradable as well. An example of plastic made from renewable resources is PE, which is derived from bio ethanol is renewable but not biodegradable due to the inert nature of the PE bond. In fact, some oil based polymers are also degradable e.g. Polycaprolactone. (Clause 2009)

Talking about biodegradable (compostable) plastics, they are defined as 'polymers that are susceptible to meet degradation by biological activity, with degradation accompanied by lowering the molar masses. There are certain scientific standards set for bio degradability and compost-ability of plastics used in packaging products. Some BDG’s comprise of mixtures of oil based polymers and Bio-polymers. BDG polymers must be completely broken down by microorganisms in the environment into nontoxic compounds i.e. CO₂, Water, bio mass and methane under anaerobic conditions (Clause, 2000) (PAC, 2004).

The following criteria have to be met in order to meet international standards. The packaging material must possess good IEQ (Indoor Environment Quality), reduced VOC; no CFC’s or HCFC’s, no negative effect on composting process (break down into water, bio mass and CO₂), disintegration (the material must become indistinguishable after certain time period, non-toxicity (Low levels of heavy metals and compost must sustain the plant growth) and importantly it should be biodegradable (Jonathan et al. 2009)

Reference: Material coordinate systems of Bio-plastics
Prof. Dr. Ing. H J, Endres

There exist a great need to develop a belief in the potential of Bio-polymers/plastics for the consumers and manufacturers. Although, the literature as well as scientific research proves that there exist a great potential in BP’s to replace the conventional plastics, the current market size for BDG’s is still very discouraging but growing rapidly though. Especially for EU, whose oil supplies are limited, there exists a great need of an alternative raw material along with focus on reducing the huge deposits of waste in the sea as well. BP’s will not only save the resources but also be a positive step towards a sustainable environment. Polymers are abundant in nature. From wood, leaves, fruits to animal furs, all contains natural polymers.
Bio-based polymers have a variety of different applications e.g. food, furniture, clothing etc. (Patel et al., 2005; Guilbert et al., 2011, Alvarez-Chavez et al., 2012)

### 4.1 Types of Bio-plastics

There are various resources and raw materials from which bio-plastics can be made e.g. starch sugar fermentation products, cellulose, lignin etc. Some of the main Bio-plastics are:

1. Bio-plastics based on starch, which has the potential to replace PE or PS in disposable cutlery, food packaging, plastic bags or mulch film (Barker, M. and Safford, R. 2009)
2. Starch based BP include PLA, PHA, 1.3 bio PDO and 1.4 bio BDO. PLA has appeared to be the most appealing contender to replace the conventional plastics i.e. PE and PP, in production of bottles, packaging, carrier bags and apparel. PHA has potential to replace PP for production of cups and compostable bags (Barker, M. and Safford, R. 2009)
3. Cellulose based BP’s are used in production of biodegradable films for application in food and cosmetic packaging (Tom Lindström et al. 2011)
4. Lignin based BP’s have the potential to be used in automobile industry to manufacture automotive interior parts, toys, electronic or construction components.
5. Some conventional plastics e.g. PE, PU, PA, PBT, can also be produced from renewable resources like cellulose, starch and oils (Clause 2009)(Jonathan et al. 2011)
6. Hybrid or mixed/blended BP’s can be manufactured by combining environmental friendly elements of BP’s and some important products attributes from petro plastics. Although the end of life cycle could be problematic as petrochemical part is not designed to be biodegradable. (Jonathan et al., 2011)

The following table explains the potential of Bio-based products that includes Non-Biodegradable, Biodegradable and Compostable.

<table>
<thead>
<tr>
<th>Types of Bio-plastics</th>
<th>Nature</th>
<th>Primary Stock</th>
<th>Feed</th>
<th>End Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermo Plastic Starch</td>
<td>BDG/Compostable</td>
<td>Starch</td>
<td>Disposable cutlery</td>
<td></td>
</tr>
<tr>
<td>Plastarch Material</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starch/Polycaprolactone mix</td>
<td>Hybrid Bio-based</td>
<td>Starch/Petroleum</td>
<td>Plastic Bags</td>
<td></td>
</tr>
<tr>
<td>PLA</td>
<td>BDG/Compostable/Bio-based</td>
<td>Starch sugars</td>
<td>Cold drink cups, bottles</td>
<td></td>
</tr>
<tr>
<td>PHA</td>
<td>BDG/Compostable/Bio-based</td>
<td>Starch sugars</td>
<td>cups, bottles</td>
<td></td>
</tr>
<tr>
<td>Polyester</td>
<td>Hydrolytically degradable/Compostable</td>
<td>Starch sugars</td>
<td>Glass reinforcement</td>
<td></td>
</tr>
<tr>
<td>Polyester with 1.3 propanediol</td>
<td>Hydrolytically degradable/Compostable</td>
<td>Starch sugars</td>
<td>Glass reinforcement</td>
<td></td>
</tr>
<tr>
<td>Polyester with 1.3 butanediol</td>
<td>Hydrolytically degradable/Compostable</td>
<td>Starch sugars</td>
<td>Electrical Insulation</td>
<td></td>
</tr>
<tr>
<td>Cellulose</td>
<td>BDG/Compostable</td>
<td>Wood, Cotton, Cellulose</td>
<td>Food packaging film</td>
<td></td>
</tr>
<tr>
<td>Cellulose Acetate</td>
<td>BDG/Compostable</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lignin</td>
<td>BDG/Compostable</td>
<td>Wood, Lignin</td>
<td>Electronic</td>
<td></td>
</tr>
</tbody>
</table>
4.2 Market Size

Currently, European bio-plastics (EuBP) which is an association representing EU’s interest in bio economy is one of the most authentic resources to extract market size information regarding bio-based packaging. According to European bio-plastics, the capacity in 2011 was estimated to be 1,161MTPA. The following graph disintegrates the production of bio-plastics into different categories. According EuBP, currently there is no systematization for statistics available for bio-plastics. The following information was extracted by EuBP via surveys that were sent to relevant markets players and experts. The focus was on production capacities of bio-plastics worldwide (by material, region and application type) and interpretation of available land using figures.


As for relevant bio-plastics materials, the following materials were included to obtain the production capacity.

Reference: EuBP market data: Documentation of Survey methodology.
The following table shows the application types considered by EuBP

<table>
<thead>
<tr>
<th>Consumer products</th>
<th>Pharmaceutical &amp; medical</th>
<th>Horticulture &amp; agriculture</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Household products:</em> Bathroom supplies, cosmetics, hygiene, cars, watering cans, vacuum cleaners, drinking straws</td>
<td>Implants, bone screws, tablet capsules</td>
<td>Agricultural films and liners, dispensers, plant pots</td>
</tr>
<tr>
<td><em>Office supply:</em> Writing utensils, correction rollers, rulers</td>
<td>Construction</td>
<td>Catering</td>
</tr>
<tr>
<td><em>Toys:</em> Board games, sandbox accessories</td>
<td>Tool handles, plugs, Bio-PUR-insulation, insulants, terrace surfaces, carpets, and floor surfaces</td>
<td>Disposable cutlery and tableware</td>
</tr>
<tr>
<td><em>Furniture:</em> Chairs, fruit and design-bowls</td>
<td></td>
<td>Others</td>
</tr>
<tr>
<td><em>Sport &amp; leisure:</em> Golf tees, loudspeakers, walking sticks, ski gloves, spectacle frames, watchcases, jewellery</td>
<td></td>
<td>Other products and not classifiable blend components</td>
</tr>
</tbody>
</table>

Reference: EuBP market data: Documentation of Survey methodology.

EU, after USA, holds the greatest contribution to bio-based plastics. EU increased its share from 15% in 2003 to 36% in 2007. In EU, the current application of bio-based packaging materials are used in manufacturing of products for packaging, loose fill packaging and waste collection bags with 37%, 28% and 21% bio-plastics market share respectively. In contrast, Oil based plastics cover other industries as well that includes construction, automobile industry and electronics with 37%, 21%, 8% and 6% market share respectively (Li Shen et al. 2011)

4.3 Market Projections

The coalition of bio-based plastics which includes biodegradables too, seeks to develop and evaluate commercial feasibility of bio-plastics to fulfill all functions that petro based plastics do (Magnus et al. 2011) Many bio renewable polymers such as PLA, PHA, PA, Starch etc. have emerged as potential solution. According to European Bio-plastics association, the growing demand of sustainable and green solutions resulted in growing capacities of approximately 1.2 million tonnes by 2011. Market data of EuBP, indicates a forecast of 5 fold increase in production capacities by 2016.

The growth p.a in EU is expected to evolve more steadily as compared to other states producing bio-plastics. The bio-based plastics production in EU is dominated by starch plastics followed by PLA for the entire period until 2020. In 2007, 10kt of cellulosic film were produced by EU and the volume is expected to double till 2020 but still the volumes are too small in comparison with starch or PLA. (Li Shen et al. 2009)

The European capacity developments for starch based bio-plastics are projected in literature to show substantial growth. Although the choice of polymers/monomers is quiet diverse for bio-based plastic production e.g. bio-based PE, PHA and bio-based monomers, but starch appears
to be a solo show for European bio-based plastic production i.e. 90% The production capacity still needs to grow more (Shen et al., 2009; ICIS, 2010).

<table>
<thead>
<tr>
<th>Types of bio-based plastic</th>
<th>Share of bio-based plastic</th>
<th>Production Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starch</td>
<td>89%</td>
<td>Novamont 200kt, biotec 150kt, Rodenburg 140kt, biop 80kt, Ceterplast 225kt, Livan 100kt</td>
</tr>
<tr>
<td>PLA</td>
<td>8%</td>
<td>Pyramid 60kt, PURAC, TOTAL galactic</td>
</tr>
<tr>
<td>Cellulosic Film</td>
<td>2%</td>
<td>Innova 20kt</td>
</tr>
<tr>
<td>Bio-based monomers</td>
<td>1%</td>
<td>Solvay 10kt</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td></td>
</tr>
</tbody>
</table>

Reference: Li Shen et al., 2009

The total installed capacity of bio-plastics in EU in 2007 was 140kt, which is below the projection estimated by Crank et al. 2005 (approx. 300-600kt). The total capacity production for EU for bio-based plastics is 330kt in 2013 which is also below the estimated projections, both with and without policies and measures (P&M). For 2020, the projections estimated on company announcements i.e. 915kt lies within the range of projections i.e. 875kt w/o P&M and 1,750kt with P&M. The literature suggests that bio-based plastics industry is expecting higher production than the estimated projection in EU till 2020 and the growth rate is expected to be 21% leading to a production capacity of 1,650kt.

Due to economic crisis which created an upset in the production planning for different companies, this project will towards capacity of bio-based production capacities under three criteria i.e. Business as Usual (BAU), Low, High (Li Shen et al. 2009)

Reference: Li Shen et al., 2009

The above details are related to emerging and commercialized bio-based plastics. Due to time constraints, there may be other bio-plastics, which are in their earlier phase of R&D and are not considered in this report even though they might be produced on large scale towards the end of projection time period estimated i.e. 2020. If the projections are considered in terms of production per capita, there is a great difference between bio-based and petro chemical plastics.

According to literature, in Europe in 2009, 0.27 kg of plastics is produced per capita per year in contrast with yearly per capita production of petro based plastics to be about 103kg. In the following table the quantities per capita for 2020 are shown with HIGH, LOW and BAU aspects. (Li Shen et al. 2009)
European production capacity of bio-based plastics until 2020

(1) Percentage in brackets presents share of Bio-based plastic relative to petro plastics
(2) NORD includes Norway and Iceland, CH= Switzerland
(3) Data extracted from VKE (Baumgartner, 2004)
(4) Projections that were based until 2010 for Petro plastics
(5) Projection for 2010-20 assuming 2% growth rate (Simon and Schneider 2007)

Reference: Li Shen et al., 2009

The literature that investigates the market projections of bio-based plastics are very few, the few literature studies are purely and solely dedicated to bio-based fuels and products are prepared by ADEME 2007, and the BREW study (Patel et al. 2005). This report will discuss both in short to get better insight of bio-based market to understand the barriers and drivers for the bio-based industry.

### 4.4 The Ademe Study

The Ademe study distinguishes the Bio-polymers market in 4 quadrants in France for years 2015-30. In Scenario/quadrant I, the market share of Bio-polymers is only 1.5% while in scenario IV it is assumed to be 50%. Scenario III, which is more optimistic and realistic, assumes the market share of Bio-polymers to be 12% in 2015 and 24% in 2030. The values have been estimated for the entire growth in the polymer sector from 6.7Mt in 2005 to 7.7Mt in 2015 i.e. +15%, to 9.2Mt i.e. +20% growth in 2015-30 for France.

If the same assumption is applied to EU, the total plastic demand would increase to approximately 45Mt in 2015 and 54Mt in 2030. Assuming the market shares of Ademe’s Scenario 3, the market share of Bio-polymers will be 45x12%= 5.4Mt and respectively 13Mt in 2030, Although the values are very high as compared to values discussed earlier in this chapter. (Patel et al. 2005)

### 4.5 The BREW study

This study is related to more of biotechnologically produced chemicals and distinguishes it into three rather extreme scenarios for EU till 2050. The scenario analysis is based on techno-economic analysis in which key considerations are given to oil price, the bio feed stock price which is relevant with manure management, technological progress and potential in the chemical industry. This study relates that market success for bio-based, biotechnologically produced compounds ranges vastly from negligible implementation to very substantial. In very optimistic scenario, if the oil prices rise too much, then low prices of bio feed stock and strong technological presence can replace about 30% of all organic chemicals by 2030, that includes some polymers and there precursors. The strongest effect will be on ethylene
replaced by 50%, PLA capturing 90% of PET and 50% of PS market shares, PTT fully replacing petro based PTT and PHA reduces about 25% of the most influential plastic i.e. HDPE. The BREW study does not take into account the products that have no alternative via biotechnology. The BREW study is based on only market potential and completely ignores impediments like lack of capital, economic feasibility, technological competiveness and availability of trained personnel. (Patel et al. 2005)
5 Key Factors For Bio-Based Packaging

This section explains the most important factors for bio-based packaging materials. The factors mentioned in this chapter are concluded as results of surveys and interviews (primary sources) and then explained through secondary resources due to disagreement of respondents to reveal confidential data.

5.1 Technical Substitution

According to literature, the market potential in terms of maximum technical substitution is estimated to be about 240Mt. The overall worldwide capacity in the year 2007 i.e. 360kt was 0.15% with reference to technical substitution. Based on the company announcements, the technical substitution is estimated to be 1.5% in 2009. The following graph only shows the projected market potential for technical substitution. Never-the-less, other key factors like economic feasibility, resource availability and trained personnel’s availability influence the potential impact of bio-based materials (Shen et al., 2009).

PLA has high potential to replace LDPE; HDPE; PP; PA and PET. PLA is competitive to LDPE AND HDPE when it comes to gas or aroma barrier but lags as water barrier and economically it’s not competitive to PE, since PLA is expensive then PE. According to Patel, PLA can replace PP films in some application. PLA fiber is suggested to replace PET to some extent. Due to PLA’s low abrasion resistance compared to PA, it limits the potential of substitution. PLA can only compete on stiffness or hardness with HIPS, for PS which is much more transparent but elongation and breakage are comparable. When costs for PLA and PET
reach parity, at least partial substitution in fibers and packaging should take place. According to PLA film producer, it can also replace cellophane. (Patel et al 2009)

<table>
<thead>
<tr>
<th></th>
<th>PVC</th>
<th>PE-LD</th>
<th>PE-HD</th>
<th>PP</th>
<th>GP-PS</th>
<th>PET</th>
<th>HIPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nature Works</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PURAC</td>
<td>+/-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+/-</td>
<td>+/-</td>
<td>+</td>
</tr>
</tbody>
</table>

+/- Partial Substitution with PLA  - No substitution  
+ Full Substitution

Reference: Patel et al, 2009

The literature suggests that the survey made on the projected market of bio-based plastics market results with figures varying from 15-20% market growth in the time period 2007-2020. Since the estimations made by the companies for bio-based plastics is very inconsistent, that is why three scenarios BAU, HIGH and LOW were established earlier. This section will in short discuss the probable internal and external drivers/barriers for the bio-based industry to strive for a successful future. The factors that were taken in account are considered to be the most influential by both literature and practitioners. However, this section will exclude the most important factors i.e. macroeconomics and legislation (Li shen et al, 2009)

5.2 Technical Drivers/Barriers

Before commercializing the bio-based plastics on a large scale, there are certain technological hurdles that need to be overcome and mastered in order to make the production more economically and technologically feasible (Tidd et al., 2005). For certain bio-based materials which owe greatest potential e.g. PLA, cellulosic films and especially starch, the technologies have proven the maturity and strong potential lies for further technological improvements. The production of green PE has showed a great potential in reducing the carbon foot print which actually measures the demand on bio capacity as results of burning fossil fuel in terms of the amount of forest area required to sequester the CO$_2$ emissions (Andrew 2008), by consuming 2.5kg CO$_2$/kg GPE (Braskem). The technical barriers do not only include conversion technologies available up and downstream processing technologies, but it also accounts for the availability of technologies. Some technologies are well practiced, developed and mastered by only few companies, so it relates to the possibility of development of only few polymers that are related to the companies that owe strong technology (Matsuura, Ye & He, 2008).

(i) PLA: The most important challenges lay in downstream processing of lactic acid. The two key players PURAC and NatureWorks currently use Sulphuric acid for the downstream processing of lactic acid purification. As a byproduct, large amounts of gypsum are produced. To overcome this hurdle, key processes like low pH fermentation with electro dialysis, resin ion exchange through adsorption, solvent extraction, membrane separation, and crystallization and distillation techniques have to be mastered and improved. If attention is given to bio feedstock supply, the mentioned companies make use of starch and sugar crops as key resources for the production of bio-based materials. NatureWorks planned to
(ii) produce PLA from cellulosic feedstock. However, the technology to support this process, converting cellulosic feedstock into fermentable sugars, still needs to be developed to yield high quality and low cost. (Li Shen et al., 2009, Matsuura, Ye & He, 2008).

(iii) STARCH: For starch based plastics, the technological benchmarks have been achieved quietly successfully but some material types such as starch acetate needs to be improved further from a technological perspective (Bastioli, 2001).

(iv) PHA: The first commercial scale plant with 50kt p.a capacity was in building process. Important factors like technological support for the processing, technical challenges, product attributes and market price by competitors will strongly influence the performance of PHA. (Li Shen et al., 2009).

(v) The first commercial scale glycerol to epicholohydrin built by Solvay under their own patented and proprietary technologies for the production of 100kt p.a and Dow epoxy 150kt p.a. So, it can be estimated that major technological barriers have been resolved (Li Shen et al., 2009).

However, the literature study also revealed that there is a huge potential for technical substitution as well, in terms of barriers and drivers from a technical perspective, following table is referred to:

<table>
<thead>
<tr>
<th>Bio-based plastics today</th>
<th>Influencing Factors</th>
<th>Expected growth until 2020 scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Technical barriers</td>
<td>Bulk applications</td>
</tr>
<tr>
<td>Well-developed</td>
<td>Starch plastics</td>
<td>++</td>
</tr>
<tr>
<td></td>
<td>Cellulose films</td>
<td>++</td>
</tr>
<tr>
<td></td>
<td>PA11</td>
<td>++</td>
</tr>
<tr>
<td>First-in-kind in operation</td>
<td>PLA</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>PTT</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Bio-based PE</td>
<td>++</td>
</tr>
<tr>
<td>First-in-kind being built</td>
<td>PHA</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Bio-based Epoxy resin</td>
<td>+</td>
</tr>
<tr>
<td>Pilot</td>
<td>Bio-based PUR</td>
<td>+/-</td>
</tr>
<tr>
<td></td>
<td>Succinic acid</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Bio-based FA6, PA 66</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Bio-based PP</td>
<td>-</td>
</tr>
</tbody>
</table>

5.3 Application Barriers

In order to increase the effectiveness of the injection of bio-based plastics in the petro plastics dominated market, an important parameter that needs to be addressed is the bulk application of bio-based plastics by which the ultimate problems faced by the bio-based industry i.e. the cost limitations, can be overcome (Shen et al., 2009; Hermann et al., 2010; Kuruppalil, 2011). In the later part of the paper, the idea of Resource Chain Product helps to understand the improvement in production of chemically or technically identical products.

For starch and PLA, considerable efforts have been exercised by research institutes including Innventia to widen its application areas to capture market share. Further, Innventia does not only seek to make bio-bags or packaging material by biodegradable plastics but are also approaching other industries like automotive, electrical appliances and construction Some of bio-based plastics like PTT, 1,3 PDO, PA 11, PA 610 although the technological barriers have been overcome and they will be improved but the literature suggests that it is not expected that they will be applied commercially due to low demand, possibly due to material characteristics (Li Shen et al, 2009)

5.4 Cost Barriers

For oil based industry, it is estimated that the future costs may rise due to the uncertainty in the oil prices and further due to the limited/scarcie oil resources e (Aleklett, 2007; de Almeida & Silva, 2009; Owen et al., 2010; Tsoskounoglou et al., 2008; Schippers et al., 2009). On the other hand, the low cost of the bio feedstock becomes the main driver for the packaging industry to utilize bio-based plastics on large scale. So there is a need for bio-based packaging products to be designed in a way that they outset the petro chemical plastics (Aleklett, 2007; de Almeida & Silva, 2009; Owen et al., 2010; Tsoskounoglou et al., 2008; Schippers et al., 2009)

<table>
<thead>
<tr>
<th>Material</th>
<th>Average Price (Euro/Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PE</td>
<td>1.2</td>
</tr>
<tr>
<td>PS</td>
<td>1.45</td>
</tr>
<tr>
<td>PP</td>
<td>1.15</td>
</tr>
<tr>
<td>PVC</td>
<td>1.05</td>
</tr>
<tr>
<td>PET</td>
<td>1.2</td>
</tr>
<tr>
<td>PA</td>
<td>2.7</td>
</tr>
<tr>
<td>PLA (NatureWorks plastic resin)</td>
<td>1.8</td>
</tr>
<tr>
<td>PHB</td>
<td>10-20</td>
</tr>
<tr>
<td>Biopol (PHB from Metabolix)</td>
<td>5-9</td>
</tr>
<tr>
<td>Mater Bi (Novamont)</td>
<td>1.5-2.4</td>
</tr>
<tr>
<td>Ecoflex (BASF)</td>
<td>4</td>
</tr>
</tbody>
</table>

Reference: Innventia Data base

All bio-plastics have production costs higher as compared to petroleum based polymers. The higher costs could possibly be associated either higher direct production costs or variable raw material costs (Shen et al., 2009; Hermann et al., 2010; Kuruppalil, 2011). Few bio-based plastics have achieved cost reduction by cheaper raw material e.g. starch blends with Cereplast, by engaging economies of scale e.g. PLA by NatureWork.
5.5 Raw Material Supply Barrier

According to literature and EU plastics, there are no second thoughts about the potential market of bio-based plastics but still there is a huge risk in terms of raw material supply since bio-based feedstock have not just to comply with food but now also with feed and bio-fuels plus its potential application for packaging industry (Gillespie et al., 2011; Hermann et al., 2011; Mathews, 2008; Bohlmann, 2007). From the market projections above, it can be estimated that since the market share of the biodegradable plastics will be relatively small, so for at least next two decades the risks associated with supply of bio-based feed stocks will be relatively low and supply would not be the bottle neck for bio-based industry. However, the issues with food supply security are expected to reduce since there will be more viable ways of biomass production (Havlik et al., 2011)

The consumption of the bio feedstock is directly associated with the food supply chain (Delshad, 2010). So, it suggests if the demand for such commodities increase, the packaging products demand will increase. The increase in demand of packaging materials can create new market opportunities for bio based packaging. Also, the bio mass required for bio-plastics is quiet low (Natureworks, 2009). Although, the basic raw material for cellulosic films and MFC are wood, so food and feed concerns are not associated here. The bio industry seeks to manufacture PLA from cellulosic source too (Li Shen et al. 2009)

In order to account the macro economic factors, it is very complex because the world is going through the worst for economic crisis and trying to survive. The effects of such unstable macro elements are very complicated and are subjected to a high uncertainty. Literature suggests that proactive approach towards sustainable solutions is often driven by external stake holder (González-Benito & González-Benito, 2006, 2010) while the government is a key player with maximum influence (Bansal & Roth, 2000)
6 Plastic Waste Management

This section explains the trends of plastic waste generation and how they can be countered. This section also explains the legislative actions taken in account to counter the waste generation problems. Waste management is a huge concern now a days, it is creating pressure on the regime and hence opening an opportunity for bio-based packaging products.

Petro-plastics have proven themselves to be most viable in terms of technical feasibility, cost, market share and diversity. Plastics have brought many incentives to society by creating jobs, economic activities and improving the quality of life. Almost all the value chain currently is aligned with petro based plastics manufacturing. The principle target of food packaging is to reduce waste and increase shelf life of packaged product by improving antioxidant and barrier properties. The packaging material should be sustainable and ecofriendly. There are enough incentives for bio-based plastics to replace conventional plastics but still in some cases prove more viable then bio-based plastics in terms of energy consumption, CO₂ footprint and cost. Conventional plastic has also been found guilty of polluting the environment by CO₂ emissions and poor end of life cycle assessment. They remain in environment for a very long time and does not bio degrade hence creating huge amounts of waste (Jonathan et al. 2011, Magnus et al. 2011)

One of the main content of interest in biodegradable packaging is to counter the ‘plastic waste’ problems. Almost all of the packaging material that goes to waste in current scenario is non-biodegradable, which creates a huge concern in environment context. Huge amounts of plastic waste go into oceans, which causes pollution due to leaching and release of toxic substances. Biopolymers, main resource being agricultural and forest based, appeared as potential ways to produce competitive plastics for food packaging. Although, there is a debate on whether agricultural resources should be consumed in plastic manufacturing as critics emphasize agricultural resources to be dedicated to food consumption only.

MFC obtained from forest based resources is another biodegradable material, which is obtained from wood fibers. It has various applications in food packaging i.e. application as barrier film (e.g. oxygen and grease) instead of aluminum films; it strengthens the paper and board with lesser raw material consumption. In trail of reducing the non-biodegradable plastic waste generating worldwide, MFC based plastics can actually prove handy in reducing the waste. The end solution for the plastic waste is believed to be in biodegradable materials, on which research is made globally to understand its sustainability and renewability (Eva Ålander 2013)

With the passage of time, societies have shown a great reliability on plastics although; it has come up with the cost of deprivation in environment and also natural nonrenewable resources. The challenges have posed new threats and challenges to the current regime and hence created an opportunity for bio-plastics (Nikki 2005). The following diagram explains the evolution of plastic with time in context of production and legislative measures.
In 2008, total post-consumer waste generated in EU 27, Norway and Switzerland was estimated to be out 24.9 Mt. Plastic packaging was estimated to be the largest contributor to the waste with 63%. There are various end of life options to handle the plastic waste which depends highly on the geography. In EU, plastic waste has a strong infrastructure for recycling and recovering so it is very obvious that recycling and recovering will be higher in EU e.g. highest recycling rate is in Germany, 34% on the other hand Greece has the lowest as 8%. (Jonathan et al. 2011)

In the food packaging (or any other packaging sector), the waste are expected to rise. The point to ponder is which sector deserves attention most. After realizing the sector to be addressed, it is important to measure the extent of policies and measures already implemented and regulations actually needed to compensate the waste problems. The current end of life methodologies for plastics is based on recycling, energy recovering, landfills, and composting or bio degradability.

Nonetheless, ISO developed a new standard ISO 15270:2008 i.e. plastic-guidelines for recovery and recycling of plastic waste. This standard provides the technical framework needed to develop infrastructure for plastic waste recovery and recycling. The standard establishes different options viable for plastic recovery in terms of waste generated from both
post and pre-consumers. Also, it indicates the quality of the recycled plastics, test standards and product specifications (ISO 15270:2008)

6.1 Trends

The European Commission has developed a framework which projected the waste generation and the probable ways of handling the waste. The framework is developed on the current competence and legislation of the EU states. The indications according to EU commission are (Jonathan et al. 2011)

1) Packaging sector will contribute 23% increase in plastic waste during 2008-15
2) Disposal of plastic waste will decline i.e. from 43-49%
3) Energy recovery will increase from 30-34%
4) Overall recovery will increase to 36%
5) Mechanical recycling will contribute an increase of 30% recovery

This scenario is just an assumption made on current competencies and infrastructure. The projection may change by most influential factors like increase/decrease in GDP, technological feasibility, adoption of innovative packaging materials such as biodegradable packaging materials, end consumer attitude and availability of resources. The plastic demand is expected to rise by 2015 followed by an increase in export of waste due to increased volumes of waste to recycled or recovered. The production of bio-plastics will increase in large proportions. China is a marked as a key player in plastic production indicating Asia leading the plastic market. Incineration will increase, decreasing the landfills as a way of end of life cycle for plastics (Magnus et al. 2011, Herald et al. 2010)

The EU commission has also projected trends about the plastic waste up to 2015. They identify increase in the waste followed by increase in the recycling with main focus on mechanical recycling. The most consequential changes on plastic waste will occur followed by changes in other sectors of plastics waste. Energy recovery will also increase followed by decrease in disposals (Jonathan et al. 2011)

Due to strong infrastructure for plastic waste relying on recycling, it has opted itself as the most viable option so far to tackle the waste by owing economic as well as environmental benefits. However, as this thesis is more convergent towards food packaging, the recycling does not appears to be a good option as compared to virgin plastics. The main concerns revolve around quality of the food which cannot be compromised. Also, there are technological and market challenges when it comes to recycling the material. Huge amount of plastic waste are needed in order make the recycling compete with the virgin materials to create cost incentives (economies of scale). The scenario becomes much narrower due to diverse nature of plastics existing creating more sources of contamination.
It is clear that for recycling, the process needs to be technologically and economically feasible to be adopted to treat waste. Some EU members do not have sufficient technology and finances to afford it or they have not yet considered it. According to EU commission, the top 3 exporters of waste are Luxemborg, Belgium and Sweden. Top importers of plastic waste are Ireland and Bulgaria followed by negative net trade of -8 and -2% respectively (Jonathan et al. 2011).

The legislative documents considering bio-plastics are difficult to find and there are very few public documents available. From the EU legislative perspective, a baseline scenario projecting the waste generation up to 2015 was declared. According to this scenario the EU legislation has proposed a ‘five policies’ proposition to tackle the plastic waste i.e. sustainable packaging guidelines, agricultural plastic recovery and recycling guidelines, WEEE and automotive plastic waste target, recycles plastic and bio plastic phased targets, research innovation on the reduction of plastic waste.

As this thesis is limited to food packaging only, two of the above options will be further discussed. During the interviews it was also concluded that sustainable packaging guide lines and recycling are two most influential current practices in the industry (Jonathan et al. 2011).

1) Sustainable Packaging Guidelines

This policy has special focus on plastic consumers such as retailers. The aim of this policy is to introduce a standardized methodology for plastic consumption. This standardization will focus on optimizing the impact of plastic waste not just to environment but also on packaging production hence, creating a better management in the value chain to confront the problem with waste. This policy will enable the retailers to measure the extent of sustainability centering the economic, environmental and ecology. This may relate to the use of alternative resources to be introduced for packaging food e.g. bio-based materials. The guidelines also include innovative packaging designs in order to reduce the food waste. The package labeling is a key factor in reducing the food waste which can make the recycling process more efficient. Labeling is supposed to communicate the identification of food, net quantity of contents, manufacturer’s identity, ingredients, nutritional facts and country of origin. This policy is believed create positive impact as the infrastructure is supporting recycling (Knight and Creigten 2004, Jonathan et al. 2011).
Industry should be enabled to label that their packaging contains recycled plastics. However, consumers should not be misled by labeling as regards recycled content. Rules for labeling of recycled plastics in relation to the content of recycled plastics have been laid down in EN ISO 14021. To ensure adequate information of the consumer when recycled plastics are labeled, they should follow transparent rules as those laid down in EN ISO 14021 or equivalent. (Commission Regulation 2008)

The recycling can be more efficient if the quality of recyclables, process of sorting and understanding of different materials are introduced. It will decrease usage of virgin materials and restore the trust in secondary materials as recyclables. The challenge in this policy lies in its inherent volunteer nature meaning it may or may not be adopted by the retail sector despite the fact these guidelines offer flexibility and potential in terms of creating economic incentives and industrial implementation. The potential lies in better environmental reputation adding in brand image and public awareness (Nikki 2005). It is estimated that sustainable guidelines can reduce up to 30% of plastic waste related to food packaging and 20% increase in recycling by 2015 (Jonthan et al. 2011). The feasibility of recycling with different materials for conventional plastics is displayed in figure below
2) Bio-plastics and Recycling

Statistics from literature and interviews revealed that practices to conquer plastic waste are more relying on recycling and recycling has emerged as the viable option other than landfills. The EU commission also projects an increase in the recycling rates till 2015. However, the problems associated with the petro-based plastics have given rise to bio-plastics. These plastics have shown viable potential to replace petro-plastics on the basis of functionalities and having hurdles in terms of cost and adoption (Patel et al. 2005). Biodegradable plastics can viably replace those plastics that suffer low recycling rates and targets. Biodegradable plastics can be introduced more effectively by labeling products about the packaging as public awareness is the back bone for the acceptance of bio-plastics. Bio-plastics are currently consumed as following:

Reference: Jonathan et al.2011

This policy is a subset of the idea of implementing a bio economy. Idea relates to replace petro based plastics with bio-plastics but the focus is still on the how to reduce the waste. There is a misconception that bio-plastics do not support the normal recycling techniques as conventional plastics do and hence it has emerged among the few most critical factors for bio-plastics. Although, bio-plastics need special composting facilities to be degraded, they may be recycled with normal plastics but they may degrade during the recycling and hence resulting in contamination of other plastics as well. European bio-plastics suggest that bio-plastics need an environment with specific ratio of CO₂, Oxygen and Nitrogen (Johansen at al. 2008, European Bio-plastics). Among the few most critical factors for bio-plastics, recycling has emerged one of them. However, this challenge may be overcome by labeling bio packaging and adopting special sorting techniques during recycling which may lead to an additional investment. It is assumed that by 2020 bio-plastics will have a share of 10% out of which 15% will be recycled. (Jonathan et al. 2011)

The inherent problem with recycling of the bio-plastics is due to the diversity in bio degradability with in itself. Biodegradability can be explained in different ways such as (Nikki 2005):

a) Biodegradable: ability to decompose under the action of biological agents e.g. bacteria
b) Hydro biodegradable: ability to decompose under action of biological agents in water
c) Photo degradable: ability to decompose under action of UV radiation
d) Bio erodible: ability to decompose from environmental conditions e.g. rain, particles in wind, UV attack and climate changes
e) Compostable: ability to decompose in way leaving a residue or organic matter useful for soil structure and provides nutrients.

Although, bio-plastics have trouble in recycling with conventional plastics the European Bio-plastics association suggest that it is not completely true. The waste management processes
available for conventional plastics can also be used for biodegradable polymers. They claim that bio degradability is an additional option for energy recovery.

As with conventional plastics, the manner in which bioplastics waste is actually recovered depends on the type of product and bioplastics material used, the inherent quantities and the recovery systems available – European Bioplastics.

Bio-plastics best contribution is towards closing the loop and therefore makes the system sustainable. They highly depend on legislation to promote recovery and recycling structure for bio-plastics (Eva Ålander 2013)

6.2 EU legislation in food packaging

Different options exist for end of life cycle of plastics e.g. recycling, reusing, incineration, Biodegradation and pyrolysis. The commission has assessed the environmental impacts and revealed that despite of high dependency on oil based plastics; biodegradable plastics are expected to rise. The rise in plastic production will increase the waste, which indicates the demand of extended waste treatment system to handle increased waste. The commission indicates that directive 2009/28/EC that many member states will be relying on the potential of bio-mass to meet their targets till 2020. Despite an increase in recycling, the landfill disposals will remain significant.

The EU legislation for food and packaging aims at protecting consumer’s health and remove the technical barriers (EU legislation)

The use of recycled materials and articles should be favored in the Community for environmental reasons, provided that strict requirements are established to ensure food safety and consumer protection. Such requirements should be established taking also into account the technological characteristics of the different groups of materials and articles mentioned in Annex I. Priority should be given to the harmonization of rules on recycled plastic material and articles as their use is increasing and national laws and provisions are lacking or are divergent. Therefore, a draft of a specific measure on recycled plastic materials and articles should be made available to the public as soon as possible in order to clarify the legal situation in the Community. (Commission Regulation 2004)

The food packaging sector in EU is highly regulated. Food packaging regulations divides itself into two main categories i.e. safety of packaging material and environmental impacts of packaging.

1) Safety of packaging materials

European Food Safety Authority (EFSA) holds the main responsibility to make sure that packaging material in contact with food is not harmful. They investigate that if any integral part of the packaging material break in food, regulatory approvals must be taken. The process to obtain indirect food additive is called food additive petition. In this petition the company offering packaging materials is requested to demonstrate quantity of packaging material breaking in the food to determine if it is in safe limits. The EU legislation notifies the safety of packaging materials as food contact materials must not transfer their components into the foods in unacceptable quantities (migration). The migration limits set by EU legislation are:
i) **Overall Migration Limit** - 10mg of substances/dm² of the food contact surface for all substances that can migrate from food contact materials to foods

ii) **Specific Migration Limit (SML)** for individual the authorized substances fixed on the basis of a toxicological evaluation

SML is set according to the Acceptable daily intake or the Tolerable daily intake established by the scientific committee on food. The limit is set on the assumption that every day throughout lifetime, a person weighing 60kg eats 1kg of food packed in plastics containing the substance in the maximum permitted quantity.

The substances material to be used in the packaging materials may be exempted from FDA if the supplier has received allowance from EFSA for its purpose. GRAS (generally recognized as safe) is another criteria which ensures the safety of packaging materials as safe to be used. The quantity of the migrant depends upon if the packaging material is used for dry or non-fat foods. Also, nature of the packaging material whether it is virgin of recycled matters.

2) **Environmental impacts of packaging** (Discussed in last chapter)

### 6.3 Future Strategies

EU commission has also projected trends about the plastic waste up to 2015. They identify increase in the waste followed by increase in the recycling with main focus on mechanical recycling. The most consequential changes on plastic waste will occur followed by changes in other sectors of plastics waste. Energy recovery will also increase followed by a decrease in disposals.

The legislative documents talking about bio-plastics are difficult to find and there are very few public documents available. From the EU legislative perspective, a baseline scenario projecting the waste generation up to 2015 was declared. According to EU bio-plastics, in order to create awareness and realize the potential of bio mass, EU commission has started ‘Europe 2020’ initiative that focuses to bring sustainability and improve the economic progression. The initiative will lay its foundations on different aspects i.e. consumption of renewable expandable resources, create alternative resources other than fossil fuels, promoting resources that have the potential to reduce GHG, raw material that is technologically feasible, improve recycling and recovery infrastructure, processes that improve energy consumption, rural development and increase in industry competiveness by injecting bio-economy. However, these advantages can only be entertained by political support (European Bioplastics association, 2013).

Other top level EU programs to support bio-plastics are:

* Europe 2020/Innovation Union
* Lead Markets Initiative for Bio-based Products
* Resource Efficiency Strategy
* Key Enabling Technologies
* FP7 & Horizon 2020
* Bioeconomy Strategy
* Waste Management Framework
7 Life Cycle of Bio-plastics

This section sheds light on the most important aspect of bio-plastics in terms of their end of life options and analysis taken from literature for comparison with petro based plastics. It relates with Rogers adoption theory, as LCA can be a motivating or demotivating factor for adoption of bio-based packaging.

Global production of bio-plastics is estimated to be about 750,000 tons/year as compared to 200million tons/year production of petro-plastics. The growth of plastic sectors is estimated to grow exponentially. Major contributors in bio plastic manufacturing are Novamont with 35,000 tons/year of Mater bi (starch based) and Nature Works with 140,000/year of PLA based plastics (Widdecke et al. 2008). One of the few motivations behind boosting the adoption of bio-plastics is to counter the CO₂ emission causing severe environmental impacts and to recover the energy invested in the plastics (Zhang et al. 2000). Bio-plastics made from starch, cellulose, wood and sugar have shown great potential to reduce CO₂ emissions. The rationale behind bio-plastics is simple i.e. balance the CO₂ released during manufacturing, consumption and disposal by CO₂ consumed during the growth cycle (Girone & Pimonte 2011). The rising oil prices are creating concern in key players motivating them to look for alternate resources.

Life cycle assessment is a technique to assess the environmental impacts of a product in all stages of its life. As mentioned already in the theoretical framework, the external pressures on the landscape can create an opening for niche level product to be incorporated into mainstream markets. Environmental concerns about the petro based plastics have created a huge pressure on the landscape of the current regime ultimately creating a ‘window of opportunity’ for bio-based materials. LCA is a tool that plays a vital role in justifying the positivity if bio-based materials. However, bio-based materials are also harmful in some ways to environment which will be mentioned later. Consumption of valuable natural resources for production of Bio-polymers has several critics’ e.g. Specific consumption per unit for biodegradable plastics vary but alimentation raises concerns. Food prices are assumed to rise (Harding et al 2007). Fermentation is one of the key processes for valuable agricultural raw materials like wheat, corn, sugar, rice, potatoes and soya to be converted into Bio-polymers. The food concerns, which are both emotional and scientific can be countered by utilizing agriculture or food industry waste and consumption of non-edible genetically modified plants grown at lands not feasible for food production (Girone & Pimonte 2011).

The second motivation factor for bio-plastics, in context with environmental concerns, is waste disposal. In 1990’s, municipal solid waste was treated by disposing them to landfills. This waste contained 20-30% plastics (Girone & Pimonte 2011). Conventional plastics have very slow degradation kinetics. The volumes required by these plastics are stable over time. On the contrary biodegradable plastics have higher degradation kinetics in landfills and volumes can be obtained easily (Ishigaki et al. 2004).

Cost is considered to be a great obstacle for bio-plastics to be adopted. However, if life cycle analysis is thoroughly performed, it may lead to different results (Girone & Pimonte 2011). Researcher’s most affirmative final disposition for bio-plastics by a composting process under a biodegradation process that converts bio-plastics into soil like residue called humus, CO₂, water and inorganic compounds with no visible or toxic residue (Davis and Song 2006). Composting can therefore be considered as a viable option for bio-plastics in terms of ‘closing the loop’, provided reasonable composting environment can be provided. Composting conditions are critical because an experiment made on biodegradation of PLA in natural and
controlled environment revealed the fact that natural composting efficiency is only 20-30% equal to a controlled environment (Kale et al. 2007).

The addition of additives in order to strengthen the mechanical properties of plastics may lead to adverse effects when it comes to composting. This will not only cause reduction in degradability but also cause severe eco-toxic effects (Girone & Pimonte 2011).

Beyond cost efficiency, technical feasibility, lead time of technology, most influential factor is to examine biodegradable plastics on their environmental impacts. This study is referred to as Life Cycle Analysis or LCA in general. This study assesses the impacts of plastic from production to final disposal. The key factors to assess environmental impacts are (Girone & Pimonte 2011):

(i) Abiotic depletion: This factor measures the potential of abiotic depletion of minerals and fossil fuels. It is measure in antimony (Sb) equivalent per Kg of extracted mineral.

(ii) Global warming: This factor measures the potential of global warming per each greenhouse gas emission in environment. It is measures in kg of CO$_2$ equivalent per Kg of emission.

(iii) Human toxicity: This factor measures the potential human toxicity of toxic substances released to air, water and soil. It is measured in Kg of 1,4-dichlorobenzene (1,4-DB) equivalents per Kg of emission.

(iv) Fresh water aquatic toxicity: This factors measures the potential of fresh water aquatic toxicity of each substance released to air, water and soil. It is measured in 1,4-DB equivalents per Kg of emission.

(v) Marine aquatic toxicity: This factor measures the potential of marine aquatic toxicity of each substance released to air, water and soil. It is measured in 1,4-DB equivalents per Kg of emissions.

(vi) Terrestrial ecotoxicity: This factor measures the potential of terrestrial ecotoxicity of each substance released to air, water and soil. It is measured in 1,4-DB equivalents per Kg of emissions.

(vii) Photochemical Oxidation: This factor measures the potential of photochemical ozone formation of each substance emitted to air. It is measures in ethylene (C$_2$H$_4$) equivalents per Kg of emission.

(viii) Acidification: This factor measures the acidification potential of each acidifying emission to air. It is measured in Kg of Sulphur dioxide (SO$_2$) equivalents per Kg of emission.

(ix) Eutrophication: "The process by which a body of water acquires a high concentration of nutrients, especially phosphates and nitrates. These typically promote excessive growth of algae. As the algae die and decompose, high levels of organic matter and the decomposing organisms deplete the water of available oxygen, causing the death of other organisms, such as fish. Eutrophication is a natural, slow-aging process for a water body, but human activity greatly speeds up the process" (Art, 1993).

This factor measures the potential of eutrophication of each eutrophying emission to air, water and soil. It is measured in Kg of phosphate ion (PO$_4$) equivalents per kg of emission.
The following table is a compilation of LCA data to compare the environmental impacts of different bio-plastics. The results were obtained via incineration and energy recovery as final provision. Although this choice is unfavorable due to low calorific value (Patel et al. 2005)

<table>
<thead>
<tr>
<th>Types of Plastics</th>
<th>Energy Requirement Mj/Kg</th>
<th>Global Warming, Kg CO₂ eq/kg</th>
<th>Warming, Kg CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>From non-renewable sources</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HDPE</td>
<td>80.0</td>
<td>4.84</td>
<td></td>
</tr>
<tr>
<td>LDPE</td>
<td>80.6</td>
<td>5.04</td>
<td></td>
</tr>
<tr>
<td>Nylon 6</td>
<td>120.0</td>
<td>7.64</td>
<td></td>
</tr>
<tr>
<td>PET</td>
<td>77.0</td>
<td>4.93</td>
<td></td>
</tr>
<tr>
<td>PS</td>
<td>87.0</td>
<td>5.98</td>
<td></td>
</tr>
<tr>
<td>PVOH</td>
<td>102.0</td>
<td>2.70</td>
<td></td>
</tr>
<tr>
<td>PCL</td>
<td>83.0</td>
<td>3.10</td>
<td></td>
</tr>
<tr>
<td>From renewable sources</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TPS</td>
<td>25.4</td>
<td>1.14</td>
<td></td>
</tr>
<tr>
<td>TPS+15% PVOH</td>
<td>24.9</td>
<td>1.73</td>
<td></td>
</tr>
<tr>
<td>TPS+60% PCL</td>
<td>52.3</td>
<td>3.60</td>
<td></td>
</tr>
<tr>
<td>PLA</td>
<td>57.0</td>
<td>3.84</td>
<td></td>
</tr>
<tr>
<td>PHA</td>
<td>57.0</td>
<td>NA</td>
<td></td>
</tr>
</tbody>
</table>

Reference: Gironi and Pimente 2011

The above table shows the advantage of bio-plastics over conventional plastics when compared in terms of energy requirement for production and global warming caused by the respective plastics. The above data clearly indicates that there is a compelling increase in energy demand and CO₂ emissions for bio-plastics when a non-biodegradable copolymer is added to increase the mechanical performance of bio plastic.

<table>
<thead>
<tr>
<th>Types of Plastic</th>
<th>Acidification (g SO₂ eq.)</th>
<th>Eutrophication (g PO₄³⁻ eq.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pallets</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LDPE (1kg)</td>
<td>17.4</td>
<td>1.1</td>
</tr>
<tr>
<td>TPS (1kg)</td>
<td>10.9</td>
<td>4.7</td>
</tr>
<tr>
<td>Starch foam (1kg)</td>
<td>20.8</td>
<td>2.8</td>
</tr>
<tr>
<td>Starch film (1kg)</td>
<td>10.4</td>
<td>1.1</td>
</tr>
<tr>
<td>Loose fills</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starch foam(1m³ = 10kg)</td>
<td>276.0</td>
<td>39.0</td>
</tr>
<tr>
<td>PS foam (1m³ = 4kg)</td>
<td>85.0</td>
<td>8.0</td>
</tr>
<tr>
<td>Films and Bags</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TPS (100m²)</td>
<td>239.0</td>
<td>103.0</td>
</tr>
<tr>
<td>Starch-polyester (100m²)</td>
<td>26.5</td>
<td>2.8</td>
</tr>
<tr>
<td>PE (100m²)</td>
<td>236.0</td>
<td>15.0</td>
</tr>
</tbody>
</table>

Reference: Gironi and Pimente 2011

Unlike the energy consumption and global warming, bio-plastics have negative effects in terms of acidification and eutrophication. The fertilizers and chemicals used in the cultivation of renewable raw materials are the reason for this negative impact. The above results may be confusing for choosing either category of plastics as some environmental factors are in favour of bio-plastics and some are against.
There are various methodologies for analyzing each factor in the context of environmental impact focusing to measure ‘one single index’ e.g. ‘distance to target’ methodology as LCA. This method compares a pair of plastic from each family resulting in a single index of environmental impact as pair itself. (Weiss et al. 2007)

This methodology chooses a pair of plastics having commercial scope. The table to assess the environmental impacts has cumulative index for the attributes to be measured. Zero value shows the balance between two materials, positive value indicate superiority of conventional plastic while negative value indicates bio-plastics as winner. However, this technique also allots weights to different indices depending on the target. Again, the choice of plastics is linked with the priority given to different sections in environmental impact (Weiss et al. 2007, Gironi and Piemonte 2011).

Reference: Girone & Piemonte 2011

Ecoindicator-99 is another tool to assess the environmental impacts of respective category of plastics in several indices. This methodology divides impacts into three main categories i.e. Human health, Eco system quality and resources (Goedkoop et al. 2000). Human health accounts for factors like Carcinogens, Respiratory organics, Respiratory inorganics and Climate change. Ecosystem quality counts for factors like Eco toxicity, Acidification, Eutrophication and Land usage while Minerals and fossil fuels are grouped under resources.

Reference: Goedkoop and Spirensme 2001
The three categories can also be represented by a mixing diagram graphically presented as a triangle. Each point within the triangle represents a weighing combination. The relative weights always sum up to 100%. The deciding factor is weight attached to a certain impact category out of 100%. This factor brings Eco indicator in criticism as this can be politically manipulated. Each corner in the triangle presents 100% weight of each main category. The global impact index ‘I’ is hence measured by allotting weight to each of three macro-categories. It must not be forgotten that Eco indicator works on the principle of ‘distance to target’ values.

\[ I = \sum_i p_i c_i \]

\[ P_i = \text{Assigned weight to the macro-category for impact } i \]
\[ C_i = \text{Value of macro-category of impact} \]

Reference: Girone and Piemonte 2011

The LCA analysis for bio-plastics is very tricky and a complicated issue. It strongly depends on the user preferences and priorities. In industrial world, the application of LCA is highly influenced by the weightage given to each category. The criticism faced by LCA for bio-plastics is framed analogous to comparing apples and oranges. However, Never-the-less, bio-plastics show their superiority over conventional plastics in many regards. The LCA of bio-plastics can be further improved if standardization is achieved. For market like bio-plastics which is less than 1% of total plastics market, it seems far ahead. appendix D shows LCA results for different categories of bioplastics (Matsuura et al. 2008)

The figure below represents analysis of PLA/PET water drinking bottles.

Reference: Gironi and Pimonte 2010
8 Analysis

This section will elaborate the information obtained in terms of key strengths and weaknesses along with different opportunities for bio-based packaging via primary resources. This section is entirely based as a conclusion of interviews done with brand owners, raw material and packaging suppliers.

In order to assess the increasing emergence of bio-based products it is important to understand the challenges faced by a niche product. This chapter will discuss the challenges and opportunities that can bring great improvements from a strategic point of view. Strong emphasis will be given on strength of resources such as biomass that is readily available. Capacity resources that include productive human work force, knowledge sharing, manufacturing facilities and a transportation system are all important. Last but not the least, the most important challenges faced due to technological resources which are primarily related to the actors involved in creating and exploring innovative technological solutions for packaging industry.

8.1 Identification of key challenges

The main contribution of this thesis lies in discovering the challenges and hidden potential in those challenges. The methodology devised to reach the target is to divide the challenges into three categories, the third category being challenges in terms of Research and Development. Due to time constraint, the paper will address the two challenges from primary resources in SWOT analysis.

1) Identification of challenges i.e. in terms of bio mass feed stock
   - Primary sources i.e. crops and wood
   - Secondary sources i.e. waste (pre/post-consumer)

2) Identification of challenges i.e. in terms of bran owners
   - Existing Manufacturing facilities i.e. technological solutions

The list of bio-based raw materials is huge, although not every raw material resource can be efficient enough to end up being cost efficient in processing or fulfilling customer’s demand. Innventia’s most potential source of bio mass is Wood. The first step is analyzing the resource product chain (RPC), which relates to the concept that each feedstock or raw material connects with its applicable process and then forms its own RPC. RPC is mentioned here to elevate the potential in the bio mass especially in cellulosic resources i.e. forest based industry. There are multiple packaging products that can be manufactured using the same raw material but with modifications in the process. This is written in order to bring in notice for the manufacturers that are thinking to widen their business scope.
Including the above RPC, a set of 19 screening questions was prepared. The questionnaire was more of a qualitative nature because this industry has just emerged and it is not easy to get reliable data, so the focus was to extract as much information as possible by applying the fundamental principles and ideas by which this industry can grow.

The probable challenges/concerns according to fundamental principles for bio mass feed stock are:

- The availability of biomass suppliers, the strength of the existing suppliers of bio-based raw materials
- The quantity already harvested, transported geographically to other countries for multiple end user purposes
- The quantity of bio mass sufficient to achieve economies of scale in order to make process more cost efficient.
- Availability of raw materials for conventional plastics at a relatively lower price for incumbents which limits the scope of emergence for established bio mass users.

The probable challenges/concerns according to fundamental principles for the conversion technologies are:

- Application of process/technology that proves it’s maturity
- Use of biotechnology for manufacturing bio-based plastic products by market leaders
- Capability of technology to attract investors
- Leverage related to their existing technical competence
- Implication of benefits both upstream and downstream to leverage through complementary technologies
- A technology capable to revive the energy accompanied in waste streams

The probable challenges/concerns according to fundamental principles for bio-based products from market perspectives are:

- The scope of bio-based products must not be limited to simply consumed on site rather they must have wider market applications
- The existing market share of bio-based packaging products, specifically special concerns are there for biodegradable
- Energy and cost efficiency attributes
- The existence of complementary elements e.g. branding, distribution channels etc.
- Better performance as compared to conventional plastics both upstream and downstream regarding total life cycle.
- Products should be near tipping point i.e. financial or regulatory incentives could create market

The above framework is developed on very fundamental principles of probable attributes that can drive a niche product from incubation/protected chambers to mature technology. This is also related to the theoretical framework developed in the beginning. The complex web that contains the whole value chain, accounts for the landscape that will be created and the effects of legislations on the whole process. Based on the RCP, a first cut conceptual model can be proposed i.e. a technology level that creates process suits, using one process to turn multiple feedstock into multiple end products, provided that time factor to switch between different processes for different products interact is ignored. This concept arise the importance of
feedstock/biomass that can anchor the process i.e. the biomass that is rational to be applied for packaging material and the one which is too marginal to be considered. The consideration also includes the probable transportation cost is incurred in delivering the raw material to production sites.

### 8.2 Identification of key drivers

In order to understand the dynamics of injection of bio-plastics in the market the concepts of supply chain must be under taken, searching for the rationale that will drive stake holders i.e. starting from the raw material suppliers, manufacturers, retailers, consumers and the secondary entities like government, universities and NGO’s. Starting from raw materials supplier, they can be driven by the desire to increase in the value of their feed stock, this can relate to the fact that farmers may demand higher price of their crops to manufacturers of bio-based packaging materials seeking to increase revenue streams to packaging products users for different food products striving to retrieve energy/resources compensated in the process.

This project seeks to define bio-based plastics for primary and secondary packaging as demand driver, since it is the most viable commodity and creating huge deposits of waste in the sea causing damage not just to the food chain associated to sea life but also due to the environmental concerns.

![Diagram of supply and demand drivers](image)

- **Supply:** Raw materials provider will seek to increase value of their material
- **Demand:** To make ecology more viable Better quality attributes/Lower cost

- **Supply Channels:** Industrial waste streams, Wood residues, Bio-waste
- **Demand Channels:** Bio-based materials, Dedicated tech.

Further there is also a technology push by scientific research institutes like Innventia to bring evolution in the packaging industry. In this case the Research and Development capacity will become the main supply driver while institutes supporting such ideas plus private industrial scientific community become main supply drivers.
‘Technology Push’ as Driver
Scientific research institutes will strive bring evolution in packaging industry

There are various sets of analytical tools that can be used to investigate all channels e.g. PEST analysis, SWOT analysis, Maps or Case studies. This project will make use of SWOT analysis as it comprehends all macro factors that determine success or failure. Since, there is also absence or even unavailability of some concrete data, SWOT analysis is one of the most reasonable ways to investigate each channel, each technology.

On the next page is the SWOT analysis performed on the basis of interviews performed with different actors during the course of master thesis. The set of questions that was in the context of the interview is given in appendix A. The discussion was not made merely about biodegradable packaging materials but on the whole about bio-based packaging as well. The results obtained from surveys and semi structures interviews were kept in mind while delivering the presentation to the audience in order create more sense and logic about bio-based packaging materials. SWOT analysis is performed in order to make the factors that can create pull more transparent for INNVENTIA and other readers from bio-based packaging industry.

8.3 SWOT Analysis

The SWOT analysis was helpful in a way that it helped the author to analyze the most influential parameters for the adoption of bio-based packaging. Many factors like recycling, sustainability strategy and key actors dependence on each other was concluded to be important elements, which were not known to be crucial in the beginning. However, the key actors seemed to be hopeful about the potential of bio-mass to resolve sustainability issues in their business and help them to contribute towards society along with their business incentives.

As expected by the survey results, the most critical factors that appeared are:

1) Price
2) Technological feasibility
3) Material performance (as in oxygen barrier, water vapor barrier etc.)
4) Recycling measures
5) High capital investment
## Strengths

**Bio-mass Suppliers**
- Renewability of raw material.
- Alternative source of energy.
- Supreme abundance of cellulosic resources.
- Strong funding dedicated in bio economy.

**Packaging Suppliers**
- Bio-based packaging can reduce waste.
- Fits in the charter of sustainability.
- MFC to replace aluminum is of great interest for suppliers.
- Healthy for brand image.
- Strong bargaining power as a supplier can force brand owners and retailers to adopt bio based packaging.

**Brand Owners**
- Bio-based packaging can reduce waste.
- Fits in the charter of sustainability.
- MFC to replace aluminum is of great interest for suppliers.
- Healthy for brand image.
- Strong bargaining power as a supplier can force brand owners and retailers to adopt bio based packaging.

## Weakness

**Bio-mass Suppliers**
- Difficult to process i.e. technology not mature.
- No intentions to replace petro-plastics with bio-based due to price concerns.
- Problems associated with recycling.
- No ‘willingness’ to offer bio-based packaging to brand owners, until and unless requested by them.
- No demand observed by suppliers from either retailers or brand owners.

**Packaging Suppliers**
- Higher price is a key barrier for adoption.
- Technological feasibility is poor.
- Performance of bio-based packaging is not satisfactory.
- Confusion regarding knowledge of bio-based products.
- As business strategy, focus is more on cost differenatiation then adopting new products.
- No demands received from retailers.
- Customers unwillingness to pay premium price.

**Brand Owners**
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- As business strategy, focus is more on cost differenatiation then adopting new products.
- No demands received from retailers.
- Customers unwillingness to pay premium price.

## Opportunities

**Bio-mass Suppliers**
- New packaging materials could reduce food waste.
- Accepted as the ‘Next big thing’.
- Economies of scale can improve the price factor.

**Packaging Suppliers**
- Increasing the performance can enhance the adoption.
- Bargaining power of giant brand owners can push bio-based packaging in industry.
- SME’s can trigger change with new packagings.
- Economies of scale can resolve cost issues.
- Taxation incentives can create business logic.

**Brand Owners**
- Increasing the performance can enhance the adoption.
- Bargaining power of giant brand owners can push bio-based packaging in industry.
- SME’s can trigger change with new packagings.
- Economies of scale can resolve cost issues.
- Taxation incentives can create business logic.

## Threats

**Bio-mass Suppliers**
- Packaging is not a part of core business model.
- R&D not dedicated towards bio-based packaging.
- Nervousness of brand owners related to potential of bio-mass.
- Recycling infrastructure is favorable for petro plastics.
- Risk in high capital investment due to economic crisis.
- High dependancy on retailers in cost structure.

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- Recycling infrastructure is favorable for petro plastics.
- Risk in high capital investment due to economic crisis.
- High dependancy on retailers in cost structure.
8.3 Proposed value chain for bio-based plastics

Based on the observations and interviews, following value chain has been proposed for injection of bio based packaging in the value chain. The extraction of this value is based on key factors that motivate and demotivate the adoption of bio-based packaging in the plastics industry.

<table>
<thead>
<tr>
<th>Key Actors</th>
<th>Responsibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmers</td>
<td>Sustainable farming, livestock breeding.</td>
</tr>
<tr>
<td>Food companies</td>
<td>Providing RM* for eco industrial system.</td>
</tr>
<tr>
<td>Biomass companies</td>
<td>Common harvest, agricultural growth.</td>
</tr>
<tr>
<td>Waste treatment facilities</td>
<td>Supply of sludge to e.g. bio fuel production</td>
</tr>
<tr>
<td>Waste collection companies</td>
<td>Supply of bio waste</td>
</tr>
<tr>
<td>Bio plastic manufacturers</td>
<td>Production of bio-plastics commercially (earn max. market share)</td>
</tr>
<tr>
<td>Bio plastic producers (R&amp;D)</td>
<td>Provide commercial production with innovative solutions</td>
</tr>
<tr>
<td>Suppliers</td>
<td>Strengthen the supply base, provide brand owners with innovative packaging products</td>
</tr>
<tr>
<td>Retailers</td>
<td>Introduce green products to consumers</td>
</tr>
<tr>
<td>Primary food packaging</td>
<td>Use of green products</td>
</tr>
<tr>
<td>Secondary food packaging</td>
<td></td>
</tr>
<tr>
<td>End consumption by customers</td>
<td></td>
</tr>
<tr>
<td>Financiers</td>
<td>Providing needed financing for actors</td>
</tr>
<tr>
<td>Engineering companies</td>
<td>Providing standard solutions for bio-plastics</td>
</tr>
<tr>
<td>Media</td>
<td>Information about aim, target and available info</td>
</tr>
<tr>
<td>Decision makers</td>
<td>Commitment and incentives, leading and coordinating</td>
</tr>
<tr>
<td>Local authorities</td>
<td>Ensuring all regulations are followed</td>
</tr>
<tr>
<td>Ministries</td>
<td>Clear directives and governance</td>
</tr>
</tbody>
</table>

*Raw Material
9 RESULTS

In this section results are concluded on the basis of SWOT analysis and the potential of bio-based polymers discussed. The result will be associated with the hypothesis proposed in the theoretical framework chapter.

The conclusion of the research is very complicated. However, based on the results, this thesis will close on strong emphasis provided by ‘Proposition 3’ in theoretical framework. There is an external pressure on the landscape and there is window of opportunity for bio-based packaging. On the contrary, bio-based packaging materials are not yet ready to take over the market. They face strong challenges in terms of cost and performances issues. Researchers believe that these challenges will be overcome but if too much time is consumed, as it is an upstream innovation, actors in status quo will keep the charge by strategizing new ideas e.g. reduction in energy and water consumption or CO₂ emissions.

Bio-based packaging are also highly influenced by the geographical factors e.g. in countries like India or China. In Europe, bio-based packaging is highly dependent on legislation now. The likely hood that political interests can influence the implementation of bio-based packaging as a ‘must’ is very high.

The most important aspects for bio-based packaging as discussed earlier are price, raw material availability, technical feasibility, lead time of technology, complementary technologies and customer’s attitude. During the interviews the strongest concerns were regarding either the price or the technological feasibility followed by supplier’s strength. Few important and key players were spotted like brand owners and suppliers. The retailers appeared to be more of a transit point for the commodity products to reach the final customers. The role of the retailers is crucial but surprisingly retailers did not show any commitment towards bio-based packaging and pointed it to be suppliers or brand owners fault. However, they claim to have new teams and projects to discuss bio-based packaging.

The most important parameter for bio-based packaging is the ‘Price’. An effort was made to explore the cost structure for the bio-based packaging materials but responsible the authorities in different companies involved in bio-based packaging manufacturing showed secrecy concerns on cost structure. Therefore, the cost issue cannot be discussed in the thesis in detail. Never-the-less, the references attached in this thesis are extensive and some literature is related to the cost of bio-based materials (related to 2008). In short, currently the cost of bio-based polymers is higher than the petro based polymers.

Most of the brand owners after showing their concern towards price were not sure about supplier’s strength. The overall scenario becomes complex, as the brand owners do not rely on bio-based material suppliers and the suppliers cannot manage the cost due to failure to achieve economies of scale. This is where legislation has to play its role. The brand owners show their interest more towards recycling the plastic waste and reduction of CO₂ emissions.

In order to associate the results with the hypothesis, there is pressure on the landscape which is immense due to the sustainability issues. Therefore, bio-based packaging has an obvious window of opportunity if they overcome the mentioned challenges. The results are coherent with the ‘proposal 3’ in the theoretical framework. It is important to state that bio-based packaging must comply with the complementary technologies of petro-based polymers. Otherwise, the lead time will extend giving current regime an opportunity to rule out Bio-polymers.
<table>
<thead>
<tr>
<th>Factors/Companies</th>
<th>Unilever</th>
<th>Nestle</th>
<th>Kraft</th>
<th>ICA</th>
<th>Procordia</th>
<th>Storenso</th>
<th>Elopak</th>
<th>Innovia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic (Compatibility Relative Advantage)</td>
<td>Variation in Oil price</td>
<td>+</td>
<td>-/+</td>
<td>-/+</td>
<td>+</td>
<td>+</td>
<td>NA</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Price of bio feed stock</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Uncertainty with investments made with bio-plastics</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>NA</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Policy measures in order to control GHG</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Economic compatibility and feasibility</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Calculation of Interest Rate</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Technology (Compatibility Relative Advantage)</td>
<td>Maturity of the technology</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Longer lead time of technology to Industry</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>NA</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Availability of new technology via licensing</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Complementary technologies (Maintenance infrastructure, distribution channels etc.)</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Intellectual cross intersection (Complexity)</td>
<td>Integration with agro-companies</td>
<td>+/-</td>
<td>+/-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>NA</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Knowledge sharing</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>NA</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Application of co-products</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Regulation (Policy &amp; Measures)</td>
<td>Product labeling</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Recycling measures</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Public awareness programs</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Eco friendly products</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+/-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Taxation on use of oil based products</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>NA</td>
<td>+</td>
</tr>
<tr>
<td>Market Pull (Trial ability)</td>
<td>VOC* triggering demand for bio-based products</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+/-</td>
<td>+/-</td>
</tr>
<tr>
<td>Observability)</td>
<td>Company’s strength (as in market share)</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Market projections for future indication the potential in renewable resources</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>NCA</td>
<td>+/-</td>
<td>-</td>
</tr>
<tr>
<td>Policy measures creating tax incentives</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>NA</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Govt. provides financial support, to reduce cost of innovation</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Innovative designs</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Technology Push (Trial ability Observability)</td>
<td>Measures to avoid dominance of specific technology</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>NA</td>
<td>-</td>
<td>NCA</td>
<td>+/-</td>
</tr>
<tr>
<td>Strongly funded R&amp;D</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+/-</td>
<td>+/-</td>
<td>+</td>
</tr>
<tr>
<td>Longevity in investment pay off</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>NA</td>
<td>-</td>
<td>+/-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Trained Personnel (Relative Advantage)</td>
<td>Availability of trained personnel</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+/-</td>
</tr>
<tr>
<td>Heuristic solutions</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>NCA</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Company awareness about bio-based packaging (Y/N)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Is their R&amp;D working on bio-based packaging</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
</tbody>
</table>

This table is a blend of Geels and Rogers theories created by the author to assess key players’ perception about bio-based packaging.

*Voice of customer

+ Motivating factor for adoption  - Demotivating factor for adoption  +/- Neutral  N/A  Not Answered
10 DISCUSSION AND CONCLUSIONS

A discussion of the results and the conclusions that the authors have drawn during the Master of Science thesis are presented in this chapter. The conclusions are based from the analysis with the intention to answer the formulation of questions that is presented in Chapter 1.

10.1 Discussion

In order to inject bio-based materials in the manufacturing systems of the plastic world, it is really important to align the whole value chain of actors using bio-based materials. Currently, the bio-based materials are being recognized as highly potential materials for applications in different fields e.g. textile, packaging etc. The current industry utilizing bio-based materials needs a strong infrastructure based on bio materials. A possible example of another utilization of bio-materials is in the bio-gas production units which can utilize raw material from different landfills e.g. bio waste from fisheries. This bio waste could be utilized more efficiently if treated in a bio gas plant. Other kinds of bio masses can also be used as raw materials for production of bio gas. The CO\textsubscript{2} emission from bio gas production can be utilized in a green house. In this way the energy produced can be utilized in different applications from a CHP e.g. energy can be used in fish farm or as bio fuels in transportation purposes.

Reference: Magnus et al. 2011

Above is an ideal framework for sustainable food and energy production. Same model can be implemented on packaging plants in order to make the overall cycle ecological.

In Linkoping, a city in Sweden, bio gas has been chosen as an alternative to diesel to run the local fleet of buses. The bio mass used for the production of bio gas is manure and waste from food industry e.g. waste fat, vegetable fat, and slaughter waste and so on. Further, Organic
fertilizers are also produced as byproducts of bio gas can be used for farming under Swedish certification system. The utilization of bio mass in bio gas production is sustainable as it is one of the best ways to manage the pre consumer waste and bring greenhouse emission to minimal level.

10.2 Conclusions

The paper will close by saying that if packaging or any other industry is segregated from the typical oil based system to a bio-based economy, the system will sooner or later collapse. The rationale behind is the complex web of legislation, economic volatility, uncertain market which leads to confusion in market pull, technology push and severe competition. If bio-based economy has to emerge the pieces have to fall in place linearly. The bio economy needs to be believed in. It’s not about targeting any single or specific industry to be injected with bio-based materials. It is about the landscape that needs to be created after which all the actors in the value chain have to contribute for their own roles. The big players may survive having dual procurement of raw materials i.e. bio-based materials and oil, but the incumbents will fall for the current technology. If the strategy is not properly designed, it will create polarity in the industry which will misalign the whole value chain. A bio-based packaging, textile or any other system will only run successfully if the whole system is completely run by using bio-based materials e.g. using bio-mass for bio-gas and utilization of bio-gas in industries as source of energy to run their machines which produce bio-based products, the waste (pre and post-consumer) being completely recycled or completely compostable to be again used as raw material from the starting point. In this way the system will become completely sustainable without jeopardizing the needs of future generation. For this perfect ecological loop, the technology needs to be completely viable, the research needs to be on its peak meanings it needs great investment, the actors need to share their knowledge and the government needs to play their role to save the world.


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This section is dedicated to key questions asked to different players involved in packaging value chain

1) What are the challenges faced in terms of bio mass security i.e. the problem addressing the strength of bio mass ers is a big question in conventional plastic industry?
2) What are the most important attributes for biodegradable packaging to compete the current plastic industry?
3) What other incentives you see in commercializing biodegradable packaging?
4) What are the weakest points of biodegradable packaging from market perspectives?
5) How do you see customer perception about paying premium price for biodegradable packaged products?
6) How is the legislation helping or hindering your business for commercializing bio-based packaging products?
7) What are the most prominent raw materials that you use? Is the technology mature enough to be commercialized globally?
8) How do you see recycling infrastructure? As, it is one of the weakest points for biodegradable.
9) What are the most important leveraging factors for you in business of biodegradable plastics?
10) How does your company strategize to attract investors in biodegradable plastics business?
11) How do you see the market projections for biodegradable in 2020?
12) How are retailers reacting to such radically innovative product?
13) How are other key suppliers like Tetra Pak or Elopack looking to this?
14) What are your suggestions to create market pull for biodegradable plastics?
15) What are your suggestions for research specialists like Innventia? How can it contribute according to you?
16) How articulate is the infrastructure for biodegradable plastics from recyclign, maintenance, government policies, market, societal parameters and production network?
17) How would you react if your competitor steps it up by adopting bio-based packaging to strengthen their brand appearance?
18) How much are you aware of sea waste accumulation in the seas?
19) To what extent particular elements e.g. brand name producer name, color, imagery, shape, body copy and statutory information, will be influenced by biodegradable packaging solutions?
APPENDIX B: Research Framework

This section is dedicated to framework which was set while interviewing and sending questionnaires.

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<td></td>
<td>• Variation in Oil price</td>
<td>• Maturity of the technology</td>
<td>• Integration with agro-companies</td>
<td>• Product labeling</td>
<td>• VOC triggering demand for bio-based products</td>
<td>• Measures to avoid dominance of specific technology</td>
<td>• Availability of trained personnel</td>
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<td></td>
<td>• Price of bio feed stock</td>
<td>• Lead time of technology to Industry</td>
<td>• Knowledge sharing</td>
<td>• Recycling measures</td>
<td>• Market projections for future indication the potential in renewable resources</td>
<td>• Strongly fund R&amp;D</td>
<td>• Knowledge sharing</td>
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<td></td>
<td>• Uncertainty with investments made with bio-plastics</td>
<td>• Availability of new technology via licensing</td>
<td>• Application of co-products</td>
<td>• Public awareness programs</td>
<td>• Policy measures creating tax incentives</td>
<td>• Understand the dynamics and longevity of investment pay off of certain specific technology</td>
<td>• Heuristic Solutions</td>
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<td>• Policy measures in order to control GHG</td>
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<td>• Eco friendly products</td>
<td>• Govt. provides financial support, to reduce cost of innovation</td>
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<td></td>
<td>• Economic compatibility and feasibility geographically</td>
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<td>• Taxation on use of Oil based products</td>
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<td>• Calculation of Interest Rate</td>
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Compatibility
Relative Advantage
Complexity
Trial ability
Observability
This section is dedicated to the companies whose officials were interviewed during the thesis.

- Unilever
- Nestle Zeogas
- Elopak
- Procordia
- Kraft foods
- Coca Cola
- Innovia Films
- European bio-plastics
- Coca Cola
- Mondi Packaging
- COOP
- Storenso
- Billerud Korsnas
- Borregård
## APPENDIX D: Life Cycle Assessment

<table>
<thead>
<tr>
<th>Source</th>
<th>Characteristics</th>
<th>Main conclusions</th>
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<tbody>
<tr>
<td>Morken, J. and Nyland, C. A. (2002) ITF Rapport: life cycle assessment of BioBags used for collection of household waste.</td>
<td>Comparison of Mater-Bi BioBags to PE bags Cradle to grave (land application of the compost excluded), composting, waste-to-energy and landfill assessed</td>
<td>The life cycle of BioBags is more energy intensive and produces more greenhouse gas emissions than the life cycle of PE bags (disposed of by composting or landfill). Incineration of Biobags for heat and power generation produced a global warming potential (GWP) only slightly higher than incinerated PE due to the oil saved by burning Biobags.</td>
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<td>Novamont SPA <a href="http://www.materbi.com/ing/html/prodotto/considerazioni_sustainability.html">www.materbi.com/ing/html/prodotto/considerazioni_sustainability.html</a></td>
<td>Comparison of Mater-Bi BioBags to PE bags and paper bags Cradle to grave (transportation excluded), disposal by composting or incineration</td>
<td>Mater-Bi bag manufacture uses slightly less energy than equivalent PE bags and significantly less than paper bags. The GWP for the life of Mater-Bi bags is significantly lower (over 60% reduction) than that for PE bags.</td>
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<td>Bio Intelligence Service (2006) for Eco-Emballages, <a href="http://www.ecoemballages.fr/fileadmin/contribution/pdf/etudes/bilan-environnemental-filiere-traitement-plastiques.pdf">www.ecoemballages.fr/fileadmin/contribution/pdf/etudes/bilan-environnemental-filiere-traitement-plastiques.pdf</a></td>
<td>Gate to cradle, comparisons of end-of-life options for LDPE, PET, PLA, PBAT (non bio-based, biodegradable), Mater-Bi and an oxo-degradable polymer</td>
<td>Recycling is the most beneficial option for petrochemical polymers (PE, PET, oxo-degradable). For PLA, PBAT and Mater-Bi, waste-to-energy, not composting, seems the most environmentally-friendly option, except with respect to global warming impacts if carbon is captured during composting. When modelled like PET recycling, Mater-Bi recycling has the lowest impacts (except for sediment ecotoxicity).</td>
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<tr>
<td>Source</td>
<td>Description</td>
<td>Notes</td>
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<td>Vink, E.T.H. et al. (2007) The eco-profiles for current and near-future NatureWorks polylactide production</td>
<td>Cradle to grave (recycling or incineration) PLA clamshell packaging compared to equivalent products made of PP, PS, PET</td>
<td>PLA clamshell manufacture, use and disposal use less fossil-fuel resources (75% less than PET) and produce less greenhouse gas emissions than other plastic types (50% less than PET).</td>
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<tr>
<td>Bio Intelligence Service (2007) for Eco-Emballages, <a href="http://www.ecoemballages.fr/fileadmin/contribution/pdf/institut/etudes/acv-emballages-plastique.pdf">www.ecoemballages.fr/fileadmin/contribution/pdf/institut/etudes/acv-emballages-plastique.pdf</a></td>
<td>Cradle to grave LCAs of PET, PE, PLA, PBAT (non bio-based, biodegradable) and an oxo-degradable polymer</td>
<td>The production phase dominates in terms of impacts for all packaging resins. The end-of-life phase has low impacts by comparison, except for PET and PE recycling which have positive end-of-life management characteristics. With the current non-selective collection scheme, composting options do not significantly improve the overall environmental impacts of bioplastics.</td>
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<tr>
<td>National Non-Food Crop Centre (2008) LCA of biopolymers for single use carrier bags.</td>
<td>Comparisons of degradable/non-degradable HDPE bags with starch based Mater-Bi bags and PLA/petroplastics mix bags Cradle to grave (landfill, incineration, recycling, composting considered)</td>
<td>Using and recycling HDPE bags results in the least environmental impact. The next best option is the incineration of Mater-Bi bags. The most important life-cycle phase is the extraction and production of material for all types of plastics. There was no evidence of energy savings in the production of bioplastics. Future improvements in energy efficiency of resin manufacture may help reduce this impact. Incineration with energy recovery is the best option for the end-of-life of bioplastics bags and composting is not a clear winner.</td>
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