INTRODUCTION ON ADVANCEMENT OF PACKAGING MATERIALS TOWARDS SUSTAINABILITY

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In the current developed world, packaging is an integral part of a product; and yet, with today's environmental concerns, reducing waste and energy usage while increasing overall product sustainability has been the priority. A major challenge faced by packaging technology advancement relates to sustainable packaging. Innovation in sustainable packaging technologies can play a vital role in supporting the United Nations (UN) 2030 sustainable development agenda - *"Transforming our world: the 2030 Agenda for Sustainable Development".*

However, Sustainable packaging is no longer focused on just recycling; rather, it now has to qualify multiple dimensions - serving consumer preferences and enabling business growth while promoting environmental protection. Other drivers are government, regulation, public health and retailers.

Stringent measures adopted by governments such as directive 94/62/EC[1] by the European Union, the National Environment Agency (NEA) of Singapore's[2] mandatory requirements for sustainable packaging are examples of government initiatives. Companies such as The Coca-Cola Company, Danone, BASF[3,4,5], and others are proactively developing initiatives or materials for sustainable packaging which also gives them a competitive advantage. Large retailers such as Amazon, Wal-Mart[6] and others are developing supply chain processes to progressively meet their targets of sustainability. The sustainable packaging market is estimated to reach USD 303.60 Billion by 2020, with a projected CAGR of 7.17 % from 2015 to 2020[7].

These encouraging developments suggest that sustainable packaging is no longer a nice-to-have, but an essential part of doing business. In response to the vital needs of sustainable packaging, the industry has been focusing on innovation across three key areas – design, materials and manufacturing techniques. The sustainability goals emphasize on the following points:

- ✓ Reducing weight and volume of packaging
- ✓ Eliminating or minimizing toxic additives

- ✓ Reducing energy consumption
- ✓ Creating sustainable business models

Given that, the scope of research for sustainable technologies is vast, the current study puts an emphasis only on the relevance of packaging materials in sustainable packaging development. Packaging materials play an important role in the packaging value chain as it usually comprises of over half of the total cost of packaging.

Evolution of packaging began with natural sources such as bark, leaves, leather, etc. Later, taking into consideration their strength and durability properties, glass, metal and ceramics gained popularity. In the early 20th century, milk was commonly transported in glass bottles. However, these materials had their own disadvantages with regard to fragility, flexibility, manufacturing cost, hygiene issues and ease of delivery. This was when thermoplastics came into the picture and replaced the earlier packaging materials, but their disadvantage is that they are not found to be environmentally friendly. With the awareness of environmental friendly packaging commencing in the late 80's, research on bio-degradable materials began.

In order to assess how packaging raw materials can address the sustainability requirements, the following methodology was adopted to derive our insights.

STEP 1: CATEGORIZATION

As packaging materials spans across a wide spectrum, it was first necessary to group those into three broad categories based on their material characteristics as per Figure 1:

1. **Reusable materials** comprise metal, glass and ceramic which are reusable
2. **Synthetic materials** comprise plastics that are derived from fossil-based resources and are non-biodegradable
3. **Bio-derived materials** comprise bioplastics that are made fully, or partly, from biomass, which are biodegradable. While some conventional bio-based plastics, such as Polyethylene (PE), Polyethylene terephthalate (PET), etc. which are non-biodegradable also fall in this category.

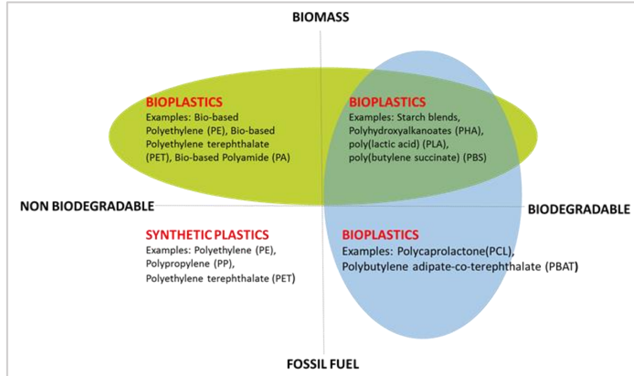

Figure 1: Classification of packaging materials

STEP 2: PATENT RESEARCH

To understand evolving patterns in the three categories of packaging raw materials, patent research was conducted covering two decades each during Pre-2000 and Post-2000.

STEP 3: PACKAGING PERFORMANCE METRICS

The three categories of packaging materials were benchmarked against a framework designed around packaging performance.

STEP 4: COMPARISON OF INNOVATION TRENDS

Key innovations during Pre-2000 and Post-2000 timeframes were studied for two prominent categories.

STEP 5: LATEST INNOVATION TECHNIQUES

Our research also considered most recent innovation methods that will define the future trends in research on sustainable packaging.

PATENT RESEARCH:

Our observations from the patenting trends are listed below:

- Reusable materials did not draw as much attention Pre-2000 due to dominance of plastic and papers in the packaging industry. However, Post-2000 there is a significant interest (CAGR 8.1%) due to introduction of cans for beverages and pressurized aluminum containers for aerosols

- Consistent upward patenting patterns of synthetic materials indicates a preferred category. Eventhough, a brief decline in patenting pattern during 1992-1996 is correlated to several factors including the "1990 oil price shock"[8], which resulted in finding alternatives and increase in awareness of bio-degradable materials
- Although, Post-2000, a steady growth (CAGR 3.75%) in bio-derived materials is observed, they are trailing in comparison to synthetic materials. This fact can be attributed to prolonged time required to develop novel bio-derived materials that would effectively address the key issues pertaining to packaging performance metrics.

It can be concluded from the above observations and Figure 2, that synthetic materials and bio-derived materials display parallel growth patterns. Therefore, our focus shifts to further understand the drivers that will impact choices in future for packaging materials.

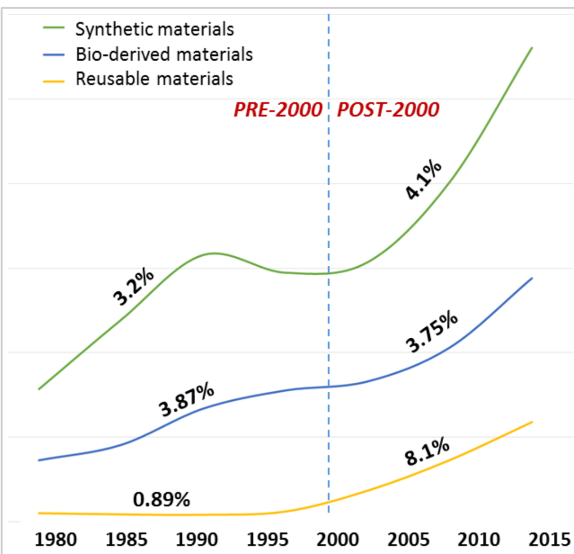

Figure 2: Patenting trends for Pre-2000 and Post-2000

PACKAGING PERFORMANCE METRICS

To appropriately channelize the efforts in continuous development of sustainable packaging options, it is important to define performance metrics for packaging. Therefore, we have designed a framework of packaging performance metrics as in Figure 3. The following are the key factors to measure:

- **DURABILITY:** Mechanical strength and puncture resistance for protection and safe transportation
- **COST:** Economical options for consumers and manufactures
- **BARRIER PROPERTIES:** Resistance to light, moisture, water vapour and gas
- **RAW MATERIAL AVAILABILITY:** Abundant and high quality material
- **PROCESS ABILITY:** Ease of fabrication with available equipment and machinery
- **USER FRIENDLINESS:** Non-toxic and easily recoverable raw materials
- **MATERIAL IMPROVISATION:** Ability to innovate new materials or optimize properties of materials

Figure 3: Packaging performance metrics

The packaging performance metrics were used to rate the three categories of packaging materials between values 1(lowest) to 5(highest). From Figure 4, it is observed that the top two categories of materials (synthetic materials and bio-derived materials) substantiate the patenting trends.

PACKAGING PERFORMANCE METRICS	SYNTHETIC MATERIALS	BIO-DERIVED MATERIALS	REUSABLE MATERIALS
DURABILITY	3	3	2
COST	4	2	3
BARRIER PROPERTIES	3	2	3
AVAILABILITY	4	3	3
PROCESS ABILITY	4	3	2
USER FRIENDLY	4	4	3
MATERIAL IMPROVISATION	3	4	2
AVERAGE	3.5	3	2.5

Figure 4: Ratings for packaging performance metrics

Hence, the remaining part of the study is concentrated on only synthetic material and bio-derived materials.

COMPARISON OF INNOVATION TRENDS

The study of key improvements in technologies during Pre-2000 and Post-2000 period for both synthetic and bio-derived materials is presented as below:

	SYNTHETIC MATERIALS	BIO-DERIVED MATERIALS
DURABILITY	▪ Flexibility in packaging was obtained by varying crosslinking density in polymers; ▪ While in Post-2000, polymer blending was used to exhibit both thermal stability and flexibility	▪ Usage of additives improved durability of de-structured starch; ▪ While in Post-2000, thermoplastic starch compositions were developed to attain durability
BARRIER PROPERTIES	▪ Stabilizing agent was incorporated in the synthetic plastic; ▪ While in Post-2000 stabilizing agents were replaced by absorptive inner layer	▪ Improved barrier resistance was achieved by the aid of metallic compounds. ▪ While in Post-2000, usage of metallic compounds has been avoided
PROCESS ABILITY	▪ Poor output rates due to multi stage processing were improved in Post-2000 period by adding reactants within an extruder	▪ Pre-2000 had challenges on scalability due to requirement of special manufacturing process ▪ However, in Post-2000, commercial production was successfully achieved
MATERIAL IMPROVISATION	▪ In Pre-2000 period, recycling of material was of importance. Therefore, laminate material with excellent adhesion properties was used between layers ▪ While in Post-2000 period, the focus shifted on recovery and reuse of materials	▪ Effective utilization of bioplastics was the focus during Pre-2000 period; ▪ While in Post-2000 period, focused on enhancing properties of bioplastics for example controlled rate of degradation

LATEST INNOVATION TECHNIQUES

Findings on current innovation trends in sustainable packaging indicates promising progress and novel techniques that will have a great impact on offering sustainable packaging solutions.

SYNTHETIC MATERIALS:

The major focus of companies on synthetic materials has been towards process improvements enabling reduced density and usage of raw material; and improved recovery and reuse of materials. The following are some examples:

1. The MuCell® Technology[9] reduces density of the bottle and the amount of plastic required (Unilever, ALPLA and MuCell Extrusion)

2. Micro foaming technology[10] reduces density in coextruded films (The Dow Chemical Company)
3. Industrial injection compression[11] system reduces 20% weight due to reduced wall thickness (Coveris, Unilever and Plastisud)
4. The “EPS-Fish” project[12] to recycle expanded polystyrene waste from fresh fish packages to achieve a high quality, non-odor recycled material (Spain’s plastics technology center, **Aimplas** and **Acteco Productos y Servicios)**

BIO-DERVIED MATERIALS:

Companies doing research & development in this area are working towards leveraging inherent properties of bioplastics and enhancing barrier properties, durability, process ability and material improvisation. The following are some examples:

1. A biodegradable material for cheese and fresh pasta developed by employing wax coating derived from olive leaves to provide water vapor resistance (AIMPLAS) [13]
2. A new technology for producing compounds that can be processed into flexible packaging films with low thickness as low as 8 micron while retaining high puncture resistance (**FKuR**) [14]
3. A new bio-based and fully compostable flexible packaging solution that biologically decomposes in just 180 days and becomes a fertilizer for soil (TIPA) [15]

Though, a lot of research, on bio-derived plastics is focused in material improvisation, there is scope for process innovation as well. Many conventional manufactures have equipment/processes for synthetic plastics and hence, are hesitant to make separate investments for new equipment favorable for bioplastics.

An unique model that leverages equipment for both synthetic and bio-derived materials is that of Bosch VFFS[16] - Bosch Packaging Technology developed a vertical form, fill and seal machine (VFFS) with ZAP-Module, which allows coating with the sealing agent on a minimal surface area, preserving the paper’s mono-material character.

CONCLUSION

Most of the current packaging solutions fall within linear economy model which is “*take, make, waste*". The foundation of sustainable packaging lies in making a big leap towards a circular economy model which is the “*take, make, restore/recover and remake*". The following inferences are drawn based on our research:

- It is clearly evident that synthetic materials are most preferred across various industrial applications as they are economical, attractive to consumers, and available in abundance
- However, fluctuation in prices of synthetic materials and serious initiatives to reduce adverse environmental impact are forcing manufacturers to improvise processing abilities to reduce their usage and accelerate usage of bio-derived materials
- Although, Post-2000 there is a steady growth towards utilization of bio-derived materials, yet they lack pace in comparison to synthetic materials; the reasons being extended time required for development of novel materials, inferior barrier- and mechanical-properties
- Overall, there exists a healthy competition between synthetic materials and bio-derived materials to collectively develop sustainable packaging solutions

FUTURE PROSPECTS FOR RESEARCH

1. Synthetic materials require support of process improvements to reduce density and usage of raw materials

2. The future of bio-derived materials lies in enhancing inherent properties of bioplastics and inventing novel materials
3. Design and development of cross compatible equipment for processing / fabricating synthetic and bio-derived materials for optimized manufacturing

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