Title: Nexus among Bioplastic, Circularity, Circular Value Chain & Circular Economy.

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Abstract

Bioplastic is an innovative and emerging industry that brings hope as well as ambiguity from materials sourcing to end life management. Circular economy (CE) which is to decouple economic growth from a carbon footprint and maximum utilization of renewable resources, that keep creating pressure on emerging bio-plastic industry to save our planet from the adverse effect of traditional plastic industry. Through the article, bioplastic circular value chain and a flow chart have been developed to understand, how circularity works in the value chain and stimulate competitiveness and necessity of practicing circularity in the bioplastic industry. This technical research article has been conducted by mini literature review, information and knowledge gain from stakeholder’s publications, website, books, case study as well as direct and indirect involvement in bio-plastic industry. We observed bioplastic industry also needs to practice circularity in the value chain that will ensure more competitiveness and gain sustainability leadership index.

Keywords

Bio-based, Bioplastic, Circular Economy, Industrial Ecology, Bioplastic Circular Value Chain, Circularity, Competitiveness.
1. Introduction:

Attributes of bioplastic are biodegradable, bio-based and could be both. Bioplastic is biodegradable, but it is from renewable (biomass) sources and vice versa. The definition of bioplastic is based on raw materials sourcing (biobased) to end life management (biodegradable). Biobased that denotes renewable biomass source of raw materials; whereas, biodegradable which is a chemical process that uses natural existing microorganism to convert materials into natural substance (e.g. water, Carbon dioxide and compost) at specific environmental condition (e.g. temperature, location). (B. European, n.d.-b), which helps to balance our planet’s ecological system, but conventional plastic industry uses materials from limited sources that not only limited, but it also non-biodegradable for 100s of year. Conventional plastic material’s after use effects are much more adverse than the benefits are offered. Our planet is degrading due to imbalance management of sourcing, production and uses to meet growing diversified human demand of easing lifestyle, but whose hostile effects mostly ignored. Nature doesn’t depend on human but human fully depends on nature by taking oxygen to foods chain. In return, our planet gets toxic garbage and falls into a challenge to uphold the ecosystem. On the other hand, bioplastics are derived from biomass or renewable sources (e.g. Jute, Corn, Sugarcane, cassava etc.) that helps to tradeoff carbon dioxide and oxygen. If we consider the contribution of the Jute plant which is a renewable source of bioplastic materials, a natural blessing, has the power to help nature by captivating carbon dioxide and yield oxygen. A hectare of jute plants consume about 15 tons of carbon dioxide and release 11 tons of oxygen in nature (“Future Fibres: Jute,” n.d.) that’s called natural trade-off. So, whatever, we do source and produce; it is required to consider the natural trade-off and gradually reduce the imbalance. It’s high time to rethink; what, how, why and where we should source and use materials by ensuring renewable sources which balance absorbing carbon dioxide and producing oxygen.
Renewable resources (bioplastic raw materials) are born circular, that are grown over time and degraded by the natural system, but when it is converted into value-added products that creates pressure on life cycle management. Bioplastic industry aims to be a complete substitute of fossil plastic (very user-friendly, durability and inexpensive); that’s why, it has to go through technical as well as chemical process to make purposeful and competitive, and the transformation causes damaging of mechanical and chemical property as well as inherent nature of biodegradability & compost ability; which address the needfulness of circularity (10Rs) over the products life cycle and through the value chain. For example, recently invention of bioplastic like jute polymer bag (Sonali Bag) (Hejase, H.J., Hejase, A.J., Tabsh, H., Chalak, H.C., Wamitu, S.N. and Pavel, 2018; Pavel & Supinit, 2017) for packaging industry as well as Jute Reinforced Fiber Composite (RFC) for automotive & laminate industry, which both are value-added product opens a door to rethink value chain management in a circular way to make more sustainable and efficient waste management. Products are made by biomass which 100% bio-degradable & recyclable, that had already been recycled since born, but it is not enough. Because, this product’s or materials’ also have life after life that can be extended with proper management by practicing circularity principle (10Rs). The best way could be followed circular value chain that will make the industry more competitive in terms of sustainability and will be benefited from value proposition to value consumptions from producers to consumers end by ensuring economic, social, and environmental well-being. Nevertheless, circular economy always emphasis on three principles: 1. Design out waste and pollution 2. keeping products & materials in use and 3. Regenerate natural systems (“What Is The Circular Economy?,” n.d.). Bioplastic industries are now amalgamated with different industries (Amaechi, Agbomerie, Orrok, & Ye, 2019; Faruk, Bledzki, Fink, & Sain, 2012; Ravenstijn, 2010; M. Sayeed, Sayem, & Haider, 2019) to supply biomass/plant, fiber, cellulose, starch to make environmental friendly materials, but when it is shifted from industry to industry
and converted into different products & uses creates concern on the products’ end life management and value maximization. In the circular economy concept, there are nothing to loss or discarded to environment. On the other hand, every materials or products should be counted and go into circularity to ensure greater value maximization.

Should we throw away bioplastic (materials or products) after first life (one-time use) to the environment? It is the fact now; the end life management of the bioplastic product depends on the design (Life Cycle Analysis & Biodegradability) of the products. As all bioplastics are not naturally biodegradable due to resin, additive and hazardous chemicals (even phthalate) are used to make purposeful, that prevents us to throw-away to our landfill. There are also some special bioplastics products that are designed for home compostable or 100% biodegradable (not industrial compostable) could be discarded to landfill, but sometimes it also is needed pretreatment.

Then, why is bioplastic needed or how does it offer benefits to nature? Firstly, we need to consider the source of the raw materials, benefits for mother nature and lastly ease of the products’ end life management. In addition, extracting material from limited sources means-degrading the nature and concluded a huge challenge to protect our planet, and unlikely decouple economic growth to the carbon footprint. Bioplastic industry is fully based on innovative technology from harvesting, sourcing and producing biomass to offer industrial and consumer goods.

The fourth industrial revolution which brings hope to compensate linear system (take-make-dispose) to regenerative economic system by getting the involvement of digital technology: blockchain, robotics and IoT which have the power to facilitate the transition from linear to circular economy, by radically increasing virtualization, de-materialization, transparency
(Certifications), and feedback-driven intelligence. Circular business model is enabled by closing, narrowing, slowing, intensifying and dematerializing the loop. The enablers of circular business model depend on the (10Rs) circularity principles (Refuse, Rethink, Repair, Reuse, Repair, Refurbish, Remanufacturing, Repurpose, Recycle and recover) has been presented to articulate bioplastic circular value chain in the article.

This article could be classified as a combination of mini review, technical analysis as well as opinion. The main objective of the article is to illustrate the prospects of practicing circularity principles in bioplastic industry value chain. Here, we will develop a framework and flow chart on circular value chain for bioplastic industries. The framework which helps to understand a holistic circular value chain, and lastly the flow chart will help general consumers, producers, stakeholder and policy makers to apprehend the stage in decision-making on purchasing, uses and management. The circular value chain helps to understand; how to extend and retain value of bioplastic products to achieve the objectives of circular economy and sustainability – systemic shift to build long-term resilience, create business & economic opportunities and deliver societal & environmental benefits through technical and biological/organic cycles. This article is not only focus on products circularity, but it also on the raw materials even value-added products.

As bioplastic is emerged as hopping to reimburse adverse effects of conventional plastic, and for greater benefits, which is ensured through verifying by third party organization and even every countries and organizations have set up specific guide line with testing procedure to ensure the biodegradability and end life management. The resting methods and required certification are presented through the article, which will help to understand in depth.
2. Literature Review:

Through the literature review, we try to define key elements and understand relationship among Sustainable Development, Ecological Transaction, Green Economy, Circular Economy (CE), Shared value, Cradle to Cradle (C2C), Functional economy, LCM (life cycle management), Eco-design, LCA (life cycle assessment) and Circular Value Chain. Secondly, we define Bio-based, Polymer, Bio-polymer, Bio-plastic, Bio-degradable, Incineration, Compostable. In addition to review on block chain, international organizations guideline and certifications, concept of circular value chain and circularity (10 Rs), and then we develop a framework on bio-plastic industry circular value chain and will observe how circularities (10 Rs) work from value generation (early life) to value recover (end life) as well as how an organization could be benefited and achieve competitive advantages from value proposition to value retain. As most of terms are scientific, that are related to biology & chemistry. As a framework of the value chain is the closest concern of business department, that needs to define as simple as possible to understand in a generic form.

The Ellen MacArthur (Ellenmacarthurfoundation, 2019) Foundation puts three principles: design out waste & pollution, keep products & materials in use and regenerate the natural system. Nevertheless, sustainability has also three pillars: economic (profit), environmental (planet) and social (people) (Slaper, 2011) that concentrate on meeting the needs of the present without compromising the ability of future generations to meet future needs.

Circular economy (CE) is not only stressed on materials and products end life management, but it also emphasis on the sourcing of raw materials, CE is an approach to meet the bottleneck of resource scarcity and waste disposal. Many philosophies, frameworks, procedures and tools [Fig-1] had been developed & defined by the think tanks to simplify value chain aiming to achieve sustainable development goals. Before discussion of circular value chain, we should
understand the relationships among the developments that will help to connect all concepts and importance of the circular value chain. Sustainable development (SD), Ecological Transition (ET), Green Economy (GE) and Circular Economy (CE) are high-level vision for societies to achieve sustainable development goals, but CE is a philosophy as well as provide guideline and closely related to implementation and gaining economic benefits in a sustainable way. The concept circular value chain is enhanced by the tools like Eco-design & life cycle assessment in the organizational level. But the procedures: functional economy (e.g. selling service instead of products) & LCM (Life cycle management) for company or industry value chain, which helps to uphold circularity (10Rs). Furthermore, the frameworks like shared value focuses on value chains and local community level to share and manage of value among companies, industries & local community. C2C (Cradle to cradle) that also provides guideline and applied at value chain by ensuring all materials input and output pass through the technical and biological cycle to conclude closed loops (Kumar, Sameer; Putnam, 2008). All the concepts aim to stand under the umbrella sustainable development and lastly executed in the circular value chain.

**Fig- 1 Relationship among SD, ET, CE, LCT, SV, C2C, FE, LCM, ED, LCA and CVC.**
Table-1 Common plant-based and fossil-based materials and approximate prices.

| Material                                                                 | Sources                        | Price ($/lb.) |
|--------------------------------------------------------------------------|--------------------------------|---------------|
| Lignocellulose fibre                                                    | Plant                          | 0.2-0.6       |
| Cellulose esters/Ethers                                                | Plant/petrochemical            | 2.0-10.0      |
| Starch                                                                  | Plant                          | .10-1.0       |
| Starch/polymer blends                                                  | Plant, petrochemical           | 1.0-2.0?      |
| **Polylactic acid (PLA)**                                               | Plant                          | 1             |
| Polyhydroxyalkanotes (PHAs)                                             | Plant                          | 2.0-6.0?      |
| Poly (butylene Succinate/adipate) (PBS/A), polybutylene adipate phthalate (PBAT) | Plant, petrochemical           | 2.0-3.0       |
| Polyamides (Nylon 10, 11)                                               | Castrol oil                    |               |
| Zein                                                                    | Corn                           |               |

Source: (Fallis, 2013) & author re-arrange.
| Bio polyurethanes | Plant, petrochemical |
|-------------------|----------------------|
| Bio epoxies       | Plant, petrochemical |
| **Bio-polyethylene (Bio-PE), Bio-polypropylene (Bio-PP)** | Ethanol from corn, sugarcane, etc. |
| Bio-polyethylene terephthalate (bio-PET) | Plant sugars |
| Polytrimethylene terephthalate (PTT) | Corn glucose, petrochemicals |
| Polyethylene furanote (PEF) | Corn Sugars |
| PE | Petrochemicals | .65-.80 |
| PP | Petrochemicals | .85-.95 |
| PET | Petrochemicals | .85-.90 |
| PS | Petrochemicals | 1.0-1.2 |
| PVC | Petrochemicals | .85-.90 |

**Source:** (Shogren, Wood, Orts, & Glenn, 2019) & authors re-arrange

Bio-based materials or products [Table-1] which are derived from biological & renewable resources (“What is biobased?,” n.d.), biodegradable and compostable (Syed Ali Ashter, 2016) is broken down (decomposed) rapidly by the action of microorganisms. The prefix “bio” relates only to the feedstock (bio based) used to manufacture the material. Biodegradable whose polymeric bonding will be broken down by the presence of microorganisms, that raw materials (poly) could be sourced from bio-based (biomass) or fossil based (crude oil). So, whatever the source (fossil or biomass) of the raw materials; if the products or materials are degraded in the presence of microorganisms then it is to be called bioplastic [Table-2] It helps to understand the difference and implementation.
Table 2: Bio-based and Oil-based poly and uses.

| Biodegradable Plastics | Bio-based plastics                  | Example of Use | Oil-based plastics                  | Example of Use |
|------------------------|------------------------------------|----------------|------------------------------------|----------------|
|                        | Poly (lactic acid) (PLA)           | Medical        | Poly (ε-caprolactone) (PCL)        | PVC glue       |
|                        | Polyhydroxyalkanoate (PHA)         | Medical        | Poly (butylene succinate/adipate) (PBS/A) | Agriculture |
|                        | Polysaccharide derivatives         | Food packing   | Poly (butylene adipate-copterephthalate) (PBA/T) | Paper cups |
|                        | Poly (amino acid)                 | Medical        |                                   |                |

| Non-biodegradable Plastics | Polyethylene (bio-PE)            | Packaging      | Polyethylene (PE)                 | Packaging       |
|                           | Poly-polyurethane                | Tyres          | Polyethylene (PP)                 | Packaging       |
|                           | Polysaccharide derivatives       | Food packaging | Polystyrene (PS)                  | Packaging       |
|                           | Poly (ethylene Terephthalate) (bio-PET) | Water Bottles | Poly (ethylene terephthalate) (PET) | Water Bottles |
|                           |                                   |                | Polymethylmethacrylate (Perspex)  | Optical materials and others |

Source: (Kjeldsen, Price, Lilley, & Guzniczak, 2018) & authors re-arrange
Table-3 Bio-degradability of bio-based polymers

| Material           | Compost (ASTM D6400) | Soil (ASTM D5988) | Marine (ASTM D6691) |
|--------------------|-----------------------|-------------------|---------------------|
| Kraft Paper        | Y                     | Y                 | Y                   |
| Cellulose acetate  | Y                     | Y                 | Y                   |
| Corn Starch        | Y                     | Y                 | Y                   |
| PLA                | Y                     | N                 | N                   |
| PHA                | Y                     | Y                 | Y                   |
| PBS                | Y                     | Y                 | N                   |
| PBAT               | Y                     | Y                 | ?                   |
| PE                 | N                     | N                 | N                   |
| PP                 | N                     | N                 | N                   |
| PET                | N                     | N                 | N                   |
| PS                 | N                     | N                 | N                   |

Source: (Shogren et al., 2019) & authors re-arrange.

We can define bioplastic that is a diverse family of materials which is derived from natural (bio-based-renewable or fossil oil-based- nonrenewable or both) monomers, and then through the different process the monomers forms polymers and the final blend of the polymers which have biodegradable or non-biodegradable attributes. Bio-polymers composite [Table-3] have developed significantly over the past years because of significant processing advantages, biodegradability, low relative density, high specific strength and renewable nature. Biobased plastics or bioplastic materials as reinforced matrices for bio-composites that one of the most attractive growing sectors over the world, the average annual growth rate globally was 38%
from 2003 to 2007. At the same time, the annual growth rate was as high as 48% in Europe.
The worldwide capacity of bio-based plastics is expected to increase from 0.36 million metric
ton (2007) to 2.33 million metric ton by 2013 and to 3.45 million metric ton in 2020. The the
best polymers in terms of production volumes will be starch-based plastics, PLA and PHA.
(Faruk et al., 2012). Green composites also include at least one biodegradable, either matrices
or fillers, or both. It also can be separated into two groups, partially biodegradable and fully
biodegradable (M. M. A. Sayeed, Sayem, & Haider, 2019).
Bioplastic is a sustainable substitute for conventional plastic, but it also has some drawbacks
or confusion in materials sourcing to end life management. To ensure objectives of developing
bioplastic industry some international organizations like ASTM (American Society for resting
and materials) [www.astm.org], ISO (International Standards Organization) [www.iso.org],
CEN (European Committee for standardization as EN) [www.cen.eu], AS (Standards
Australia) provide specific guideline and testing standards on maintaining bio-based or bio-
degradable properties in raw materials and products [Table-4].

Table-4. Biodegradability Standards

| Standard            | Description                                                                 | Final Disposal |
|---------------------|-----------------------------------------------------------------------------|----------------|
| AS 4736-2006        | Biodegradable plastics-biodegradable plastic suitable for composting and other microbial treatment | Compost        |
| ASTM D5338-98       | Standard test method for determining aerobic biodegradation of plastic materials under controlled composting conditions | Compost        |
| Standard | Description | Environment |
|----------|-------------|-------------|
| ASTM D6002-96 | **Standard guide** for assessing the compost ability of environmentally degradable plastics | Compost |
| EN 13432: 2000 | **Requirements** for packaging recoverable through composting and biodegradation- test scheme and evaluation criteria for the final acceptance packaging. | Compost |
| ISO 14855:1999 | Determination of the ultimate aerobic biodegradability and disintegration of **plastic materials** under controlled composting conditions- method by analysis of evolved carbon dioxide. | Soil |
| ASTM D5988-03 | **Standard test method** for determining aerobic biodegradation in soil of plastic materials or residual plastic material after composting | Soil |
| ISO 17556: 2003 | **Plastics-determination** of the ultimate aerobic biodegradability in soil by measuring in the oxygen demand in a respirometer or the amount of carbon dioxide evolved. | Marine |
| ASTM D6691-01 | **Standard test method** for determining aerobic biodegradation in marine of plastic materials in the marine environment by a defined microbial consortium | Marine |
| ASTM D6692-01 | **Standard test method** for the determining biodegradability of **radiolabelled polymeric** plastic materials in seawater. | Marine |

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So, bioplastic can be biodegradable or nonbiodegradable that depends on the materials of polymers and it’s polymeric bonding. The biodegradable plastic also has drawbacks that only be compostable under certain conditions (Present of microorganism – bacteria and fungus). As an example- PLA (Poly Lactic Acid) which is a very common types of bioplastic polymer, but it could be composted under industrial environment, not in/on soil and the marine environment, which needs a very special treatment for end life management as well as designing for products. Circular economy business model can help managing the industrial biodegradable products or materials through the value chain,
The enablers of the circular business model (Geissdoerfer, Morioka, de Carvalho, & Evans, 2018): closing, narrowing, slowing, intensifying and dematerializing, and the resources looping depend on 10Rs principles (Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacturing, Repurpose, Recycle, Recover) (Vermeulen, Walter; Reike, Denise; Witjes, 2018). In this literature, the 10Rs principles are considered as key elements of circularity and implement in different stages in the value chain. The value chain in linear & circular economy are differentiated into the uses of the Rs; in liner economy inputs and outputs are straightforward from taking to disposal, but in circular economy output is regenerative. In circular economy, 10Rs help looping materials over time and reduce using of primary raw materials by converting used materials into secondary raw materials.

The circularities (10Rs) from linear to circular have been presented into three groups (Kirchherr, Reike, & Hekkert, 2017) – 1. Useful applications of materials, 2. Extend the lifespan of products and parts and 3. Smarter product use and manufacturing. The circularities (R8, R9) related to materials recycle (R8) and recovery (R9), but second group (R3-R7) of circularities work on products and parts circularity, and the third group of circularities (R0-R2) works on products raw materials sourcing to end life thinking to target appropriate circularity.

The circular value chain can be defined as “A process and activities by which organizations retain and regenerate values to an article from secondary raw materials through reverse logistics and propose regenerative value by practising sustainability in supporting activities: human resources, procurement, technology and firm infrastructure”.
Fig- 2 Circularities & Circular Value Chain

In the circular value chain [Fig-2], all functions & activities which are considered that will help organizations to adapt circularity and gaining sustainability. In the circular value chain, the primary activities: circular input (secondary raw materials) (Vercoulen Roy, Barneveld Joost van, Saccani Sira, 2017) or partial inbound logistics (virgin raw materials, if not avoidable) input, design innovation, outbound logistics, marketing and sales & service, consumer purchase & uses, reverse logistics and evaluation activities. Though consumption & uses are not considered as a part in the linear value chain, although here the circular value chain included it, due to its important functions in value transfer from purchase to reverse logistics. The beauty
of circular value chain; consumers’ contributions in reverse logistics and intensifying the loops could not be ignored. CE suggested keeping materials value & circulate over time that means value could not be zero, and just transferring from producer to consumer end, that’s why consumption & uses are considering as a part of circular value chain. The supporting activities are mostly same as linear value chain, but sustainable procurement and practicing sustainability in supporting activities are added. Here, Circularities (R0-R2) have been presented in the extended form as innovation in design and system thinking (refuse conventional system), rethinking on technical and biological circular innovation, and reduce complexity in system all over the circular value chain that is a continuous process.

3. Research Method:

3.1 Literature Review:

The literature search has been conducted in the Scopus, Science Direct, Google Scholar, books and guideline and publications from the website of international organizations and stakeholders. The most publishing journals on the circular economy are Resources Conversion & Recycling, Journal of Industrial ecology (Publisher-Wiley Online Library), Journal of cleaner production, Procedia CIRP (Publisher-Science Direct), Sustainability Science (Publisher-Springer), Sustainability (Publisher-MDPI). Production Planning & Control (Publisher- Taylor & Francis). The active organizations are working on Circular economy-Ellen MacArthur Foundation, European Commission, World Economic Forum, United Nations.

Our aim to present a realistic and holistic framework on circular value chain for bio-plastic industry and an appropriate presentation of circularity in value chain. To present the framework, we consider the important term “Value Chain”, “Circular Value Chain”,
“Circularity (9Rs)”, “Bioplastic”, “Biodegradable” and other key terms that we have defined through the literature review. The term “Circular Value Chain” has been defined just one article but have many research articles on the circular supply chain. There are some articles which present and define Circularity, but enough research articles are presented on Bioplastic, Biodegradable plastic, Bio-based economy, bio-economy, technical recycling, biological recycling, microorganism metabolism, and even value chain. Through the literature reviewed we have selected only some articles that are very closely related to circularity, circular economy & circular value chain and bioplastic plastics. The articles that catch our attention and inspires to work on the framework which are “Circular Economy: A Critical Literature Review of Concepts” (Fallis, 2013) which helps to gain knowledge on different philosophy, frameworks and tools that are connected to circular value chain, “Targets for a circular economy” (Morseletto, 2020) which represents circularity (9Rs) as targets based on purpose and helps us to execute circularity in pursued area in value chain and “Opportunities With Renewable Jute Fiber Composites to Reduce Eco-Impact of Non-renewable Polymers” (M. Sayeed et al., 2019) & “ Economic Aspects of Fiber Reinforced Polymer Composite Recycling” (Amaechi et al., 2019) that make us rethink on the bio-plastic circular value chain and end life management. “Circular Economy: The Beauty of Circularity in Value Chain” (Pavel, 2018) that presents the circular value chain based on Michael Porter’s value chain model (E. Porter, 2001). This article represents the concept: the circular economy, sustainability, value chain, circularity as well as present a framework helps us to understand how circular value chain works and how it connects stakeholders (Consumers, Business organizations and even society) in a common interest or goal – sustainable development.
3.2 Framework:

A framework is a basic conceptual idea or outline or skeleton of interlinked items which supports a particular approach to a specific objective and serves as guide that can be modified as required by adding or deleting items. A conceptual framework as a visual or written product, one that “explains, either graphically or in narrative form, the main things to be studied—the key factors, concepts, or variables—and the presumed relationships among them.” (Miles, Huberman, Huberman, & Huberman, 1994)

The above-mentioned [Fig-2] circular value chain shows only materials circularity on technical recycling and optimistic uses area of 10Rs but in our proposed bioplastic circular value chain [Fig-3], we design for technical as well as biological recycling that helps understand a holistic view of circular value chain in a complete form. In the diagram, we shift circularity (R5, R6 & R7) after secondary sourcing to redesign and manufacturing that helps to understand the circularity more specifically and a treatment plant also added after reverse logistics due to more visibility of technical and biological recycling. Most of the articles try to link directly from reverse logistics to manufacturing for circularity of parts or components (R5, R6, R7) but we would like to present as a secondary sourcing and that also needs life cycle assessment after first life and evaluate the goals of eco-design and if needed redesign for effective and efficient circularity.
Fig. 3  Bio-plastic Industry Circular Value Chain.

Primary Activities: 10Rs, Biomass production, Materials Sourcing, Design, Manufacturing, Distribution, Marketing & Service, Consumption and uses, Reverse Logistics, Evaluation & sorting, and Treatment.

Supporting Activities: Firm infrastructure, Human Resource, Technology, and Sustainable Procurement.

Source: Authors

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Primary and Supporting activities have been connected and facilitated by the innovation and stimulate- long-term and short-term achievement on industrial ecology, relationships with customers, competitiveness and environment friendly outlook of organizations.

4. Limitations:

This article based on perceived knowledge gain through literature reviewed and indirect working experience with bioplastic industry. This article has been developed to understand scopes of circularity implementation in emerging bioplastic industry as well as minimize knowledge gap and confusions among the stakeholders from sourcing to end life management of bio-based or biodegradable products & materials and lastly to show off the necessity of exercise circular economy concepts in the organizational and industrial level which stimulates competitive advantage but without any scientific evaluation of the framework. It fully depends on the core concept without detailing in clarity.
5. Results and Discussion:

5.1 Primary activities in circular value chain [Fig-3]:

| BIOPHASTIC | 1. AGRICULTURE CROP TO RAWMATERIALS | OBJECTIVES |
|------------|------------------------------------|------------|
| Biodegradable | At first life, feedstocks: cellulose, hemicellulose, lignin and starch are extracted from crops and then through the process bio-refinery, the organic materials are converted into chemicals: ethanol, hydrogen, carbon char, bio-oils, flavorings industrial glues and other industrial chemicals that are comparative to petrochemicals. The first life of used products or parts or components are ended up through recovering energy and nutrition (compost) for agriculture crop plantation, this conversion to biomaterials help to close the loop to protect our planets from garbage collector to nutrition or \( \text{CO}_2 \) consumer and in return produce \( \text{O}_2 \) to balance ecosystem. |
| Compostable | (R9, Recover) [RENEWABLE VALUE GENERATION, CONSUME (CO2, NUTRITION)] |
| Non-Biodegradable |  |  |
| BIOPLASTIC | 2. MATERIALS SOURCING TO DESIGN | OBJECTIVES |
|------------|--------------------------------|------------|
| Biodegradable | Innovative thinking in (SCOR) (D’heur, 2015) supplier selection, management & partnership and uses of disruptive technology (Block chain) in data management (MSDS-EN 16848, LCA- ISO 14067, EN 16760) (B. European, n.d.-b) and to simplify certifications & communications (EN 16935) will help to be more economical & competitive. The first decision regarding materials sourcing starts from this stage through refusing natural virgin materials, reducing complexity in system, minimizing uses of primary raw materials and ensuring maximum utilization of secondary raw materials (used parts/ components). The main goal is to narrow the loops or sometimes closed the loop by avoiding input virgin materials (whatever bio-based or biodegradable or not). Here, the best ways to rethink and pay more attention to use secondary raw materials (used products or materials). For bioplastic industry, this stage starts with sourcing granules from biorefinery plant at first life cycle, and afterwards life cycle starts into secondary materials sourcing followed by circularity | | |
| Compostable | [RENEWABLE VALUE SOURCING - PRIMARY & SECONDARY] | | |
| Non-Biodegradable | | |
Lastly, value sourcing, creation and holding from a renewable source through the mechanism- Eco-effectiveness.

| BIOPLASTIC | 3. DESIGN TO MDMS | OBJECTIVES |
|------------|-------------------|------------|
| Biodegradable | Innovative design or eco-design (For making born circular) at first & afterwards life for achieving the goals and the objectives of circular economy - narrowing, slowing, intensifying and closing the loops. Design thinking to accelerate recovering (R9) energy from biomass and nutrition though biodegradation and composting. And the process ensures capturing & holding value through organic and technical recycling. At this stage, life cycle assessment LCA (ISO 14040, EN 16760) [Table-4], user guide line and industrial standards & policies are implemented. Sourced raw materials and a prototype are proceeded for getting concern organizations’ certificate that (EN 16640) determine availability of the bio-based carbon content of the products using the radiocarbon method (carbon isotope C14) and obtained certificate will be carried out (B. European, n.d.-a) through the value chain. |
| Compostable | [ ECODISEIGN FOR VALUE ADDING, TRANSFER, REESTORATION, END LIFE MANAGEMENT] | |

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| Non-Biodegradable | [ ECO-DESIGN FOR VALUE ADDING, TRANSFER, REESTORATION, END LIFE MANAGEMENT] | As the products or materials are not biodegradable for that it will be needed more organized thinking at design stage to ensue reverse logistics and circularity (R8, R9, R7, R6 & R5). After ensuring reverse logistics, the materials or products should be tested again to match with objectives of circularity design and eliminate the complexity in materials design to ensure again circularity (R5, R6 & R7) to value restoration [Fig-2]. |

| BIOPOLYMER | 4. MDMS TO CONSUMPTION & USE | OBJECTIVES |
|------------|-------------------------------|-------------|
| Biodegradable | R0-Refuse, R1-Rethink, R2-Reduce, R3-Reuse, R4-Repair, R5-Refurbish, R6-Remanufacture, R7-Repurpose [VALUE ADDED TO VALUE PROPOSITION, HOLDING, SHARING] | For newly developed products/materials - It is lunched to market with user manual (for products) and material’s data sheet (for materials). The process goes thought rigorous verifications and getting approval from concern organization. For used products or materials- after resourcing and revising on life cycle management of secondary raw materials or parts value are restored by using in new products with same or different functions (R5, R6 &R7). It is executed only in manufacturing plant by manufacturer or brand or third-party expertise and bring back to main stream value |
| Compostable | | |
proposition. At this stage, the vital point is to ensure maximum utilization of value through the circularity (R3-R4) in industry level as well as customers end and lastly recover energy from biomass and compost for plant nutrition through biological/organic recycling (R9). Brands or manufacturers should provide specific guidelines on products properties, usability and end life management based on certification which achieved from materials sourcing to product manufacturing and as international organizations or local government guideline (ISO 14020, ISO 14021, ISO 14024, ISO 14025, ISO 14063) [Table-4] on attribute of biodegradability as well as composability of the products. The end user has the responsibility to follow the prescribed way for helping waste management (for home or industrial compostable) and holding the value or reuse as much as possible before discarded to landfill.

| Non-Biodegradable | Here, customers hold the major responsibility (Dilkes-Hoffman, Ashworth, Laycock, Pratt, & Lant, 2019) to ensure products circularity: Reuse (R3), Repair (R4), refusing (R0) non-biodegradable products, rethink (R1) on value sharing and holding products, reduce (R2) and prevent through away to landfill and by ensuring follow the user manual for helping in waste management. Brands can be taken initiative for products |

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as service system (PSS) (Bocken, M.P., de Pauw, Bakker, & van der Grinten, 2016) that will increase competitiveness and helps to maintain long-term relationships with customers.

| BIOPlastic | 5. Consumption & Use to Reverse Logistics | Objectives |
|------------|------------------------------------------|-------------|
| Biodegradable | [Value Transfer to Energy & Nutrition and Collection] | After consumption and use, the products or components are organized to biodegrade on/in soil & water through aerobic (Presence of O2) and anaerobic (absence of O2) bacteria digestion to recover (R9) H2O (Water) and CO2 (Carbon dioxide) and energy (methane, CH4). (Siracusa, Rocculi, Romani, & Rosa, 2008; Syed Ali Ashter, 2016; Zheng, Yanful, & Bassi, 2005). The end user should be careful about not to letting to environment as much as possible because – it also take time to degrade that could be deadly cause for other living organisms. |
| Compostable | Compost might be facilitated in two places - home and industry. To create more useful attribute in products some additives are mixed with the resin / granules of bioplastic that also needs specific temperature to degrade and compost. At home, biomass or compost could be used make plant nutrition or bioenergy through organic recycling that requires (AS 5810, NF T 51-800) at least 90% degradation in 12 months at ambient temperature. But for industrial compostable products should be collected through the reverse logistics, and lastly send to plant for proper treatment. |
| --- | --- |
| Non-Biodegradable | At this stage, the used less value products (waste) or parts are collected from through municipal or industrial waste management facilities by engaging manufacturers, brands or expert organizations. For ensure reverse logistic and proper management, it could be needed to ensure breakthrough technology, rethinking the system, refusing old system, preventive measurement (awareness campaign, training & guideline), ensuring health and safety of employees. The collector could be municipal, brands or third party but needs a teamwork and sharing ideas and collective collection mechanism. |
| BIOPLASTIC | 6.REVERSE LOGISTICS TO SORTING/EVALUATION | OBJECTIVES |
|------------|------------------------------------------|------------|
| Biodegradable | n/a | Industrial compostable parts or materials are collected, and it sends to compost plant to extract nutrition. Transportation as well as other facilities should be cost effective and state of art. In this stage, the products or materials are the less value but not zero. In the circular economy concept, the products value would not be zero at all and just need a proper management to get the value in different forms. |
| Compostable | VALUE TRANSPORT FACILITIES | |
| Non-Biodegradable | | For non-biodegradable products or materials which has a possibility to maintain afterwards life cycle through recycling. It sends to treatment plant to get a secondary raw materials (R8) (products or parts or components) for ensuring circularity (R5-R7). It is nearly solid products that needs to sort for grading and separating based on value of the products. |
| BIOPOLYSTIC | 7. EVALUATION AND SORTING TO TREATMENT PLANT | OBJECTIVES |
|-------------|---------------------------------------------|------------|
| Biodegradable | | Evaluation and sorting play a big part in circular value chain that needs advances technology and experts to categorize the collected products for specific treatment based on inherent value. For industrial compostable or nonbiodegradable products (Faruk et al., 2012) need to capture and transport to treatment plant for technical or biological or chemical recycle to close the loop, and to prevent leakage in environmental in an innovative and cost-effective ways. |
| Compostable | [VALUE EVALUATION] | |
| Non-Biodegradable | | |
| BIOPLASTIC | 8. TRATEMENT PLANT TO MATERIALS/PARTS SOURCING | OBJECTIVES |
|------------|---------------------------------------------|------------|
| Biodegradable | R9 -Recover [VALUE CONVERSION TO NUTRITION AND BIOGAS] | After evaluation and sorting the products are processed to industrial compost/dgradation that requires (EN 13432, EN14995) at least 90% disintegration after 12 weeks (Calabro & Grosso, 2018), 90% biodegradation (carbon dioxide evolvement) in 6 months. The organic recycle (R9) (ISO 18606, ISO 17088) is executed through bacteria digestion or metabolism and then converted into nutrition for crop production as well as methane for bio-energy. (B. European, n.d.-a) |
| Compostable | R8-Recycel, R9-Recover [VALUE CONVERSION TO ENERGY AND SECONDARY SOURCE OF VALUE ] | Non-biodegradable or partial biodegradable products are used for chemical or technical recycle (R8) (Payne et al., 2019) and at the end the materials converted into nearly raw materials (resin) or incineration (R9) for recovering energy. Here, solid parts are collected as a target for next circularity (R5-R7). (ISO 14067). |
| Non-Biodegradable | | |
5.2 Secondary Activities for supporting circularities [Fig-3]:

5.2.1 Firm Infrastructure:

Bioplastic a technology-based innovative industry which is likely a chemical industry which comparative to fossil-oil based industry, but bioplastic or bio-based industry differ with petrochemical industry in raw materials sourcing and processing. Bioplastic needs renewable biomass as feedstocks, but conventional plastic wants fossil fuel that makes the difference in procurement/sourcing, which needed to setup biorefinery plant, biomass production to chemical exaction. The organization requires a vertical integration structure and integrated teamwork among departments to gain competitive advantages like cost leadership, quality and overcome the challenges of sustainable development following the circular economy. To ensure circularity in value chain organizations need to be excel in two areas – technical or mechanical innovation and biological innovation that will help to bridge the gap between linear to the circular business model. Both innovations require expert manpower, digital accounting system, tech-savvy management, smart planning & financing, quality control mechanism, always need to rethink the system improvement, refuse the complexity and reduce communications gap within & outside of the organization. Lastly, the bio-plastic industry needs government support in factors of production (land, labor, capital & entrepreneurship) ensuring infrastructure development, soft loan as well as a integrated policy for this emerging industry.

5.2.2 Human Resources:

Human resource management plays a crucial role in manpower sourcing that needs to develop through training & motivation, and well-educated management to get optimum output and competitive advantages. Now, it is the high time to think of artificial intelligence management.
that works side by side with employees. Innovative industry or organization must facilitate IOT and tech-savvy employee to get cost & quality leadership through cost and quality has a positive relationship only technology development and implementation can change the relationship in reverse. Adapting knowledge-based culture (Zhang, 2018) in an organization could be a great way to cope up fast-changing customer demand and industrial competitiveness.

5.2.3 Technology:

To ensure circular value chain, an organization should work out some important areas- bio-based value sourcing, design, maintain, collection and restore that required technological expertise to minimize communication gap among raw materials producer to consumer to reverse logistics. To enable reverse logistics in bio-based circular value chain, trust-building through certification and information sharing, virtualization, dematerialization, transparency and in extended to cutting edge technology requires in fermentation, polymerization, product design, production and even for recycling and energy recovering plant and to solve agency problem involves smart technology like blockchain (Aggarwal et al., 2019; Min, 2019; Muzammal, Qu, & Nasrulin, 2019), IoT (Internet of things), Bigdata Management, ERP etc.

5.2.4 Sustainable Procurement:

Sustainable procurement can be defined as the pursuit of sustainable development objectives through the purchasing and supply process. Sustainable procurement ‘is consistent with the principles of sustainable development, such as ensuring a strong, healthy and just society, living within environmental limits, and promoting good governance’. (Grandia, Groeneveld, Huipers, & Steijn, 2013; Walker & Brammer, 2009)
In the circular value chain, procurement is the enabler of secondary raw materials or parts sourcing to get the restored value in mainstream. Getting technological excellence requires a huge capital investment and risk but the third-party partnership could be cost-effective. Sustainable procurement means to avoid non-renewable sources and keep the pressure on secondary raw materials sourcing that helps to reduce and tradeoff carbon foot-print. For producer or farmers are mostly live day to day whose needs support and guideline to produce feedstocks, so extended or supportive procurement is required that will help an organization to be more competitive in quality & cost leadership and social welfare.

GPP (Green public procurement) is an extensive practice of procurement from government to private organization to confirm benefits and to justify triple bottom line approach (economic, social & environment). Green public procurement works as a holistic platform among supplier, purchaser and government which ease and ensure purchasing green materials that is defined by the EU as “a process whereby public authorities seek to procure goods, services and works with a reduced environmental impact throughout their life cycle when compared to goods, services and works with the same primary function that would otherwise be procured” (COM (2008) pg. 400 “Public procurement for a better environment” (U. European, 2015))

6. Flow Chart on Bioplastic Industry Circular Value Chain

We have separated the flow chart into four parts based on stakeholder’s involvement in the circular value chain.

The first parts for materials sourcing and key players are farmers, bio-refinery organization (raw materials supplier) and international organization for certificate and testing, and the second part for a product manufacturer, distributor, and brands, in more extend the third part for customers or consumers and the final part reverse logistics facilitator.
This part [Fig-4.1] helps to understand the steps involved in green or sustainable procurement and likely primary sourcing from renewable biomass that is produced by farmers and then organization like biorefinery or chemical holds the responsibility to convert biomass to raw materials of plastic by extorting starch or cellulose or chemical through fermentation and polymerization. As some fossil-based polymers also biodegradable that why sometimes fossil based poly is mixed with bio-based poly and makes a bio-degradable polymer or resin or matrix that are a complex process and biodegradation depends on the bonding of the polymer that need to test and certified by third party that will helps to keep faith on the polymeric bonding as well as sourcing and products design to manufacturing.
The make more faithful through the supply chain block chain technology could be implemented to minimize communication gaps and sharing data.

Fig-4.2 Flow chart part-2 (Primary raw & secondary materials Sourcing)

Is it produced by third party or brand or manufacturer?

Third party

Is it certified?

No

Refuse sourcing

Yes

Verify certificate and organization

Product eco-design (target-circularity: 85%, 70%, 10%)

Manufacturing

Is it certified?

No

Apply for certificate

Yes

Mention test method number, logo, labels, user guideline on product or packaging

Sales, distribution, service

Source: Authors

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This part starts with primary sourcing or green procurement of renewable or biodegradable raw materials [Fig-4.2] which involves product manufacturer and again third-party certified organization. And another key area is secondary sourcing which enables and connects recycled raw materials or parts or components to add again in mainstream of sourcing and production line. But there are some key decisions have to have made from the sourcing organization end to verify primary and secondary raw materials or components. If the primary or secondary raw materials or parts are produced and manufactured by the same organization then it could escape the third-party certification for raw materials or parts for both primary and secondary. After manufacturing the designed products, the manufacturer needs to get a third-party (local and international concern organization) certificate (Horvat Petra; Kržan Andrej, 2012) on the LCA (life cycle assessment) (Hjuler & Hansen, 2017; Mondello & Salomone, 2019; Rostkowski, Criddle, & Lepech, 2012) along with the prescribed labels and testing methods which helps end life management and confusion among customers to consumers and even facilitating reverse logistics and finally the goals of circularity (R0-R9).

**Fig-4.3 Flow chart part-3 (Product consumptions & uses)**
Here, the main key players of the circular value chain are customer or consumer [Fig-4.3] who is the final user of the bioplastic products and pays key roles to facilitate reverse logistics and end life management through the guide line and labels are embedded with products. Here, municipality waste management team helps and provide facilities on value collection and helps cascading or sharing the acquired value (in circular value chain all products and materials are value-oriented and just converted into different form of value, it could be less or more value but value could not be zero) to same or other industry compost or energy (R9) for plant nutrition and bio-gas. The consumers should reuse (R3) and repair (R4) the product till it is solved the purpose and then keep the place in an appropriate place for the further process instead of throwing away for environmental footprint. And now, if the used products are biodegradable and home compostable then the consumers or end-user can use it for nutrition & energy but if
not, it should be sent back or keep in prescribed area for recycling (R8) for raw materials or parts or industrial composting (R9) for energy or nutrition’s. The concept extended producer responsibility or PSS (Mourtzis, Boli, & Fotia, 2017) (product as a service system) could be implemented for both bio-degradable and non-biodegradable products. Through the process, the organizations could hold a long-term bonding or relationship with the customer and gain economic as well as achieving higher sustainability index leadership (Searcy & Elkhawas, 2012).

**Fig-4.4 Flow chart part-4 (End life management)**

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Here, Third-party organizations or brands or manufactures [Fig-4.4] play the rolls to give a good shape through the processing of collected fewer value items to recover and restore the value. After reverse logistics (Kumar, Sameer; Putnam, 2008) the treatment plant helps to restore or recover the value by composting or incineration or restore parts to ease secondary sourcing of raw materials (R8) or parts (R5, R6, R7) or energy (R9). Though most of the article shows (R5, R6, R7) directly from consumption to remanufacturing that escape collection or reverse logistics step. On the other hand, here we are showing the recycled parts as secondary sourcing for the organizations that make us understand to represent the circularity (R5-R7) before sourcing and redesign stage. The objectives of a circular economy or C2C (Cradle to Cradle) fully implemented here through the technical (R8-R5) and biological cycle (R9). (McDonough, 2002)

7. **Conclusion:**

Sustainable development a global philosophy that has 17 goals (No poverty, Zero hunger, Good health & well-being, quality education, gender equality, clean water and sanitation, affordable and clean energy, decent work and economic growth etc.). To full fill these goals, thinktanks developed different philosophy, frameworks and tools. The circular economy is also a global philosophy to accelerate sustainable development goals which are very closely related to the framework C2C (Cradle to cradle) and both hold the same objectives. The goals and objectives of the circular economy and C2C are implemented in the circular value chain.

The circular value chain that helps to regenerate values to an article from secondary raw materials through reverse logistics and propose regenerative value and promote practicing sustainability in supporting activities: human resources, procurement, technology and firm infrastructure.
An emerging industry like bioplastic has many opportunities to sustain in long-run. Circular economy helps the bioplastic industry to rethink value chain management in circular ways that certainly help achieving competitive advantage from value proposition to value capture.

Bioplastic is either bio-based (renewable raw materials), bio-degradable (renewable or nonrenewable but biodegradable) or both. So, like other industry or organization bioplastic products also have afterwards life because all bioplastic materials are not biodegradable and repair or reusable which promote rethinking circular value chain implementation for technical as well as biological recycling and converted into secondary sourcing to afterwards life.

Bioplastic industry also an innovation-based industry and still a challenge to keep circularity in the value chain in a cost-effective way due to lack of infrastructure development, innovative technology for production of biomass and especially for technical and biological recycling that requires collaboration in local and international level. Technological and biological innovation will enhance circularity in the value chain in a cost-effective way that will certainly help the organization to get competitiveness and sustainability.

Farmers play a big role in bioplastic value chain whose need special take care by concern from organization to government as well as collaborative farming in the local, country and even international level will boost biomass productions and supply.

Consumers, producers and even supplier’s responsibility should be extended to facilitate reverse logistics and recovery energy and nutrition’s and lastly prevent throw-away culture.

This article will help business organizations as well as stakeholders to realize and get a holistic view of the circular value chain and circularity execution in bioplastic industry or organization level. The circularity or circular value chain framework will open a new arear of thinking for further research on industrial implementation.
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