# Chapter 13
# Research Gap and Needs

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## 13.1 Introduction

The economic progress of the latest century is proved unsustainable. Since resources are limited as well as the ability to absorb pollution is curbed, our current linear economy has to be eventually replaced with the Circular economy as it majorly demands a sustainable consumption and production of resources through re-using and re-cycling. To accomplish the Circular Economy, systemic drivers such as "bio-economy" needs to be incorporated. Thus wastes generated can be integrated into the Circular Economy through sustainable bio-economy processes.

## 13.2 From Waste to Wealth Using Green Chemistry: The Way to Long Term Sustainability

The linear economy currently configured is not only unsustainable but also unstable. It is expected the global population will increase to 9.2 billion by 2050, further exacerbating increasing energy and resource demands.

The issue is focused on economic growth which is strongly dependent on raw materials, but we're living on a planet with finite resources. Therefore it's mandatory to strike a balance between growth and resource management.

Economic growth will occur at 1.5–3% per annum, which will have compounding effects on both the depleting 'proven fossil fuel reserves by 2069 (i.e. marketable reserves of oil, gas, coal and for nuclear energy), and ultimately recoverable reserves by 2088 (Stephens et al. 2010).

Not much has been done about it until the governments started giving, at environmental protection, its due importance while drafting the national policies. Sustainable development has become a priority for the world's policymakers too since mankind has been able to destabilize all the major ecosystems of the planet in



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a few decades. Therefore, the challenge we face is to make a fast transition towards society and an economic system that should be based on recycling and valorizing of wastes to new biomaterials easily degraded able to substitute the conventional materials.

Radical changes are required and it's necessary to rethink the links between re-use, re-cycling, and valorization of food wastes, biomass residuals, in a new perspective of economic prosperity, bolstered by huge investments in new financial tools, technologies, and innovations toward a circular bioeconomy (Venkata Mohan et al. 2019).

Green chemistry is based on the substitution of fossil resource consumption by using green alternatives processes (Biorefineries) for a new supply of biobased products and Bioenergy. In this context, green chemistry contributes to improving plenty of key pathways concerning the valorization by biomass wastes, with a further reduction of fossil carbon intensity.

Recently it has seen significant growth in the demand for chemical products and new materials. However, this demand has not been met with similar growth in green chemistry solutions and practices. While green chemistry and adoption of best practices have certainly occurred, this is demonstrated by an increasing number of success stories, it is still considered for a niche growth. Green Chemistry needs to be still integrated into the Industry and SME sectors, educational systems, as well as in government programs.

Through extensive analysis several barriers have been identified, (Fennelly and Associates 2015) including:

1. the complexity of global supply chains and exiting and consolidated infrastructures;
2. costs and time to scale to new technologies,
3. the incumbency of existing technologies that are cost-effective, high performing but maybe problematic environmentally,
4. concerns about the risks involved in moving to green chemistry solutions (performance, process changes, material incompatibility or costs of recertification and potential for substitutes to be later designated chemicals of concern);
5. limited investment, incentives, education, and metrics for green chemistry.

Despite that, concrete strategies, and bottom-up approaches can be adopted to accelerate green chemistry implementation, development, and adoption, with the view to reaching a point where all production sectors can become sustainable, (GC3. 2015).

Tickner J. and Becker M. identified a wide range of strategies to accelerate green chemistry innovation, which is being identified (Tickner and Becker 2016) in:

– to enhance Market Dynamics: building comprehensive, green chemistry enablers, effective interventions that create market shifts to support green chemistry research, development, and adoption.
– to support Smart Policies: designing for innovative state policies that can effectively support the supply of and demand for green chemistry solutions.

– to foster collaboration: facilitating the flow of information about green chemistry solutions among biomass suppliers (i.e. farmers) and product makers (i.e. chemical industry and SMEs) as well as assembling partnerships to tackle priority challenges can support the collaborations necessary to grow the marketplace for green chemistry solutions (ENABLING Project 2020).
– to inform Marketplace: strengthening the dissemination activities and potential Best Practices about the opportunity given by valorization of biomass residues and their conversion into the new BBPs, the potentiality of green chemistry business benefits from the socio-economic and environmental point of view (ENABLING Project 2020).

As more governments, industries, and companies are adopting green chemistry as base of their production, there is also a critical need to understand the toxicity of chemicals in terms of ecological and health impact. Thus, the biorefineries should furthermore evaluate toxicity and relative impacts throughout the BBP's development lifecycle, minimize the toxic waste generation, and use of toxic raw materials or produced.

The European Chemicals Agency (Echa) is asking EU member states to evaluate 74 substances under the Community Rolling Action Plan (CORAP) for 2020–2022. This contains substances suspected of posing a risk to human health or the environment. Fourteen of these are slated for evaluation in 2020, while 60 substances are planned for evaluation in 2021 and 2022 (ECHA/NR/19/38, 2019).

ViridisChem has built a comprehensive toxicity database on 90 million chemicals and 2.4 billion properties and toxicity data by the implementation of the chemical database available at the global (Vaidya 2019). The ViridisChem toxicity database evaluates toxicity products (covering most organic and inorganic chemicals, bio-polymers, petrochemical-related mixtures, including nutraceuticals, cosmetics, and drug interaction products) by using 44 different endpoints defined by NSF/ANSI 355 standard per United Nations, EPA, and EU-REACH guidelines that recommend comprehensive breakdown of ecological, health and safety hazards. Utilizing this information, it is possible to know the toxicity of any chemicals, even the new and postulated molecules, mixtures/formulations, and processes with further benefits to pharmaceutical, biochemical, agrochemical industries as well as biomass and chemical suppliers. That tool is useful:

– to predict the toxicity of new molecules, and their derivatives in real-time.
– to avoid the use of toxic raw materials, and find lesser toxic chemicals that satisfy the reaction-specific requirements.
– to fully understand the health, safety, and ecological risks of toxic formulations, and find better formulations that offer the same benefits.
– to avoid the use of a cocktail of formulations that may be nontoxic individually, but become very potent when combined.
– to define sustainable processes for products development by avoiding toxic reagents and wastes during every step of the chain.

Considering toxicity aspects, especially in the emerging sector as green chemistry, is extremely important. These solutions will have a huge global addressable market and can offer a tremendous revenue-generating opportunity for most SMEs and industries operating in the (BBP) BioBased Products sector (Vaidya 2019).

Green chemistry, innovative technologies, and processes applied are issues essential to reduce the gap among industrial needs and research applied on the new valorization of organic wastes to new resources.

The research interventions allowing reducing the fossil carbon intensity of our economy need to be better investigated deeply, such as the substitution of fossil resources with alternatives for material and energy supply.

The innovative materials sector and potential substitution of fossil carbon-based products will be mainly based on several biomass and wastes recycled, therefore applied conversion technologies such as fermentation, gasification, pyrolysis will be taken into consideration, as well as further researches are in progress on the lignocellulosic processing and other biobased products (i.e.chemical building blocks) (Gerssen-Gondelach et al. 2014). A further research field that should be deeply investigated is "recycling of carbon" contained in existing and future materials by using photocatalysis, without consuming further resources. As described in e.g. Tahir and Amin, recycling technologies are in the early research phase (Tahir and Amin 2013).

Despite there is plenty of international pro-active policy about the environment, the literature on medium and long-term potential pathways for circular bio-economy is incomplete, as confirmed by Fabian Shipfer (Schipfer et al. 2017). This is due to uncertainly still existing technologies to be applied to biomass waste towards new biobased products in a new concept of biorefinery. Therefore it is also difficult to plan substantial investments for innovative biorefineries without having long-term potential scenarios of development.

A wide literature (Matzenberger et al. 2015; Patel et al. 2007) confirms several options about possible developments concerning bioenergy (conventional biofuels), food and feed sectors (Chap. 3). On the contrary, the literature on possible development scenarios and planning relating to in advanced biomaterial production and consumption is still in the research stage, and stands out as relatively scarce (Patel et al. 2007; Daioglou et al. 2014). Only some researchers and experts tried to outline short-term expectations (Scarlat et al. 2015; Dammer et al. 2013).

For example, the fermentation of lignocellulose to ethanol is expected to be in an R&D and demonstration phase (Gerssen-Gondelach et al. 2014) to reach a ripe technology and stabilization of materials. This makes it useful to discuss the commercialization of lignocellulosic-based materials and biofuels and their planning for 2025–2030, despite electric sector seems to be the best solution for transport sector in the coming years. Meanwhile, the installed production capacities for Bioethanol and BBPs from sugar and starch-based plant utilization are held constant until 2050 and only additional advanced biomaterials production are assumed to be based on wood.

In addition to the above-mentioned literature, a huge of EU Projects, for example "BIOYAWS" Project (Bioways Project 2020), "ENABLING" Project (Enabling

Project 2020) are monitoring the progress of several advanced biobased products by Biomass residues, biomass estimation and example cases of best practices as well as future trends. However, no detailed medium and long-term biobased material scenarios are still well delined so far (Schipfer et al. 2017).

De facto, part of this lack determines the key gap between the research not still ready to face the market and industry sector still waiting for the validated results as solutions of unresolved issues, as:

- Potential capacity of advanced biobased materials to substitute substantial amounts of fossilbased materials in competitive pathways.
- Traceability and monitoring production of more promising advanced biobased materials, their certification, and testing with a guaranty for health and environment in all their life cycles.
- Selection of biomass residues and organic wastes for ensuring a supply of biobased products, and production rate of such biobased products to allow the phasing out of fossilbased counterparts.
- Investigations relating to the possible cascading biomass along BBPs chains, and comparison with existing biomass use for the bioenergy sector.
- Investigations on the potential distribution of additional biomass supply and demand that can be globally distributed among industrialized and developing countries, and analyses on the possible implications of international biomass trade, (Schipfer et al. 2017).

## 13.3 Exploitation of Non-Food Feedstock as Smart Alternative to Crops Usage for a Sustainable Bioeconomy

During this transition phase, bioeconomy has been considered a requirement for sustainable growth, and it has been defined by various organizations around the globe. The Organization for Economic Cooperation and Development defines it "as a world where biotechnology contributes to a significant share of economic output" (OECD 2009). While FAO – Food and Agricultural Organisation defines bioeconomy as "the production, utilization, and conservation of biological resources, including related knowledge, science, technology, and innovation, to provide information, products, processes, and services across all economic sectors aiming toward a sustainable economy" (FAO 2019).

The German Bioeconomy Council defines bioeconomy as the "knowledge-based production and use of biological resources to provide products, processes, and services in all economic sectors within the frame of a sustainable economic system". Bioeconomy is focusing the attention on implementing innovative biological approaches through collaboration with researchers, stakeholders and policymakers (European Commission 2012a; Council G.B. 2018). Based on the latest definition given by European Commission, bioeconomy can be considered as "the production of renewable biological resources and the conversion of these resources and waste streams into value-added products, such as food, feed, biobased products, and bioenergy" (European Commission 2012b). Also, Obama Administration mentioned bioeconomy strategy as "one based on the use of research and innovation in the biological sciences to create economic activity and public benefit" (White House 2012).

But how many pathways of bioeconomy are real sustainable? It borns the gap among different ways to conceive the economic growth and a more sustainable evolution approach, from an older linear economy concept based on the fossil resources to a circular bio-economy principally based on the new concept to conceive the "wastes as resources". But this needs high expertise of "bio-technological" cascades sectors and processes from organic wastes to new added high-value products (BBPs and Biofuels) (Davis et al. 2016).

The importance of circular bioeconomy is now realized globally and in many nations, including developing countries. The international community and Governments are working on strategies to achieve a greater sustainability level. Many technological sectors applied to eco-biological issues have a strong potential to innovate enabling to reach greater technology readiness levels and ready to support a more sustainable market. India is gearing up to meet the challenge of achieving US$ 100 billion worth circular bioeconomy by 2025 as it already has necessary sources such as booming biotechnology industries and an enthusiastic scientific workforce, (Venkata Mohan et al. 2019). In this context, petroleum-based refinery (mirror of the linear economy) are shifting to new emerging biorefinery (Clark and Deswarte 2008), where non-edible based feedstock/biogenic wastes are being used as raw materials for producing a range of products as: biofuels, industrial biochemicals, and biomaterials, including biopolymers (Clark and Deswarte 2015; De Jong et al. 2013). The conventional biorefineries have still dedicated feedstocks like fuel crops (Corn, Sugarbeet, Sugarcane, Vegetable Oils) but the focus is now shifting towards utilizing the process residuals or the waste generated from daily life. Biomass and its residues, municipal solid waste (MSW), food waste, aquatic waste and industrial gases are among a few potential feedstocks for waste biorefineries (Bioways Project 2020; Venkata Mohan et al. 2019). The greatest challenge for a sustainable biorefinery is also to integrate technologies toward biological systems and bioprocesses especially in those operating across the food waste management systems, (Schieb et al. 2015).

Notably, municipal solid waste (MSW) is one of the major wastes generated around the globe, and approximately 50–60% is represented by biogenic composition. The proper valorization of MSW can help in the simultaneous reduction of the environmental impacts associated with waste management and respective disposal into landfills. Around 1.3 billion tonnes of food is wasted annually accounting for one-third of its total global production that incurs a cost of USD 900 billion to the global economy (Dahuya et al. 2018). Re-directing the biogenic waste, from landfills to waste biorefineries, would lead to incredible employment opportunities in industries and academia especially in the sectors of Agri-food, chemical and healthcare, pharma, and logistics (Clark and Deswarte 2015; Dahuya et al. 2018; Cristóbal et al. 2018).

The agri-food waste biorefinery (González-García et al. 2019; Beltrán-Ramírez et al. 2019) as well as sugar-based and starch-based pulp wastes (Adiletta et al. 2019) and lignocellulosic residues (Hassan et al. 2019), are the focus of extensively discussed by several researchers because represent promising agro-food wastes to industrial scale.

MSW also has enormous potential to be used as feedstock for the production of several commodity chemicals, biofuels, bioenergy and compost through the deployment of appropriate methods and systemic approaches (Fig. 13.1). However, while designing such biorefineries, economic feasibility in line with environmental sustainability, a lower carbon footprint should be taken into consideration (Venkata Mohan et al. 2019). More than 100 good model examples have actually implemented in real Best Practices around 16 European Countries and collected by part-

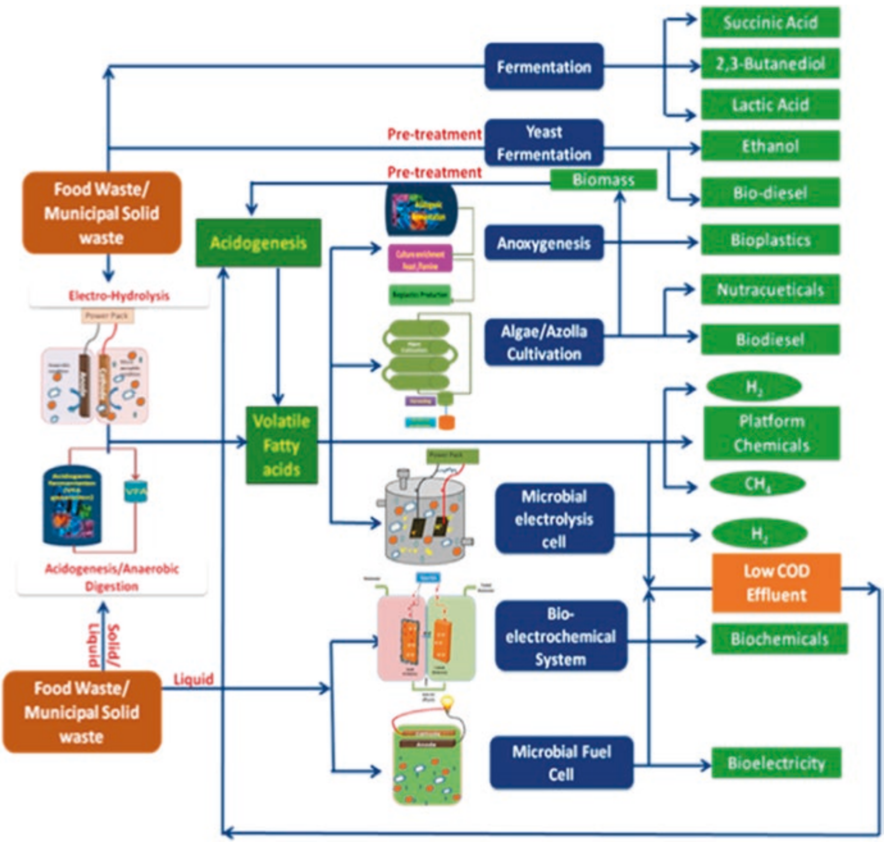


**Fig. 13.1** A scheme of food waste biorefinery: spectrum of products that can be generated in a closed loop by the valorization of organic food wastes (Venkata Mohan et al. 2019). (Reprinted from Bioresource Technology Reports, Vol. 7, Venkata Mohan S., Dahiya S., Amulya K., Katakojwala R., Vanithaa T.K.,, "Can circular bioeconomy be fueled by waste biorefineries — A closer look", copyright 2019, with permission from Elsevier)

ners of Enabling Project (2019) in the specific platform (https://www.enablingproject.com/platforms#best-practices-atlas). Best Practices confirm the concrete implementation of the biorefinery concept by using a sustainable bottom-up approach that aims to exploit local biomass wastes. It is the case of agro-industrial by-products listed below:

(a) Vegetable Oil-based Residues:

- A Bulgarian company evolved in a small biorefinery able to produce food vegetable oils and biodiesel from oil crops cultivated in marginal lands (rape, soya, and sunflower). The by-products of processes (glycerin and rare fatty acids) are valorized in-house as new bio-based products for pharmaceutical and cosmetic production (including as stabilizers and foam suppressors). Other process residues are used as biological forage. The company has the possibility to construct stock-breeding farms for pigs and cattle and feed these with produced biological forage. It places the accent on the development of biological stock-breeding. This allows the circular economy of the whole firm to be closed with internal byproducts fully valorized.
- By the refining soybean oil process, an Italian firm developed an epoxidized oil transformed in bio-polyurethane material, used for coating panels and walls. The lightness of the materials, only 1.2 kg/m2, facilitates their transport, management, and installation. The digital printing decorations are incorporated within the resin itself. The biomaterial can become even smart when the low energy sensors are inserted inside them, which allow navigation and the use of contents, making the wall itself a wifi hotspot. In addition to allowing a dialogue with smartphones, these installations can contain sensors of all types (e.g. to detect air quality or acquire images), and with selected APPs, several options to work with virtual reality or with augmented reality are possible.

(b) Winery-based By-products and Grapes Residues:

- Italian wineries (30 wine cooperatives cover 35,000 hectares), and distillery company have transformed themselves into a biorefinery able to use by-products of their processes for BBPs and chemical building blocks production. The biorefinery uses grape wastes from internal processing (around 540,000 tons/year), with a fully recycling of their organic wastes, (only 0.1% of the discarded materials is considered real waste). The byproducts of the agro-industrial process are valorized for polyphenols, enocyanin, and tartaric acid production, destined for pharmaceutical, nutraceutical, and cosmetic sectors, while lignocellulosic wastes are valorized by using bioenergy pathways. Biogas plant (1 MW) is fed by cellulosic wastes for biomethane (advanced Biofuel), internal energy, and digestate production. This last one is transformed into compost and delivered as biofertilizer to the wineries associated with biorefinery. While lignocellulosic residues are valorized into the biomass plant as solid biofuels for heat production.

(c) Apple Peel-based By-products:

- An Italian company patented a sustainable apple-peel-based biomaterial, with reducing 50% of solvents and synthetic polyurethane. Patented apple-based material born from the exploitation of apple peel, an abundant by-product deriving from apple juice industry. More than 3 million tons/year are produced close to the Alpine Regions causing problems for correct disposal of fruit residues deriving from agro-industrial transformation. The company is able to collect apple peel residuals from local farmers associated with the apple juice industry, and valorize into innovative engineering biomaterials applied to the textile sector.

(d) Rural and Agro-industrial Residues for Bioplastics:

- A French Company recently started to working with fibers and by-products, and bio-composites with the creation of a real "green business model". They aim to valorize cereal, seashells, fruit kernels, vegetable fibers, and textile waste to produce original and new compounds that may later be used by other companies to produce original plastic products with a unique design. The company started new production lines working local bio-residues. The aim was to create high-performance and bio-based compounds sold to the packaging industry to develop products for several sectors. The innovation lies in the mixed uses of different biomass by-products as fillers in polymers in order to produce Bio-packaging for several sectors. Biomass from cereal waste (wheat, barley, and corn), Biomass from aquatic co-products (scallops, oysters, algae), Biomass from agro-industry: nutshells kernels (hazelnut, almond, rice, olives), processing of fruits (coffee ground, cacao shells, apple pomace, grape seed) Biomass from vegetal crop-fibers (miscanthus, flax, hemp, wood, cork) results as a suitable input for primary injection molding processes in the production of rigid secondary packaging, regular consumer goods, technical parts, agriculture and horticulture products, cosmetic. The feedstock needs to be ground, dried, and sieved before being used by the plastic industry. The company delivered added value to biomass residues delivered by local farmers, giving benefits to their revenues.

(e) Phyto-stimulants by Animal Feathers:

- A cluster of zootechnical companies and the Faculty of Food and Biochemical Technology of Prague (Republic of Czech) have implemented a promising model for the exploitation of selected animal residues. Feathers account for 5–7% of the total weight of the chickens. Currently, this waste, mixed with other slaughter waste, is usually converted to biogas by anaerobic digestion. Feathers consist of 91% protein (keratin), 1% lipids, and 8% water, and can be better valorized to produce added-valuable products. The business model foresees to process by hydrolysis in the pressure tank. The result is protein hydro-isolated solutions containing amino acids and partially soluble proteins. The resulting hydrolysis products have significant effects on plant growth. When used as toppings, biomass growth, increased nutrient uptake, photosynthesis, increased stress resistance of plants and other positive factors have been demonstrated. The hydrolysis based-technology is currently being tested in a pilot plant. Significant factors for widespread use include the form of waste materials (ratio of quill vs. plumage in the feathers used). One of the targets of the project is also to extract and isolating aspartic acid from hydrolysate. The business model could be also extended to the treatment of other types of animal waste (i.e., animal hair), or to a possible mixture of animal and vegetable waste. Furthermore, an important factor is the ability to offer primary livestock producers a service that will help them to better locate and recover hard-to-treat waste materials for innovative uses.

(f) Potato and Corn Residues for Starch and Cellulose-based Diapers:

– A Germany small enterprise produces sustainable diapers, which consist almost completely of renewable materials and are 100% compostable. The company has developed an innovative method able to replace the SAP – Super Absorbent Polymer with a biodegradable biomaterial by using potato and corn residues. The supply of biomass residues is agreed from local farmers and suppliers. The whole concept of the company can be labelled as "environmentally friendly" and responds to the concept of circular economy. Despite the approach fully responds to the circular economy model, the solution has costs twice the price of normal diapers. Yet, the German company is growing fast, and their demand for bio-based products is expected to increase in the coming years. The idea is capturing the public interest and made its appearance on the media several times while being nominated for the GreenTec-Awards 2017.

(g) Corn Starch and Seed Hulls for Coffe Caps:

– The innovative Coffe Cap product consists of the coffe capsules and an environmentally friendly cellulose-based lid that needs no additional glue for sealing the capsule. The coffee capsule consists of the innovative material made of sunflower seed hulls, mineral filler, and by patented Biopolymer. The hulls of sunflower seeds are a waste product from the extraction of sunflower seeds, while innovative biopolymer is a starch-based and biodegradable plastic. Extra barrier packaging is unnecessary due to excellent oxygen transmission rates of the overall material composition, thus saving further waste. The whole product completely degrades on the home compost within 12 months. Given the ready availability of corn residues in terms of production and processing in Europe, its sugar molecules are used as raw material. The valuable proteins of the plant are not used and can be further processed, for example as animal feed. Hence, there is no conflict with the food industry and a double income for corn producers is generated. Other farmers can specialise in or complement their production (processes) with sunflower seeds and providing opportunities for business diversification.

(h) Biorefinery Model for Zootechnical Sector:

– In specialized rural areas with a higher density of animal farms, valuing animal manure as well as reducing the animal wastes are a major issue, since intensive livestock are causing a significant phosphate surplus in rural areas. A Dutch Company (part of International Group) is creating a sustainable model in the context of the circular economy where food, feed, bio-based products, and fuels are ingredients and solutions of the same model by processing all animal by-products into different valuable products. The International Group and companies affiliated have a strong believe that both edible and in-edible residuals can and should be transformed into valuable products in order to realize economic and ecological sustainability. Each company of the Internatioanl group focuses on processing one or more different residual waste flows and are mostly complementary on a regional scale: biodiesel process from fat waste. Biogas, biomethane, and phosphate-rich biofertilizers by anaerobic digestion process, bio-based products by animal by-products (i.e. keratin, added value proteins). These three processes take place at the same biorefinery place in Netherland. The process is an example of closing the loop on economic and ecological sustainability for urgent challenges in the agricultural and zootechnical sectors. Through chain collaboration and high dedicated technology, this business model enables to create of a stable economic opportunity out of animal and food waste streams like pig manure, animal by-products, and food residues

(i) Potato Residues for Biopolymers and Biomaterials:

– A Dutch Company expert in Biopolymers, started to valorize agricultural residue streams right after World War II, by processing waste streams from the potato industry into cattle feed products. In the late 90s, the business in cattle feed started to decline and from that moment the company started to look for alternative businesses. The company could rely on a strong and established network, availability of biomass/residual streams, and therefore took the opportunity to experiment with bioplastics based on potato waste streams. It kept on investing in innovative production processes and extensive R&D and is now one of the experts in bio-based (biodegradable) compound development and production. Intensive R&D work has been realized in order to process potato wastes streams into valuable granulate. Besides the processing technology, also knowledge and R&D work is done to create a niche market in bioplastic products (same strength, lifespan, biodegradable characteristics). Furthermore, by-products are valorized in other markets using the extensive networks and expertise of the company. For the bio-based company, an increasing profit and turnover is realized since more and more consumers and plastic product companies are willing to use a nonfossil-based granulate. A few years ago, it was responsible for 2 tonnes of bio-based plastic products per month. In 2019 this has been increased to 30 tonnes of bio-based plastic products per month. With increasing scale,

> the costs of producing the bio-based granulate lower, but it has still a higher cost price than fossil-fuel-based granulate. The business model of company processes based on potato residues of agro-industry into several semi-finished products. The main goal is the production of bio-granulate (bioplastic), processed from potato starch. Bioplastic can be used in industrial processes (extrusion/compounder) to produce all-kind of daily-life plastic products. Based on the characteristics of the end product, the granulate can be made for different product lifespans and/or in a biodegradable variant. The business model sees the collaboration of two main actors: the potato industry, supplying potato residual streams, and Rodenburg, processing waste streams into bio-(degradable) granulate; valorizing by-products into PET-food, wood- and paper binder, lubricate for drilling applications. There is an increasing demand and supply of bioplastic products based on bio-granulate (made out of potato starch). Any plastic product can be produced out of the different bio-granulate semi-finished products. The potato industry, which is the main actor involved in the management of potato processing, has now a financial benefit in valorizing a former waste stream (cost). The biomass comes from Belgium, Netherlands, and Germany, which supply potato residue streams from potato industry. A major strength behind this business model is the fact that Dutch Company has a reliable and well-established network in the agricultural waste stream industry and can therefore benefit from the continuous supply stream.

Further innovative applications are listed in the Enabling Atlas (Enabling Project 2019), like pineapple fibers used for textile materials, wool for bio-packaging solutions, spent brewery grains and dried distilled grains for bioplastic ingredients, and high-demand biochemicals like L+ D-lactic acid, and ethyl lactate, and many other best practices.

Accomplish this vision requires involving insitutions and entities able to deliver key data, to re-define rules, and local waste licensing regulations for transportation, processing, and disposal of food waste quikly. Furthermore, COVID-19 demonstrated how important is to conside the prevention and risks pertaining to health due to transmission of diseases, and potential contaminations. The implication of food and organic waste recycling, disposal or composting, and further valorization through biorefineries, and the public perceptions, and their impacts on local economies must be checked thoroughly. World Health Organization (WHO) confirms Coronaviruses need a live animal or human host to multiply and survive, therefore COVID-19 cannot multiply on the surface of materials, including food packages or biomaterials. Nevertheless, Kampf (Kampf et al. 2020) after having analyzed more than 22 studies related to the several coronaviruses persistence (both deriving from human that veterinary) on inanimate surfaces like metals, paper, ceramics, glass, including plastics, and others, found that human coronaviruses can remain temporarily infectious on these surfaces until to 9 days, depending on the material type. The same authors point out that the coronaviruses may be inactivated by disinfecting the potentially contaminated surfaces. Data about the lifespan of SARS-CoV-2 in different surfaces have been also summarized by Nghiem (Nghiem et al. 2020), and show that the virus can remain viable for 3 h in aerosols, 4 h in copper, 24 h in cardboard, 2–3 days in stainless steel, 3–4 days in solid faces, and 3 days in plastics and sewage. Despite the several CoronaVirus cannot multiply in different materials, first evidence confirm their survival on organic waste and several materials for a certain timeframe. During the pandemic period, several measures and recommendations for solid food waste handling and management have been developed by international organizations (Santos et al. 2021). The World Health Organization (WHO) has provided guidance on how to safely manage fecal waste and wastewater, and to manage both healthcare and household waste generated by people in quarantine (WHO 2020). Likewise, other organizations have conducted debates on virtual platforms (ISWA 2020a, 2020b), and developed guidelines aiming at raising awareness and encouraging local actions related to safe solid waste management (SWM) to protect the environment and public health, including the solid waste workers (CDC 2020; European Commission 2020; SWANA 2020). Such initiatives are of utmost importance, since waste traceability and management infected by SARS CoV-2, along with water and sewage treatment, are still unsolved issues, especially in developing countries where most of the organic food wastes are manually collected and recycled. In a future outlook of the circular economy, the current circumstances force certainly, to reassess habits and approaches to manage organic and food waste in an approach called “reboot” able to ensure that all procedures used for food waste valorizing to new bio-based products follow regulations to “contamination-proof”, with particular attention to the biomass residues originated from the urban and zootechnical sector.

## 13.4 BioBased Product Recycling

Circular Economy represents an economic system based on the recycling products and reuse of raw materials while maintaining the restorative capacity of the natural resources (OECD 2018). The circular Economy replaces ‘the end of life concept’ with “restoration” by minimization of material use, shifting towards the use of renewable energy, eliminate the use of lesser toxic chemicals and supports zero waste discharge through enhanced modifications in the design of products, systems, materials and business models. The economy’s linear model of “take, make and dispose of” is being modified as the “take, make, reuse, recycle and remanufacture” which facilitates a significant reduction of the waste generated (OECD 2018; Carus 2017).

Valorizing the wastes as new resources should be considered by the industries at the design level itself and the most suitable “end of life” option for their product(s) should be implemented also including the toxicity approach. But it’s not sufficient. Which will end of life of BBPs be once created? Which will degradation time BBPs be? How will BBPs be recycled? Can new BBPs be re-used? Can BBPs change intended use after the End of their Life Cycle?

Part of the solutions to those questions is possible to find if the circular economy (CE) would be also applied to the BBPs once their uses will be terminated. The concept of CE basically works on the two-cycle principle, represented in the famous "butterfly" (Venkata Mohan et al. 2019). According to this model, the biological resources cycle separately from the abiotic materials, taking into account the regenerative capacity of the biological resources. The focus of the biological cycle is to cascade the extraction of bio-materials/chemicals and returning nutrients to the biosphere wherever possible for example by composting, anaerobic digestion, etc. It means that part of biomaterials is created in order to close the loop themselves, (i.e. Biofertilizers from food wastes) (Rorat and Vandenbulcke 2019).

For several BBP's life cycles, closing their natural cycle analyses could be conflict or in most cases not complete (Belboom and Léonard 2016), despite the perceptions regarding BBPs as bioplastic uses are positive. This is the case of polymers, which represent one of the most used materials with a production of 107 $Mty^{-1}$ globally, and principally derived by fossil fuels (Cherubini and Strømman 2011). Ethylene is the main polymer precursor of several chemicals, e.g. vinyl chloride, ethylbenzene, ethylene oxide, or ethanol, among them several types of its polymer form. The production of polymers consumes fossil fuels but also induces other environmental impacts as their accumulation in the environment, in landfills, or even in the ocean, if they are non-recycled due to their chemical, physical and biological inertness. In this context new Biopolymers replacing those traditional, have to also be thought for reducing, reusing, and recycling the biogenic material. The replacement of traditional polymers with biodegradable biopolymers could be to solve part of the solution, despite biodegradability is not the only criteria to take into account in the environmental aspects of polymers. All the value chains should be analysed (LCA – Life Cycle Assessment) from the biomass supply until the end-of-life, (Ojeda 2013), including the potential re-using and re-cycling and biodegradation.

As an example, the use of sugarcane feedstock for Bioethanol production is used, in turn, as the chemical building block for biobased polymer production in Brazil, (Caldeoron and Arantes 2019; IRENA 2013). The environmental impact of biobased ethylene produced from sugar cane has already been assessed in the literature using LCA and shows a reduction of GHG emissions and fossil fuel consumption when replacing fossil fuel with biobased ethanol, (Liptow and Tillman 2012; Alvarenga et al. 2013a, b; Van Uyvanck et al. 2014).

Other investigations demonstrate LCA's improvement from traditional polymers and respective bio-polymers. Van der Harst and Potting studied the results of ten LCA based on disposal cups produced from fossilbased plastics to Biobased plastics, (Van der Harst and Potting 2013) and showed conflict in results in terms of Global Warming Potential (GWP). The comparison in terms of energy and GHG emissions and energy consumption has been assessed for fossilbased PET and the biobased PEF (polyethylene furandicarboxylate). Results desmontrated environmental benefit of the PEF based on cornstarch, (Eerhart 2012). Furthermore, the sustainability (in terms of GWP and energy consumption) of biopolymers (polylactic acid, poly hydroxyl-alkanoate, and thermoplastic starch) has been further compared to other fossil polymers, and confirming the influence of the end-of-life in the global assessment, (Hottle et al. 2013). In some cases, BBP's LCA could result not optimal due to not eco-friendly technological processes and/or biomass used. The BBPs deriving by dedicated crops can mitigate the environmental impacts o due to direct and/or indirect land-use change (ILUC) as mentioned by Liptow and Tillman (2012).

The main important step for bioproducts is the supply of the selected biomass feedstock, like dedicated cultivations or food wastes or biomass residuals. This initial step is very sensitive Grabowski et al. (2015) explain the importance of specific data relative to crop production to ensure the quality of the environmental impacts of biobased polymers. In fact Belboom and Léonard (2016), shows a reduction of impact of around 60% for both climate change and fossil fuel depletion categories when using biobased HDPE – High Density PolyEthylene (by biobased ethanol deriving from sugar beet and wheat residues) instead of its fossil counterpart HDPE by fossil fuels. But for all other impact categories, fossil HDPE achieves better results than the biobased products.

Further considerations have to be treated for specific BBPs like bioplastics. Approximately 99% of plastics are produced through petrochemicals (CIEL 2017). China's announcement that it would no longer accept international plastic waste for recycling from December 31, 2017, has exacerbated this problem and increased the need for sustainable bioplastic-based solutions by 2030, as 111 Mt of plastic waste will be displaced through that policy changes (Brooks et al. 2018). Therefore need to replace plastic material with respective bioplastic is becoming a crucial point of most international policies.

Currently, there are a wealth of natural biobased polymers as well as monomeric feedstocks for bioplastic production. Karan et al. (2019) summarizes the main classes of currently developed biobased plastics. These include plastics based on starch, polyhydroxyalkanoates (PHAs), polylactic acid (PLA), cellulose, renewable polyethylene, and polyvinyl chloride (PVC), as well as protein-based polymers. Each Bioplastic has got a specific degradability and strength characteristics, therefore specific uses. Because of high amount of blends in which the monomers can be mixed or cross-linked, their properties can be modified through chemical derivatization, as well as by introduction of additives as plasticizers, stabilizers, fillers, processing aids, and colorants. By their combinations can be produced several varieties of plastics with different physical characteristics (e.g., melting point, density, shelf life, biodegradability, UV resistance, transparency, thermoplastic versus thermosetting materials) (Fig. 13.2).

There are several options for bioplastics production. The attractive option is represented by microalgaland cyanobacterial plants for bioplastic production, as these offer a series of advantages that contribute to sustainability goals (i.e., Good Health, Renewable Energy, Economic Growth, Industry, Innovation and Green Infrastructure, Sustainable Cities and Communities, Responsible Consumption and Production).

Biobased plastics are becoming part of an expanding circular bioeconomy. Their production includes both non-degradable and biodegradable plastics. Both are important for sustainable solutions on the basis of different needs (Karan et al. 2019).

Non-biodegradable Bioplastic can also be considered a sustainable solution if it has seen as Carbon sinks stock, and to contribute to carbon capture and storage

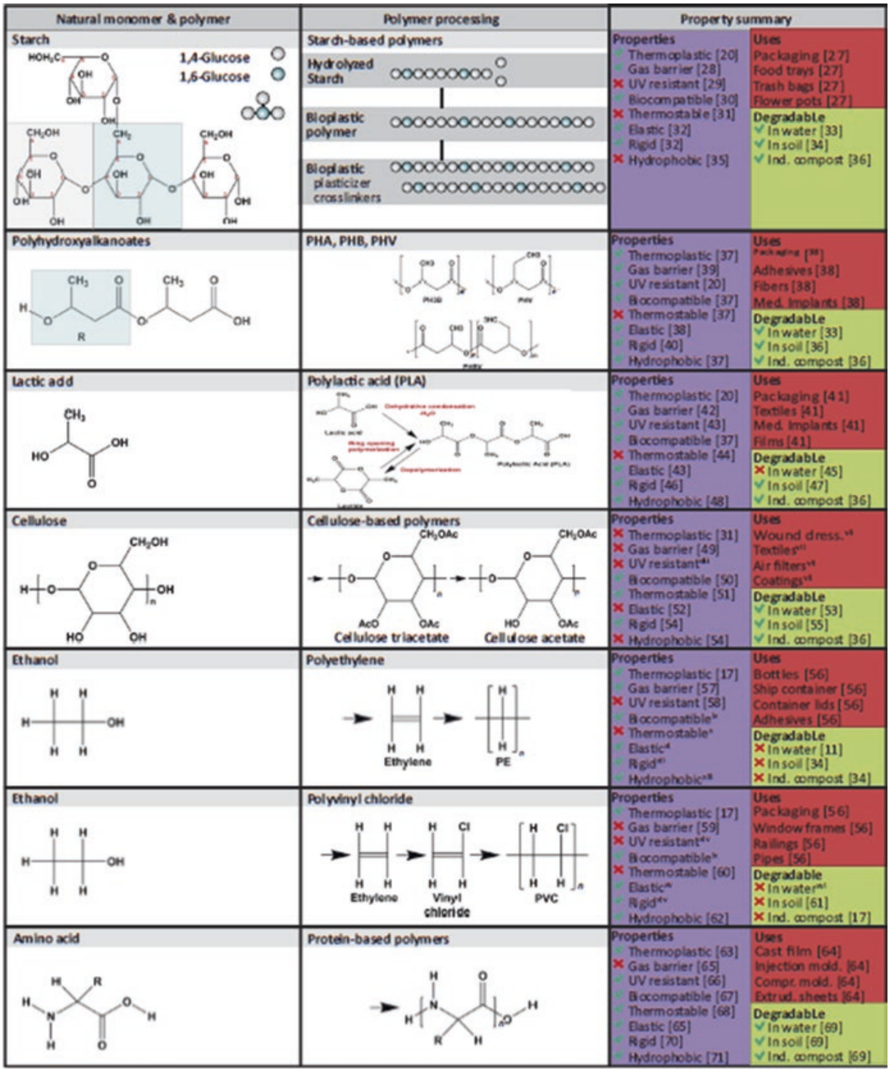


**Fig. 13.2** Bioplastic categories, their properties, and uses (Karan et al. 2019). (Reprinted from Trends in Planc Science, Vol. 34, Karan H., Funk C., Grabert M., Oey M., Hankamer B, "Green Bioplastics as Part of a Circular Bioeconomy", Copyright 2019, with permission from Elsevier)

through integration into nondegradable long-term infrastructures including road surfaces, PVC Tube sewer piping, and building materials. Therefore, a replacement of petrochemical-based feedstock with available bio-derived material like biobased polyethylene (bio-PE) could enable this transition. This process should be supported by a legislated accreditation making such infrastructure eligible for carbon credits (Carus and Dammer 2013).

Degradable bioplastics can be instead designed to be either totally biodegradable in a matter of months or years (Rutkowska et al. 2002). They can be used to produce

$CH_4$ (by using AD – Anaerobic Digestion process) (Bátori et al. 2018), short-to-medium shelflife products that degrade fully to minimize their environmental impact. The timescale over which plastics deteriorate should theoretically be tailored to the product's design. In that context, technical standards are critical for leading environmental-friendly bioplastic design process, and ensurig a sustainable Industrial development for emerging bioplastics.

From the legislative point of view, there are already developed standards regulations for tightly controlled industrial composting systems of Bioplastics. Key Technical Standards are actually in force nowadays: ISO 17088 at the international level (ISO 17088 2012), EN13432 (UNI EN 13432 2002) and EN 14995 (UNI EN 14995 2007) at EU level, and ASTM 6400 (ASTM 6400 2019), ASTM 6868 (ASTM 6868 2019) in the USA. Despite that, further efforts should be carried out in order to establish the degradation time of bioplastics in home composting as well as in terrestrial and aquatic ecosystems without releasing toxic byproducts.

An example of replacement with degradable bio-plastic is represented by food packaging industry PET-based. Petrochemically food packaging PET- based, such as soft-drink bottles, food containers, has been shown to persist in the environment for over 90 years (Edge et al. 1991).

Furthermore, its specific recycling rate is still only around 20% (Geyer et al. 2017) and is not sufficient to avoid environmental impacts like the great seas garbage patch or plastic soup (Lebreton et al. 2018; Van Sebille 2015). Furthermore, degradation is often only partial and in many cases leads to harmful products such as microplastics and toxic constituents (Wright and Kelly 2017). Theoretically, biobased plastic formulations can be considered in their LCA to deliver products with a fit-for-purpose shelf life. For example, plastic water bottles could be designed to degrade under precise conditions with a shelf-life within 2–5 years. Considering that over half of the global biodegradable plastic demand is for packaging materials (Scarfato et al. 2015), such packaging could yield significant benefits in the future.

The degradation bioplastics process seems, therefore, be one of the most important key points for the future that will have to be taken into account into the BBP's LCA approach.

The most detailed guidelines on bioplastic degradation have been developed for industrial composting systems and these define the time required for degradation, the percentage of $CO_2$ emitted from the bioplastic, and any toxic residues remaining.

In addition to biodegradability conditions, for a competitive bioplastics market, advancements in biotechnology and processing techniques are also paramount to improve performance and reduce their cost, still considered too higher if compared with traditional plastics.

By remaining in a biorefinery approach, Kwan et al. performed a techno-economic study on a biorefinery design for food waste valorization through fungal hydrolysis and microalgae cultivation, which ultimately leads to the production of plasticizer, lactic acid, and animal feed to lower costs. Economic feasibility was only achieved when the production was focused on plasticizer and lactic acid, which are high-value products (Kwan et al. 2015). The production of multiple added-value products (i.e., several chemical building blocks, biomaterials, precursors of bioplastic) from the same biomass resources is a key point to these strategies, as it helps to offset the relatively high costs (CAPEX and OPEX) very often due to their fractioning and purification. Detailed techno-economic and LCA modeling tools are being developed to fast-track biorefinery systems optimization, the development of robust business models, and to derisk scale up. Through such model, it is possible to identify the most valuable and promising production streams, capital and operational costs associated with these, and to plan biorefinery processes able to deliver good economic (e.g., profitability), social (e.g., energy efficiency), and environmental (e.g., greenhouse gas emissions) performances.

## 13.5 Conclusion

Driving the sustainable industrial development in a new concept of a biorefinery based on organic waste valorization, it will be essential not only to regulate the ability of biobased products growth but improving their full degradation without the release of harmful residual chemicals. The production of BBPs, as well as their degradation or recycling, represents a long-term challenge, which will likely be addressed as technology progresses develop down the cost curve (Karan et al. 2019). For biobased products to compete with the well-established petrochemical products, maintaining consistency while drafting policies is a major gap that needs to be addressed by the policymakers.

The inclusion of biological components in the Circular Economy needs several policies and new legislation that should be formulated in a short time, and their goals should be addressed until to reach more sustainable regional developments (OECD 2018).

The biorefineries can create value from waste but they require high aknowledgment of the process with “re-thinking waste treatment” and a concrete valorization to resources.

Biorefineries can change the perspective of waste and can deviate it from the standard waste management practices, leading to disruption in its management hierarchy. Introducing the biorefinery also necessitates a “re-defining of raw materials” and a modified waste management policies and regulations.

For a national government or regional authorities to consider waste biorefining and to plan adequate investments, there must be a sufficient knowledge of issues that needs to be considered, as the origin of waste and the quantities of waste generated, their recycling and reuse, therefore to the waste management and valorization techniques, as well as their logistic, transport, and storage. In addition, the type of biorefineries to be constructed, their location, type of chemical products to be extracted, and type of pre-processing of feedstock, should also be considered.

Circularity or cascading processes usually enhance the effective use of resources including the valorizing of food wastes. However, accounting for associated emissions, as well as resources and energy consumed, and of the economical sustainability as a whole, is usually more complex.

Furthermore, renewable energy integration to the production of BBPs will be a further challenge to be reached in a short time. Conduct a comprehensive sustainability assessment (LCA) of cascade bioproducts chains should certainly represent a key requisite. Besides along with the BBP's cascade processes, there is a possibility of toxic chemical accumulation, which can hinder recycling or energy exploitation. Therefore, it is mandatory to have a clearly articulated approach where the research needs more time in order to highlight the main weakenesses. The primary target must not just be focused on the maximization of circularity or cascading but also optimise overall outcomes and rewire the economy for equity and ecological sustainability.

The major challenge, especially in developing countries, will be to trust and creating consolidated networking among Governments, Industries, R&D sector, SMEs and citizenship, by sharing the Best Practices about biomass residues exploitation, and food wastes, in the new added-value products.

All these actions have to be planned before setting up biorefinery and management of wastes plans by policymakers and key stakeholders, with a common vision of the future, especially after pandemic period that upset priorities worldwide.

Accomplish this vision requires involving institutions and entities able to deliver key data, to re-define rules, and local waste licensing regulations for transportation, processing, and disposal of food waste quickly. Furthermore, COVID-19 demonstrated how important is to consider the prevention and risks pertaining to health due to transmission of diseases, and potential contaminations. The implication of food and organic waste recycling, disposal or composting, and further valorization through biorefineries, and the public perceptions, and their impacts on local economies must be checked thoroughly. World Health Organization (WHO) confirms Coronaviruses need a live animal or human host to multiply and survive, therefore COVID-19 cannot multiply on the surface of materials, including food packages or biomaterials. Nevertheless, Kampf (Kampf et al. 2020) after having analyzed more than 22 studies related to the several coronaviruses persistence (both deriving from human that veterinary) on inanimate surfaces like metals, paper, ceramics, glass, including plastics, and others, found that human coronaviruses can remain temporarily infectious on these surfaces until to 9 days, depending on the material type. The same authors point out that the coronaviruses may be inactivated by disinfecting the potentially contaminated surfaces. Data about the lifespan of SARS-CoV-2 in different surfaces have been also summarized by Nghiem, (Nghiem et al. 2020), and show that the virus can remain viable for 3 h in aerosols, 4 h in copper, 24 h in cardboard, 2–3 days in stainless steel, 3–4 days in solid faces, and 3 days in plastics and sewage. Despite the several CoronaVirus cannot multiply in different materials, first evidence confirm their survival on organic waste and several materials for a certain timeframe. During the pandemic period, several measures and recommendations for solid food waste handling and management have been developed by international organizations (Santos et al. 2021). The World Health Organization (WHO) has provided guidance on how to safely manage fecal waste and wastewater, and to manage both healthcare and household waste generated by people in quarantine (WHO 2020). Likewise, other organizations have conducted debates on virtual platforms (ISWA 2020a, b), and developed guidelines aiming at raising awareness and encouraging local actions related to safe solid waste management (SWM) to protect the environment and public health, including the solid waste workers (CDC 2020; European Commission 2020; SWANA 2020). Such initiatives are of utmost importance, since waste traceability and management infected by SARS CoV-2, along with water and sewage treatment, are still unsolved issues, especially in developing countries where most of the organic food wastes are manually collected and recycled. In a future outlook of the circular economy, the current circumstances force certainly, to reassess habits and approaches to manage organic and food waste in an approach called "reboot" able to ensure that all procedures used for food waste valorizing to new biobased products follow regulations to "contamination-proof", with particular attention to the biomass residues originated from the urban and zootechnical sector.

More efforts are required for a real implementation of circular economy and radical changes are necessary to rethink the links between use of resources sustainably and economic prosperity, bolstered by huge investments in financial, technical, and social innovations to achieve the real circularity. Therefore, all solutions require contributions from all stakeholders (producers, transformers, and consumers) and emphasis should be on bringing out participatory initiatives among citizens globally (Venkata Mohan et al. 2019; Dilkes-Hoffman et al. 2019). Tackling global gaps through "holistic vision", covering the entire value chain, can spur growth, create jobs and innovation, making a transition towards reduced GHG's while giving people a cleaner and safer environment. Thus, implementing the strategies and plans with concrete actions, sustainable utilization of waste, developing proper infrastructure can make, in practice, the biorefineries an essential tool to achieve the vision of circular bioeconomy.

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