5 Valorization of Biowastes into Food, Fuels, and Chemicals: Towards Sustainable Environment, Economy, and Society

M. Iniya Kumar, S. Naveen, and A. Ramalakshmi

Abstract

The ever increasing global population, continuous dependence on fossil fuels for chemicals, fuels, feeds, and food substitutes, movement of population towards urban, and emergence of more urban cities, have created a shift towards more renewable technologies for sustainable development of environment, economy, and society. One of the renewable technologies which promotes sustainability is efficient waste management technologies. Existing waste management technologies such as open dumping, land filling, and incineration results in generation of more greenhouse gas emissions. The concept of circular economy against existing linear economy emphasizes, if the wastes are managed properly more resources can be extracted out if it, which not only contributes to sustainable economic development but also to environment and society in general. Wastes can be broadly classified into degradable (biowastes) and non-degradable waste, at present the per-capita generation of waste is 0.74 kg/day; as the population continues to rise the amount of wastes generated will double causing serious environmental, public, health, and socio-economic and political concerns. In order to be more sustainable, in the recent years global attention is focused towards valorization of biowastes into energy, food, feed, chemicals generation. This chapter deals with different types of wastes viz., biomass, food, industrial, animal, municipal solid wastes, their characteristics and scope for valorization into fuels, chemicals, and food.

M. I. Kumar (✉) · S. Naveen
Department of Crop Management, Kumaraguru Institute of Agriculture, Erode, India

A. Ramalakshmi
Department of Agricultural Microbiology, Tamil Nadu Agricultural University, Coimbatore, India

V. Venkatramanan et al. (eds.), *Sustainable Bioeconomy*,
https://doi.org/10.1007/978-981-15-7321-7_5

Keywords

Biowastes · Valorization · Fuels · Chemicals · Food · Circular economy · Environment · Sustainable development

5.1 Introduction

According to United Nations report, the global population will continue to rise in a steady state phase; it will reach 8.5 billion in 10 years from now and will be 9.7 billion in 30 years from now and around 80% of the mentioned population will live in cities (Wilson et al. 2016). As the population increases the demand for food, fuels, chemicals will increase simultaneously with consequent utilization of natural resource also increases tremendously. Besides these, the dependence of global population for their primary source of energy has not reduced significantly. The current balance of fossil fuels such as coal (3,789,934 ktoe), Natural Gas (3,106,799 ktoe), Nuclear (687,481 ktoe), and oil (4,449,499 ktoe) indicate its finite quantity and if the current rate of utilization continues, the remaining years for complete depletion of fossil fuels are 53 years for oil, 54 years for natural gas, and 110 years for coal (Ritchie and Roser 2020). The consumption rate far exceeds the production of fossil fuels. The transportation sector continued to be the highest consumer of total energy produced during 2017 (IEA 2019). This unprecedented utilization of fossil fuels has emitted more CO_2 adding to the global climate change (IEA 2019).

Besides these negative effects on the environment, the burgeoning population levels lead to generation of enormous quantity of wastes to the environment. Wastes are defined as unwanted and unsuitable materials or by-products. Depending on degradation nature, wastes can be classified into biodegradable and non-biodegradable. The most common and abundant waste of all, is Municipal Soil Waste (MSW). Worldwide, the total MSW generation for the year 2018 was 2.01 billion metric tonnes (Kaza et al. 2018). The USA was among the highest in terms of generation (267.8 million tonnes) followed by Europe (249 million tonnes) which was followed by China (215 million tonnes) during the year 2017 (Bhatia et al. 2018). It is predicted that by 2050, 3.40 billion metric tonnes of MSW alone would be generated (Kaza et al. 2018). Accumulation of waste seems to be on increasing trend, for instance, the most notorious plastic waste generation was over 8 million tonnes in the year 2017 and unfortunately most of them were dumped into sea (Xu et al. 2019). The most common methods of treatment of wastes are land fill, open dumping, and incineration with very less amount goes for recycling. Such management practices add more greenhouse gases (GHGs) to the environment, for example, 3% Methane was emitted by open dumping, land fill, and direct incineration of MSW in the year 2017 (Wilson et al. 2016).

Therefore, the world is confronted on one side with the explosion of population, the other side with increased waste generation due to increased consumption of fuels, chemical, food, and feed. Thus, the developed and developing countries think of

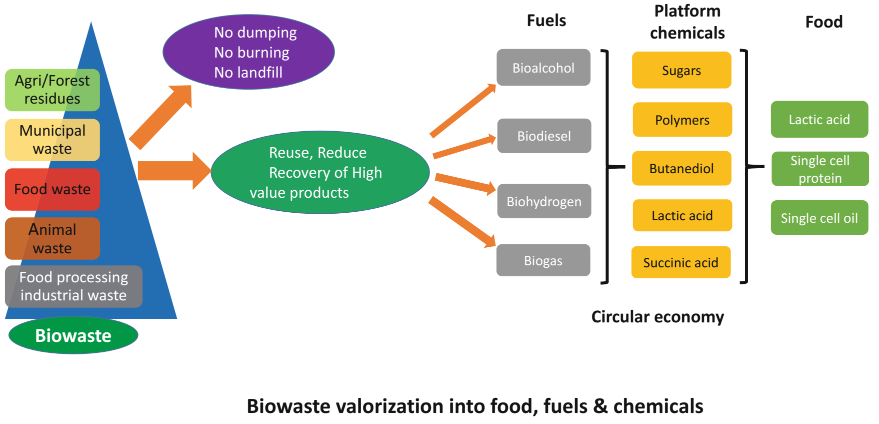

Fig. 5.1 Valorization of biowastes into fuels, chemicals, and food—an effort towards circular economy

management of waste in more sustainable way which would significantly contribute to economy, environment, and society. In the past decade, the concept of "circular economy" was introduced which describes maintaining the market value of the products, resources instead of disposing them as in the case of linear economy (Bos et al. 2017; Dahiya et al. 2018; Kaur et al. 2018; Maina et al. 2017; Vea et al. 2018). In other words the circular economy matches with green chemistry of bio-based product generation from wastes. Thus eliminating disposal of wastes, rather producing new products/recycling and reusing in more sustainable way. It is high time to develop new technologies to extract value added products from the biowastes. Hence, this chapter aims to review the biowastes valorization into chemicals, fuels, food, and feed additives. This chapter covers the various types of biowastes, ways to utilize them, products generated out of it, and their future scope (Fig. 5.1).

5.2 Biowastes

According to European Union definition, biodegradable garden and park waste, food and kitchen wastes, office waste, restaurant waste, whole sale waste, and food processing plant waste are included in the biowastes (Fava et al. 2015). However, increased evidence of literature suggest that agricultural wastes can be one of the main feedstock for the production of biofuel and chemicals. This chapter focusses on agricultural residues, food wastes, animal wastes, and industrial wastes for generation of chemicals, fuels, food as described in Fig. 5.2.

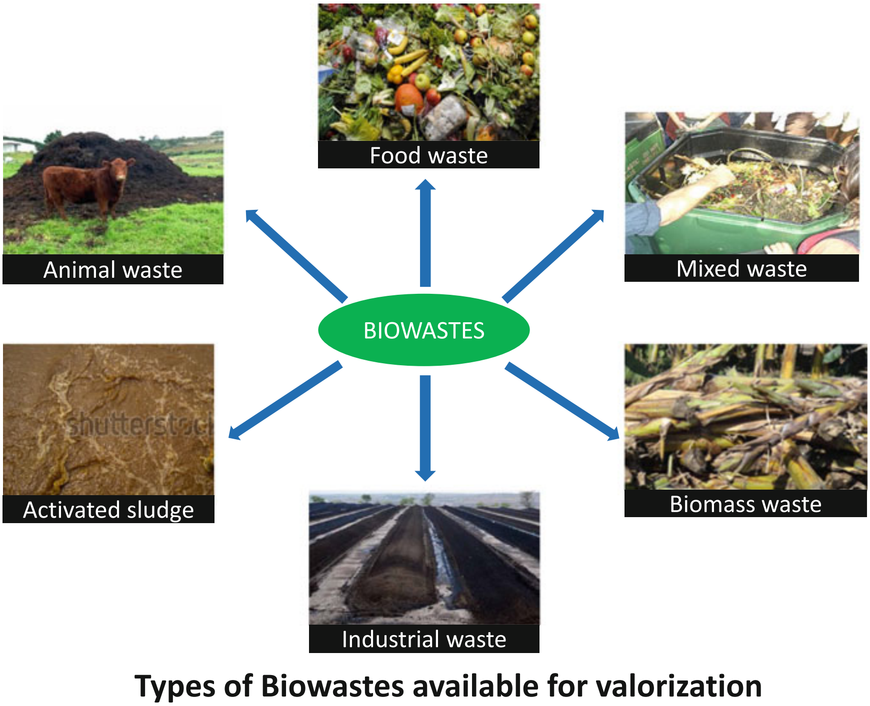

Fig. 5.2 Biowastes available for valorization

5.2.1 Valorization of Biomass into Fuels and High Value Added Products

Biomass constitutes largest resource of carbohydrates and lignin. Every year 2×10^{11} tonnes of biomass is generated worldwide (Appels and Dewil 2012). Among the biomass, the estimated global production of lignocellulosic biomass is about 181.5 billion tonnes per year (Narron et al. 2016). Due to increasing energy demand, environmental, geo-political factors of fossil fuels utilization, biomass as a renewable alternative was considered for production of different types of biofuels. Biomass can be divided into four types based on the origin.

- Biomass exclusively produced for fuel purposes. For example, sugar beet, corn, sugarcane, etc.
- Lignocellulosic biomass includes all agro-residues rich in carbohydrate for biofuel production.
- Organic fraction of municipal soil wastes rich in fuel properties
- Crop residues that include residues after harvest of crop (Fig. 5.3).

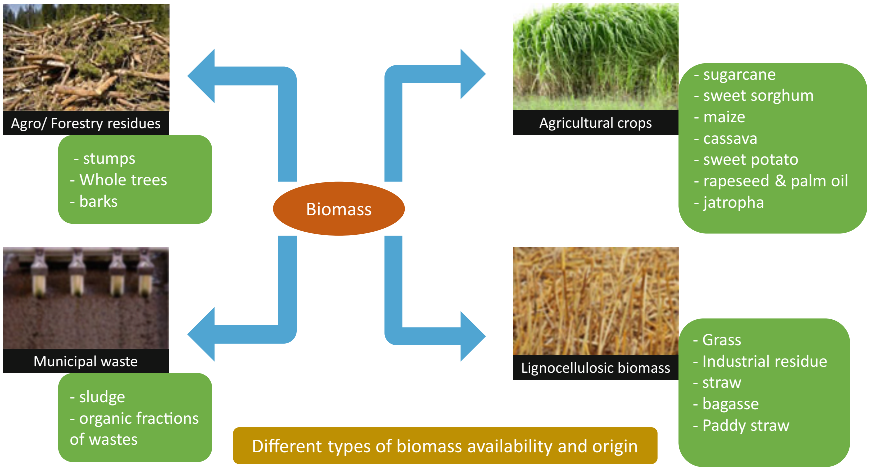

Fig. 5.3 Availability of biomass for valorization based on origin

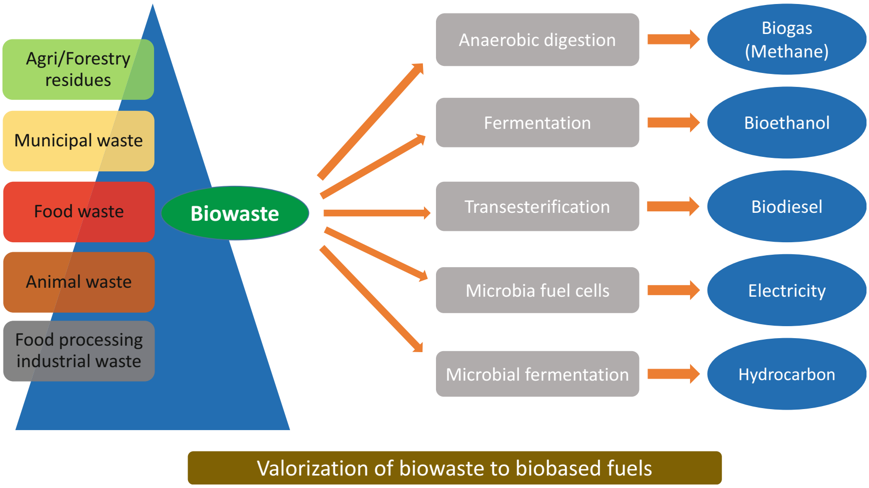

Fig. 5.4 Valorization of biomass into fuels

All of the different types of biomass can be used for generation of biofuels. The major pathways used for generation of biofuel from biomass is given in Fig. 5.4. For efficient conversion of biomass to biofuels initially it needs to undergo pretreatment to remove the recalcitrant molecule lignin and enable the sugars such as cellulose and hemicellulose to be fermented by microorganisms to produce biofuel (Narron et al. 2016).

5.2.1.1 Anaerobic Digestion of Biomass

The carbohydrates in the biomass using anaerobic digestion (AD) can be transformed into biogas which constitutes methane (60%) and CO_2 (40%). The AD technology, although known for many years, in recent times gained more attention. The home based AD has become more popular in developed and developing countries. In India, AD of biowastes has gained traction in different sectors namely as home based AD, community based AD, and large scale AD depending on the quantity and quality of waste generated in the region (Breitenmoser et al. 2019). Although AD generates energy out of biomass, this technology also generates digestate to be used as bio-fertilizers or soil enhancer. However, if the AD is to be completely operated throughout the sector from home to large scale units, it needs to accommodate more innovative ways such as co-digestion with other wastes, design and development of suitable reactor for individual sector, synergy between public, private, and industrial sectors (Bhatia et al. 2018).

5.2.1.2 Bioalcohol Production from Biomass

Among the different sectors of energy consumption worldwide, the major share (28%) goes to transportation sector which contributes to global warming. It is predicted that the global mobility will increase triple fold in the 2030; use of petroleum products will also likely to increase (Balan 2014; Fatih Demirbas et al. 2011). Many countries started producing biofuels from lignocellulosic biomass. Among the biomass, lignocellulosic biomass (LCB) is the most preferred option for generation of bioalcohol. The LCB contains 40–50% cellulose, 30–40% hemicellulose, and 20–30% lignin. Cellulose and hemicellulose are polysaccharides which mainly contain Beta 1, 4 linkages. Lignin the abundant aromatic polymer finely laced between cellulose and hemicellulose hindering many pretreatments and prevent accessible of hydrolytic enzymes (Manisha 2017). General bioalcohol production methods first remove lignin and depolymerize cellulose and hemicellulose into glucose and xylose units. After enzymatic hydrolysis, microorganisms convert the carbohydrates into bioalcohol. Lignin although not valorized is mostly burnt to generate electricity. However enormous value added products can also be generated from lignin (Narron et al. 2016).

5.2.1.3 Biodiesel Production from Biomass

Although bioalcohols were significantly produced, recently biodiesel production from biomass is gaining attention. Europe is the forerunner in biodiesel production worldwide. Biodiesel are lipids from oleaginous microorganisms. In nature, certain bacteria, fungi, yeast, and algae are capable of accumulating lipids in their biomass more than 70% of their dry weight under high carbon and low nitrogen conditions (Bhatia et al. 2018; Intasit et al. 2020). These lipids are similar to any vegetable oils in terms of their biodiesel properties. Use of microorganisms for lipid production although known for more than 100 years, due to its high cost they were not commercialized. Recently they are gaining momentum as the use of renewable biomass is available as a cheap source for biofuels. Biodiesel from oleaginous microorganisms has many advantages over plant oils, as they do not require huge land, time, labour, and no seasonal disturbances. Microbial biodiesel can be produced significantly under controlled conditions. Although several research efforts are still needed to commercialize this technology on larger scale. Biomass to biodiesel continues to be an important source of energy in the recent years (Dahiya et al. 2018).

5.2.1.4 Biohydrogen Production from Biomass

In the current wave of renewable energy generation out of wastes, anaerobic digestion, municipal solid waste, organic waste, agricultural waste, waste water, and sludge are considered as renewable source of biohydrogen production. Although the continuous production of biohydrogen has some disadvantages such as low H_2 yields, the technology can be improved by mixing photosynthetic microbes with anaerobes to degrade carbon rich and less toxic raw materials. Under anaerobic conditions, hydrogen production proceeds with photo fermentative as well as dark fermentation (Balan 2014). Biohydrogen production is an anerobic fermentation of organic substances. The most studied anaerobic bacteria *Clostridium butyricum* can serve as a candidate for biohydrogen production. The theoretical yields of hydrogen is 4 mol of H_2 per mole of glucose or 2 mol of H_2 per mole of acetate. In order to be competitive with other biofuels, the H_2 production should be enhanced by isolation and identification of novel microorganism with high titres, bioreactor designs, use of mixed culture, and more advanced phototrophic microorganism for higher yields (Venkata Mohan et al. 2016).

5.2.1.5 Bulk Chemicals from Biomass

As mentioned biomass constitutes a largest renewable resource for chemicals production. There has been renewed interest to produce fine chemicals and platform chemicals from biomass. Although the concept is promising, and high value added products can be generated, the industry must also think of producing bulk chemicals initially to sustain its production (Ahorsu et al. 2018; Appels and Dewil 2012; Balboa et al. 2015). The major limitation with fine chemicals is that they have very small market. On the other hand, chemicals such as surfactants, plastic monomers, lubricants, fibres, and industrial solvents serve as bulk chemicals with huge market potential. High value added fuels and chemicals currently replace 300 million gallons of petroleum per year. The market for high value chemicals is growing rapidly and will have a better future in contributing to economy of the nation (Biddy et al. 2016).

For the production of bulk and fine chemicals, focus must be paid to use the food processing waste. The residues left on the field although in enormous quantity, they may be preferred to be retained on the field, as they add more value to soil. On volume basis, rice husks and sugarcane bagasse are the two important processed residues from rice processing plant and sugar industry, respectively. These two high volume renewable sources are available for production of fuels and chemicals. Organic fraction of municipal solid waste is also another important source of biowastes that can be efficiently transformed into fuels and chemicals (Gallezot 2012).

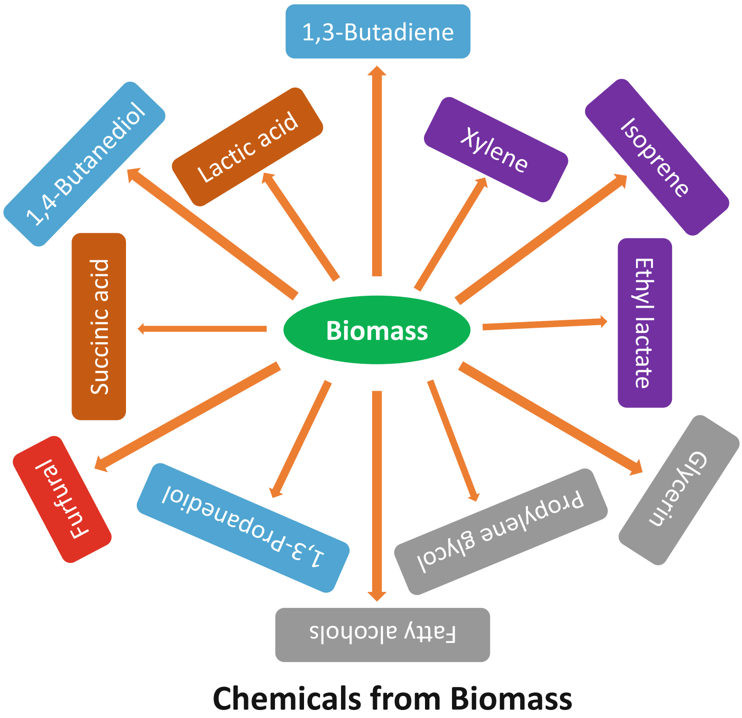

Fig. 5.5 Fine and platform chemicals production from biomass

Majority of industry focus on biofuels especially bioethanol from biomass. However, a high value compound ethylene is produced by dehydration of ethanol. Then ethylene could serve as platform chemical for production of multiple high value chemicals. Oxidized form of ethylene is ethylene oxide or ethylene glycol. The National Renewable Energy Laboratory (NREL) has released a list of bio-based chemicals with near-term market potential (Fig. 5.5) (Biddy et al. 2016). The chemicals mentioned in Fig. 5.5 can serve as building blocks for production of several other chemicals. Polybutadiene and styrene butadiene rubbers can be produced from 1,3-butadiene (BD). 1,4-butanediol (BDO) is a platform chemical from which polymers and solvents are synthesised. Surfactants are the products produced from fatty alcohols and are used as floor cleaners (Gallezot 2012; Rosales-Calderon and Arantes 2019). Furfural alcohol (FA) and product of furfural obtained via chemical condensation of hemicellulose are widely used in resin preparation. Glycerine, a well-known hygroscopic substance is used in variety of industries. Lactic acid, a fermented product of sugars by microorganisms can be used in many fine chemical transformations. 1,3-propanediol (PDO) has gained popularity in polymer industries and cosmetics industry. Similar to lactic acid, succinic acid has multiple product transformations with high market potential. Xylene, an important platform chemical serves as an integral part of polyethylene bottle manufacturing

Table 5.1 Industries involved in production of chemicals from biomass

S. no.	Company	Country	Product
1.	Braskem	Brazil	Polyethylene
2.	Genomatica	USA	1,4-Butanediol
3.	INVISTA	USA	2,3-Butanediol and butadiene
4.	LANZATECH	USA	2,3-Butanediol and butadiene
5.	International Furan Chemicals	Netherlands	Furfural
6.	Archer Daniels Midland	USA	Glycerol
7.	Amyris	USA	Bio-isoprene
8.	NatureWorks	USA	Lactic acid
9.	Cellulac	UK	Lactic acid

Source: Adapted from Biddy et al. (2016)

(Rosales-Calderon and Arantes 2019; Shahbazali 2013; Singhvi and Gokhale 2019) Several industries involved in production of fine and platform chemicals from biomass is described in (Table 5.1).

5.2.2 Valorization of Food Waste into Chemicals and Fuels

Management of food waste is another critical issue in both developed and developing nations. It is estimated that globally, about 30–40% of food is wasted during the supply chain (Dahiya et al. 2018). The trend in low income countries suggests that more food loss occurs at initial stages of supply chain due to improper infrastructure, lack of finance to maintain the supply chain. On the other hand, the food loss is found at the end of supply chain for high income nations. Together both high and low income nations contribute equally to food waste. It is estimated that about 1/3 of the world's food was lost or wasted per annum. It is not only the food that is wasted without consumption, but also loss of the resources that played a part in the food production. Further, food production also involves release of greenhouse gases emissions. Hence, food loss and waste is cause of concern. Global agenda on SDGs also focusses on this problem, as SDG 2 (Ending hunger) and SDG 12 (Responsible consumption and production) are connected to this problem. In fact the target 12.3 of the SDG "calls for halving per-capita global food waste at retail and consumer levels by 2030, as well as reducing food losses along the production and supply chains". Further, potential exists in the valorization of food waste into value added chemicals and fuels.

5.2.2.1 Existing Methods of Management of Food Wastes

Aerobic decomposition (compost production) and anaerobic digestion are currently followed worldwide to manage the food wastes. Both the technologies are operated in the mode of biodegradation of organic matter. Composting is aerobic degradation of food waste with the help of decomposing microorganisms to produce compost. Compost is excellent manure that adds nutrients to soil and enhances the water holding capacity of soil. Composting also has several limitations such as release of odour, NH_3, GHG, and leachate. While AD works well for biomass, waste water, sludge, industrial by-products, food waste to methane has several shortcomings. Due to high nutrient load in food waste, the methane yield gets reduced. Further, increased production of free fatty acids which are volatile in nature results in formation of foams. In some countries the digestate can be of excellent fertilizer to soil; however, it increases the nutrient content in soil. Hence, the demand for sustainable methods of valorization of food wastes are increasing from the past decade (Mirabella et al. 2014).

5.2.2.2 Fuels from Food Wastes

The rich nutrient content in food wastes makes them suitable feedstocks for generation of biofuels. In the past years enhanced research efforts have been oriented towards valorization of food waste into biofuels. Potential of food wastes in generating different biofuels are given in Fig. 5.6.

Anaerobic Fermentation

Anaerobic fermentation (AF) is the most popular method of food waste valorization towards generation of methane, volatile fatty acids, hydrogen, and other organic acids such as butyric acids, propionic, iso-butyric, valeric acids. However, the AF to be competitive over other platforms, use of mixed microbiome for utilization of different nutrients should be performed. Combining anerobic fermentation with bioelectrode systems to generate electricity from methane is one of the promising way of valorization. Anaerobic fermentation consumes all organic load for platform chemicals production and reduces the carbon foot print (Dahiya et al. 2018; Venkata Mohan et al. 2016).

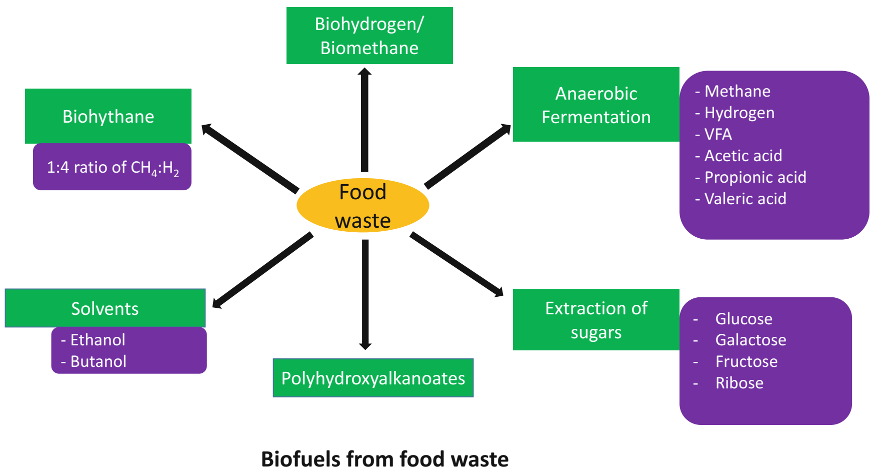

Fig. 5.6 Fuels production from food wastes

Extraction of Sugars from Food Wastes

Due to the rich organic content of food wastes, research has been directed at the possibilities of extraction of sugars from food wastes for production of fuels and chemicals. To extract sugars from food wastes, pretreatment step is necessary. Dilute acid pretreatment yields more sugars than other methods. Similarly, amylase enzyme digestion leads to production of glucose, fructose, galactose, and ribose. Such sugars can then be used to make platform chemicals, fuels, and food additives. It is worth noting that during any pretreatment either it be chemical, physical, or biological, product recovery should be maximum (Dahiya et al. 2018).

Biohydrogen

Highly degradable organic material content in food wastes makes it a potential candidate for biohydrogen production. Biological production of hydrogen involves photo-fermentation, biophotolysis, and anaerobic fermentation. Biohydrogen production using anaerobic fermentation is directly dependent on nature and property of microbial inoculum, type of treatment adopted, pH, inclusion of inducer, design of bioreactor, etc. In addition, integration of anaerobic fermentation with photo-fermentation to increase the yield is an additional option. Similarly fusing dark and photo-fermentation also increases the yield of hydrogen fermentation (Arancon et al. 2013; Maina et al. 2017; Mirabella et al. 2014).

Biomethane

The most preferred technology for energy generation from food wastes is methane production through anaerobic digestion. The major bottleneck while using food waste as a substrate is their rich nutrient content and foaming in the reactor. To overcome such shortcomings process should be optimized with better C/N ratio, newer reactor design, co-digestion with other wastes to improve methane yield (Bhatia et al. 2018; Jobard et al. 2017; Marin-Batista et al. 2019).

Biohythane

Biohythane is a combined fuel of methane and hydrogen prepared at 1:4 ratio to improve the calorific value of fuels. Such type of adding a small percentage of hydrogen with methane improves efficiency of methane fuels. Food wastes as a source of biohythane production has received attention and semi-pilot scale studies reveal that they are the good source for production of biohythane.

Volatile Fatty Acids

During the generation of H_2 production, a combination of short chain volatile fatty acids as co-products are generated under anaerobic fermentation. Currently these volatile fatty acids are produced from petroleum refinery and not benign to the environment. Hence volatile fatty acids generated from the anaerobic fermentation of food waste has got renewed interest. Production of volatile fatty acids has numerous advantages in textile, pharmaceutical, and food industries (Posmanik et al. 2017).

Bioethanol

Global demand for bioethanol has increased considerably. Currently biomass to biofuels route are most commercialized and many pilot and industrial plants are operated. Due to the increased demand, alternative feedstocks are explored simultaneously. It was observed that fermentation of food wastes at high solids content with a vacuum recovery system yielded higher amounts of bioethanol than the conventional fermentation (Huang et al. 2015). Thus food waste can also be a suitable substrate for bioethanol production as they do not require multi-step pretreatment processes for biofuel production.

Biodiesel Production

Biodiesel is a mixture of esterified fatty acid and is conventionally produced from non-edible and few edible oils, cooked oils, and fats from animal origin. However, their supply is very limited and cannot meet the increasing demand. There are microorganisms called oleaginous microorganisms that can accumulate lipid in their biomass. These oleaginous microorganisms have potential to convert food wastes into lipids. The lipids are trans-esterified with chloroform and methanol in the presence of KOH (potassium hydroxide) to form biodiesel.

5.2.2.3 Chemicals Production from Food Wastes

Food wastes are not only good candidates for biofuels production, owing to their nutrient content they are also good source for extraction and recovery of value added chemicals. An overview of chemicals generated from food waste is given in Fig. 5.7 (Dahiya et al. 2018; Mirabella et al. 2014). The three major wastes vegetable waste, dairy products, and meat industry wastes contribute to food wastes.

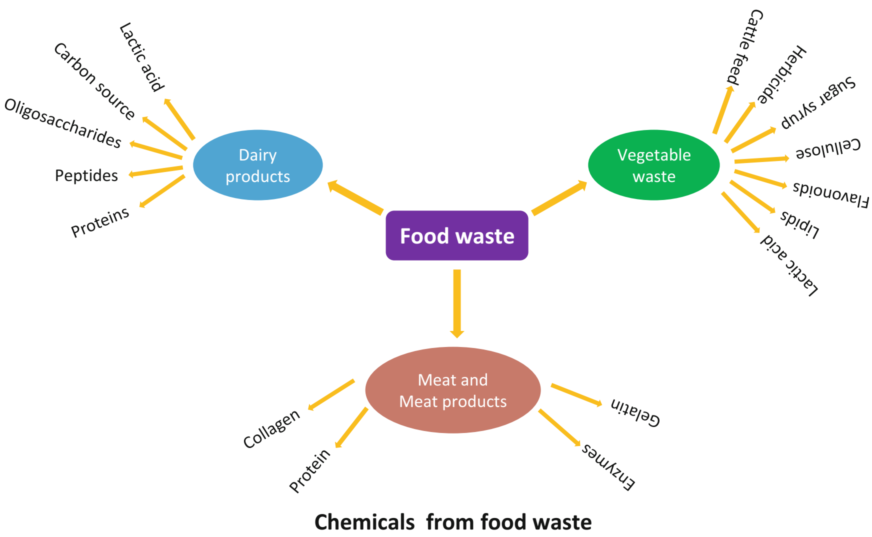

Fig. 5.7 Chemicals production form food wastes

Fruits and vegetables waste constitutes to be largest fraction of food wastes. It has significantly high solids, high COD and BOD, and it can be used for production of high value chemicals. During processing of vegetables and fruits viz., apple, potato, tomato, berries, olives, citrus, enormous amount of wastes has been generated. Their production potential has been reviewed by (Mirabella et al. 2014). Several food industry, pharmaceutical industry produces can be generated from fruit and vegetable wastes (Fig. 5.7). Biologically active phenols and pectins are extracted from apple pomace, citrus peel residues, and berries. Gelling and thickening agents are also obtained from fruit wastes.

Dairy industries generate enormous quantity of liquid wastes with different nutrient content. The liquid of dairy waste mainly contains proteins, salts, fatty substances, lactose, etc. Precipitation, filtration techniques were followed to purify the whey from different cheese whey. Such treated whey is a rich source of lactose which can be used for production of chemicals, especially industrial production of kefiran, an exopolysaccharide rich in glucose and galactose. Whey permeate was used as sanitizing agent to treat fruits and vegetables.

Global meat consumption has increased significantly due to increased demand for protein rich food. One of the causes of concern with respect to recovery of chemicals from meat and meat processing waste is health and hygiene issue. For instance, Bovine Spongiform Encephalopathy is found to be one of the most dangerous diseases that affect the value and consumer chain, calling for much attention during handling of meat wastes. Meat wastes are also a rich source of proteins, hence several extraction methods were tried to extract meat proteins from lungs and beef pork. Such proteins can be a flavour enhancer, nutritional additive, etc. (Arancon et al. 2013; Dahiya et al. 2018; Ibarruri and Hernandez 2019; Imbert 2017).

5.2.3 Industrial Wastes

During the processing of organic material into high value products, a significant quantity of wastewater is generated. In most cases they are not treated properly either land filled or directly disposed into water bodies causing environmental problems. Valorization strategies are followed for such industrial wastewater. Starch processing wastewater is one such waste composed of high quantities of starch from peelings of potato. Starch containing wastes also have significant amounts of total soluble nitrogen and total soluble phosphorous which can be recovered/ removed by biological wastewater treatment (Muniraj et al. 2013). With regard to Olive mill waste (OMW), the wastewaters contain enormous amounts of organic load. In this case, biogas production can be a better option. The digestate after treatment with appropriate concentration of nutrients can be composted and used as soil amendment to enhance the organic carbon content. Further, the reclaimed wastewater can be a good source for irrigation of agriculture and horticultural crops (Fritsch et al. 2017).

5.3 Conclusion

Valorization of biowastes (agricultural, food, industrial wastes) is an important step towards sustainable economy, environment, and society. Valorization technologies and their adoption vary with type, composition, availability of biowastes, energy demand, economic and technological feasibility. However, there are challenges that need to be sorted, for instance, sorting different wastes, storing them, instability of microorganisms in the wastes, and high heterogeneity of by-products. The challenges warrant development of new and innovative technologies. Further, while the valorization of biowastes into value added products is a good option, many of the technologies available for valorization of biowastes are costly. Hence, concerted effort is required to reduce the cost of technology and upscale the economic returns.

References

Ahorsu R, Medina F, Constantí M (2018) Significance and challenges of biomass as a suitable feedstock for bioenergy and biochemical production. Rev Energ 11:3366. https://doi.org/10.3390/en11123366

Appels L, Dewil R (2012) Biomass valorization to energy and value added chemicals: the future of chemical industry. Resour Conserv Recycl 59:1–3. https://doi.org/10.1016/j.resconrec.2011.09.021

Arancon RAD, Lin CSK, Chan KM, Kwan TH, Luque R (2013) Advances on waste valorization: new horizons for a more sustainable society. Energy Sci Eng 1:53–71. https://doi.org/10.1002/ese3.9

Balan V (2014) Current challenges in commercially producing biofuels from lignocellulosic biomass. ISRN Biotechnol 2014:31. https://doi.org/10.1155/2014/463074

Balboa EM, Moure A, Dominguez H (2015) Valorization of *Sargassum muticum* biomass according to the biorefinery. Concept Mar Drugs 13:3745–3760. https://doi.org/10.3390/md13063745

Bhatia SK, Joo H-S, Yang Y-H (2018) Biowaste-to-bioenergy using biological methods – a mini-review. Energy Convers Manag 177:640–660. https://doi.org/10.1016/j.enconman.2018.09.090

Biddy MJ, Scarlata C, Kinchin C (2016) Chemicals from biomass: a market assessment of bioproducts with near-term potential. National Renewable Energy Lab. (NREL), Golden, CO. https://doi.org/10.2172/1244312

Bos H, Annevelink B, Rv R (2017) The role of biomass, bioenergy and biorefining in a circular economy. Wageningen University & Research, IEA Bioenergy, Paris

Breitenmoser L et al (2019) Anaerobic digestion of biowastes in India: opportunities, challenges and research needs. J Environ Manag 236:396–412. https://doi.org/10.1016/j.jenvman.2018.12.014

Dahiya S, Kumar AN, Shanthi Sravan J, Chatterjee S, Sarkar O, Mohan SV (2018) Food waste biorefinery: sustainable strategy for circular bioeconomy. Bioresour Technol 248:2–12. https://doi.org/10.1016/j.biortech.2017.07.176

Fatih Demirbas M, Balat M, Balat H (2011) Biowastes-to-biofuels. Energy Convers Manag 52:1815–1828. https://doi.org/10.1016/j.enconman.2010.10.041

Fava F et al (2015) Biowaste biorefinery in Europe: opportunities and research & development needs. New Biotechnol 32:100–108. https://doi.org/10.1016/j.nbt.2013.11.003

Fritsch C et al (2017) Processing, valorization and application of bio-waste derived compounds from potato, tomato, olive and cereals. Rev Sustain 9:1492. https://doi.org/10.3390/su9081492

Gallezot P (2012) Conversion of biomass to selected chemical products. Chem Soc Rev 41:1538–1558. https://doi.org/10.1039/C1CS15147A

Ibarruri J, Hernandez I (2019) Valorization of cheese whey and orange molasses for fungal biomass production by submerged fermentation with *Rhizopus* sp. Bioprocess Biosyst Eng 42:1285–1300. https://doi.org/10.1007/s00449-019-02127-4

IEA (2019) World energy statistics 2019. IEA, Paris. https://www.iea.org/reports/world-energy-statistics-2019

Imbert E (2017) Food waste valorization options: opportunities from the bioeconomy. Open Agri 2:195. https://doi.org/10.1515/opag-2017-0020

Intasit R, Cheirsilp B, Louhasakul Y, Boonsawang P, Chaiprapat S, Yeesang J (2020) Valorization of palm biomass wastes for biodiesel feedstock and clean solid biofuel through non-sterile repeated solid-state fermentation. Bioresour Technol 298:122551. https://doi.org/10.1016/j.biortech.2019.122551

Jobard M, Pessiot J, Nouaille R, Fonty G, Sime-Ngando T (2017) Microbial diversity in support of anaerobic biomass valorization. Crit Rev Biotechnol 37:1–10. https://doi.org/10.3109/07388551.2015.1100584

Kaur G, Uisan K, Ong KL, Ki Lin CS (2018) Recent trends in green and sustainable chemistry & waste valorisation: rethinking plastics in a circular economy. Curr Opin Green Sustain Chem 9:30–39. https://doi.org/10.1016/j.cogsc.2017.11.003

Kaza S, Yao LC, Bhada-Tata P, Van Woerden F (2018) What a Waste 2.0: a global snapshot of solid waste management to 2050. World Bank Publications, Washington, DC. https://doi.org/10.1596/978-1-4648-1329-0

Maina S, Kachrimanidou V, Koutinas A (2017) A roadmap towards a circular and sustainable bioeconomy through waste valorization. Curr Opin Green Sustain Chem 8:18–23. https://doi.org/10.1016/j.cogsc.2017.07.007

Manisha YSK (2017) Technological advances and applications of hydrolytic enzymes for valorization of lignocellulosic biomass. Bioresour Technol 245:1727–1739. https://doi.org/10.1016/j.biortech.2017.05.066

Marin-Batista JD, Villamil JA, Rodriguez JJ, Mohedano AF, de la Rubia MA (2019) Valorization of microalgal biomass by hydrothermal carbonization and anaerobic digestion. Bioresour Technol 274:395–402. https://doi.org/10.1016/j.biortech.2018.11.103

Mirabella N, Castellani V, Sala S (2014) Current options for the valorization of food manufacturing waste: a review. J Clean Prod 65:28–41. https://doi.org/10.1016/j.jclepro.2013.10.051

Muniraj IK, Xiao L, Hu Z, Zhan X, Shi J (2013) Microbial lipid production from potato processing wastewater using oleaginous filamentous fungi *Aspergillus oryzae*. Water Res 47:3477–3483. https://doi.org/10.1016/j.watres.2013.03.046

Narron RH, Kim H, Chang HM, Jameel H, Park S (2016) Biomass pretreatments capable of enabling lignin valorization in a biorefinery process. Curr Opin Biotechnol 38:39–46. https://doi.org/10.1016/j.copbio.2015.12.018

Posmanik R, Labatut RA, Kim AH, Usack JG, Tester JW, Angenent LT (2017) Coupling hydrothermal liquefaction and anaerobic digestion for energy valorization from model biomass feedstocks. Bioresour Technol 233:134–143. https://doi.org/10.1016/j.biortech.2017.02.095

Ritchie H, Roser M (2020) Fossil fuels. Published online at OurWorldInData.org. Retrieved from: https://ourworldindata.org/fossil-fuels [Online Resource]

Rosales-Calderon O, Arantes V (2019) A review on commercial-scale high-value products that can be produced alongside cellulosic ethanol. Biotechnol Biofuels 12:240. https://doi.org/10.1186/s13068-019-1529-1

Shahbazali E (2013) Biorefinery: from biomass to chemicals and fuels. Green Process Synth 2:87. https://doi.org/10.1515/gps-2012-0094

Singhvi MS, Gokhale DV (2019) Lignocellulosic biomass: hurdles and challenges in its valorization. Appl Microbiol Biotechnol 103:9305–9320. https://doi.org/10.1007/s00253-019-10212-7

Vea EB, Romeo D, Thomsen M (2018) Biowaste valorisation in a future circular bioeconomy. Procedia CIRP 69:591–596. https://doi.org/10.1016/j.procir.2017.11.062

Venkata Mohan S, Nikhil GN, Chiranjeevi P, Nagendranatha Reddy C, Rohit MV, Kumar AN, Sarkar O (2016) Waste biorefinery models towards sustainable circular bioeconomy: critical review and future perspectives. Bioresour Technol 215:2–12. https://doi.org/10.1016/j.biortech.2016.03.130
Wilson DC et al (2016) Global waste management outlook. United Nations Environment Programme. https://doi.org/10.18356/765baec0-en
Xu C, Nasrollahzadeh M, Selva M, Issaabadi Z, Luque R (2019) Waste-to-wealth: biowaste valorization into valuable bio(nano)materials. Chem Soc Rev 48:4791–4822. https://doi.org/10.1039/C8CS00543E