Chapter 6
Biogas from Kitchen Waste

S. M. Bhatt

Abstract Biogas production is the best renewable technology which has opportunity to convert various biowaste released from agricultural, animal, industrial, and kitchen waste into energy. Biogas development has opportunity not only to improve sanitation but also to reduce air pollution and greenhouse gases.

India's current production of biogas is 2.07 billion m^3/year which should be around 29–48 billion m^3/year.

Anaerobic digestion process has widely been employed for treatment of various organic wastes for conversion into biogas and bio-fertilizer. A complex microbial community is used to degrade various organic compounds into final products such as methane and carbon dioxide, collectively called biogas. This has been explored in detail in the current book chapter based on recycle, reuse, and reduce. Most of the public are now aware and using dustbins as per government guideline. Organic composting is not possible without microbial community.

Keywords Methane · Biogas · Acetate · BioCNG

Abbreviations

AD	Anaerobic digestion
BMP	Biochemical methane potential
HVPD	High-voltage pulse discharge
McoDi	Mesophilic co-digestion of food waste and manure
MDi	Mesophilic digester
OFMSW	Fraction of municipal solid waste
TcoDi	Thermophilic co-digester
VFA	Volatile fatty acid

S. M. Bhatt (✉)
Agriculture Department, Amritsar College of Engineering and technology, Amritsar, Punjab, India

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6.1 Introduction

Food waste includes both precooked and peels of vegetables, left over of the food after eating, waste discharge from food processing industries and restaurants, and mess. FAO estimates food waste generated worldwide is around 1.3 billion ton which has been released from various sources such as vegetable mandi, fruit seller, bakery shop, and dairy and meat products, and these food waste degrades in open air causing so much pollution and inviting airborne infections (Ananno et al. 2021). In the next few 25 years, food waste generation is projected to increase almost more than double due to huge population growth mainly in Asian growth. According to an estimate, there may be rise in waste from 278 million tonnes to 416 million tonnes from 2005 to 2025. In India solid waste generated per year is around 62 million tonnes while 377 million by urban society, out of which 50% is food waste (Ghosh et al. 2018) is generated each year.

The major questions arises how to manage these food waste. In India basically fraction of municipal solid waste (OFMSW) technology is used to manage food waste. In this technology basically fraction of waste generated is segregated and pretreated.

Dissemination of waste does occur in bio-methanation plant where most of kitchen waste and food waste undergoes anaerobic digestion (AD) for production of compressed biomethane for running vehicle in the city (Shanmugam et al. 2019).

It has been noted that due to mismanagement of these biowastes, there is huge loss of nutrients useful for the plant, and biodegradation of waste leads to release of various metals and thereof pollutants in water (Chandra Manna et al. 2018).

Food waste digestion is done under anaerobic condition after proper treatment of organic waste which include shredding of waste into fine particle and then treatment at various stages to yield biogas and fertilizers. The yield depends on KPI.

6.2 Biofuel Classifications

As mentioned in Figs. 6.1, 6.2 and 6.3 based on food source, classification for biofuel into first, second, and third generations can be done. Bioethanol and biodiesel is an example of first-generation biofuel, while ethanol production via biomass such as lignocellulosic biomass is an example of second-generation biofuel, and bioethanol production from algae is an example of third-generation biofuel.

Food wastes like starch and vegetable are often categorized under first-generation biofuel. Bioethanol production with direct bioprocessing can be done after hydrolysis using yeast as microbes.

Naturally, Biogas production occurs of organic materials is digested under anaerobic condition, which needs rightly designed anaerobic biodigester with optimized condition for growth of microbes. Integrated modelling of bioreactor

Fig. 6.1 Different types of kitchen waste

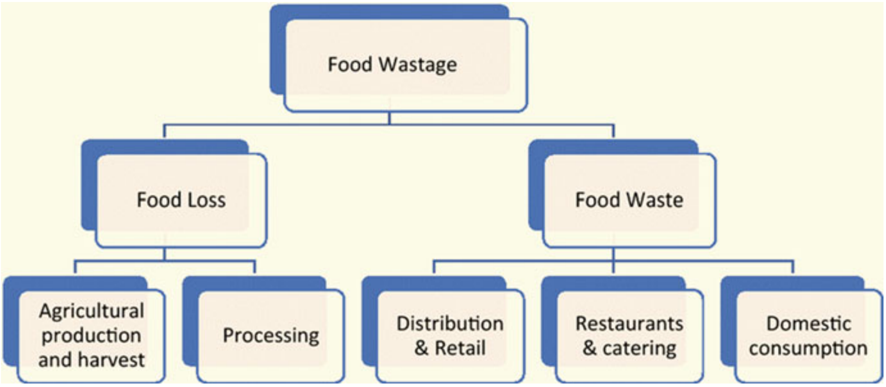

Fig. 6.2 Food waste classifications. (Modified from Lytras et al. (2021). Source: https://en.wikipedia.org/wiki/Food_loss_and_waste)

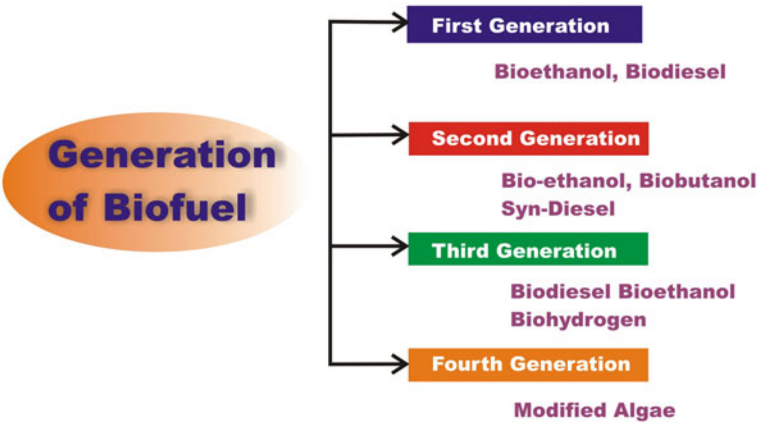

Fig. 6.3 Biofuel generation. (Source: https://en.wikipedia.org/wiki/Food_loss_and_waste)

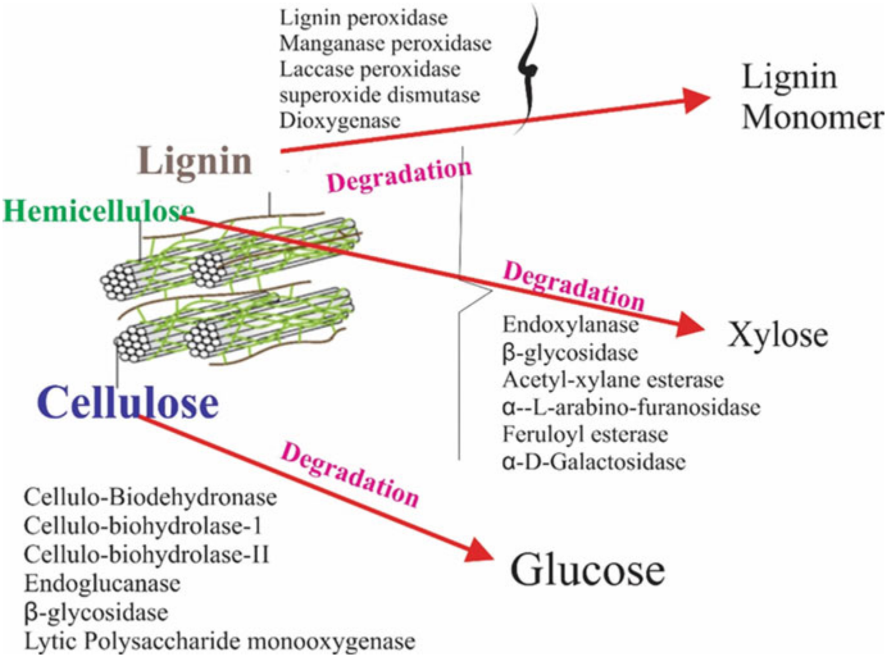

Fig. 6.4 Hydrolysis of lignocellulose various enzymatic steps involved (Champreda et al. 2019)

condition had a dual advantage that besides production of biogas, useful manure is also recovered.

Syngas synthesis gasification method is used to produce *syn*gas where oxygen organic matter gets pyrolysis after combustion. The carbon monoxide helps in converting gas.

Cellulase, Lignase Hemicellulase Pectinase Xylanse enzyme used in lignocellulosic based ethanol also depicted in Fig. 6.4.

6.2.1 Kitchen Waste Composition

Composition analysis of food waste, in many reviews, shows the basic components are carbohydrates, proteins, and lipid. The composition varies: (1) 60–80% moisture, (2) 3–5% ash, (3) 40–60% carbohydrate, (4) 18–30% volatiles, (5) 10–30% protein, (6) 15–40% fat, and (7) 45–65% carbon (Palaniveloo et al. 2020).

Protein-based meals are rich in mostly protein content. With moisture content of 4–7%, wheat meals are high in carbohydrates (range of 88–92%).

6.2.1.1 Biochemical Methane Potential (BMP)

Technique is applied for checking methane production potential with anaerobic biodegradation of wastewater and waste biomass.

Organic substrate degrades and releases methane and carbon. Generally BMP test assay is applied for mixed food waste containing boiled rice, peels of cabbage, and left over of cooked meat which are digested with cellulase as control (since greater rate of production of methane; 472 mL/g VS with total reduction in V Sup to 86%).

Another study conducted over canteen waste when mixed with wheat straw in different ratios in order to increase total methane production. As a result BMP reported was around 0.26 and 0.16 m^3 CH_4/kg-VS, respectively, and we conclude that food waste is easily biodegradable as high VS, while due to lignin the straw is difficult to degrade anaerobically.

Four phases involved in the biogas production such as (1) enzymatic hydrolysis, (2) acidogenesis, (3) acetogenesis, and (4) finally methanogenesis.

Steps in methanogenesis and biogas production:

1. Hydrolysis: These microbes secrete various types of enzymes that hydrolyzes complex food materials into its monomer like glucose fatty acid and amino acids.
2. Then monomer like glucose FA and amino acid get converted to higher volatile fatty acids, into propionic and butyric acids, by hydrogen-producing acetogenic bacteria produced, to H_2, CO_2, and acetic acid.
3. Finally, methanogenic bacteria convert all acetate and others products to CH_4 and CO_2.

   (a) Kitchen waste first collected.
   (b) Shredded into fine particles.
   (c) Substrate hydrolysis.
   (d) Acidogenesis convert hydrolysed substrate into acid which is used by microbes which convert acid into acetate E) ACETATE is used as substrate to methane and CO_2.
   (e) Hydrolytic enzymes (lipases, proteases, cellulases, amylases) are released to convert waste into various types of acids which are being converted into acetic acid.
   (f) Lipases convert lipids to long-chain fatty acids. *Clostridia and the micrococci* known for extracellular lipase production. The long-chain fatty acids produced are further degraded by *p*-oxidation to produce acetyl CoA.
   (g) Proteins are generally hydrolyzed to amino acids by proteases, secreted by various microbes such as *Clostridium*, *Bacteroides*, *Butyrivibrio*, *Fusobacterium*, *Streptococcus*, and *Selenomonas*. The amino acids produced are then degraded to fatty acids such as acetate, propionate, butyrate, and ammonia as found in *Clostridium*, *Peptococcus*, *Selenomonas*, *Campylobacter*, and *Bacteroides*.
   (h) Polysaccharides such as cellulose, starch, and pectin found in the kitchen waste are hydrolyzed by enzyme secreted by the cellulases, amylases, and pectinases. The majority of microbial cellulases are hydrolyzed to produce glucose. While Raw starch present in food waste is converted to glucose by

amylolytic activity of amylase enzyme. Five amylase species need to be active which includes (a) α-amylase (cleaves 1–4 bonds), (b) β-amylase (cleaves 1–4 bonds), (c) amyloglucosidase (cleaves l-4 and l-6 bonds), (d) debranching enzyme (cleaves l-6 bonds), and (e) maltase that acts on maltose-liberating glucose. Pectins are degraded by pectinases, while xylans to produce xylose.

Microbes Required for Hydrolysis

To know the microbes required for hydrolysis of food waste. There are five types of food waste that were investigated in anaerobic digester to produce biogas (Chen et al. 2010). Waste used from soup-processing plant and kitchen waste of fish farm were under experimental analysis.

Anaerobic digestion mostly yield 60% methane and 40% CO_2, and it has been observed and reported that formation of methane is good by using thermophilic microbes such as *Syntrophaceticus schinkii* acetogenic microbes which release acetate and methane but requires hydrogenotrophic methanogens. The diversity of thermophiles analyzed in biogas was *Syntrophaceticus* (38.24%), *Gelria* (23.53%), *Thermogymnomonas*, etc. (Kushkevych et al. 2020) (Tables 6.1 and 6.2).

Table 6.1 Microbes and their reaction and product (Krzysztof Ziemiński 2012)

Reaction Type	Microorganism	Active Genera	Product
Fermentation	Hydrolytic bacteria	*Bacteroides, Lactobacillus, Propionibacterium, Sphingomonas, Sporobacterium, Megasphaera, Bifidobacterium*	Simple sugars, peptides, fatty acids
Acidogenesis	Syntropic bacteria	*Ruminococcus, Paenibacillus, Clostridium*	Volatile fatty acids
Acetogenesis	Acetogenic bacteria	*Desulfovibrio, Aminobacterium, Acidaminococcus*	CH_3COOH
Methanogenesis	Methanogens (Archaea)	*Methanosaeta, Methanolobus, Methanococcoides, Methanohalophilus, Methanosalsus, Methanohalobium, Halomethanococcus, Methanolacinia, Methanogenium, Methanoculleus*	CH_4

Table 6.2 C/N ratio in different wastes

Material	% N	C : N
Animal urine	15–20	1
Cotton stalks	1.7	30
Cow, buffalo manure	1.4–3	15–40
Oat straw, flax straw	1–1.2	50–60
Wheat and rice straw	0.3–0.5	120–150
Sawdust	0.1–0.25	200–500

For enzymatic hydrolysis by *Streptococcus* and *Enterobacter* are the main genera of anaerobic microbes that are responsible for enzymatic hydrolysis and degradations mainly for degradation of polysaccharide into monomer various mesophilic bacteria, under optimal conditions.

Hydrolytic product forms such as acetate, butyrate, propionate, and valerate (volatile FA products), along with isobutyrate some carbon dioxide, NH3, and hydrogen.

Under anaerobic condition, facultative anaerobes require some amount of oxygen and carbon to produce methane. The main substrates used for methane productions are acetate, carbon, and hydrogen.

One study was conducted by co-digestion of kitchen waste/food waste by mixing cow dung/manure during methanogenic production (Zamanzadeh et al. 2017).

In the mesophilic digester, the highest methane yield (480 mL/g VS) was observed when fed with food waste alone. While codigestion of manure yielded more methane (26%) which is sum of individual digestions of manure and food waste. The main volatile fatty acid (VFA) in the mesophilic systems was acetate, averaging 93 and 172 mg/L, respectively.

The main VFAs found in most of the digester were acetate and propionate. The prominent bacteria present and reported were *Firmicutes*, *Thermotogae*, and *Synergistetes* present in the digesters, however, the relative abundance of these phyla were different (see Tables 6.1 and 6.2).

Methanogenesis

Substrate for methane production mostly uses acetate, hydrogen, and carbon dioxide, but VFA like valerate, propionate, butyrate, and isobutyrate are the most relevant and mostly is used by the acetogenic bacteria to convert them into the acetate and hydrogen. As we know More will be the acetate in the media that is reduced finally and changes into the methane.

Methane production is also affected by C/N ratio and it must be more than >19.6 (See Table 6.2). Use of thermophilic microbes is more beneficial as compared to mesophilic microbes as temperature mostly rises beyond optimal level.

Therefore, Methanogens are of two types: (a) acetoclastic methanogens (basically produces methane from acetic acid) and (b) hydrogenotrophic methanogens (hydrogen is used to reduce carbon dioxide) (Fig. 6.5).

Methanogenesis uses CO_2 as a terminal electron acceptor to convert other substrates into methane. Thus, methanogens mostly grow and found in such habitats where electron acceptors are present such as O_2, NO^{3-}, Fe^{3+}, and SO_4^{2-} (Berghuis et al. 2019; Kato and Igarashi 2019).

Kitchen waste must be degraded into simple more simple products (H_2, formate CO_2, and acetate) which get converted into ethyl-containing compounds, substrates for most of the methanogens. Thus methane is produced.

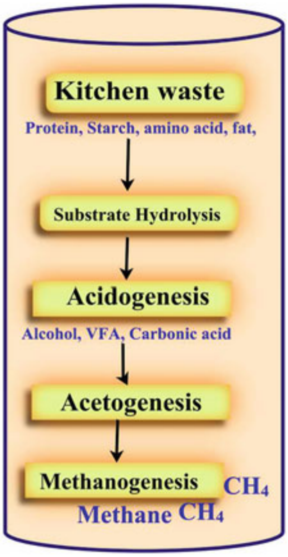

Fig. 6.5 Depicting flow chart in biogas production. To enrich high methane production >70%, it's essential to follow each step since all the steps are connected to each other. The product of one step is a substrate of other steps (Paritosh et al. 2017)

Classification of methanogens based on their substrate:

1. Hydrogenotrophic.
2. Aceticlastic.
3. Methylotrophic.

Hydrogenotrophic methanogens reduce CO_2 to CH_4. Hydrogenotrophic methanogens were found in deep marine sediments, termite hindguts, and human and animal gastrointestinal tracts, which altogether contribute a third of biologically generated methane emissions. There are about 1.5 billion cows on earth, and a cow releases around 200 L of methane per day. Thus, the total methane by is released about 300 billion liters per day or 72 Tg per year (Zhuang et al. 2018).

Aceticlastic methanogens convert acetate into CH_4 and CO_2. Hydrogenotrophic methanogens have the capacity to reduce H_2 to make conducive environment for acetate formation. Aceticlastic methanogens mostly found in anaerobic digesters play important role in methane production.

In the aceticlastic pathway, formation of acetyl-coenzyme leads to oxidation of acetate and CO_2 with ferredoxin as the electron acceptor.

In an anaerobic digester, a consortium of microorganisms exist which are involved in breakdown of organic waste into biogas. Hexose metabolism via the Embden-Meyerhof-Parnas pathway (EMP) utilized by most anaerobic bacteria which convert hexoses and pentoses to C2 and C3 intermediates (with reduced electron carriers (e.g., NADH) produces pyruvate with NADH. The pyruvate and NADH are converted into lactate, propionate, acetate, and ethanol.

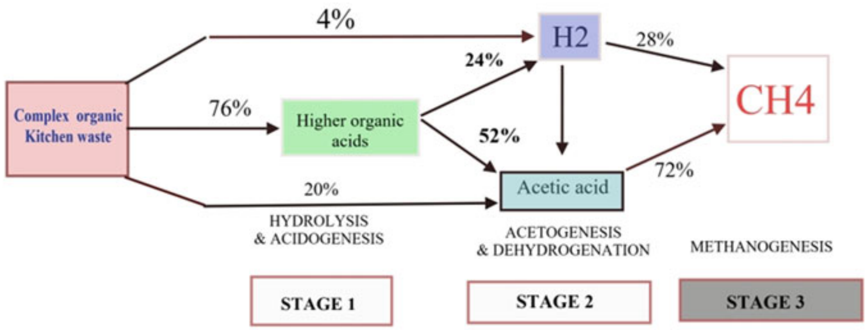

Fig. 6.6 Stages in kitchen waste conversion source http://www.fao.org/3/w7241e/w7241e0f.htm

In Fig. 6.6 decomposition of VFA has been mentioned which is degraded into acetate and hydrogen (VFA is a long-chain fatty acids, into acetate and H_2 by an *acetogen* and *Clostridium formicoaceticum*, respectively.

6.2.1.2 Pretreatment Methods for Food Waste

To increase the crystallinity of the food waste, they must be pretreated before actual hydrolysis. There are various types of pretreatment technology available, but their application is decided by the type of food waste. Mechanical, thermal, chemical, and biological types of pretreatment are existing and can be applied, thermal method (Ariunbaatar et al. 2014) at low temperatures (<120 °C) only. The result obtained was 647.5 ± 10.6 mL CH_4/gVS, thermal pretreatment at 80 °C for 1.5 h.

Chemical pretreatment include acidic pH, results in increased ammonia, and accumulation of volatile fatty acids.

The dairy waste, brewery waste, and livestock waste mostly are suitable for ammonia production (Meena et al. 2020).

Pretreatment of food waste using microwave (7.8 °C/min) resulted in biogas production with 24% higher COD solubilization (Paritosh et al. 2017).

Food waste valorization has been recommended in some case (Lytras et al. 2021); it has advantages that it yields almost pure methane and separates all other toxic components. Largest arising of food waste occurs from households; however, domestic food waste has been excluded from the scope of valorization to animal feed in REFRESH. This is due to the greater uncertainty regarding additional process controls required to mitigate risks and meet acceptable feed safety and quality standards.

Some researcher worked on optimization of H_2 production via methane route from waste oil (Rafieenia et al. 2019). Nonbiodegradable, recalcitrant organic food waste was pretreated with fungal mash with the prolonged hydrolysis, for the methane production (Ma et al. 2018). High-voltage pulse discharge (HVPD) pretreatment is the new technology to enhance the production of methane, and successfully it was able to enhance the production up to 160% (Zou et al. 2016).

6.2.2 Biogas Digester

Biogas digester is an airtight anaerobic digestion used for digestion of various kitchen wastes and other waste. Biogas digesters may be classified into (1) passive systems (low control of the anaerobic digestion process), (2) low-rate systems, and (3) high-rate systems (methane-forming bacteria is trapped in the digester to enhance the biogas production efficiency) (Alkhalidi et al. 2019).

Small biogas systems (portable bio-digester) often used with small volumetric capacity ranging from 1 to 10 m^3) biogas per day where feedstocks is kitchen waste producing biogas and bio-slurry (can be converted as organic fertilizers). As compared to small-scale biogas plants and industrial-scale plants, it has larger capacity of 1000–5000 m^3 biogas/day. Such large-capacity biogas is largely utilized in the municipal or industrial organic wastes to generate biogas.

Biogas used as cooking fuel known as LPG is produced mostly by PP mode so that biogas produced at large scale may be utilized properly.

Feedstock type generally varies in India, so digester type has to change every time (He et al. 2021; Song et al. 2014a, b).

6.2.3 Barriers in the Biogas Production (Mittal et al. 2018)

The following are barriers in commercial productions of biogas:

1. High cost of installations.
2. Lack of financial support.
3. There are variations in feedstock supply which may affect supply chains.

Plant profitability depends on various factors if really someone wants to do it in the long run in India.

6.3 Conclusion

In conclusion biogas has numerous advantages: (1) it can be elevated, (2) it can be bottled and easy to transport, and (3) biomethane is also used in CNG vehicles without engine modification (Vijay et al. 2015).

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