A Review of Sustainable Biofuels from Waste Materials: Development and Challenges

Submitted by

Antara Washima
15226005
Tarannum Raka
16226004
Mariha Fazrin
16326005

A thesis submitted to the Department of Mathematics and Natural Sciences in

partial fulfillment of the requirements for the degree of

Bachelor of Science in Microbiology

Department of Mathematics and Natural Sciences

BRAC University

December, 2021

Declaration

It is hereby declared that

1. The thesis submitted is my/our own original work while completing a degree at Brac University.
2. The thesis does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The thesis does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. We have acknowledged all main sources of help.

Student's Full Name & Signature:

Antara Washima	**Tarannum Raka**
15226005	16226004

Mariha Fazrin

16326005

Approval

The thesis/project titled "A Review of Sustainable Biofuels from Waste Materials: Development and Challenges." submitted by Antara Washima (15226005) of Fall 2015, Tarannum Raka (16226004) of Fall 2016 and Mariha Fazrin (16326005) has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Bachelor of Science in Microbiology on 01 January 2022 .

Examining Committee:

Supervisor: ________________________________

(Member) Md. Hasanuzzaman

Lecturer, Mathematics and Natural Sciences

BRAC University

Program Coordinator:

(Member) ________________________________

Dr. Mahbubul Hasan Siddiqee

Assistant Professor, Mathematics and Natural Sciences

BRAC University

Departmental Head: (Chair)

____

A.F.M Yusuf Haider, PhD

Professor and Chairperson, Mathematics and Natural Sciences

BRAC University

Abstract

Biofuel is a fuel derived from living things or their wastes (biomass) that is considered as the most potential and alternative energy source. It includes bioethanol biodiesel, biohydrogen, biogas, etc. Due to its environmental merits, biofuels production is increasing all over the world to deal with the energy crisis. Usage of biofuel has already shown promising results to deal with reducing greenhouse gases, non-renewable and unsustainable resources. Though biofuels may concern food security, developing countries are trying to project numerous targets for producing biofuels using various waste materials such as food waste, sewage sludge, food industry waste, etc. The purpose of our review article is to gather data on the production of biofuels from different waste raw materials reported globally and further analyze the possibility as well as the potentiality of those biofuels in Bangladesh.

Keywords: biofuels; waste materials; renewable energy; development

Acknowledgement

Throughout the writing of this review literature, we have received a great deal of support and assistance.

We would first like to thank our supervisor, Md. Hasanuzzaman Lecturer, Microbiology Program Department of Mathematics & Natural Sciences, whose expertise was invaluable in formulating the research questions and methodology. He guided us through each stage of the process and the insightful feedback pushed us to sharpen our thinking and brought our work to a higher level.

In addition, we would like to thank all of our respected faculty. We had a great learning experience under their shelter where we were taught with great passion and skill over the past four years. Finally, we would like to extend our gratitude to Dr. Mahboob Hossain, Professor, Department of Mathematics and Natural Sciences, and course coordinator, Dr. Mahbubul Hasan Siddiqee, Assistant Professor and Program Coordinator (Microbiology), Department of Mathematics and Natural Sciences.

List of Tables

List of Acronyms

ABE	Acetone-Butanol-Ethanol
ASTM	American Society of Testing and Materials
BW	Brewery Wastewater
CBP	Consolidated Bioprocessing
CD	Cow Dung
CMcase	Carboxymethyl Cellulase
CM	Cow Manure
CSTR	Continuous Stirred Tank Reactor
COD	Chemical Oxygen Demand
DBR	Defatted Rice Bran
EM	Effective Microorganism
FAO	The Food and Agriculture Organization
FW	Food Waste
FAME	Fatty Acid Methyl Ester
FTIR	Fourier Transform Infrared Spectroscopy
GD	Goat Dung
HPR	Hydrogen Production Rate
HRT	Hydraulic Retention Time
HY-IM	Hybrid Immobilized

KW	Kitchen Waste
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
MSW	Municipal Solid Waste
NMMA	National Marine Manufacturers Association
OLR	Organic Loading Rate
OMSW	The Organic Matters Fraction of Municipal Solid Waste
OP	Orange Peel
pH	Potential of Hydrogen
Ppm	Part per million
PPW	Potato Peel Waste
RPM	Revolutions Per Minute
SWS	Sewage Sludge
TS	Total Solid
UCO	Used Cooking Oil
VS	Volatile Solid
VHPR	Volumetric Hydrogen Production Rate
Wt%	Weight-Percent

Chapter 1

Introduction

Renewable energy, biofuels are fuels that are derived from biomass including waste feedstocks, and an excellent alternative to fossil fuels due to the reduction of CO_2 emissions [1]. Biofuels are primarily produced using modern procedures rather than geological processes, such as plant and animal matter exposed to severe heat and pressure within the earth's crust over thousands of years in the production of fossil fuels [2]. The developing world is confronted with huge challenges during the last few decades due to the excessive demand and high expenses of fossil fuels. At the same time, excessive usage of fossil fuels exerts a lot of pollutants, emits harmful gases like CO_2 which contribute to global warming. Therefore, the world's merchandise has necessitated the improvement of the opportunity of biofuel energy since the demand for fossil fuel has become very worrisome and challenging, and also it is going to be a major issue within the years to come [3]. Though fossil fuels are widely used and cheaper, scientists are opting for fuels or energy sources that have less pollution, clean and renewable energy which can be a better alternative to fossil fuel [4].

There are many more disadvantages of fossil fuels such as non-renewable energy, environmental pollution, greenhouse effect, and uneven distribution among different nations, etc. Negative consequences of fossil fuels have driven us to discover the opportunity of renewable energy for example biogas, bioethanol, biodiesel, biomethane, etc. The economically developing countries are trying to lessen their dependence on fossil fuels for the global crisis as well as environmental issues related to nonrenewable fuels. Bioenergy and clean-burning biofuels (biogas, bioethanol, biodiesel) ought to lower the dependence on nonrenewable energy/fuel sources by serving as a great alternative to fossil fuels [5], [6].

As raw materials of biofuel production, crops, and consumable cereals are well known as promising sources of potential sustainable energy. However, the usage of these raw materials is associated with the possible increase in food prices which will worsen the global hunger crisis [7].

According to the global estimates, almost 700000000 people around the world are suffering from a lack of food. Food protection is a fundamental human need and it is maintained when everybody at some point in time has physical, social, and financial opportunity to get sufficient quantities of nutritious meals, which meets their food demand and lets them lead an active and healthful way of life [8]. In 2008, FAO (Food and Agriculture Organization) reported that the increasing demand for agricultural resources as raw substances for biofuel production had increased the cost of food in both city and rural areas. Competition among global food systems and crops for biofuel production evokes such effects because of the growing demand for sustainable and clean energy supply on an international scale [7]–[9].

Considering these devastating outcomes of using food materials as the source of biofuel production, scientists around the globe are experimenting with the feasibility of using different waste materials for the production of biofuel [5].

The primary goal of this review study is to look into the possibilities of producing biofuels from waste materials that may be used as alternative fuels specifically in Bangladesh. We have gathered published articles around the globe that have demonstrated the production of biofuels from different types of waste materials. Finally, we aim to look for suitable raw materials for the production of biofuels in Bangladesh, considering the availability of waste materials and possible challenges which raw materials may be used. In this literature review article, we sought to answer the following questions.

- What kinds of biofuels have been made out of waste?

- What are some of the most common waste feedstocks for biofuel production?
- How many biofuels can be produced from different waste materials?
- Which biofuel has the most potential in the perspective of Bangladesh?

Chapter 2

Research Methodology

2.1 Search strategy

In this study, the collection of data was divided into 2 main steps. First of all, databases like Google Scholar and Pubmed were searched mainly focusing on the following interests:

(a) biofuel production (b) biofuel and food (c) biofuel and waste materials

The search result initially presented 17,319 articles in total.

In the second step, we narrowed down the search strategy focusing on the production of biofuel from waste materials, resulting in 963 interrelated articles. Three readers independently read the title and abstract of selected 85 articles that match our interests.

2.2 Inclusion criteria

Original literature that described biofuel production from waste, food waste, biofuel from sewage waste, agricultural, commercial, domestic, or industrial wastes were included.

Moreover, literature that mentioned the prospect of biofuels in Bangladesh and the efficiency of biofuel production was also included.

2.3 Exclusion criteria

Literature that only described the technologies for biofuel production, the advantages and disadvantages of biofuels and biofuels from crops were excluded. In addition, literature abstracts that are not relevant were also excluded.

Chapter 3

Results

After analyzing the data from 85 selected articles, we found bio-ethanol, biogas, bio-diesel, biomethane, biobutanol, and bio-hydrogen the fuels produced from different waste materials across different parts of the world.

3.1 Bioethanol production

Industrial algae waste

One of the most promising bio-feedstocks for sustainable fuel production is macroalgae [10]. V Alfonsín, R Maceiras, et al (2016) showed in their article that by using microalgae residue of the industrial waste of agar, bioethanol of the third generation [11] can be produced . In their experiment, *Eucheuma denticulatum* (Spinosum), a species of red algae, was used as the raw material due to its higher amount of carbohydrate content. As the source contains 35% of water, it was dried for 24 hours at room temperature. A pretreatment procedure was undertaken to decrease the cellulose content of the *Eucheuma denticulatum* (Spinosum). After the pretreatment process, H_2SO_4 of different acid concentrations, which was mixed with 10g of microalgae used in acid hydrolysis followed by fermentation with 0.5 g of *Saccharomyces cerevisiae* at 30℃ (optimum temperature) for 24 hours. After 70 minutes, in a 9% acid concentration with an acid/dried algae ratio of 7:1, the highest bioethanol yield was seen. Finally, by the distillation process, the fuel was separated from the crude mixture. Using acid hydrolysis and yeast fermentation, macroalgae waste could yield 0.1 g bioethanol/g waste.

Potato Waste Material

Potato waste is one of the most potential feedstocks for bioethanol production, which can be used in several forms; potato peel waste, potato processing waste, and sweet potato residue (SPR).

1. In Kharagpur, India, Anjani Devi Chintagunta et al (2016) experimented on converting potato peel and mash from the potato processing waste to bioethanol. The obtained waste was inoculated with the co-culture of *Aspergillus niger* and *Saccharomyces cerevisiae*. The study aimed to compare the production of bioethanol from potato peel and mash wastes using a co-culture of *Aspergillus niger* [12] and *Saccharomyces cerevisiae* [13] at different incubation times (24–120 hours) instead of enzymes. Bioethanol production was 6.18 percent (v/v) and 9.30 percent (v/v) from enzymatic saccharification and solid-state fermentation of potato peel and mash inoculated with co-culture, respectively. In 72 hours of incubation time at 37℃,

the maximum ethanol production of 9.30 percent (v/v) was obtained from the second treatment of mash.

2. Abdullah-Al-Mahin et al (2017) in Bangladesh conducted an experiment in Jahangirnagar University where the team isolated 28 amylolytic microorganisms that are capable to produce bioethanol from potato peel waste by the process called as Consolidated Bioprocessing (CBP), which combines liquefaction, saccharification, and fermentation in a single phase, is a potential strategy for biofuel production that addresses this difficulty by lowering both enzyme and operating costs [14]. The objective was to screen out the best microorganism which can be used as a fermenter for the highest production of bioethanol. The selected amylolytic isolates were grown in an enzyme production medium at 30 °C, pH 6.8–7.0, and 150 rpm for 48 hours in secondary screening. Based on greater production-amylase, the authors choose 5 isolates. After molecular identification, *Wickerhamia sp.* were found the most potential as it produced 30.4 g/L of ethanol at day 4, the highest among all the isolates which were identified. When potato peel waste was added with 25 g/L malt extract, 2.5 g/L KH_2PO_4, and 0 g/L tryptone, the maximum ethanol production was observed. The experiment concluded that per liter of potato peel waste can generate 21.3g of ethanol using *Wickerhamia sp.* as a medium optimizer.

- Being the largest producer of sweet potatoes in the world, more than 2 million tons of sweet potato residue (SPR) is generated every year in China [15]. SPR consists of different polysaccharides which makes it a potential feedstock for bioethanol through the process of enzymatic hydrolysis using *S. cerevisiae*. Fangzhong Wang, Yi Jiang (2016) mentioned in the article that bioethanol production through acid-catalyzed hydrolysis methods of releasing sugar from potato wastes cannot be produced industrially, rather he prefers the enzymatic hydrolysis method. When highly concentrated SPR was treated with cellulose, 153.46 g/L glucose was produced, followed by fermentation using *Saccharomyces cerevisiae,* 73.37 g/L ethanol was produced. But when the same raw material was treated with the mixture of cellulase and pectinase, followed by fermentation using *Saccharomyces cerevisiae.* 79.00 g/L ethanol was produced. Following the above procedure, 1 kilogram of dry sweet potato residue can be converted into 209.62 and 225.71 g of ethanol, respectively.

Cornstalk:

A research team of Islamic Azad University of Savar, [16] Bangladesh carried out an experiment using different concentrations of diluted H_2SO_4 (0.5, 1.0, 1.5, 2.0, and 2.5%) in the pretreatment stage at 100 °C for 1 hour reaction time to convert cornstalk into bioethanol . The team showed that if concentration was increased more than 2%, the ethanol production was decreasing gradually. At 48 hours of fermentation, this pretreatment cornstalk yields 26.17 g/L ethanol when fermented with Saccharomyces cerevisiae. By increasing the inoculum to 5%, bioethanol production can be enhanced to 32.53 g/L.

Another research team [17] from Savar, Bangladesh showed alkali pretreatment at 100°C can also be used to convert cornstalk into bioethanol. After collecting the cornstalk sample, the contents of cellulose, hemicellulose, and lignin were determined by a two step process [18]. Various concentrations of NaOH were applied to different sets of cornstalks, ranging from 0.5 to 2.5%. When the concentration was increased from 0.5 to 2.0 %, the bioethanol yield increased from 20.61 to 24.63 g/L, indicating a positive relationship between the two. The article showed that the yield of bioethanol production decreases by more than 2% when the concentrations rise by more than 2%. Effect of organism loading was also observed in the experiment with a sample obtained from 2.0% NaOH-pretreated cornstalk. At 1, 2, 3, 4, and 5 % organism (*Saccharomyces cerevisiae***)** loading, yields of 31.11, 32.22, 35.93, 39.63, and 43.80 g/L, respectively, were achieved. The result showed that increasing 1 to 5% resulted in a 1.41-fold increase in bioethanol production.

Fecal Waste

As 50–84% of the carbohydrate in feces may be converted to simple sugars, feces can be used as a bioethanol feedstock [19]. The excrement of fresh calves, goats, chickens, and sludge was employed as a sample source in an experiment done in Oman [20]. Two forms of carboxymethyl cellulose (CMCase) to compare the results [21]. Firstly, CMCase enzyme is produced by feeding the cow manure to *Bacillus subtilis.* The inoculum of the strain was prepared by growing on LB broth at 37 °C for 24 hour followed by re-suspension in Tris-HCl buffer (pH 8.0) and was added directly to the fecal biomass. The incubation was carried out at 37 °C for 72 hour. Secondly, saccharification was made by mixing 7 g of homogenized fecal material with the extracted CMCase. At 37°C, the mixture was incubated for 10 days, followed by fermentation using the acquired reducing sugars. The amount of bioethanol production was tested using gas chromatography-mass spectrometry. In the case of commercial CMCase, the amount of bioethanol generated was similar or higher. The bioethanol yielded by chicken feces treated with commercial CMCase was the highest, at 1.6 g/l. The amount of ethanol produced by fermented chicken feces treated with biological CMCase was reduced by 38%. Fermentation of other feces treated with commercial and biological CMCase produced bioethanol with a concentration of less than 1 g/l.

Rice Bran

According to FAO, Brazil which is the largest producer of rice, The article "Feasibility of bioethanol production from rice bran" published in Brazil by Francieli Begnini Siepmann et al (2020) described that using *Saccharomyces cerevisiae* bioethanol can be produced. In that study, defatted rice bran (DBR) is used as the source of bioethanol. The reason for using defatted rice bran is due to a lower rate of fat and a higher rate of protein and carbohydrate. The result was published after changing inoculum concentration, temperature, pH, and adding enzymes several times. Bioethanol concentration determined in ultra-high liquid chromatography. It was observed that the addition of *Saccharomyces cerevisiae* in each step has a positive effect on bioethanol production. The hydrolysis of DBR proteins by treatment with protease before amylolytic hydrolysis and alcoholic fermentation by *S.cerevisiae* allowed an increase in final bioethanol production. The addition of protease also positively affects bioethanol production. Finally, the article concluded that 31.5 °C and 70 g L^{-1} inoculum concentration is the optimum condition for 40.70 g L^{-1} bioethanol production.

Another study conducted in Japan by Masanori Watanabe et al (2016) showed that bioethanol can be produced from rice washing drainage and rice bran. The demand for "rinse-free rice," is increasing day by day in Japan [22]. In this rice, bran is eliminated which is used for bioethanol production. Anaerobic batch fermentation was used in the experiment. Rice washing drainage (30 ml), lactic acid as a bactericidal agent, and various weights of rice bran were mixed and then 1.0 ml of pre-culture yeast broth was inoculated. Before pre-culture inoculation, the pH of the culture mixture was adjusted to 4.5. Inoculating *S. cerevisiae* into a yeast pre-culture, the pre-culture was cultured at 30 °C for 3 days without shaking. Centrifugation at 5000 g for 10 minutes at 4 °C was used to collect cells, which were then washed with sterile water [23]. To examine ethanol production, rice bran was added to the rice washing drainage. Using 3–5 g rice bran in 30 ml rice washing drainage, 0.8–1.2% ethanol was produced. To investigate more, the authors experimented by adding protease and lipase in different concentrations. The addition of both enzymes boosted ethanol output. Adding over 30 mg 100 ml of protease M and 3 mg 100 ml[1] of lipase resulted in the greatest ethanol concentration (3.0–3.4% ethanol).

Table 1: Overview of bioethanol production

Feedstock	**Organism/ Enzyme/Innoculam**	**Process/methodology**	**Bioethanol yield**	**Location**	**Author**
Industrial Algae Waste	*Eucheuma denticulatum* *S.cerevisiae*	Pretreatment Hydrolysis Distillation	0.1g bioethanol/g algae waste	Spain	[24]
Potato peel and mash	*Aspergillus niger* *Saccharomyces cerevisiae*	Saccharification Fermentation	Potato peel: 6.18% (v/v) Potato mash:9.30% (v/v)	India	[25]
Potato Peel Waste	*Wickerhamia sp*	Consolidated Bioprocessing	40 g/L(on dry basis)	Bangladesh	[26], [27]

			can generate 21.7g/L		
Sweet Potato Residue	*S.cerevisiae*	Enzymatic Hydrolysis	1 kilogram can be converted into 209.62g	China	[28]
Cornstalk	*Saccharomyces cerevisiae*	Pretreatment concentrations of NaOH	43.80 g/L	Bangladesh	[17]
Cornstalk	*Saccharomyces cerevisiae*	Pretreatment concentrations of diluted H_2SO_4 Enzymatic hydrolysis and fermentation Distillation	32.53 g/L	Bangladesh	[16]
Fecal Waste	CMCase enzyme *Bacillus subtilis*	Saccharification Fermentation	Chicken feces treated with commercial CMCase was	Oman	[20]

		Gas chromatography-mass spectrometry	the highest, at 1.6 g/l.		
Rice Bran	*Saccharomyces cerevisiae*	Enzymatic hydrolysis Alcoholic fermentation Ultra High Liquid Chromatography	40.70 g L-1	Brazil	[29]
Rice washing drainage and rice bran.	*Saccharomyces cerevisiae* Protease, Lipase	Anaerobic batch fermentation	3.0–3.4 %	Japan	[30]

3.2 Biogas and biomethane production

Kitchen waste and Water Hyacinth

A comparative study conducted in Bangladesh by Farzana Tasnim et al (2017) used cow manure (CM), sewage sludge, kitchen waste (KW) & water hyacinth as raw materials for biogas production. Using digesters, a basic lab-scale experiment was conducted. Experiments were carried out in a mesophilic environment (37 ℃) using 1.5 wt% NaOH and the pH was maintained at 7. Into a 1 liter batch reactor, CM with KW along with water and CM with Water Hyacinth and Sewage Sludge were fed. Sewage Sludge was added with Water Hyacinth instead of normal water. On both tests, the loading ratio of each batch was kept constant at 1:1 with a loading rate of 100 gm/L. Kitchen waste and cow manure showed encouraging improvements until the 120th hour. After 254 hours, the total output of a 1 L batch of Water Hyacinth, Cow Manure, and Sewage Sludge was 812 ml, with 65 percent methane, 14 percent CO, and 21 percent other gases, whereas kitchen waste & cow manure produced 335 ml, with 60 percent methane, 18 percent CO, and 22 percent other gases. The results showed that mixing sewage sludge with commonly used cow manure can speed up the reaction.

Waste fibre and fibre sludge

Katariina Kemppainen et al (2012) showed that biogas and bioethanol can be produced from waste fiber fractionated from solid recovered fuel, and pulp and paper mill fiber sludge combinedly. This fiber is an excellent feedstock as these are available all year long [31]. The advantage of using the waste fibers as raw material is they can be liquefied and hydrolyzed by enzymes faster without heat or acidic pretreatment, although they contain certain complex mannose- and galactose-containing polysaccharides that require extra enzymes for complete hydrolysis to monosaccharides. After 6 hours of continuous liquefaction and 21 hours of fermentation, the average biogas production rate for fermentation residue from the waste fiber was 655 dm^3 kg^1 and for fiber, sludge was 400 dm^3 kg^1 with a methane content of 69-75 %. According to other findings, if the period of fermentation is increased, a hydrolysis yield of 75% can be achieved with this process. 1000 kilograms of dry feedstock provided 170 kg ethanol, 310 kg biogas, 360 kg waste sludge, and 170 kg CO_2.

Silkworm waste

Silk has been used to create valuable and beautiful fabrics for centuries. The mulberry silkworm (*Bombyx mori L.*) is the most widely domesticated insect that has been commercially used [32]. Insect breeding is directly related to the problem of waste, such as excreta and leaf debris. Small-scale farmers can produce 250–300 kg of silkworm waste or 2500 kg of farm manure [33]. Małgorzata Łochyńska et al (2018) explained that this silkworm waste is a potential feedstock for the production of biomethane and biogas through an anaerobic fermentation process under mesophilic conditions. The study showed that methane production was lower than CO_2 and other gases during the first days of the fermentation process, which is called methanogenesis. However, in the beginning, on the fifth day, and continuing until the completion of the experiment, CH_4 production predominated. The hydrolytic bacteria quickly degraded the simple organic molecules of the substrates in the early days of the experiment. As a result, on the second day of waste fermentation, there was a significant surge in biogas generation. Following that, biogas and methane output remained relatively high until the eleventh day. Under the mesophilic condition, silkworm excreta generates 167.32 m^3 / mg TS of methane and 331.97 m^3 /mg TS of biogas, whereas silkworm breeding waste produces 256.59 m^3 /mg TS of methane and 489.24m^3/mg TS of biogas.

Goat and chicken manure:

Hanafiah et al (2017) conducted a study in Malaysia to investigate the amount of biogas produced from goat dung(GD) and chicken dung(CD) using industrial inoculum and traditional bokashi which is produced using effective microorganisms (EM). Firstly, organic dried mass was fixed at 4 g/L. As a catalyst, each substrate was combined with 500 mL industrial inoculum. Lastly, it was placed inside the biomethane potential machine. The temperature was kept at a mesophilic (37°C) level using a water bath machine, and readings were made every 20 days. Using industrial inoculum biogas and methane production was higher than the traditional bokashi. From 3.6g goat dung and cow dung, 2141 mL and 1118ml biogas is produced respectively. Methane gas is also produced using industrial inoculum whereas traditional bokashi is not capable of producing it.

Fecal waste

Mohamed A. Gomaa et al (2017) discussed several techniques, such as gasification, pyrolysis, and anaerobic digestion, which can be used to produce methane-containing biogas from feces. In an anaerobic chamber, 5 grams of fresh fecal waste biomass were added to 165 ml pre-autoclaved serum glass vials. For 49 days, the vials were incubated in the dark at 37 °C in a shaking incubator with an 80 rpm mixing speed.

The gas chromatography technique was used to measure the amount of methane produced in the headspace of each vial. As the most productive methanogenic colony was found in cow feces, it was clear that the highest amount of biomethane was produced by cow excrement. In the research, the maximum biomethane yield was 433 ml CH_4/g of cow excrement. Biomethane from chicken and goat feces was also produced but with low yields.

Table 2: Overview of biogas and biomethane production

Feedstock	**Organism / Enzyme/Innoculam**	**Process/methodology**	**Biomethane/Biogas yield**	**Location**	**Author**
Kitchen waste and Water Hyacinth		Water displacement method Liquefaction Hydrolysis Fermentation	Biogas -from sewage sludge: 812 ml -from kitchen waste & cow manure: 335 ml	Bangladesh	[16]

Fiber waste	Red star Yeast Commercial econase b-glucosidase	FibreEtOH process high performance liquid chromatography (HPLC)	Biogas: 655 dm^3 kg^1	Finland	[34]
Silkworm waste	*Bombyx mori L*	anaerobic fermentation process	167.32 m^3 / mg TS of methane 331.97 m^3 /mg TS of biogas	Poland	[35]
Goat and chicken Manure		Anaerobic Digestion	Biogas from Goat dung: 2141ml Biogas from cow dung: 1885.7 ml	Malaysia	[36]

Fecal waste		Anaerobic Digestion	433 ml CH_4/g	Oman	[20]

3.3 Biodiesel production

Scum oil

Ma et al (2016) developed an experimental process that can convert the scum oil into low sulfur content biodiesel. Scum oil is a floating by- product which is rich in waste oil, vegetable oil, grease, soap, and other impurities, [37] could be an alternative feedstock for biodiesel production. However, one of the major drawbacks in scum based biodiesel is high sulfur content ranging from 600 to 1000 ppm (parts per million) [38], [39]. To maintain the sulfur content in biodiesel, American Society for Testing and Materials (ASTM) D6751(2015) specify the sulfur content in biodiesel to be less than 15 ppm. A study by Bi et al (2015) found that the scum based biodiesel contains 33.6 ppm sulfur which is double the sulfur limit allowed by the ASTM specification. Therefore, to lower the sulfur content in scum based biodiesel a new distillation method integrating the traditional reflux distillation and adsorptive desulfurization was developed to remove the sulfur impurities [37] proposed six general steps that includes filtration, acid washing, heptanes washing, glycerolysis, base catalyzed transesterification, and fractional distillation. To reduce the sulfur content and meet the ASTM specification three oil rendering process routes (R I, R II, R III) are illustrated and compared after acid washing. The comparison showed that the sulfur content (13.3 ppm) in R lll of the final biodiesel passed the ASTM specification (<15 ppm) [39] and the total biodiesel yield 70% (The total biodiesel yield was calculated based on the dry weight of the filtered scum oil before acid washing).

Municipal waste in Makkah

According to Shahzad et al (2017) Kingdom of Saudi Arabia (KSA) is one of the largest tourist places due to the presence of two holiest places for Muslims and millions of Muslims visit these places to perform pilgrimage. Thereby, thousand tons of Municipal solid waste (MSW) is generated every year and the total estimated amount of MSW was 970 thousand tons during 2014 which includes 50.6% food waste (meat, rice, fat bones, used cooking oil) [40]. In the presence of acid or base catalyst, the transesterification process was applied in two main stream waste used cooking oil (UCO) and slaughtering waste to obtain biodiesel and glycerol was produced as a byproduct [41].

In 2014, the calculated amount of fat/oil fraction was 64 thousand tons and around 62.53 thousand tons of biodiesel could have been produced from all these fat content of food waste generated in Makkah city using 98% production yield.

Fecal waste

Gomaa et al (2017) showed the potential of fecal waste in terms of producing biodiesel and other biofuels. Every year millions kilograms of fecal waste are being produced by dairy cattle, goats, chickens and humans, estimated at 2372 kg per cattle per year [42]. Lipid content in fecal waste which is referred to as fatty acid methyl ester (FAME) (7 and 36%) can be utilized for biodiesel production (fatty acid methyl esters) through lipid extraction and transesterification process [43], [44]. To produce biodiesel, dried and homogenized fecal biomass was used for simultaneous lipid extraction and transesterification [45].

It's been calculated that 40-119 mg Fatty Acid Methyl Ester (FAME) can be gained from 1 gram of dried fecal biomass.

Waste cooking oil

Mohamed et al (2019) developed an environmentally friendly catalyst (RS-SO_3H) prepared by fast sulfonation of fast pyrolysis rice straw which will have a positive effect on the production of biodiesel from waste cooking oil (WCO). The activity of the catalyst was examined on the transesterification of the oil process in terms of producing biodiesel. The transesterification of oil is the only operable method of biodiesel production [46]. However, the physico-chemical characteristics of the obtained biodiesel are near to the industrial diesel and the American Society for Testing and Materials (ASTM) standard biodiesel D6751.

The optimum conditions of the operating parameters are temperature 70°C, reaction time 6 h (hour),10 wt% (weight-percent) catalyst and methanol: oil molar ratio (20:1) has the maximum biodiesel yield 92.5%.

WCO in China

According to Zhao et al (2021) approximately five million tons of waste cooking oil (WCO) is generated in China's large and medium cities and creates serious environmental and human health risk [47]. Converting WCO to biodiesel is a multiple advantage solution that minimizes waste and environmental pollution, strengthening energy security and safeguarding food safety. However, WCO based biodiesel requires a pretreatment process and involves complex collections, compared to crude oil based conventional diesel. In this study two approaches, life cycle assessment (LCA) and life cycle cost (LCC) have been employed to evaluate the environmental impact and economic feasibility of WCO based biodiesel in China. The endpoint analysis showed environmental impact of WCO based biodiesel include the depletion of resources and damage to human health. Additionally, the midpoint analysis result showed the impact of biodiesel are higher than those of conventional diesel including climate change, fossil fuel depletion, particulate matter formation and water depletion. The majority of the environmental impacts are due to the transesterification process except water depletion which is caused by transportation of the biodiesel fuel. However, compared to WCO based biodiesel the total cost of fossil diesel is 4921 RMB/t which is 35% lower than WCO based biodiesel [48]. Therefore, this unfavorable economic performance of WCO based biodiesel prevents its commercial scale utilization in China.

According to Bhatia et al (2020) biodiesel is getting more popular due to its production from renewable sources [3], [49], [50]. Waste cooking oil (WCO) is found to be an economically viable way to produce biodiesel [51]. According to Loizides et al (2019) nearly 16.5 million tons of WCO produced per year and its conversion into biodiesel could facilitate its disposal drawback. Biodiesel consists of fatty acid alkyl ester derived from transesterification of oil with alcohol [52]. To make the transesterification method more effective and economic, usage of heterogeneous catalysts (biochar) for biodiesel production has gained new interest [53]. Cork made from Quercus suber plant that is used as a stopper in wine bottles was used as raw material to formulate the catalyst. Additionally, cork is simply a waste matter after wine consumption and is a cheap and easily available material for heterogeneous catalyst preparation using pyrolysis process. To activate biochar, first of all the biochar was grounded then concentrated H_2SO_4 was added and mixed by incubating the mixture. Furthermore, the solid particle was incubated at 100°C overnight. The activated biochar was named according to their pyrolysis temperature such as ACB400, ACB600 and ACB800 and used as a catalyst to perform transesterification reaction to produce biodiesel [54].

The experiment result showed that maximum fatty acid methyl esters (FAMEs) conversion 98% where the heterogeneous catalyst synthesized at 600°C, alcohol: oil ratio (25:1), catalyst loading (1.5 wt %) and temperature at 65°C.

3.4 Biohydrogen production

Different industrial wastewater

Preethi et al (2019) reviewed articles of biohydrogen production from different industrial wastewater as it is considered as a well substitute to the fossil fuel due to its high energy content and non-polluting features. In the acidogenic phase of an anaerobic digestion the hydrogen is produced as a by-product and the yield is very low therefore an alternative method of dark fermentation has been established to enhance the production. Dark fermentation is an indirect technology that uses various genres of bacteria and uses carbohydrates & other nutrients to produce hydrogen and other organic matter through acidogenic pathways (Handbook of Microalgae-Based Processes and Products, 2020). According to a study Yun et al (2017) biological hydrogen production processes are more environment friendly than physico-chemical ones and among all the biological processes dark fermentation is found to be the most effective one. However, dark fermentation is still not the suitable method in the production of hydrogen on a commercial scale. The improvement of dark fermentative hydrogen production is pretreatment of substrate or inoculums by physical, chemical, mechanical and biological pretreatment in order to suppress the activity of methanogens and increase the activity of hydrogen producing bacteria. Although the operating parameters (pH, temperature, volatile fatty acid, bioreactor configuration etc.) have great influence on biohydrogen productivity.

Bacteria such as *Clostridium sp* and *Enterobacter sp* were used for dark fermentation of carbohydrates [55]. The physical parameters like pH, temperature, substrate, nutrition feed etc should be maintained for efficient biohydrogen production. In a study by Ginkel et al (2005), the production of hydrogen increased by 60-70% at pH 5.5-8. In a study by Ozmihci and Kangi et al (2011), *Clostridium butyricum* was used for continuous production of biohydrogen in dark fermentation. In addition, the parameters pH and temperature plays a crucial and major role which affect the efficiency of hydrogen production. In mesophiles (30-49°C) *Clostridium* and *Enterobacter sp* showed higher yield whereas in thermophiles (50-64°C) *Thermobacterium sp* showed higher yield.

Table 3: Hydrogen yield in different types of industrial wastewater at different operating conditions

Industrial wastewater types	**Inoculum**	**pH**	**Temperature (°C)**	**Substrate concentration (gCOD/l)**	**Hydrogen yield**	**Authors**
Cassava wastewater	Sludge from swine wastewater treatment	5.00+	28+-2	4	1.91mol H_2/mol glucose	[56]
Pulp and paper mill effluent	Anaerobic sludge	5	37	5	55.4mL/g-COD	[57]
Paper mill wastewater	Paper mill sludge	5	35	2.217+-0.169	1.22+-0.11 mmol/g COD initial	[58]
Paper mill wastewater	Mixed culture	5	35	2.217+-0.169	5.29+- 0.16 mmol/g COD initial	[58]
Rubber industry	Pretreated mixed	7	37	0.45	55.6ml/g substrate	[59]

effluent	microflora					
Beverage wastewater	Mixed culture	5.5	37	20	3.76 mol H_2/mol-sucrose	[60]
Dairy industry wastewater	Biomass from fermentation	3.7-4.3	24-30	8.12-15.44	2.56 mol H_2/mol carbohydrate	[61]
Molasses wastewater	Pure culture *Enterobacteraerogenes*		30	40	6.02 mm/g sugar	[49], [53], [60], [62]
Brewery wastewater	Anaerobic granulated mixed consortium	5.5	37	2	1.5 mol H_2/mol fructose	[63]

Food waste

Yun et al (2017) reviewed the production of biohydrogen from food waste (FW) through dark fermentation method due to its less corrosiveness and doesn't require external energy. Since food waste (FW) is rich in high carbohydrates and easily degradable, it has high potential in H_2 production. The current H_2 production performance by batch and continuous (Batch process requires a sequence of action that pursue in a specific order and continuous process refers to the continuous flow of product between every step of the process without any break in time, substance etc) operation are illustrated in Table 1 and Table 2

Table 4: Batch H_2 production performance from FW by dark fermentation

Substrate	**Temperature**	**H_2 yield per**	**Strategy to**	**Author**

		added substrate	enhance performance	
30g Carb.COD/L 30g Carb.COD/L	35°C 35°C	2.26 mol H_2/mol hexose 153.5mL H_2/g VS	Heat-treatment (90°C for 20 m) Heat -(90°C for 20 m).acid-(pH 1 for 1d)	[44], [64]
30g Carb.COD/L 30g Carb.COD/L	35°C 37°C	1.74 mol H_2/mol hexose 162 mL H_2/g VS 1.71 mol H_2/mol hexose 133 mL/g COD	Acid treatment (pH 1.0-4.0) Alkali treatment (pH 9-13, 6 h)	[65], [66]
30g Carb.COD/L 5-80g Carb.COD/L	35°C 35°C	1.92 mol H_2/mol hexose 1.71 mol H_2/mol hexose	Initial pH change (5.0-9.0) Substrate concentration change (5-80g Carb.COD/L)	[65], [67]

30g Carb.COD/L 30g Carb.COD/L	35-60°C 35°C	1.79 mol H_2/mol hexose 2.11 mol H_2/mol hexose	Temperature change (35-60°C) Co digestion (FW:SWS=10:0-10:4,0:10)	[68]
5-50 g VS/L	37°C	1.05 mol H_2/mol hexose	Co digestion (FW:SWS=0:10 0-100:0)	[65]

Table 5: Continuous H_2 production performance from FW by dark fermentation

Organic Loading Rate	**Hydraulic Retention Time**	**Temperature**	**H_2 yield per added substrate**	**Volumetric H_2 production rate**	**Strategy to enhance performance**	**Author**

29-47g COD/L/d	1.6 d	35°C	12.9 mL H_2/g COD	0.4 L H_2/L/d (29g COD/L/d)	OLR change (29,36,47 g COD/L/d)	[69]
19,28 g COD/L/d	4 d	55°C	38.1 mL H_2/g COD	1.0 L H_2/L/d (28g COD/L/d)	OLR change (19,28 g COD/L/d)	[70]
70.2-125.4 g COD/L/d	18.7, 14.0,10.5 h	55°C	111.1 mL H_2/g VS	10.7 L H_2/L/d (125.4 g COD/L/d)	OLR change (70.2,89.4, 125.4 g COD/L/d)	[70]
19.0-57.0 g COD/L/d	24-8 h	35°C	11.2 mL H_2/g VS	0.4 L H_2/L/d (38 g COD/L/d)	OLR change (19-57 g COD/L/d)	[71]
15.4-27.0 g COD/L/d	42-24 h	35°C	61.7 mL H_2/g VS	2.7 H_2/L/d (HRT 24 h, SRT 100 h)	HRT change (42-24h) SRT change (160-124	[72]

					h)	

Brewery wastewater

Arantes et al (2019) demonstrated the production of biohydrogen from brewery wastewater as it contains high organic compounds from processing of different raw materials as well as suspended solids. However, the development of inoculums which is capable of degrading these organic compounds present in wastewater plays an important role in terms of producing biohydrogen. The Enterobacterium *Klebsiella pneumonia* has shown the potential for the production of biohydrogen from several substrates. A study by Liu and Fang et al (2007) used glycerol as substrate obtaining H_2 production yields of up to 0.53 mol H_2 mol^{-1} glucose and 118 mmol H_2 L^{-1} substrate. Niu et al (2010), tested the same substrate with synthetics media and different carbon sources found the best results for glucose 2.1mol H_2 mol^{-1} glucose and 0.48 L^{-1} h^{-1}. In addition to the biomass support, expanded clay proved to be a suitable support for the pure culture of *Klebsiella pneumoniae* for fermentation of the brewery wastewater. The characterization of the expanded clay such as surface area (3.41 m^2 g^{-1}), low pore volume (3.83 x 10^{-3} cm^3 g^{-1}) was suitable for the colonization of bacteria. The best result was achieved in mean volumetric productivity 0.88 L H_2 L^{-1} Day^{-1} and mean hydrogen yield 0.70 mol H_2 mol^{-1} glucose with applied volumetric organic loads of 12.6 g carbohydrate L^{-1} day^{-1} and cycle length 12 h.

Beverage wastewater

Sivagurunathan et al (2015) has given more attention to dark fermentation than other physico-chemical methods due to its less energy consumption and higher hydrogen production rate (HPR). To improve the hydrogen production; more efficient immobilization technologies have been developed and applied that are generally characterized as surface attachment, entrapment and cell aggregation [73]. At present, a newly developed hybrid immobilized-material (HY-IM) as an entrapment carrier for hydrogen producing bacteria showed stable hydrogen production in cycle operation [74]. Therefore, the immobilized cell was prepared by adding the pellet biomass of freshly grown enriched mixed culture and mixed with sodium alginate, activated carbon, wokogel and chitosan.
However, the immobilized beads don't affect the performance due to using non toxins polymers in preparation step. However, the operating parameter hydraulic retention time (HRT) influenced the hydrogen production rate and operational stability of a biohydrogen producing reactor [62]. The performance of immobilized cell CSTR (continuous stirred tank reactor) under steady state conditions of various HRT (8 h -1.5h) and the constant substrate concentration at 20 g/L while the organic loading rate was increased from 60 to 320 g/L-d has shown. However, the most effective result of hydrogen production rate was found 55 L/L-d at HRT 1.5 h, whereas the organic loading rate 320 g/L-d and the substrate concentration is 20 g/L and the maximum hydrogen yield of 1.7 mol H_2/mol hexose was gained at 6 h (hour) HRT along with the maximum biomass cluster was found at HRT 3 h due to the presence of self-flocculating *Selenomonas spp*.

3.5 Biobutanol production

Municipal Solid Waste (MSW)

Municipal Solid Waste (MSW) which is commonly known as garbage or trash (wastes such as paper, plastics, glass, metals, wood, leather etc.) that are produced in households, offices, hotels, shops, schools, and other institutions [75]. According to a study by Farmanbordar et al (2020), Butanol can be produced from municipal solid waste co-processing with biomass (plant dry matter) for upgraded biobutanol production. A large amount of Municipal Solid Waste is produced everyday around the world that creates many negative impacts on our environment such as water pollution, land pollution, spread of infectious disease and blockage of drain etc [75].

MSW is enriched with carbohydrates like pentose and hexose sugars that lower the cost of biobutanol production [76]. In a study by Farmanbordar et al (2020) showed that the organic matters fraction of municipal solid waste (OMSW) with biomass (especially lignocellulosic wastes-garden waste and waste paper) could be synthesized through traditional acetone–butanol–ethanol (ABE) fermentation process using solventogenic [77] *Clostridium* species (species that used in solventogenesis: the biochemical production of solvents) for instance *C. acetobutylicum* NRRL B-591 for butanol production.

a. In the waste processing plant in Isfahan city, Iran, approximately 310,000,000 kg per year, urban waste (OMSW) was collected. In this experiment, after collecting OMSW, the waste is directly air- dried and disposed of to the ball mill, resulting in the milled OMSW in 20 and 80 meshes to separate an average particle size between

833 and 177µm [78]. 30 g of the substrate (dry weight basis) was soaked in 300 g of 0.5 or 1% (w/w) sulfuric acid solution in a high pressure reactor. The reactor's temperature was increased to 140 or 160 °C with 10 °C/min heating rate in an oil bath for 30 min and the optimum temperature is 140 °C and 160 °C for dilute acid pretreatment of OMSW and lignocellulosic waste, respectively. Finally, the neutralized solids were freeze dried and stored at 4 °C and therefore, liquors were separated and stored at 18 °C to be evaluated for ABE production [78], [79]. The hydrolysates are prepared to be used in fermentation tanks and all ABE fermentations were conducted by using *Clostridium acetobutylicum* NRRL B-591. The bacterial spores were activated at 75 °C for 2 min when 0.5 mL of spore suspension was heat shocked and then added to 25 mL of a medium containing 60 g/L cooked meat and 10 g/L glucose [76], [78]. After enzymatic hydrolysis, the hydrolysates (25 mL) were mixed with 1 g/L yeast extract and 3 g/L peptone in a 118 mL serum bottle. The bottles were closed after adjusting the pH to 6.8 using 5 M NaOH. They were autoclaved at 115 °C for 10 min and after cooling down to room temperature, 1% (v/v) of P2 stock solution was accelerated in the mixture and purged with deoxygenated nitrogen gas for 10 min. Deoxygenation of the nitrogen was conducted at 200 °C. Then, the media was inoculated and fermented at 37 °C for 72 hours [78].

Table 6: Overall ABE yields (g/kg raw material) of fermentation metabolites for different wastes pretreated at different conditions as well as raw materials

Pretreatment conditions: *Mild (0.5% acid, 140 °C, and 30 min)	**Butanol (g/kg raw material**)	**ABE yield (g/kg raw material)**	**Author**

*Severe (1% acid, 160 °C, and 30 min)			
Garden waste			[78]
Mild	28.0	46.8	
Severe	32.5	54.4	
Wastepaper			
Mild	0	57.8	
Severe	0	91.7	
OMSW			
Mild	101.4	169	
Severe	110.1	177	
Composite I (combining wastepaper with OMSW)			
Mild	55.7	123.4	
Severe	59.3	147.7	
Composite II (combining garden waste with OMSW)			
Mild	86.2	146	
Severe	108.0	172.6	

Untreated materials			
Garden waste	3.0	2.7	
Wastepaper	2.0	18.4	
OMSW	24.8	38.4	

Press Mud (Sugarcane Industry Waste)

According to a study by Nimbalkar et al (2017), butanol can be produced by a promising feedstock known as press mud (sugarcane industry waste). When the clarification process separates the dissolved and suspended solid substances to get the clear juice, then the remaining compressed sugar industry waste (filter cake) is termed as press mud [80]. Press mud is used as a substrate with the help of *Clostridium acetobutylicum* NRRL B-527 for butanol production and finally the batch fermentation resulted in a higher butanol production of 4.43 g/L with a total ABE of 6.69 g/L. In this study by Nimbalkar et al (2017), ABE production involves sequential acidogenic (lag phase- the initial 10 h) and solventogenic phases (at approximately 17–20 h). The control P2 medium (standard production medium) was able to produce higher ABE and the total solvents dried at 100 and 120 °C, were higher than the samples dried at different temperatures.

Table 7: Overall production of ABE (g/g sugar consumed) from press mud and slurries (sample dried and pretreated)

Sample	Butanol yield (g/g sugar consumed)	ABE yield (g/g sugar consumed)	ABE productivity {g/(L h)}	Author
P2 control (standard production medium)	0.16	0.27	0.14	[81]
Non-dried	0.09	0.16	0.05	
Dried—60 °C	0.11	0.15	0.05	
Dried—80 °C	0.09	0.16	0.05	
Dried—100 °C	0.13	0.20	0.06	
Dried—120 °C	0.12	0.18	0.06	

Potato Peel Waste

Potato peel waste (PPW) can be used as a high potential feedstock as it has been considered as less used residues [82] and the annual worldwide PPW amount was approximately 70 to 140 thousand tons from the food processing industry [83]. Therefore, according to the Food and Agriculture Organization (FAO), the annual potato generation was over three (3) hundred million tons worldwide in 2016 [83]. According to a study by Kamboj & Ms (2021), the batch fermentation was performed by *Clostridium acetobutylicum* MTCC 11274 for 120 h at 37°C and the butanol yield was upgraded after addition of orange peel (OP) extract. The orange peel extract used as a substrate had a significant effect on potato peel waste for butanol production since butanol yield and ABE yield was improved by increasing the concentration of PPW in OP extract.

Butanol production from different PPW (Potato peel waste) concentrations in OP (Orange peel) extract at 72 h. After 72hours, butanol production from different PPW (Potato peel waste) concentrations in OP (Orange peel) was observed. At 20, 40 and 60 PPW conc. in OP extract (g/L), butanol yield(g/g) was observed 0.04, 0.19 and 0.35 respectively [82].

Table 8: Overview of biobutanol production

Feedstock	**Organism**	**Process/methodology**	**Butanol yield**	**ABE yield**	**Location**	**Author**
Municipal Solid Waste (MSW)	*C. acetobutylicum* NRRL B-591	Pretreatment, Enzymatic Hydrolysis, fermentation	Composite I (combining wastepaper with OMSW): 59.3 g/Kg Composite II (combining garden waste with OMSW): 108.0 g/Kg	Composite I (combining wastepaper with OMSW): 147.7 g/Kg Composite II (combining garden waste with OMSW): 172.6 g/Kg	Iran	[78]

Press Mud	*Clostridium acetobutylicum* NRRL B-527		0.16 g/g (standard production medium) 0.13 g/g (Dried-100 °C)	0.27 g/g (standard production medium) 0.20 g/g (Dried-100 °C)	India	[81]
Potato Peel Waste	*Clostridium acetobutylicum* MTCC 11274		0.35 g/g (PPW conc. in OP extract 60 g/L)	0.35 g/g	India	[82]

Chapter 4

Discussion

Different types of waste material including the solid and liquid forms of wastages can be used for the production of different important biofuels as evidenced by articles published globally.

Through the literature review, we have found that municipal solid waste, potato waste, fecal waste, waste cooking oil, sewage sludge, and cornstalk are the common feedstock for biofuel. Though rice bran showed the highest efficiency in the production of bioethanol, only few countries use it as a raw material for the production of the fuel. In the case of biobutanol, municipal solid waste (MSW) is the most potential feedstock but the total solvent production, solvent yield, and solvent productivity are comparatively not so encouraging from these studies, countries are still trying to develop the process for the higher production of biobutanol. Biobutanol has also been designated by the National Marine Manufacturers Association (NMMA) as an acceptable and safe biofuel alternative to ethanol though biobutanol production is very limited all over the world. From the perspective of Bangladesh potato waste, fecal waste and municipal solid waste can be used for large scale biofuel production. For example, bioethanol in the range of 122,786,678.73 to 143,670,082.36 US gallons can be produced by using the surplus and non-marketable portion of the potato in Bangladesh [84]. This amount is sufficient to meet the annual bioethanol blending requirement of 5%. However, the most difficult aspect of biodiesel is lowering the price to that of diesel due to expensive feedstock and complex procedures. Raw materials for biogas are also studied in this article. Again, according to estimates from 2005, 7690 tons of municipal solid trash were generated daily in Bangladesh in six biggest cities: Dhaka, Chittagong, Khulna, Rajshahi, Barisal, and Sylhet. A calculation shows that adopting an active biogas collection procedure in the major landfills of the main cities can produce 319989.36 kWh of electricity. Another biofuel we have studied is biohydrogen. Only a few countries are producing biohydrogen on a large scale because the major challenges that prevent the commercialization of the hydrogen production process are the selection of microorganisms, optimization of operational factors, and design of reactors. In addition the lack of storage facilities, fuel cell technology, and distribution network. In the studied articles, BWW has been found as a potential culture medium for the growth of microalgae. Bangladesh currently has 0.73 million hectares of dry land, 3.16 million hectares of low marshy area, and 0.218 million hectares of saline coastline land [85]. These grounds are unsuitable for the cultivation of food crops which could be used to grow algae, suitable feedstock for both biodiesel and biohydrogen. In January 2021, our government launched an established hydrogen production project. 1 kg of hydrogen fuel produces approximately 33.33 kWh of energy, whereas petrol and compressed natural gas (CNG) produce just 12 kWh/kg and 14.7 kWh/kg, respectively. A kilogram of hydrogen powers a fuel cell automobile for 100 to 131 kilometers, whereas a Kilogram of gasoline powers a typical car for 16 kilometers. From 2030 to 2041, our government plans to have hydrogen fuel ready for industrial and vehicle use. Lowering production costs and increasing availability is to use cheap and abundant lignocellulosic resources for biochemical production which is the way to persuade governments and private investors to adopt biofuels as a green fuel to avoid the negative effects of fossil fuels is to produce it at a low cost. This literature review provides a new insight that appears to aim at two main goals: production of biofuels from waste material and the selection of the source of waste material from the perspective of Bangladesh.

Extensive research has been conducted in the last few decades to improve technological process to produce biofuels but further research is needed to reduce the world reliance on fossil energy sources.

Chapter 5

Conclusion

The energy crisis in Bangladesh is currently increasing hence, an alternative renewable energy source needs to be found to alleviate this emerging demand. Biofuel is eco-friendly and clean burning alternative fuel and the radiation of the biofuels are also environmentally friendly compared to conventional biofuel. Biofuels of the first and second generation are a step toward cleaner, renewable energy, but they lag behind in terms of cost and food crisis. Third-generation biofuels show the most potentiality, but more research is required to lower production costs and make this type of fuel commercially viable. Therefore, this review paper demonstrated the sustainable biofuel (Bioethanol, biobutanol, biodiesel, biohydrogen, and biogas) that can be gained from waste materials with high efficiency in Bangladesh. Different types of biofuel from different wastage have been discussed in this review paper that can be used in Bangladesh for future use. Though all the waste materials are not feasible in the case of Bangladesh, we found municipal solid waste, potato waste can be an excellent raw material for the production of bioethanol. By the June next year, Bangladesh will have the first hydrogen fuel production plant initiated by the Bangladesh Council of Scientific and Industrial Research (BCSIR) and the plant will produce hydrogen from different household waste and water to a highly combustible fuel.is the only fuel that Bangladesh is producing from municipal solid waste and the total biogas potential in the country is 5368 Mm^3/year. The production of biofuel from different waste material has so many difficulties that mentioned in the challenge section and came out with several viable solution that could maximize the potential of this energy resources.

References

[1] R. Ruan *et al.*, *Biofuels: Introduction*, no. x. 2019.

[2] A. G. Capodaglio and A. Callegari, “Feedstock and process influence on biodiesel produced from waste sewage sludge,” *J. Environ. Manage.*, vol. 216, pp. 176–182, Jun. 2018, doi: 10.1016/j.jenvman.2017.03.089.

[3] S. K. Bhatia *et al.*, “A clean and green approach for odd chain fatty acids production in Rhodococcus sp. YHY01 by medium engineering,” *Bioresour. Technol.*, vol. 286, p. 121383, 2019, doi: 10.1016/j.biortech.2019.121383.

[4] A. Demirbas, “Biofuels sources, biofuel policy, biofuel economy and global biofuel projections,” *Energy Convers. Manag.*, vol. 49, no. 8, pp. 2106–2116, 2008, doi: 10.1016/j.enconman.2008.02.020.

[5] M. Review, B. O. Abo, M. Gao, C. Wu, W. Zhu, and Q. Wang, “A review on characteristics of food waste and their use in butanol production,” 2019.

[6] D. Kumari and R. Singh, “Pretreatment of lignocellulosic wastes for biofuel production: A critical review,” *Renew. Sustain. Energy Rev.*, vol. 90, no. March, pp. 877–891, 2018, doi: 10.1016/j.rser.2018.03.111.

[7] K. Kurowska, R. Marks-Bielska, S. Bielski, H. Kryszk, and A. Jasinskas, “Food security in the context of liquid biofuels production,” *Energies*, vol. 13, no. 23, pp. 1–16, 2020, doi: 10.3390/en13236247.

[8] T. Koizumi, “Biofuels and food security,” *Renew. Sustain. Energy Rev.*, vol. 52, pp. 829–841, 2015, doi: 10.1016/j.rser.2015.06.041.

[9] K. Bozbas, “Biodiesel as an alternative motor fuel: Production and policies in the European Union,” *Renew. Sustain. Energy Rev.*, vol. 12, no. 2, pp. 542–552, 2008, doi: 10.1016/j.rser.2005.06.001.

[10] S. V. Vassilev and C. G. Vassileva, “Composition, properties and challenges of algae biomass for biofuel application: An overview,” *Fuel*, vol. 181, pp. 1–33, 2016, doi: 10.1016/j.fuel.2016.04.106.

[11] S. A. Jambo, R. Abdulla, S. H. Mohd Azhar, H. Marbawi, J. A. Gansau, and P. Ravindra, “A review on third generation bioethanol feedstock,” *Renew. Sustain. Energy Rev.*, vol. 65, pp. 756–769, 2016, doi: 10.1016/j.rser.2016.07.064.

[12] D. Arapoglou, T. Varzakas, A. Vlyssides, and C. Israilides, “Ethanol production from potato peel waste (PPW),” *Waste Manag.*, vol. 30, no. 10, pp. 1898–1902, 2010, doi: 10.1016/j.wasman.2010.04.017.

[13] J. Itelima, F. Onwuliri, E. Onwuliri, I. Onyimba, and S. Oforji, “Bio-Ethanol Production from Banana, Plantain and Pineapple Peels by Simultaneous Saccharification and Fermentation Process,” *Int. J. Environ. Sci. Dev.*, no. December 2015, pp. 213–216, 2013, doi: 10.7763/ijesd.2013.v4.337.

[14] A. Aruna, M. Nagavalli, V. Girijashankar, S. P. D. Ponamgi, V. Swathisree, and L. Venkateswar Rao, “Direct bioethanol production by amylolytic yeast Candida albicans,” *Lett. Appl. Microbiol.*, vol. 60, no. 3, pp. 229–236, 2015, doi: 10.1111/lam.12348.

[15] H. Liu, “Post-harvest processing technology of sweet potatoes in Sichuan, China,” pp. 49–61, 1994.

[16] T. Rabeya, F. Jehadin, M. A. Asad, O. O. Ayodele, A. E. Adekunle, and M. S. Islam, “Alkali and Intensified Heat Treatment of Corn Stalk for Bioethanol Production,” *Sugar*

Tech, vol. 23, no. 3, pp. 643–650, 2021, doi: 10.1007/s12355-020-00908-w.

[17] F. Jehadin, T. Rabeya, M. A. Asad, O. O. Ayodele, A. E. Adekunle, and M. S. Islam, "Efficient conversion of cornstalk to bioethanol using dilute H2SO4 pretreatment," *Int. J. Energy Environ. Eng.*, vol. 12, no. 2, pp. 203–211, 2021, doi: 10.1007/s40095-020-00366-w.

[18] A. Ecology, M. Tayyab, F. Agriculture, A. Noman, S. Waheed, and F. Agriculture, "Bioethanol production from lignocellulosic biomass by environment-friendly pretreatment methods : A review BIOETHANOL PRODUCTION FROM LIGNOCELLULOSIC BIOMASS BY ENVIRONMENT-FRIENDLY PRETREATMENT METHODS : A REVIEW," *Appl. Ecol. Environ. Res.*, no. December, 2017, doi: 10.15666/aeer/1601.

[19] W. Liao, Y. Liu, C. Liu, Z. Wen, and S. Chen, "Acid hydrolysis of fibers from dairy manure," *Bioresour. Technol.*, vol. 97, no. 14, pp. 1687–1695, 2006, doi: 10.1016/j.biortech.2005.07.028.

[20] M. A. Gomaa and R. M. M. Abed, "Potential of fecal waste for the production of biomethane, bioethanol and biodiesel," *J. Biotechnol.*, vol. 253, no. February, pp. 14–22, 2017, doi: 10.1016/j.jbiotec.2017.05.013.

[21] P. Vijayaraghavan, A. Arun, N. A. Al-Dhabi, S. G. P. Vincent, M. V. Arasu, and K. C. Choi, "Novel Bacillus subtilis IND19 cell factory for the simultaneous production of carboxy methyl cellulase and protease using cow dung substrate in solid-substrate fermentation," *Biotechnol. Biofuels*, vol. 9, no. 1, pp. 1–14, 2016, doi: 10.1186/s13068-016-0481-6.

[22] S. Naito, E. Matsumoto, K. Shindoh, and T. Nishimura, "Effects of polishing, cooking, and storing on total arsenic and arsenic species concentrations in rice cultivated in

Japan," *Food Chem.*, vol. 168, pp. 294–301, 2015, doi: 10.1016/j.foodchem.2014.07.060.

[23] H. Iwata, T. Suzuki, K. Takahashi, and I. Aramaki, "Critical importance of α-glucosidase contained in rice kernel for alcohol fermentation of rice polish," *J. Biosci. Bioeng.*, vol. 93, no. 3, pp. 296–302, 2002, doi: 10.1016/S1389-1723(02)80031-7.

[24] V. Alfonsín, R. Maceiras, and C. Gutiérrez, "Bioethanol production from industrial algae waste," *Waste Manag.*, vol. 87, pp. 791–797, 2019, doi: 10.1016/j.wasman.2019.03.019.

[25] A. D. Chintagunta, S. Jacob, and R. Banerjee, "Integrated bioethanol and biomanure production from potato waste," *Waste Manag.*, vol. 49, no. 2015, pp. 320–325, 2016, doi: 10.1016/j.wasman.2015.08.010.

[26] T. Hossain, A. B. Miah, S. A. Mahmud, and A. Al Mahin, "Enhanced Bioethanol Production from Potato Peel Waste Via Consolidated Bioprocessing with Statistically Optimized Medium," *Appl. Biochem. Biotechnol.*, vol. 186, no. 2, pp. 425–442, 2018, doi: 10.1007/s12010-018-2747-x.

[27] I. Ben Atitallah *et al.*, "On the evaluation of different saccharification schemes for enhanced bioethanol production from potato peels waste via a newly isolated yeast strain of Wickerhamomyces anomalus," *Bioresour. Technol.*, vol. 289, no. April, p. 121614, 2019, doi: 10.1016/j.biortech.2019.121614.

[28] F. Wang *et al.*, "An environmentally friendly and productive process for bioethanol production from potato waste," *Biotechnol. Biofuels*, vol. 9, no. 1, pp. 1–10, 2016, doi: 10.1186/s13068-016-0464-7.

[29] F. B. Siepmann, D. L. Kalschne, C. Zabotti, E. L. de Moraes Flores, C. Canan, and E.

Colla, “Feasibility of bioethanol production from rice bran,” *Semin. Agrar.*, vol. 41, no. 6, pp. 2951–2966, 2020, doi: 10.5433/1679-0359.2020v41n6Supl2p2951.

[30] M. Watanabe *et al.*, “Bioethanol production from rice washing drainage and rice bran,” *J. Biosci. Bioeng.*, vol. 108, no. 6, pp. 524–526, 2009, doi: 10.1016/j.jbiosc.2009.06.014.

[31] A. Hagelqvist *et al.*, *Sludge from pulp and paper mills for biogas production : Strategies to improve energy performance in wastewater treatment and sludge management*. 2013.

[32] B. R. Patil, K. K. Singh, S. E. Pawar, L. Maarse, and J. Otte, “Sericulture : An Alternative Source of Income to Enhance the Livelihoods of Small-scale Farmers and Tribal Communities,” *Pro-Poor Livest. Policy Initiat. A Living from Livest. Res. Rep.*, no. 09, pp. 1–26, 2009.

[33] M. Łochyńska and J. Frankowski, “The biogas production potential from silkworm waste,” *Waste Manag.*, vol. 79, no. September, pp. 564–570, 2018, doi: 10.1016/j.wasman.2018.08.019.

[34] K. Kemppainen *et al.*, “Ethanol and biogas production from waste fibre and fibre sludge - The FibreEtOH concept,” *Biomass and Bioenergy*, vol. 46, pp. 60–69, 2012, doi: 10.1016/j.biombioe.2012.03.027.

[35] M. Łochyńska and J. Frankowski, “The biogas production potential from silkworm waste,” *Waste Manag.*, vol. 79, pp. 564–570, 2018, doi: 10.1016/j.wasman.2018.08.019.

[36] M. M. Hanafiah *et al.*, “Biogas production from goat and chicken manure in Malaysia,” *Appl. Ecol. Environ. Res.*, vol. 15, no. 3, pp. 529–535, 2017, doi: 10.15666/aeer/1503_529535.

[37] C. hao Bi *et al.*, “Process development for scum to biodiesel conversion,” *Bioresour. Technol.*, vol. 185, pp. 185–193, 2015, doi: 10.1016/j.biortech.2015.01.081.

[38] J. Bu, G. Loh, C. G. Gwie, S. Dewiyanti, M. Tasrif, and A. Borgna, "Desulfurization of diesel fuels by selective adsorption on activated carbons: Competitive adsorption of polycyclic aromatic sulfur heterocycles and polycyclic aromatic hydrocarbons," *Chem. Eng. J.*, vol. 166, no. 1, pp. 207–217, 2011, doi: 10.1016/j.cej.2010.10.063.

[39] B. K. Jung and S. H. Jhung, "Adsorptive removal of benzothiophene from model fuel, using modified activated carbons, in presence of diethylether," *Fuel*, vol. 145, no. January, pp. 249–255, 2015, doi: 10.1016/j.fuel.2014.12.088.

[40] A. S. Nizami *et al.*, "An argument for developing waste-to-energy technologies in Saudi Arabia," *Chem. Eng. Trans.*, vol. 45, pp. 337–342, 2015, doi: 10.3303/CET1545057.

[41] M. I. Loizides, X. I. Loizidou, D. L. Orthodoxou, and D. Petsa, "Circular bioeconomy in action: Collection and recycling of domestic used cooking oil through a social, reverse logistics system," *Recycling*, vol. 4, no. 2, 2019, doi: 10.3390/recycling4020016.

[42] J. P. Chastain and J. J. Camberato, "Dairy manure production and nutrient content," *Confin. Anim. Manure Manag. Certif. Progr. Man. Dairy Version*, pp. 1–16, 2004.

[43] D. M. Kargbo, "Biodiesel production from municipal sewage sludges," *Energy and Fuels*, vol. 24, no. 5, pp. 2791–2794, 2010, doi: 10.1021/ef1001106.

[44] E. E. Kwon, S. Kim, Y. J. Jeon, and H. Yi, "Biodiesel production from sewage sludge: New paradigm for mining energy from municipal hazardous material," *Environ. Sci. Technol.*, vol. 46, no. 18, pp. 10222–10228, 2012, doi: 10.1021/es3019435.

[45] J. FOLCH, M. LEES, and G. H. SLOANE STANLEY, "A simple method for the isolation and purification of total lipides from animal tissues.," *J. Biol. Chem.*, vol. 226, no. 1, pp. 497–509, 1957, doi: 10.1016/s0021-9258(18)64849-5.

[46] M. Di Serio, M. Cozzolino, M. Giordano, R. Tesser, P. Patrono, and E. Santacesaria,

"From homogeneous to heterogeneous catalysts in biodiesel production," *Ind. Eng. Chem. Res.*, vol. 46, no. 20, pp. 6379–6384, 2007, doi: 10.1021/ie070663q.

[47] H. Zhang, L. Li, P. Zhou, J. Hou, and Y. Qiu, "Subsidy modes, waste cooking oil and biofuel: Policy effectiveness and sustainable supply chains in China," *Energy Policy*, vol. 65, no. 1, pp. 270–274, 2014, doi: 10.1016/j.enpol.2013.10.009.

[48] J. Xu, Z. Yuan, and S. Chang, "Long-term cost trajectories for biofuels in China projected to 2050," *Energy*, vol. 160, pp. 452–465, 2018, doi: 10.1016/j.energy.2018.06.126.

[49] S. Anto *et al.*, "Algae as green energy reserve: Technological outlook on biofuel production," *Chemosphere*, vol. 242, 2020, doi: 10.1016/j.chemosphere.2019.125079.

[50] H. C. Nguyen, M. L. Nguyen, F. M. Wang, H. Y. Juan, and C. H. Su, "Biodiesel production by direct transesterification of wet spent coffee grounds using switchable solvent as a catalyst and solvent," *Bioresour. Technol.*, vol. 296, no. August 2019, p. 122334, 2020, doi: 10.1016/j.biortech.2019.122334.

[51] S. K. Bhatia *et al.*, "Recent developments in pretreatment technologies on lignocellulosic biomass: Effect of key parameters, technological improvements, and challenges," *Bioresour. Technol.*, vol. 300, p. 122724, 2020, doi: 10.1016/j.biortech.2019.122724.

[52] S. K. Bhatia, R. K. Bhatia, and Y. H. Yang, "An overview of microdiesel — A sustainable future source of renewable energy," *Renew. Sustain. Energy Rev.*, vol. 79, no. March, pp. 1078–1090, 2017, doi: 10.1016/j.rser.2017.05.138.

[53] F. R. Oliveira, A. K. Patel, D. P. Jaisi, S. Adhikari, H. Lu, and S. K. Khanal, "Environmental application of biochar: Current status and perspectives," *Bioresour.*

Technol., vol. 246, pp. 110–122, 2017, doi: 10.1016/j.biortech.2017.08.122.

[54] S. K. Bhatia *et al.*, "Bioconversion of barley straw lignin into biodiesel using Rhodococcus sp. YHY01," *Bioresour. Technol.*, vol. 289, p. 121704, 2019, doi: 10.1016/j.biortech.2019.121704.

[55] D. B. Levin, L. Pitt, and M. Love, "Biohydrogen production: Prospects and limitations to practical application," *Int. J. Hydrogen Energy*, vol. 29, no. 2, pp. 173–185, 2004, doi: 10.1016/S0360-3199(03)00094-6.

[56] N. C. S. Amorim, I. Alves, J. S. Martins, and E. L. C. Amorim, "Biohydrogen production from cassava wastewater in an anaerobic fluidized bed reactor," *Brazilian J. Chem. Eng.*, vol. 31, no. 3, pp. 603–612, 2014, doi: 10.1590/0104-6632.20140313s00002458.

[57] E. Vaez, M. Taherdanak, and H. Zilouei, "Dark Hydrogen Fermentation From Paper Mill Effluent (PME): The influence of Substrate Concentration and Hydrolysis," *Environ. Energy Econ. Res.*, vol. 1, pp. 163–170, 2017, doi: 10.22097/eeer.2017.47243.

[58] A. Farghaly, A. Tawfik, and A. Danial, "Inoculation of paperboard mill sludge versus mixed culture bacteria for hydrogen production from paperboard mill wastewater," *Environ. Sci. Pollut. Res.*, vol. 23, no. 4, pp. 3834–3846, 2016, doi: 10.1007/s11356-015-5652-7.

[59] a G. Murugesan and K. B. Amutha, "Sequential Evolution of Bio-Hydrogen from Rubber Industrial Effluent and its Microbial Interaction to Fermentation Kinetics," *Energy*, vol. 78, pp. 1–8, 2010.

[60] G. Kumar, G. Zhen, T. Kobayashi, P. Sivagurunathan, S. H. Kim, and K. Q. Xu, "Impact of pH control and heat pre-treatment of seed inoculum in dark H2 fermentation: A feasibility report using mixed microalgae biomass as feedstock," *Int. J. Hydrogen*

Energy, vol. 41, no. 7, pp. 4382–4392, 2016, doi: 10.1016/j.ijhydene.2015.08.069.

[61] A. N. da Silva *et al.*, “Biohydrogen production from dairy industry wastewater in an anaerobic fluidized-bed reactor,” *Biomass and Bioenergy*, vol. 120, no. October 2018, pp. 257–264, 2019, doi: 10.1016/j.biombioe.2018.11.025.

[62] C. Y. Lin *et al.*, “Fermentative hydrogen production from wastewaters: A review and prognosis,” *Int. J. Hydrogen Energy*, vol. 37, no. 20, pp. 15632–15642, 2012, doi: 10.1016/j.ijhydene.2012.02.072.

[63] R. Pachiega *et al.*, “Hydrogen bioproduction with anaerobic bacteria consortium from brewery wastewater,” *Int. J. Hydrogen Energy*, pp. 155–163, 2019, doi: 10.1016/j.ijhydene.2018.02.107.

[64] D. H. Kim, S. H. Kim, and H. S. Shin, “Hydrogen fermentation of food waste without inoculum addition,” *Enzyme Microb. Technol.*, vol. 45, no. 3, pp. 181–187, 2009, doi: 10.1016/j.enzmictec.2009.06.013.

[65] D. H. Kim, S. H. Kim, K. W. Jung, M. S. Kim, and H. S. Shin, “Effect of initial pH independent of operational pH on hydrogen fermentation of food waste,” *Bioresour. Technol.*, vol. 102, no. 18, pp. 8646–8652, 2011, doi: 10.1016/j.biortech.2011.03.030.

[66] S. Jang *et al.*, “Hydrogen fermentation of food waste by alkali-shock pretreatment: Microbial community analysis and limitation of continuous operation,” *Bioresour. Technol.*, vol. 186, pp. 215–222, 2015, doi: 10.1016/j.biortech.2015.03.031.

[67] D. H. Kim *et al.*, “Effect of acid-pretreatment on hydrogen fermentation of food waste: Microbial community analysis by next generation sequencing,” *Int. J. Hydrogen Energy*, vol. 39, no. 29, pp. 16302–16309, 2014, doi: 10.1016/j.ijhydene.2014.08.004.

[68] D. H. Kim, S. H. Kim, H. W. Kim, M. S. Kim, and H. S. Shin, “Sewage sludge addition

to food waste synergistically enhances hydrogen fermentation performance," *Bioresour. Technol.*, vol. 102, no. 18, pp. 8501–8506, 2011, doi: 10.1016/j.biortech.2011.04.089.

[69] A. Tawfik and M. El-Qelish, "Continuous hydrogen production from co-digestion of municipal food waste and kitchen wastewater in mesophilic anaerobic baffled reactor," *Bioresour. Technol.*, vol. 114, pp. 270–274, 2012, doi: 10.1016/j.biortech.2012.02.016.

[70] D. Y. Lee, K. Q. Xu, T. Kobayashi, Y. Y. Li, and Y. Inamori, "Effect of organic loading rate on continuous hydrogen production from food waste in submerged anaerobic membrane bioreactor," *Int. J. Hydrogen Energy*, vol. 39, no. 30, pp. 16863–16871, 2014, doi: 10.1016/j.ijhydene.2014.08.022.

[71] A. Castillo-Hernández, I. Mar-Alvarez, and I. Moreno-Andrade, "Start-up and operation of continuous stirred-tank reactor for biohydrogen production from restaurant organic solid waste," *Int. J. Hydrogen Energy*, vol. 40, no. 48, pp. 17239–17245, 2015, doi: 10.1016/j.ijhydene.2015.04.046.

[72] S. H. Kim, S. K. Han, and H. S. Shin, "Optimization of continuous hydrogen fermentation of food waste as a function of solids retention time independent of hydraulic retention time," *Process Biochem.*, vol. 43, no. 2, pp. 213–218, 2008, doi: 10.1016/j.procbio.2007.11.007.

[73] J. Y.-T. K. Ming-Ju Chen, Kreuter, "Nanoparticles and microparticles for drug and vaccine delivery.," *J. Anat.*, vol. 189 (Pt 3, no. Ii, pp. 503–505, 1996, doi: 10.1002/bit.

[74] P. Sivagurunathan, G. Kumar, B. Sen, and C. Y. Lin, "Development of a novel hybrid immobilization material (HY-IM) for fermentative biohydrogen production from beverage wastewater," *J. Chinese Chem. Soc.*, vol. 61, no. 7, pp. 827–830, 2014, doi: 10.1002/jccs.201300636.

[75] Manju & Srikantaswamy, “Composting of Municipal Solid Waste Using Sericin Rich Wastewater from Silk Industry as an Additive,” *Environ. J. Environ. Sci. Nat. Resour.*, vol. 9, no. 2, pp. 1–6, 2018, doi: 10.19080/IJESNR.2018.09.555761.

[76] P. Nazemi, M. Shafiei, and K. Karimi, “Bioresource Technology Biobutanol production from municipal solid waste : Technical and economic analysis,” *Bioresour. Technol.*, vol. 308, no. March, p. 123267, 2020, doi: 10.1016/j.biortech.2020.123267.

[77] Y. Jiang *et al.*, “Microbial co-culturing systems : butanol production from organic wastes through consolidated bioprocessing,” 2018.

[78] S. Farmanbordar, H. Amiri, and K. Karimi, “Synergy of municipal solid waste co-processing with lignocellulosic waste for improved biobutanol production,” *Waste Manag.*, vol. 118, pp. 45–54, 2020, doi: 10.1016/j.wasman.2020.07.053.

[79] Y. H. Jung, I. J. Kim, H. K. Kim, and K. H. Kim, “Bioresource Technology Dilute acid pretreatment of lignocellulose for whole slurry ethanol fermentation,” *Bioresour. Technol.*, vol. 132, pp. 109–114, 2013, doi: 10.1016/j.biortech.2012.12.151.

[80] K. Kuruti *et al.*, “Generation of bioethanol and VFA through anaerobic acidogenic fermentation route with press mud obtained from sugar mill as a feedstock,” *Bioresour. Technol.*, 2015, doi: 10.1016/j.biortech.2015.05.104.

[81] P. R. Nimbalkar, M. A. Khedkar, S. G. Gaikwad, P. V. Chavan, and S. B. Bankar, “New Insight into Sugarcane Industry Waste Utilization (Press Mud) for Cleaner Biobutanol Production by Using C. acetobutylicum NRRL B-527,” *Appl. Biochem. Biotechnol.*, vol. 183, no. 3, pp. 1008–1025, 2017, doi: 10.1007/s12010-017-2479-3.

[82] R. Kamboj and D. Ms, “Orange peel extract enhanced sugar recovery and butanol production from potato peel by Clostridium acetobutylicum,” *Int. J. Green Energy*, vol.

18, no. 10, pp. 987–997, 2021, doi: 10.1080/15435075.2021.1890083.

[83] A. Javed, A. Ahmad, A. Tahir, U. Shabbir, M. Nouman, and A. Hameed, “Potato peel waste—its nutraceutical, industrial and biotechnological applacations,” *AIMS Agric. Food*, vol. 4, no. 3, pp. 807–823, 2019, doi: 10.3934/agrfood.2019.3.807.

[84] M. Mostofa, “An Introduction to Bioethanol and Its Prospects in Bangladesh: A Review,” *J. Energy Res. Rev.*, no. January, pp. 1–12, 2019, doi: 10.9734/jenrr/2019/v2i229738.

[85] A. Z. A. Saifullah, A. Karim, and R. Karim, “Advancement of Biodiesel in Bangladesh,” *IOSR J. Eng.*, vol. 06, no. 06, pp. 59–64, 2016.