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An Introduction to Bioethanol and Its Prospects in Bangladesh: A Review

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

This study aims to present a comprehensive review of bioethanol, its prospects, and also to estimate a potential source for commercial bioethanol production in Bangladesh. In Bangladesh, the primary source of fuel comes from natural gas and petroleum oil. But the total output of fossil fuel is incapable of meeting the annual fuel demand. And also, the natural reserves are insufficient to meet the energy demand for long-term economic development. To meet the demand every year Bangladesh needs to import a huge amount of petroleum oil from overseas markets. In this situation, to manage the future demand, production of renewable energy may be an alternative solution. Bioethanol production from potato and potato peel waste maybe a prospective source of renewable energy. It can use as an alternative clean-burning fuel by replacing with regular vehicle fuel. It can not only save huge foreign currency but also lessen greenhouse effect in the environment. In this scenario, there is a huge prospect to introduce bioethanol as an alternative fuel in Bangladesh.

Keywords: Bioethanol; biofuel; potato; alternative fuel; Bangladesh.

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ABBREVIATIONS

Abbreviation	Elaboration
PPW	Potato Peel Waste
ktoe	Thousand tonnes oil equivalent
Mtoe	Million tonnes oil equivalent

Conversion factors (Reference: [7])

1 US gallon = 3.79 liters
1 Barrel = 42 US gallons
1 barrel of ethanol = 0.58 barrels of oil equivalent

1. INTRODUCTION

In this 21st century, the world demand for fossil fuel is increasing consistently over the few decades. In recent years, most of the developed countries use more than 90% non-renewable fuel sources for energy production [1]. International Energy Agency (IEA) found that 80% of world energy produced through fossil fuel i.e. oil, coal and natural gas. The world demand for fossil fuel is increasing 1.6% every year [2,3,4], and worldwide fossil energy consumption might be double in the following 20 years [5,6]. Bangladesh is not different in this situation due to the constant growth of its agricultural and industrial sectors. During 2016 and 2017 per day oil consumption was 131 and 146 thousand barrels respectively [7]. The annual requirement of petroleum products (crude and refined oil) is primarily met up through the overseas markets. During 2016 and 2017 Bangladesh has imported 71.05% and 77.73% petroleum oil (crude and refined oil) of total oil consumption [8]. During 2016-17 imported petroleum (crude) oil's estimated value was near about 481.81 million US dollar [8].

The popularity of renewable energy is increasing day by day. To save the huge foreign currency and to fulfil the future demand, it is essential to find out the prospective renewable sources. Some of the sustainable energy sources are biofuel, wind power, solar energy, hydropower, nuclear energy, wave power, fuel cell and biological hydrogen production etc. [9]. Production of bioethanol can be a probable source of renewable energy. Fossil fuel produces near about 73% CO_2 during combustion [10]. However, bioethanol can be a potential alternative source for transportation fossil fuels to reduce the total contribution of greenhouse gas from the atmosphere [11]. Because, it is an oxygenated fuel that contains 35% oxygen, which reduces NO_x during combustion [12].

Bangladesh is an agriculture-based country, where agricultural wastes are dumped in large volumes without processing. But this improper management of agricultural wastes is contributing to environmental climate change, soil and water contamination, and also local wind pollution. However, agriculture is not only an energy user but also an energy supplier in the form of bioenergy [13]. At this situation, production of bioethanol can become a viable option to use the agricultural waste. According to the United States Department of Energy, for every unit of energy input towards bioethanol production, 1.3 units are returned [14].

Potato (*Solanum tuberosum* L.) is a tuberous crop belonging to the family Solanaceae, which is the world's 4th largest crop after maize (*Zea mays* L.), wheat (*Triticum aestivum* L.) and rice (*Oryza sativa* L.). The total world potato production was estimated 376.83 million metric tons in 2016 [15]. Among the world's top 10 potato producing countries, Bangladesh ranks 7th position [15]. Potato is one of the vital vegetable crops in Bangladesh [16]. In Bangladesh, it positions 2nd after rice in production [17] and the total potato production was 10.22 million metric tons in 2017, which was 7.83% greater than the previous year 2016 [17]. It is a starchy tuberous crop, which can be used for bioethanol production [18]. There is a huge prospect to use potato and potato peel waste (PPW) as raw material for bioethanol production due to its low price and surplus production in Bangladesh.

2. PRODUCTION STATUS OF TOP BIOFUEL PRODUCING COUNTRIES IN THE WORLD

Nowadays biofuel is a trending topic around the world. Fuel demand and greenhouse effect have forced the scientists to research on it. The total biofuel production is increasing tremendously year to year in the world. According to BP [7], the total world biofuel production was 84,121.00 thousand tonnes oil equivalent (ktoe) in 2017, which was 3.5% greater than the previous year 2016. Among the biofuel producing countries, the United States and Brazil are the top biofuel producing countries in the world. Table 1 was presented top five biofuel producing countries in the world from 2013-2017.

Table 1. Top biofuel producing countries in the world (2013-2017, Thousand tonnes oil equivalent)

Countries	2013	2014	2015	2016	2017
United States	31057	32890	33849	35986	36936
Brazil	17114	18005	19332	18168	18465
Germany	2770	3460	3191	3228	3293
Argentina	2014	2644	2038	2828	3131
Indonesia	1750	3110	1314	2238	2326
Rest of the world	72415	80009	79866	81483	84121

Reference: [7]

3. PRESENT STATUS OF FUEL CONSUMPTION IN BANGLADESH

As the development of different sectors, especially the industry and transportation sector, the total consumption of fuel is increasing continuously year to year in Bangladesh. It has a good reserve of natural gas (Table 4). As a result, the major portion of fuel comes from natural gas (Table 2). But this sole source of natural gas is not enough to meet the annual demand (Table 5). Where other important sources are petroleum oil and coal are required to meet the annual demand (Table 2). During 2017 Bangladesh has imported 5.83 Million tonnes oil equivalent (Mtoe) fuel as crude and refined oil from overseas markets (Table 3). Bangladesh is also producing an average of 3.95 BBL/D/1K crude oil from 1994 to the present time [19]. Bangladesh has been using the conventional fuel for the only cooking purpose from crop residues, cow dung, plant waste mixtures etc.

But the information about the secondary categories was found inconclusive and does not able to specify exactly.

4. CLASSIFICATION OF BIOETHANOL

Bioethanol is produced from plant biomass. It can be classified as 1st generation and 2nd generation bioethanol. 1st generation bioethanol comes from starch-based (i.e. corn, wheat,

Table 2. Annual consumption of different primary fuel sources in Bangladesh (Primary energy consumption by fuel Million tonnes oil equivalent, Mtoe)

Primary Categories	2016	2017
Oil	6.7	7.5
Gas	22.7 (Harvested in the land)	22.9 (Harvested in the land)
Coal	2.2 (Harvested in the land)	2.3 (Harvested in the land)
Nuclear Energy	-	-
Hydroelectricity	0.2 (Harvested in the land)	0.2 (Harvested in the land)
Renewables	0.1 (Harvested in the land)	0.1 (Harvested in the land)
Total	**31.90**	**33.00**

Reference: [7]

Table 3. Annual consumption and import of petroleum oil in Bangladesh (Million tonnes oil equivalent, Mtoe)

Year	Consumption	Consumption Increase (%)	Import (Crude and refined oil)	Import Increase (%)
2016	6.70	-	4.76	-
2017	7.50	11.94	5.83	22.48
	Reference: [7]		Reference: [8]	

Table 4. Total natural gas reserve status in Bangladesh (Trillion cubic feet, Tcf)

At end 1997	At end 2007	At end 2016	At end 2017	Reference
10.59	14.13	7.06	7.06	[7]

Table 5. Production and consumption status of natural gas in Bangladesh (Billion cubic feet, Bcf)

Category	2013-14	2014-15	2015-16	2016-17	Reference
Production	820.43	892.17	973.25	971.60	[8]
Consumption	828.14	877.30	966.90	987.30	[8]

sorghum, potato, sweet potato etc.) and sugar based (i.e. sugarcane, sugar beet etc.) plant biomass [20].

2nd generation bioethanol comes from lignocellulosic biomass (i.e. rice straw, sugarcane bagasse, corn stover, coconut husk, sawmill etc.), which is composed of cellulose, hemicellulose, and lignin materials [20,21]. Classification of bioethanol was presented in Fig. 1.

5. BIOETHANOL CAN BE AN ALTERNATIVE SOURCE FOR FUEL IN BANGLADESH

During the 1930s biologically produced alcohols, especially ethanol was used as a source of fuel for vehicles [22]. After World War II, the plentiful and inexpensive supply of fossil fuel reduced the interest of bioethanol production from agricultural crops [23]. But presently depletion of fossil fuel and greenhouse's negative effect have forced to rethink about bioethanol. Plants, which are rich in carbohydrate components (i.e. sugars, polysaccharides) are a good source for bioethanol production. Bioethanol is easily biodegradable, less harmful and less pollutant than fossil fuel [24,25]. The United States and Brazil are the top bioethanol producing countries in the world [26,27]. Within the next 20 years, bioethanol will be the prospective renewable energy source for transportation sector [28]. In Bangladesh, the major portion of fuel comes from natural gas, which is produced from the mines. But the production of natural gas is not enough to meet the annual demand and the reserve also declining yearly (Table 4; Table 5). To meet the annual requirement, Bangladesh needs to import a huge amount of petroleum oil from the overseas markets (Table 3). In this situation to secure future fuel demand and to save the huge foreign currency, production of bioethanol can be an alternative solution for Bangladesh.

Bangladesh Government has already approved a decision and given a permission to blend 5% bioethanol with vehicle fuel [29]. This government decision is a remarkable step to inaugurate bioethanol production industries in Bangladesh.

6. POTENTIALS OF POTATO AS A RAW MATERIAL FOR BIOETHANOL PRODUCTION IN BANGLADESH

Potato is the second top produced a starchy crop in Bangladesh. Its production is continuously increasing every year (Table 6). During the 2017-18 fiscal year, the total production of potato was 10.22 million metric tons, total consumption was 7 million metric tons and total surplus was 3.22 million metric tons [17]. The main raw materials for 1st generation bioethanol come from plant biomass. Potato may be a better choice as a raw material for bioethanol production due to its huge

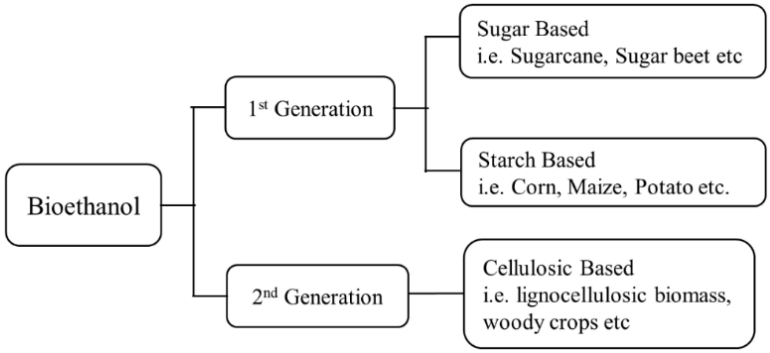

Fig. 1. Classification of bioethanol, modified
(Reference: [20])

surplus after fulfilling the country's demand annually. Every year on average 29.61% potato of total production remains surplus (Table 7). A fewer number of the cold storage facility and processing industry are the main problem to keep a huge amount of potato unused. Table 7 presented the total amount of surplus potato of five consecutive fiscal years (2013-14 to 2017-18).

7. THE USABLE PORTION OF THE POTATO FOR BIOETHANOL PRODUCTION

Every year a large amount of potato and its by-products are dumped in soil or kept unused, which comes from different reasons during and after harvesting due to curing, cleaning and sorting (i.e. off size, cutting loss, diseased, insect damage, green colored and bruised tuber at transportation). According to Hossain and Miah [30], an average post harvesting loss (non-marketable) of potato in all regions of Bangladesh was found to be 15.50% of total production. But this big portion can be used for bioethanol production. There are mainly two types of potato wastes comes from potato processing industry. First one is the liquid waste due to soluble solids and the second one is solid waste from potato tissue. French fry, chip, and starch manufacturing plants use a large quantity of water, which increase the volume of liquid waste [31]. Potato peel waste (PPW), a solid byproduct which comes from potato processing plant is a zero value waste [9]. It produces in huge amount during industrial potato processing and can range from 15-40 % of initial product mass, based on the procedures applied such as steam, abrasion or lye peeling [18]. Immature, green colored, and defect potatoes can also be considered potato processing waste. It is starch-rich content and can be utilized for commercially bioethanol production [32]. According to ICPL [33], 2% of potato from total potato production is used for the processing industry in Bangladesh. As their estimation, during 2017-18 fiscal year 204319.14 metric tons of potato was used in the processing industry in Bangladesh (Table 8).

8. ESTIMATION OF POSSIBLE BIOETHANOL PRODUCTION

The total production of bioethanol from potato and potato peel waste (PPW) is varied based on quality and production techniques. One ton of potato or PPW can be produced 25.40 to 29.72 US gallons of bioethanol [34,12,35]. During 2017-18 fiscal year the total estimated surplus potato was 3,220,000.00 metric tons, total estimated post harvesting loss was 1583473.34 metric tons and total estimated potato peel waste was 30647.87 metric tons (Table 8). So, the total potato and PPW was 4834121.21 metric tons that could be produced 122,786,678.73 to 143,670,082.36 US gallons of Bioethanol, which is identical to 1,984,015.43 barrels of oil equivalent.

Table 6. A trend of potato production in Bangladesh over six consecutive fiscal years

Production year	Total production (million metric tons)	(%) Increased of total production over fiscal year (2012-2013)
2012-2013	8.21	-
2013-2014	8.60	4.75
2014-2015	8.95	9.01
2015-2016	9.25	12.67
2016-2017	9.47	15.35
2017-2018	10.22	24.48

Reference: [17,15]

Table 7. A surplus scenario of potato over total consumption in Bangladesh

Fiscal year	Total production (million ton)	Total consumption (million ton)	Total surplus (Million ton)	% surplus	Reference
2013-2014	8.60	6.60	2.00	23.26	[58]
2014-2015	8.95	6.50	2.45	27.37	[59]
2015-2016	9.25	6.25	3.00	32.43	[60]
2016-2017	9.47	6.30	3.17	33.47	[8]
2017-2018	10.22	7.00	3.22	31.51	[17]

Table 8. Estimation of potato and PPW in respect of total production in Bangladesh (2017-2018)

Total potato production (metric tons)	Categories	(%) surplus/loss	Estimated potato (metric tons)	Reference
10,215,957.00	Surplus potato	31.51	3,220,000.00	[17]
	Total post harvesting	15.50	1583473.34	[30]
	Industries based (PPW)[a]	15	30647.87	[33, 18]
			Total = 4834121.21	

[a] *Industry based potato peel waste (PPW) was calculated based on minimum loss [18].*

9. BIOETHANOL PRODUCTION TECHNOLOGY FROM POTATO AND POTATO PEEL WASTE

Potato is a starchy crop, which does not need complicated pretreatment and can be used for bioethanol production [36]. The composition of potato tuber, flour, and peel waste were presented in Table 9.

Sugar based raw materials like sugarcane molasses can be fermented directly, while starch-based raw materials like potato peel waste need conversion into simple sugar for fermentation [37]. Starch is a complex carbohydrate, which needs to convert into simple sugar before being converted into bioethanol. This conversion process is called hydrolysis. It can be done through acid hydrolysis or enzymatic hydrolysis. Each method has own set of advantages and disadvantages for the application.

The limitations of acid hydrolysis are suppression the growth of yeast (such as 5-hydroxymethylfurfural (5-HMF)), which need neutralization before fermentation and need high priced constructional equipment due to the risk of corrosion. On the other hand, enzymatic hydrolysis needs costly enzymes and higher primary investment due to high conversion yield of glucose [38]. But based on overall consideration, enzymatic hydrolysis has lots of benefits compared to acidic hydrolysis. It can work under mild conditions, easily biodegradable, enhance yield, minimize energy, water requirement and the volume of byproducts [39]. The production of bioethanol from starchy raw material through enzymatic hydrolysis requires three different steps; firstly, liquefaction of complex carbohydrate by an endoamlyase such as α-amylase; secondly, enzymatic saccharification of liquefied product through amyloglucosidase to produce simple sugar; and finally, fermentation of sugar in anaerobic condition by using yeast to produce bioethanol [40]. Due to cheap price yeast, *Saccharomyces cerevisiae* is commonly used for fermentation [41]. An overview of starch degrading enzymes was presented in Fig. 2 and conversion of sugars to bioethanol through anaerobic microbial fermentation was presented in Fig. 3. There are different types of processes are available for bioethanol production from starchy plant raw materials i.e. Simultaneous Saccharification and Fermentation (SSF); Separate Hydrolysis and Fermentation (SHF). SSF process is advanced, economic, less time consuming and effective technology for bioethanol production using various substrates such as potato mash [42]. It

Table 9. The chemical composition of potato tuber, flour and peel waste (PPW)

Parameters	Composition (%)		
	Potato tuber	Potato flour	Potato peel waste (PPW) dry
Moisture	80.28	8.12	85.06
Starch	20.00	73.00	52.14
Total protein	2.19	10.86	8.00
Crude fibre	0.85	1.65	-
Ash content	0.65	2.15	6.34
Total Sugars	0.41	0.91	1.00
Total lipids	0.12	1.00	2.60
	Reference: [61]		Reference: [18]

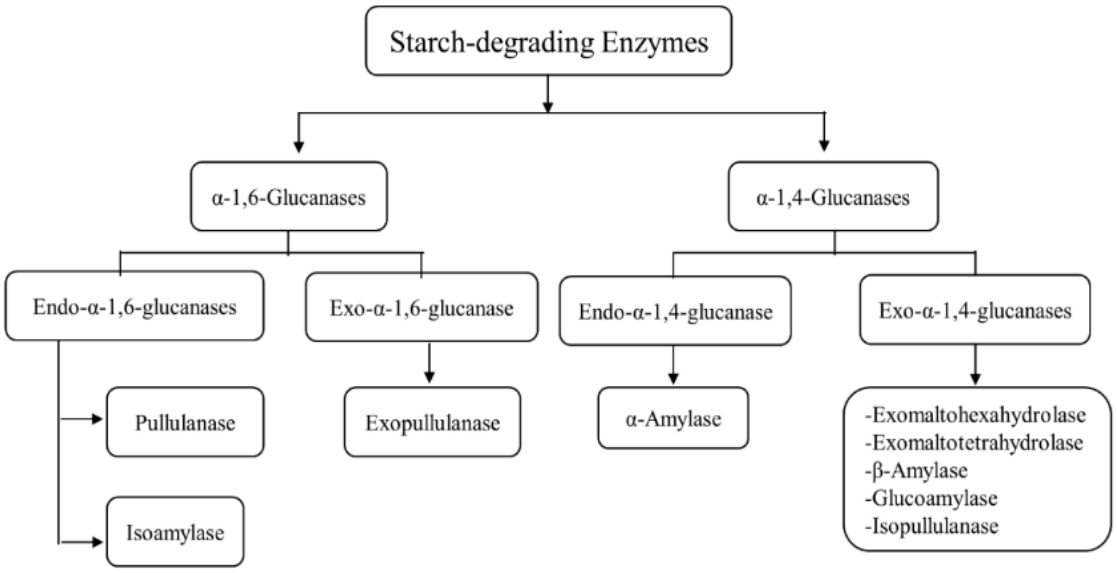

Fig. 2. An overview of starch degrading enzymes
(Reference: [62])

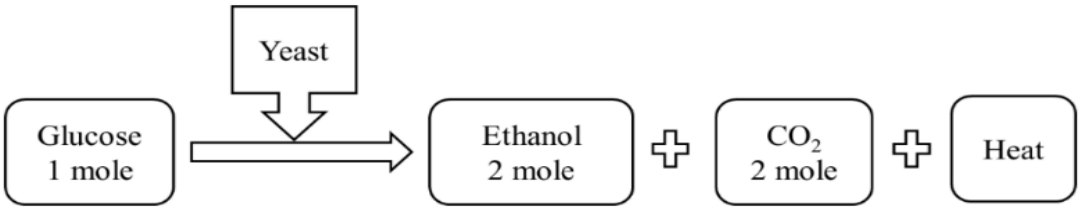

Fig. 3. Conversion of sugars to bioethanol through anaerobic microbial fermentation
(Reference: [63])

integrates the hydrolysis and fermentation process in a single container by reducing the substrate inhibition effect and overall reaction time [43,44]. The fermented mass is isolated by distillation process into bioethanol and stillage [37]. The potato-based bioethanol production process was presented in Fig. 4.

10. USE OF BY-PRODUCTS COMING FROM THE BIOETHANOL PRODUCTION PROCESS

Bioethanol is derived from plant biomass that is renewable and biodegradable [45,46]. Waste products of the bioethanol production process, which is called stillage can be used as manure and fertilizer. It is rich in nitrate, potassium and organic matter, also contains trace amounts of phosphorus, calcium, magnesium, and micronutrients [46]. It can be also used as raw fuel material in domestic and commercial boilers for heating purpose.

11. BENEFITS OF BIOETHANOL AS FUEL FOR VEHICLES

Bioethanol, which is produced from agricultural plant biomass, is an important source of carbon neutral, clean burning, sustainable and renewable fuel [47,48]. It has higher octane number, minimum tendency to happen engine knocking during spark ignition and high heat of vaporization, which makes it an excellent fuel for hybrid automobiles. A little percentage of bioethanol (5%-10%) can be mixed with gasoline in regular vehicles with almost no mechanical change or any damage in comparison to 100% use of gasoline. Modern flexible-fuel vehicles (FFV's) or dual-fuel vehicles (DFV's) are designed to run more than one fuel. To make operative flexible-fuel vehicles in every weather condition this type of vehicles uses a special type of blend called E85, which contains 85% bioethanol and 15% gasoline [49,50].

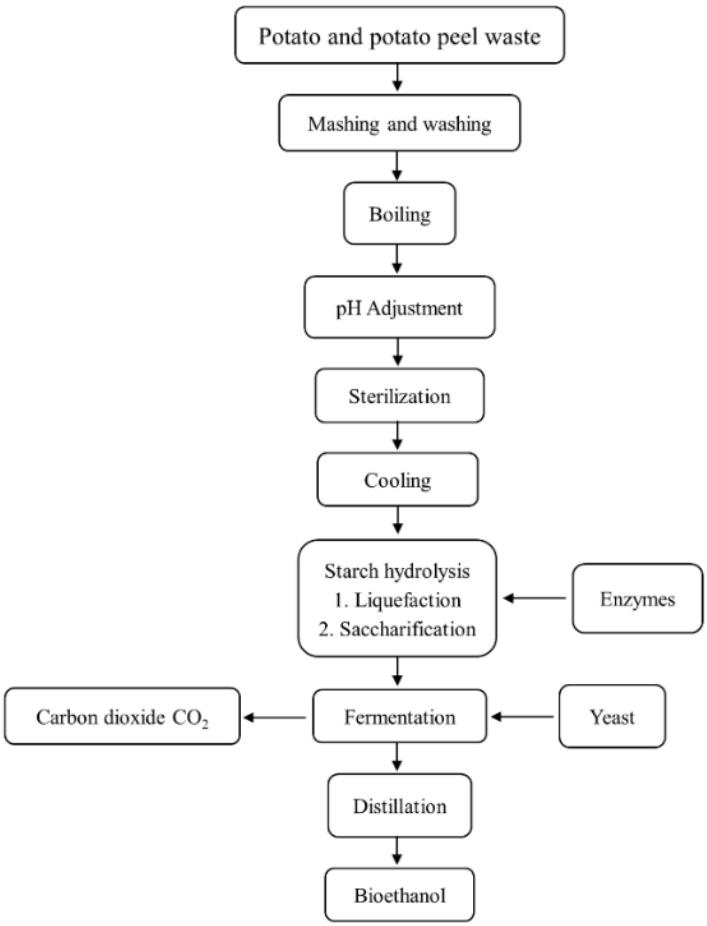

Fig. 4. Potato-based bioethanol production process, Modified
(Reference: [64,65])

12. ENVIRONMENTAL BENEFITS OF USING BIOETHANOL AS ALTERNATIVE VEHICLE FUEL

During 2017 in Bangladesh total carbon dioxide (CO_2) emission was 82.8 million ton, that was 4.02 % greater than the previous year 2016 [7]. The capital of Bangladesh, Dhaka ranks 3rd position for the worst air quality index [51]. Bioethanol, an alternative to gasoline can use as cleanest liquid transportation fuel, which can be an incredible solution to overcome this critical situation [52,53]. Carbon in bioethanol is produced by photosynthesis in the plant by using the energy of sunlight. For this reason, bioethanol is sustainable and renewable.

It contains oxygen (O_2) that improves combustion and ultimately the burning of bioethanol adds fewer greenhouse gases (CO_2, CH_4, and others) and doesn't rise carbon dioxide (CO_2) in the atmosphere. On the other hand, burning of fossil fuel, i.e. oil, coal and natural gas add more CO_2, CO, NO_x, SO_x, and others to the atmosphere because it was never released from fossilized condition [9,12]. Bioethanol can support to reduce the fossil fuel burning and CO_2 production [54]. In a study Wu et al. [55] found that CO, CO_2 and HC emissions were reduced with the increasing of bioethanol percentage in the blended fuel. The use of bioethanol blended fuel such as E85 (85% bioethanol and 15% gasoline) and E10 (10% bioethanol and 90% gasoline) can reduce the net emissions of greenhouse gases by as much as 37.1% and 3.9% respectively [56]. On the other hand, the produced CO_2 during fermentation process can be removed through carbon sequestration process, for example, the captured CO_2 can be injected into the deep underground to keep isolated from the atmosphere [57].

13. CONCLUSION

In Bangladesh potato is a potential source as raw material for bioethanol production. Only by using the surplus and non-marketable portion of potato can be produced 122,786,678.73 to 143,670,082.36 US gallons of bioethanol. This amount is enough to fulfil the requirement of bioethanol for 5% blending annually. It will also be helpful to reduce greenhouse gasses, especially from Dhaka City. There are lots of opportunity for commercial ethanol-producing companies both for local and international to produce bioethanol in Bangladesh. The abundance of raw materials is the leading prospect for this sector. Ultimately, these steps will be blessing for the potato growers, and they can sell their produce, even the non-marketable products to the growing industries.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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