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REVIEW ARTICLE

Towards the effective plastic waste management in Bangladesh: a review

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Abstract The plastic-derived product, nowadays, becomes an indispensable commodity for different purposes. A huge amount of used plastic causes environmental hazards that turn in danger for marine life, reduces the fertility of soil, and contamination of ground water. Management of this enormous plastic waste is challenging in particular for developing countries like Bangladesh. Lack of facilities, infrastructure development, and insufficient budget for waste management are some of the prime causes of improper plastic management in Bangladesh. In this study, the route of plastic waste production and current plastic waste management system in Bangladesh have been reviewed extensively. It emerges that no technical and improved methods are adapted in the plastic management system. A set of the sustainable plastic management system has been proposed along with the challenges that would emerge during the implementation these strategies. Successful execution of the proposed systems would enhance the quality of plastic waste management in Bangladesh and offers enormous energy from waste.

Highlights
1. Identification of the severity of waste generation and management in Bangladesh
2. Drawbacks of the plastic waste scenario has been figured out
3. Approach to a promising framework to mitigate the challenges towards plastic waste management

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Introduction

Plastic products hold a very important role in our daily activities due to some of its salient features like insolubility in water, resistance to corrosion and electricity, easiness of fabrication by heating and molding, long durability, light in weight (Development 2016). In plastics, the arrangement of the individual units of ethylene, propylene, styrene, and vinyl chloride may be linear or cross-linked. Linear or lightly cross-linked polymers form a class of plastics called thermoplastics that do not undergo chemical changes in their composition when heated and can be molded again and again. Heavy cross-linking plastics are called thermosetting plastics. In the thermosetting process, a chemical reaction occurs that is irreversible (Klein 2012). Thermosets can melt and take shape once; after they have solidified, they remain solid for rest longer time (Shimo 2014).

Figure 1 illustrates the historical development of plastics that reveals that modern plastic gets introduced through the "Parkesine" invented by a renowned ancient researcher and presented at the Great International Exhibition in London in the year 1862 (Parkes 1862). Before the end of eighteenth century, thermoforming techniques eased the mass production of rpm (revolution per minute) gramophone records. At the very beginning of nineteenth century, Leo Baekeland invented the first synthetic plastic derived from fossil fuel named as bakelite which opened a dimension for the following decades through the contribution of polystyrene, polyvinylchloride (PVC), polythene, nylon, and polyethylene terephthalate (PET) bottles. Plastic industries flourish commercially in the year 1960 and facing a transition from 1980 to 1986 due to the

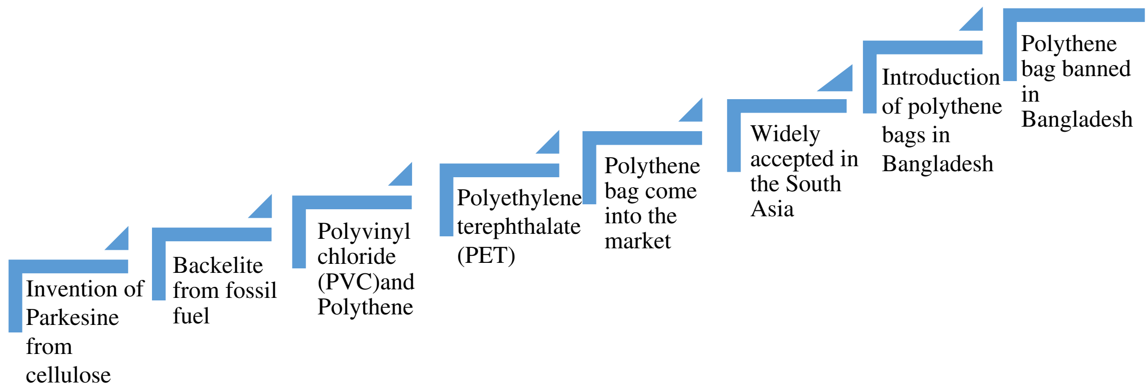


Fig. 1 Chronological flourishment of Plastics

world economic instability and oil price hike (Thompson et al. 2009; Andrady and Neal 2009; News 2016; British plastic fermentation 2016). With the blessings of the free market economy, plastic industries produce around 86 million tons of plastic products in the year 1990 (Der 2002). Plastic products getting acquainted with the South Asian region in 1974 and in Bangladesh plastic products become popular after the break out of independence. From early 1982, polythene bags gets it market at every class of people in Bangladesh and within 5 years it turned into a threat to the natural environment of this country (Halden 2010; Van Leeuwen 2013). In this consequence, the Ministry of Environment and Forest Bangladesh banned the commercial distribution, transportation, sales and uses of polythene bags with less than 55 μm in thickness from January 2002 throughout the country and the people of all classes accept this changes in a positive manner. However, the global consumption of plastics recorded around 299 million in the year 2013 and yearly 2–3% raise in consumption of the plastic materials in the developing countries (Ren 2002; Gourmelon 2015).

With the rapid industrial advancement and population growth, cities are encountered with the ever increasing and unavoidable application of organic and inorganic waste. The researcher found that currently about 1.7–1.9 billion metric tons/annum (BMTPA) waste is generated worldwide and it will reach to 27 BMTPA within 2050 and almost one-third of this waste will be contributed by the countries of Asia alone (Modak et al. 2010; Nations 2010). Among this huge waste generation, about 50–70% is collected for disposal and uncontrolled landfilling is account for 15% of the collected waste (Modak et al. 2010; Ramos and Vicentini 2012). The environmental effect of this waste becoming intensifies with the presence of plastic litter which contributes almost 5% of the municipal solid wastes (Sharmin et al. 2016). The per capita consumption of plastic driven products is 100 and 20 kg by the people from the North-America and Asia respectively (Gourmelon 2015). The non-biodegradable property of plastics makes complexities for easy and safe disposal. A major portion of this waste plastics finds their way in the landfilling, energy generation through incineration that causes hazardous emission along with particulate matters, and enormous amount about 10–20 million tons of plastics dumped into the ocean each year that gradually deteriorates the marine ecosystem (Gourmelon 2015). Moreover, about 4% of the total used fossil fuels are utilized as a feed stock for the plastic products generation and another 3–4% are needed to provide power in this manufacturing industries.

Asia possesses the position of the largest consumer of polymers for several years and generating 30% of plastic debris (Markus et al. 2014). In Bangladesh, the plastic materials market size getting bigger day by day. Around 3000 Small Medium Enterprises (SMEs) gets involved in the plastic industry and contribute 1% of the national GDP. This large domestic and export-oriented plastic market get spread out rapidly throughout the country and about 2 million people find their employment through this industry (Islam 2011b). Bangladesh earned around USD 340 million in the FY 2013–2014 by exporting plastic products (Ahmed 2014). With the advent of this large scale plastic products, Bangladesh has now encountered difficulties in coping with the vast amount of plastic waste. From a study about the plastic consumption in the urban areas of Bangladesh, it was found that the per capita plastic consumption was 2.07 kg in the year 2005 and sharply increased to 3.5 kg in 2014 (Concern 2015). A snapshot of per capita plastic consumption of Bangladesh and some selected neighboring and developed countries is presented in Fig. 2.

The plastic consumption per person between the year 2005 and 2014 getting increased on an average 25% throughout the world; whereas, in the case of Bangladesh it was 16.2% (Moazzem 2016). However, with the increase in the income of the mass population, the consumption of the plastic made product increases significantly in the recent years. Infrastructure development, adopting new technologies for the collection and recycling of wastes, reinforcement of legal framework, development of industrial processing zone

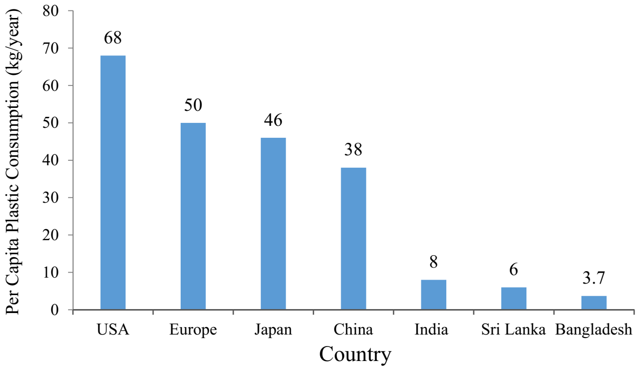


Fig. 2 Per capita waste generation rate of different developed and developing countries

facilities and above all public awareness must be needed in a vast to tackle this crisis in line with the other neighboring developing and developed countries. In this tasks, authors would like to focus on the present status of plastic waste generation in Bangladesh and other countries around the world, plastic waste management techniques in Bangladesh and also in the developed countries. Following this, some selected sustainable technologies for plastic waste management has been proposed in the light of social and economic aspects and sort out the challenges to meet the goal.

Solid waste generation in Bangladesh

Solid waste (SW) consists of the refuse or waste that takes a form of trash, garbage, and sludge from our everyday work in the form of non-liquid, no-gaseous, hazardous or non-hazardous, organic or non-organic, fresh, biodegradable or non-biodegradable useless products (Tchobanoglous 2002; Leton and Omotosho 2004; Agency 2016). Developing countries, as well as the developed countries, have been suffering heavily from the management of waste due to the gradual increase of the rate of waste generation. Taken this serious consequence into consideration, solid waste management has been pointed as the second most tenacious complexities that urban people will suffer in the near future (Zhu et al. 2008). The global solid waste generation has reached 1.7–1.9 billion tons per year and it is estimated that the amount will be almost 2.2 and 4.2 billion tons/year by the year 2025 and 2050, respectively (Nations 2010). Moreover, due to the limited collection and disposal sites, the need for recycling and recovery of the waste products becoming intensifies rather than landfilling.

The study shows that the daily production of solid waste was 70 million tons in the South-East Asia; whereas, Bangladesh produced 16,384 tons (Hoornweg and Bhada-Tata 2012). Table 1 represents the per day solid waste generation data for some of the Asian countries in the year 2012 (World Bank 2014; Mannapperuma 2015; Energy and Potential 2016; Gurung and Dhakal 2016; Nasrin 2016; Jain 2017). The economic and social status has a vital influence on the waste generation rate. Waste generation rate largely depends on the National Gross Domestic Product (GDP), Gross National Product (GNP), and Gross National Income (GNI). Table 1 reveals that, with an increase in GDP, GNP, and GNI, among different selected Asian countries, there is a considerable increase in the waste generation rate due to the higher living standard. India has the largest waste production among the selected Asian countries and Malaysia has the highest GDP with the comparatively low waste generation rate. The technological advancement and proper waste management play a significant role to reduce waste generation rate in Malaysia, Thailand, and Srilanka along with high GNP and GNI.

Figure 3 provides a closer look to the waste generation scenario of different Asian countries for the year 1999, 2012, 2015 and predicts for 2025 (World Bank 2014; Mannapperuma 2015; Energy and Potential 2016; Gurung and Dhakal 2016; Nasrin 2016; Jain 2017). According to the World Bank estimation, per capita waste generation rate for developing countries varied from 0.12 to 5.1 kg/capita/day whereas for the South-East Asian region it is about 0.45 kg/capita/day (Hoornweg and Bhada-Tata 2012). However, Bangladesh generates 0.43 kg/capita/day and 0.47 kg/capita/day during the year 2012 and 2015, respectively. Moreover, it has been estimated to reach up to 0.75 kg/capita/day in the year 2025. For the year 2012, the per capita waste generation was high for Thailand (1.76 kg/day), Malaysia (1.52 kg/day) and Vietnam (1.46 kg/day). The low incoming and developing countries like Nepal, India, Philipines, Srilanka had comparatively low per capita waste generation rate as 0.12 kg/day, 0.34 kg/day, 0.5 kg/day and 0.51 kg/day, respectively. From Fig. 3, it is also apparent that the developing countries will face a serious threat with their waste as their estimated waste generation will be two to threefold in the years ahead.

Likely, Bangladesh has been suffering from severe challenges for its organic and inorganic solid waste management in the recent years. The growth of population, the standard of living, climatic condition, rapid urbanization, and lack of technical knowledge and on top of those poor socio-economic conditions plays a long to turn Bangladesh into Least Developed Asian Countries (LDACs) (Alamgir and Ahsan 2007). Table 2 reveals a consistent growth rate among the urban population of Bangladesh for a different period. In the years 2015, almost one-third of the total population of Bangladesh live in the urban areas, which was only 4.33% in the year 1951(BBS 2017).

This large migration of the people to the urban locality can be marked as the ambition to lead a better standard life, boost up economical level and eventually threatening the ecological balance through waste generation.

The economic growth has a profound effect on the production and composition of the solid waste for any region. With

Table 1 Solid waste generation data for some of the Asian countries

Country	GNP (per capita in USD)	GDP (per capita in USD)	GNI (PPP in per capita in USD)	Total waste generation (tones/day)
Thailand	4440	5908	16,070	73,342
Malaysia	8770	9502	26,900	35,178
Philipines	2210	2951	9400	40,164
Indonesia	2940	3570	11,220	1,75,342
Srilanka	2580	3835	11,970	6400
India	1420	1709	6490	144,000
Vietnam	1270	2185	6050	60,274
Lao PDR	1130	2353	5920	192
Nepal	540	730	2520	1435
Bangladesh	780	1359	3790	22,400

PPP purchasing power parity

the rapid urbanization, a remarkable change has been observed in the purchasing power, standard of living, and socio-economic activities among the residents. Thus, the income level group as well as the urban and rural people determines the atrocity of waste generation. Figure 4 shows the variation of waste generation with the urban population for some selected years. In the year 1991, the per capita waste generation was 0.31 kg/cap/day against the total urban population of 20.8 million. However, the migration of citizen to the urban areas merely increase the waste generation almost two-fold between the years 1991 to 2014. Also, it has been predicted to generate 0.68 kg/cap/day by the year 2025 (Enayetullah and Hashmi 2006a, b; Waste Concern 2015).

Moreover, the percentage of inorganic wastes in solid waste increases with the increase in income level of the people. Also, the presence of high amount of organic solid wastes in the rural house-hold demand for frequent removal and well managed decomposition system. Dhaka is the mostly populated division among the seven others and the huge crowd of the population turns this capital city into the world's mostly populated megacity. However, in order to cope with these huge population, the waste collection and disposal methods,

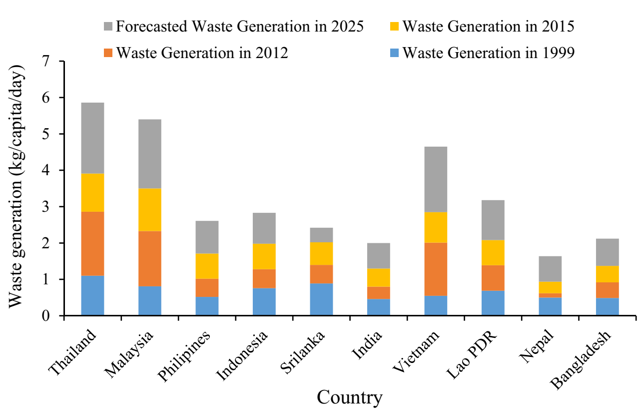


Fig. 3 Per capita waste generation rate for different developing countries in Asia

financial support, infrastructure development, formal and informal manpower has not increased (Mondol et al. 2013; Saifullah and Islam 2016; WasateConcern 2016). From Table 3, it is clear that the waste generation varies from the rural to urban region, wet to dry season as well as the composition that ultimately disturbs total collection, transportation, damping and recycling system (Visvanathan 2002).

From Table 3, it has been observed that the highest per capita waste generation was recorded for the capital city Dhaka and then the commercial city Chittagong is second with the population density of 45 and 21% of the total country respectively (Enayetullah and Hashmi 2006a, b; Saifullah and Islam 2016). Also the seasonal variation effect the waste generation rate by the consumption pattern of goods. During the rainy season, it has been found difficult to manage the waste systematically and thereby the low-lying areas, drains, streets, canals get blocked (Of, Affairs and Denmark 2010). With this high waste generation rate about 13,333.15 ton per day throughout the country, the waste collection structure is not sound. Highest waste collection efficiency was recorded 76.47% in Sylhet district and 44.30% in Barisal and a large portion of the total generation remain unmanaged (Gutberlet and Baeder 2008; Rahman et al. 2009). Moreover, lack of adequate technical expertise, capital investment on collection, transfer, and diffusion, large migration of urban population from rural areas, lack of awareness, improper disposal, scanty separation and shortage of recyclation centers has a predominant role in the poor solid management in Bangladesh system (Hoornweg and Bhada-Tata 2012; Dahlén and Anders 2008; Kawai and Tasaki 2015). The waste collection system in Bangladesh is in the under developing stage and mainly dependent on the informal sector, Community Based Management (CBM) system and a little portion of the Government funding. By this effort only 13% of the total population among which 55–60% comprises the urban residences covered by the present waste collection system (Enayetullah and Hashmi 2006a; Alamgir and Ahsan 2007; Mechanism 2012; Alamgir 2013). Eventually, this

Table 2 Total urban population data for Bangladesh

Year	Total urban population	Percentage of urban population	Average growth in percentage
1951	18,19,773	4.33	1.69
1961	26,40,726	5.19	3.75
1974	62,73,602	8.78	6.62
1981	1,35,35,963	15.54	10.63
1991	2,08,72,204	20.15	5.43
2001	2,88,08,477	23.39	3.23
2011	4,19,43,532	28.00	4.61
2015	55,062,000	34.20	6.20

unmanaged waste has their substantial effect on the health hazards, odor, damaging land areas, ground water, polluting the atmosphere of the country as well as the world. Every year about 2.19 million CO_2 emissions was recorded from the open landfill sites of the major urban areas in Bangladesh and by the proper utilizing of the recycling system of the inorganic waste about 10,705.50 million BDT can be saved per year (Enayetullah and Hashmi 2006a; Dahlén and Anders 2008; Halder et al. 2014).

In Bangladesh Municipal waste, Agricultural waste, Industrial waste, Medical waste, and E-waste are the major sources of waste. Municipal solid waste comprises of the domestic waste it occupies a large amount about 13,332.89 tons/day as shown in Fig. 5 (World Bank 2012; Enayetullah and Hashmi 2006a, b; Rahman et al. 2009). Industrial waste includes the waste from textiles, tanneries, and chemical processing units, oil refineries which generate a huge amount of and contaminant water and the earth. Medical and agricultural waste has been termed as the hazardous waste due to their non-biodegradable property, heavy impact on the atmosphere and lack of scope for reuse or recycling (Tania 2014). Recently, E-waste is an emerging source of waste that must be properly controlled for future betterment.

After all, a sustainable solid waste management is a crying need to pursue a clean and sound environment for future, which is one of the prime demands for every human being (Masud 2014). In this very way, government alone cannot do all the needful keeping aside of its population. With the increase in investment and resource allocation for the waste management, public awareness through the economic and socio-psychological motivation is needed for the change of outlook towards waste reduction. (Milea 2009; Connell 2011; Das et al. 2013).

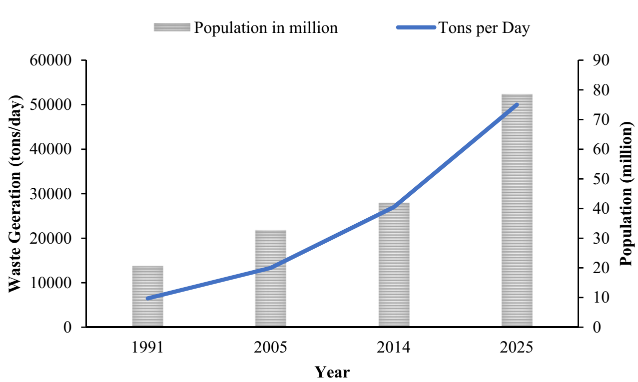


Fig. 4 Effect of urban population growth on waste generation

Plastic as a waste

To cope with the population inflation with the limited natural resources, plastics have its position from the beginning of twentieth century due to cost effectiveness, durability and easy formability (Andrady and Neal 2009; Thompson et al. 2009; Moazzem 2016). Around 4–12% of the MSW consists of different kinds of plastic waste from various sources (Hoornweg and Bhada-Tata 2012). In the year 2007, about 260 million metric ton plastic has been produced worldwide with a sharp growth rate of 9% per annum. The packaging of consumable goods, cans, and covers have used that account for 35% total plastic utilization (Andrady 2003). Moreover, 20–25% plastic is used in a wide range of diverse field of such as pipes, cables wiring, automobile, aircraft, utensils, covers, containers and the rest is from the non-durable goods (States 2007; Hopewell et al. 2009a, b). Nowadays, around 80% of the packaging, coating and some of the structural equipment was molded by the thermoplastic resin (Tomar and Dadoriya 2013). An assessment of the plastic waste composition in the MSW for Bangladesh is shown in the following Fig. 6, where the amount of mismanaged plastic incurred around 0.8 MMT/year.

From the following Fig. 7, it is obvious that Pakistan possess highest 18% plastic waste in its MSW while Bangladesh has 8%. Moreover, the average plastic content in the solid waste content was found 8% for the low-income countries whereas it was about 7% for the South-Asian countries (Hoornweg and Bhada-Tata 2012). However, among the other South-Asian countries like Nepal, Bhutan, Srilanka, and India, the MSW contains 3, 13, 6 and 2% of the plastic waste, respectively. The waste composition of Nepal supports the previous discussion that the low income level groups possess comparatively high amount of organic waste than the

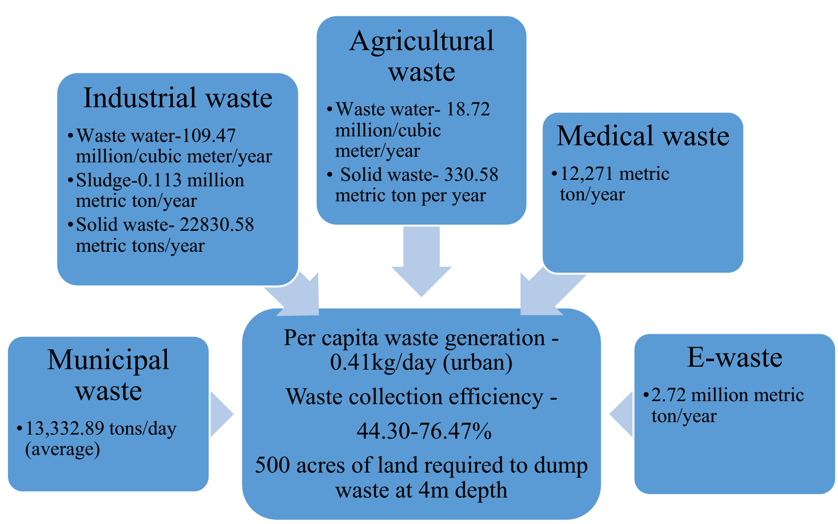
Table 3 Waste generation data for Bangladesh (Enayetullah and Hashmi 2006a, b; Saifullah and Islam 2016)

Division	Population (in lakh)[a]	Population (in lakh)[b]	Kg/capita/day waste generation rate	Waste Generation Rate (ton/day)		Number of motorized vehicles	Ultimate disposal Sites	Waste collection efficiency (%)	GHG emission potential million ton CO_2 e/year
				Dry season	Wet season				
Dhaka	155.85	67.28	0.56	3767.91	5501.14	373	2	42.00	0.76
Chittagong	69.06	26.22	0.48	1258.61	1837.57	49	2	70.00	0.25
Barisal	13.62	4.37	0.25	109.25	159.51	7	1	44.30	0.02
Rajshahi	33.17	4.68	0.3	140.51	205.18	15	1	56.67	0.03
Rangpur	21.09	–	–	–	–	–	–	–	–
Sylhet	14.63	3.87	0.3	116.07	169.46	17	1	76.47	0.02
Khulna	28.22	9.67	0.27	261.19	381.37	32	1	47.70	0.05
Pouroshavas	–	0.25	–	3803.58	5553.22	–	–	54	0.77
Other urban centers	–	0.15	–	1382.64	2018.66	–	–	52	0.28
Total	–	–	–	10,839.7	15,826.6	493	8	–	2.19

inorganic compounds. In this trend, Srilanka is the second highest producer of organic waste which is about 76%. Although the estimated organic waste generation for the low income countries comprise about 64% and for the South-Asian region it is almost 50%. Besides, Fig. 7 depicts that, excluding India, all other countries in the South-Asian region having organic waste compounds higher than 50% in their MSW generation. In addition, the presence of recyclable compounds in the MSW composition is very low for the countries in South-Asian region whereas Indonesia and Thailand possess considerable amount of metal and glass ranging from about 5–8%.

Plastic products that cannot serve any more are used for landfilling, incineration even throwing to the water body such as pond, river and even sea. The study found that around 10 million tons of plastic litters dumped on the sea that eventually damaging seabed, marine life cycle, tourism, fishing and end on the seashore (Lytle 2016; Mitra 2016). It is a matter of worry that researchers predict that 155 million metric ton trash will expand within the year 2025 and 10 bags full of plastics will be found per square foot of the coastal area (Jambeck et al. 2015; Watch 2016). Former research addressing the population size and inadequate waste management infrastructure are the prime reasons behind the unmanaged ocean litters. About 4.8 to 12.7 million metric tons (MMT) of waste plastics was dumped in the ocean from 192 coastal countries in the year 2010 (Ida 2017). The Asian countries contribute about 86% of the total global input in the ocean at an extent of 1.21 MMT per year. Plastics strike around 8% of the total waste generated by Bangladesh among which 0.79 MMT plastics are openly

Fig. 5 Sources of Solid Waste Generation in Bangladesh



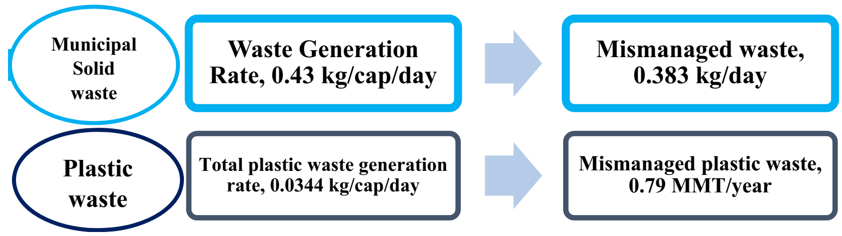


Fig. 6 Generation and mismanaged waste plastic in Bangladesh

dumped per year in the land without further processing and 0.12–0.31 MMT per year finds their way in the sea (Jambeck et al. 2015; Lebreton et al. 2017).

About 20–25% of the landfill MSW has accused as the plastic that has a long-term contribution to the infertility of soil, contamination of deep water layer and also the incineration of this plastic waste causes heavy CO_2 emission (Boavida et al. 2003; Lettieri and Baeyens 2009; Khajuria et al. 2010). Meanwhile, plastic waste from household (PET), automobiles, and textile appliances possessed potential for recycling and hereby, Europe and the USA recycled 26 and 9% respectively of their total plastic in the year 2012 and the remaining portion left as discarded or landfilling and researchers opine, recycling as the sustainable management of waste plastic compared to other methods (Thompson et al. 2009; Gourmelon 2015).

Plastic waste scenario in Bangladesh

Currently, 13,333.15 tons of waste has been produced in the six divisional cities of Bangladesh which possess a considerable amount about 5% of plastic waste (Enayetullah and Hashmi 2006a; Masud 2014). Bangladesh consumed 750,000 tons of plastic in the FY 2010–2011 with a per capita consumption of 5 kg in the form of PET (Polyethylene Terephthalate), PE (Polythene), PP (Polypropylene), PVC (Polyvinyl Chloride), ABS (Acrylonitrile Butadiene Styrene), PC (Polycarbonate), PVDC (Polyvinylidene Chloride), PTFE (Polytetrafluoroethylene: Teflon) for household utensils, packaging, construction equipment, containers, bags, covers and diverse applications whereas the world's average per capita consumption was 30 kg (Islam 2011a). The present market size of plastic industries is near about USD 3 billion comprising USD 2.2 billion domestic and USD 0.8 billion international markets and it is expected to reach USD 5 billion within the next 5 years (Islam 2011a; Ahmed 2014). With such extent of plastic consumption around 1.1 million tons of plastic wastes are generated each among which about 80% is contributed by the domestic users and a remarkable amount of plastic waste is generated in the food manufacturer and an estimation revealed that the amount is close to 70,400 tons from 500 food processing industries of Bangladesh (Markus et al. 2014). Figure 8 shows the life cycle of the plastic from the fresh products to the waste and then recycle to the suitable outcomes.

Apart from this, the plastic waste generation rate increases about 7.5% per annually whereas the solid waste increasing rate varies 5.2% per year (Corporation 2005; Markus et al. 2014). The per capita plastic consumption rate is 3.5 kg/year in Bangladesh and it is 36 kg for Asia, 139.0 kg for North America and 136 kg for Europe (Enayetullah and Hashmi 2006a).

Where within the last decade almost 33.17% increase in the total plastic consumption has been recorded and tremendous food waste about 76.05% is recorded in the year 2014 which is decreased about 3.57% in the last decades. From the present scenario of the waste generation, it shows about 8.45% plastic content in the total waste as shown in Fig. 9 (Enayetullah and

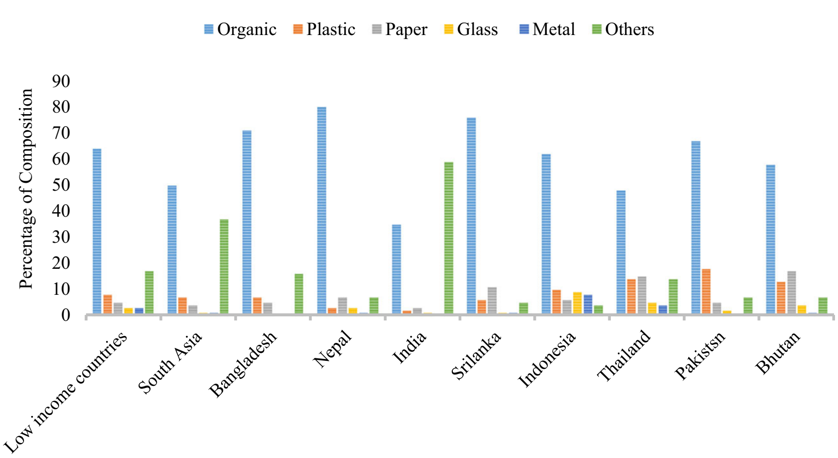
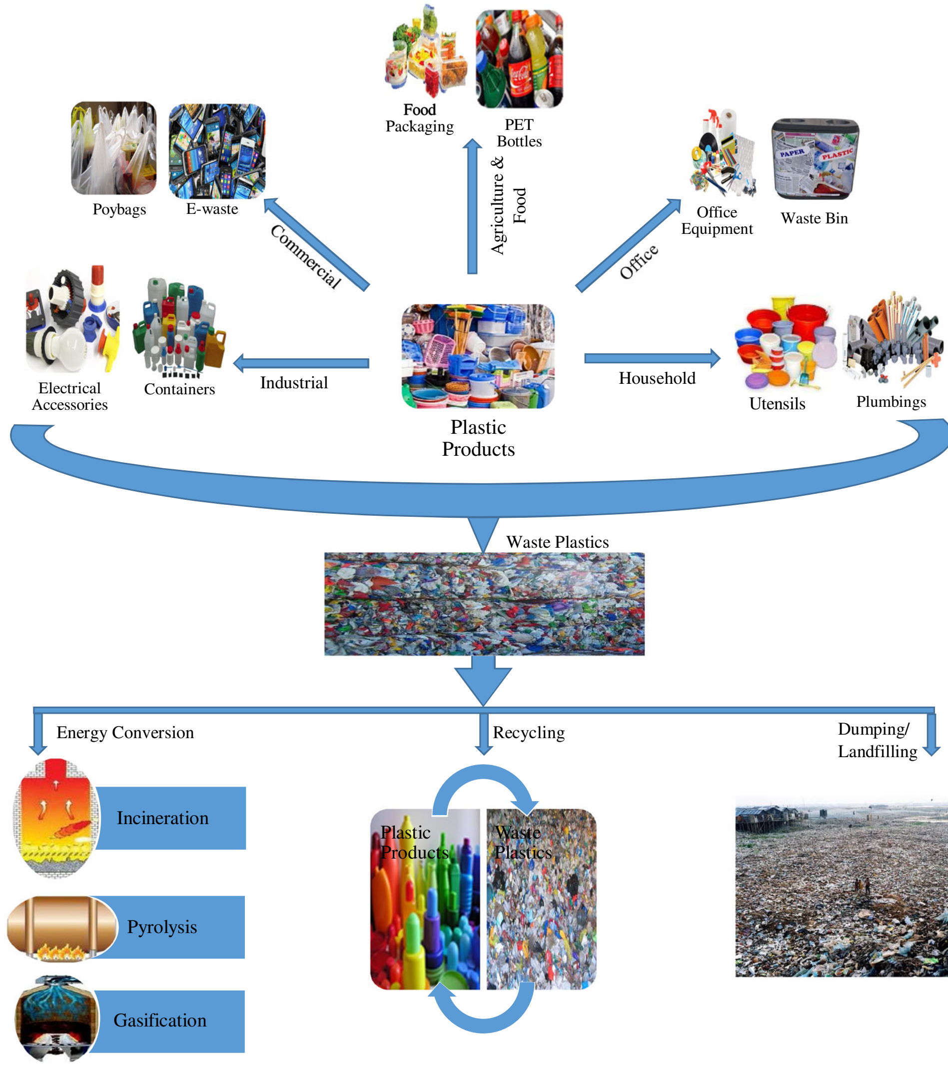


Fig. 7 Waste composition for some selected Asian countries

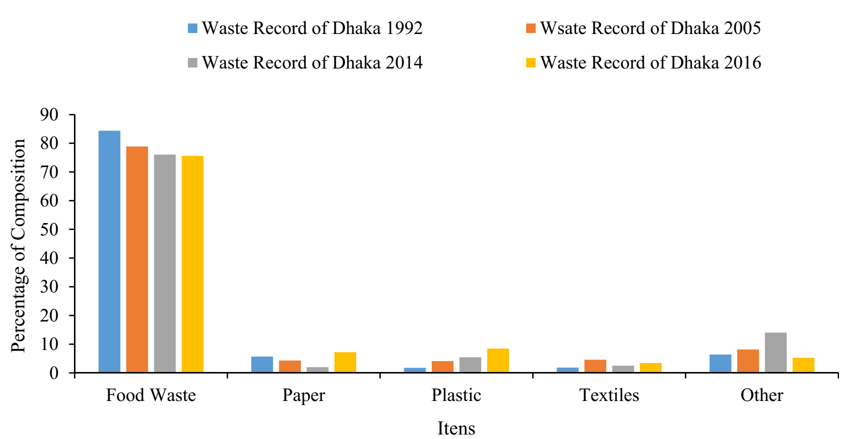
Fig. 8 Plastic products life cycle from waste to recycling



Hashmi 2006a). From Fig. 9, it is surprisingly found that the amount of waste plastic in Bangladesh is increased by 54.76% (Islam 2016).

In the year of 2014, near about 545,300 tons of plastic consumed throughout the country; out of which the number of plastic polybags were recorded as 10 million (Foley 2010; Concern 2015; Moazzem 2016). Among this high amount of plastic waste, about 50% of these plastics has collected through the waste pickers and rest of the plastic are dumped in the open places, canals drains which clogging off the waste

Fig. 9 Proportion of plastic waste in total MSW in Bangladesh



water and drainage system during the rainy season. The informal sector for the plastic waste management mainly established from the commercial point of view to collect and recycle the plastic from different waste source. In the literature it was in the year 2014 around 336,000 tons of plastic was available for recycling. From this substantial amount of waste plastic, direct collection through the middle man were around 134,400 tons and 102,816 tons were collected by the waste scavengers from the dumpsites or landfill areas, whereas, 98784 tons remain untouched (Concern 2015). Presently, the per capita consumption of plastic by the individuals of Bangladesh is 9 kg/year and recycle of this scrape plastic can be the means of saving about Tk. 133.4 million per annum (Corporation 2005; Concern 2015).

However, from some successful measure of waste plastic management around USD 43.42 million was earned in the FY 2012–13 in which 1 million people were engaged directly or indirectly. Furthermore, due to the high calorific value of plastic waste with the range of 20–46 MJ/kg, it has been reported that from the daily plastic wastes about 5115–11,760 MWh/day electricity can be generated by using gasification or incineration energy recovery or producing 920,548 l of pyrolytic fuel (Alom 2015).

Existing legislation against plastic waste in Bangladesh

The implementation of accompanying legislation, as well as a solid shift in approach against plastic bags is first arisen in South Asia especially in Bangladesh. This history of banning plastic bags is discussed in the following section (BBC 2002; Clapp and Swanston 2009; Green 2013):

- Nearly two decades ago, plastic bag was first introduced in Bangladesh, which rapidly substituting jute bags that were enormously used on that time. However, due to serious environmental hazard and clogging effect in drainage system, it becomes a serious concern.
- In 1990, Environment and Social Development Organization (ESDO) initiated several campaigns against plastic shopping bag to draw public attention, later on Ministry of Environment also taken it as a serious issue (Reazuddin 2006).
- In 1993, an initiative to ban the production and trade of polythene bags was taken by Ministry of Environment and Forest (MOEF).
- The Bangladesh Environment Conservation Act was about plastic bag was initially formulated in 1995. But, the law of section 1 under this act was reviewed in 2002.
- In 1999, after the 1998 flood, the MOEF yet again started campaign against polyethylene through its Sustainable Environment Management Program (SEMP).
- In 2002, the MOEF has ban the plastic bag initially in Dhaka city. However, due its adverse effect later on it was ban throughout the country.

The rules against the plastic ban are described in the following section. According to Rule 6(a) of Clause-5 under Section-9, restriction has been imposed in the production and uses of polythene shopping bag (Hossan 2014). According to the rule, there is restriction on the production and sale of environmentally harmful products. If it is proven that any kind of plastic bags or products made of polyethylene or poly-propylene is detrimental for environment then government could control/ban the use of these products to any selected area or all over the country.

According to rule 6(a), the penalty and punishment will be

1. For production, import and marketing: 10 years sentence of vigorous prison, or 1 million taka fine, or both punishments together.
2. For sale, exhibition for sale, store, distribution, transportation or use for commercial purpose: 6 months sentence of vigorous prison or 10 thousand taka fine, or both punishments together (Hossan 2014).

However, Bangladesh is still struggling with the issue of plastic bags and enforcing the ban. The Bangladesh government runs a number of mobile courts, which a few times per year set up at markets to target those breaking the ban by using plastic shopping bags.

Plastic waste management in Bangladesh

Waste is defined as the objects, which is dispose of by the user or intend to dispose of or required to dispose of by EU Directive (Council 2008). In 1992, government from the 178 member countries around the world agreed for a sound environment through the proper management of the solid waste both in the developing and developed countries at the United Nations Conference on Environment and Development in Rio de Janeiro, Brazil. According to the Chapter 21 of Agenda 21, the Rio Declaration on Environment and Development, the government from the different countries set the following waste management hierarchy for a better world which is presented in Fig. 10 (UNDESA 2005).

Although plastic is biodegradable, but it takes good deal of time for completely degrade depending on the composition. As the presence of organic carbon and ash content in the plastic causes the aridity of the soil by killing the helpful bacteria due to its long time taken for degradation (Islam 2016; Nasrin 2016). Also, the clogging of drains and sewerage lines, contaminations of the surface water with the sheltered unhygienic water bodies causes severe environment and

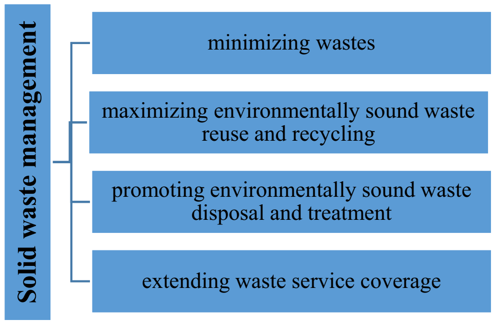


Fig. 10 Proposed waste management hierarchy (UNDESA 2005)

health hazards as the plastic takes time to completely degrade (Rajkumar 2015). Owing to this proper management is needed to save our environment from pollution. On top of this, the socio-economic aspect also needs to be considered prior to executing any management system. Recycling of plastic may help to attain the target of green ecology, moreover it saves energy, reduces various types of pollution, conserves natural resources and enabling the government to be benefited by helping them to put less effort on the disposal of plastic waste (Medina 1997). Modern waste plastic management has minimized the adverse impact on the environment (Matter and Dietschi 2013).

In Bangladesh, there are two groups who are associated with the recycling of plastic known as formal and informal (Zia et al. 2008). Formal sector is industrialized and financially backed by government agencies. Whereas, informal groups stay out of the state control along with maintaining active links with the formal ones (Katusiimeh et al. 2013). In addition, the informal groups act as a front-line service, in turn, put an impact on the whole system (Wilson et al. 2009). In Bangladesh, informal recycling is mainly managed by the poor and less privileged people. They collect the plastic product and sold to the buyers in order to conduct the recycling process (Ezeah et al. 2013).

The recycling practices in Bangladesh are still in the grow up state and people find it simpler to dump the waste recklessly near roadside or in the river or sea shore rather than reuse through recycling. Cost of recycling, lack of available technologies are the driving forces of landfilling or dumping of waste plastics in the water body such as channels, lakes, rivers and even to sea (Castaldi 2014) which consequently affects the infertility of soil and contamination of water to a greater extent (Huq 2015). Moreover, open dumping of the solid waste is a common practice among common people which causes adverse effect on the environment through the emission of green house gas (Aziz 2016; Saifullah and Islam 2016). For example, in Dhaka city, approximately 20% plastic waste has collected and around 37% remains sprinkled at the open places, in drains or in the roadsides (Corporation 2005; Tania 2014). Moreover, around 336,000 tons/year of plastic waste is generated in Bangladesh and approximately 50% of this plastics is used for unplanned land filling annually.

The most common plastic waste management follows some steps, which are the collection of plastic waste, treatment of plastic waste like composting, incineration and disposal (landfills) of plastic waste (Modak et al. 2010). As maximum plastic waste is generated in the urban areas, for this reason, the urban areas have the main responsibilities of plastic waste management, but by involving the rural people more positive result can be found. By implementing (3Rs) Reduce, Reuse and Recycle may help to lessen the load on city authorities for plastic waste management (Modak et al. 2010). This 3Rs strategy helps the government to flourish the Green Projects and Products with the help of Bangladesh Bank's Green Banking. In addition, for a better environment, import of recycling or waste plastic is prohibited in Bangladesh except for EPZ (Huq 2015).

In developing countries like Bangladesh, about 20–50% recurring budget of municipalities is spent on solid waste management in which plastic accounts for 8% of the total solid waste. In Bangladesh, open dumps and open burning are the main procedure to dispose of plastic waste although the collection of plastic waste takes 80–90% of total plastic waste management budgets (Modak et al. 2010). The conventional trend of plastic waste disposal by the householder in Bangladesh is shown in Fig. 11.

In 2011, the Dhaka City Corporation (DCC) has been divided into two parts namely Dhaka North City Corporation (DNCC) and Dhaka South City Corporation (DSCC) to ensure better services to the citizen by the Local Government Act 2009 (LGD 2016). The then Dacca Municipality was first ran its journey in the 1st August, 1864. Then, it was turned as Dhaka Municipal Corporation by the year 1983 and then it was given the status of Dhaka City Corporation in 1990. The DNCC situated at the northern part of the Dhaka City acquiring a total land area of 75 sq. km having 36 wards and the DSCC is at the southern part of the city with 42 sq. km land area and 57 wards (Kabir 2016). In order to smoothing the waste collection process, each of the wards has been grouped into five zones with considerable amount of solid waste management offices and officials. To monitor the overall waste management system a team has been assigned consisting of an assistant chief waste management officer, two conservancy officers, one conservancy inspector for each ward, and two supporting staff. Moreover, according to the Section 50 of the Local Government (City Corporation) Act, a standing committee have to be formed to accelerate the waste management in the city corporation area by the selected ward councilors and Mayor as a member (LGD 2016). The committee will act for a time period of 2 years and 6 months and after this period afresh committee will do the same. The waste management department of DNCC and the DSCC mainly look after the following activities (Kabir 2016):

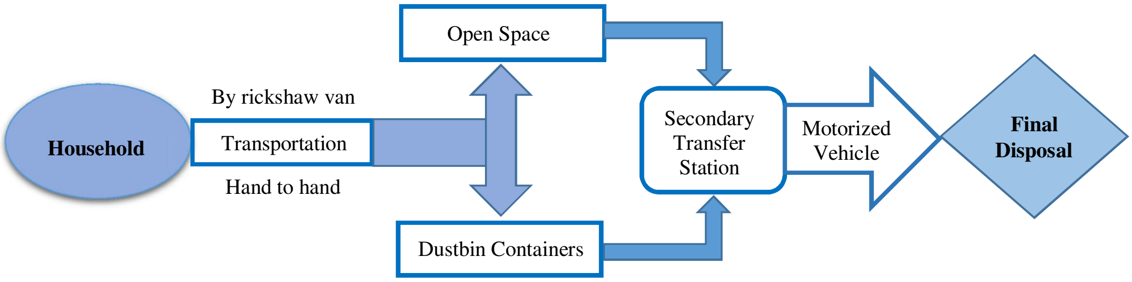


Fig. 11 Conventional trend of plastic waste disposal in the household of Bangladesh

1. Conserving and maintaining of the existing waste collection and disposal units
2. Establishing new waste collection containers, transfer stations to assist the waste collection system and proper maintenance of the dumping sites
3. Giving permissions to the door to door waste pickers and arranging regular skill development program
4. Encouraging and managing the linkage between government, private and community based waste management system
5. Proper monitoring and regular overhauling of the waste collection equipments and vehicles
6. Promoting awareness among the citizen for a healthy environment

The DNCC and the DSCC existing potentials regarding the solid waste management are summarized as follows in Table 4 (Kabir 2016; Wasim et al. 2017):

In the meantime, the two city corporations take initiatives to strengthening their infrastructure, waste collection manpower and equipment through increase the budget allocation for waste management. From a study, it has been found that the annual budget for waste management program rises every year and it is now about 3% for the FY 2015–2016 of the total budget allocation for the two city corporations. The city corporation authority now pays more attention towards the swiftly removal of the daily waste from the house holds to the secondary and finally to the dumping sites at its shortest time. In this sense, DSCC established 81 waste collection containers along with 10 STS whereas DNCC also sets 5700 waste bins under the "Clean Dhaka" campaign (Nasrin 2016). In addition, the government purchased 132 modern waste carrier including 40 compactors and 27 container carriers. This waste carrying freight get reinforced with the 100 more vehicles from Environmental Grant Aid Program (EGAP) by the Japanese government (Kabir 2016). After all of this action from the government and concerned authority, the residents play an important role to keep the environment clean and the DSCC and DNCC also expands their activities to grow public awareness among the mass people. Community-based waste management programs play a long a way to improve waste collection and disposal rate, ensure better work conditions and reduce health exposure, creating employment opportunities by engaging the residents. DNCC and DSCC take some initiatives to raise public awareness in this issue which are (Kabir 2016):

1. Arranging regular meeting and training programs to make aware about the improved waste management system among the citizens
2. Organizing rally and campaign by involving the student to spread out the awareness to save the environment
3. Distribution of leaflet, poster, sticker, newsletter to inform people about the current environmental issues and actions to keep the environment safe and sound

This collective waste management action plan and facilities ultimately strikes the waste collection efficiency of the two city corporation areas and the waste collective waste collection efficiency of the two city corporation has reached to 75.98% which was about 43% in 2005 (University 2015).

In the recent time, two Dhaka city corporations (DNCC and DSCC) have arranged a program with the help of government and non-government organization, by setting some main objectives about the better management of waste plastic. For ensuring better living environment, door to door collection of plastic, perform awareness increasing program to increase awareness among the common people about environmental sanitation and personal hygiene are some of the steps of DCC (Zahur 2007). Figure 12 represents the trend of using plastic and recycling trade chain in Bangladesh.

Figure 13 shows the steps involved in waste plastic collection process in Bangladesh (Waste Concern 2015).

Figure 14 represents the various steps connected with the plastic waste management in Bangladesh. Details description of the following steps is discussed here.

Table 4 Waste management potentials of DSCC and DNCC

Stuffs	DNCC	DSCC
Total area (sq. km)	82.68	43.64
Number of wards	36	57
Number of zones	5	5
Waste generation rate (tons/day)	2700	3300
Waste disposal site	Aminbazar	Matuail
Number of SWM offices	7	10
Number of SWM officials	257	352
Cleaner	3586	5300
Waste management drivers	108	183
Numbers of waste carrying containers	180	270
Number of waste collection trucks (EGAP vehicles 4.05 ton/trip, former city corporation motor vehicles 2.75 ton/trip)	115	235

Collection

Cost effective collection is the first step for recycling of plastic waste. Refuse containers and waste dumps are the sources for waste plastics collection and this collection is done by hand. After this collection primary traders or waste pickers done the job of rough pre-selection (Wienaah 2007). Collection of plastic waste is another stage of waste plastic management which is labor-intensive and can be done from various places such as private homes, waste bins, refuse collection vehicles and plastic waste dumps (Cointreau et al. 2010)

Sorting

The sorting of plastic waste is depending on the demand and wishes of the manufacturers to whom it may be sold. It can be done in different stages of recycling depending upon the color and type of plastic. There are different sorting methods such as manual sorting, density-based sorting methods and sorting by selective dissolution, which is practiced in Bangladesh. Figure 15 represents the sorting of waste plastic in Dhaka City (Shimo 2014; Ruj et al. 2015).

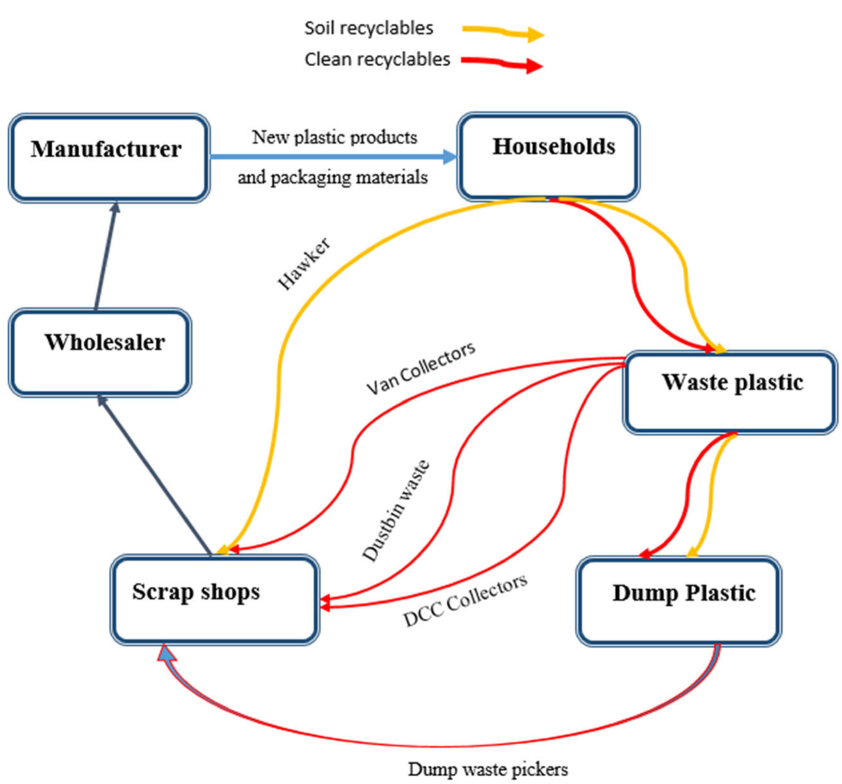


Fig. 12 Trend of using Plastic and recycling trade chain in Bangladesh

Fig. 13 Cleaning, sorting and size distribution of plastic waste

Manual sorting

In this method, while plastic materials passed through by a moving conveyor. Manual sorting is accomplished by the people who have "trained eyes" (J Sheirs 1998).

Density-based sorting methods

Sorting by density technique is performed by using float sink tank or hydro cyclone. This is not a suitable method for those materials which have very similar densities such as polyolefin. Moreover separating PVC and PET is also impossible by this method, because their specific gravity is almost same (Tall 2000).

Sorting by selective dissolution:

Batch dissolution of mixed plastics using solvents is the method to accomplish this type of sorting process. By smoothly monitoring the temperature and selecting the solvent, entire separation of the plastics can be achieved (Wienaah 2007).

However, for many plastics mechanical recycling is suitable, but due to its extensive sorting techniques for ensuring acceptable quality of the product, the profit is becoming low. While recycling, some problem may arise such as hazardous substances may outcome from some plastic products, and also several different materials may exist in some plastic products which have huge chemical diversity (Markus et al. 2014).

Cleaning

Washing and drying are the two segments which are included in cleaning stage. With the help of some illustrative practical examples which is used in different cities of Bangladesh, these two techniques are described below.

Fig. 14 Steps of plastic waste management

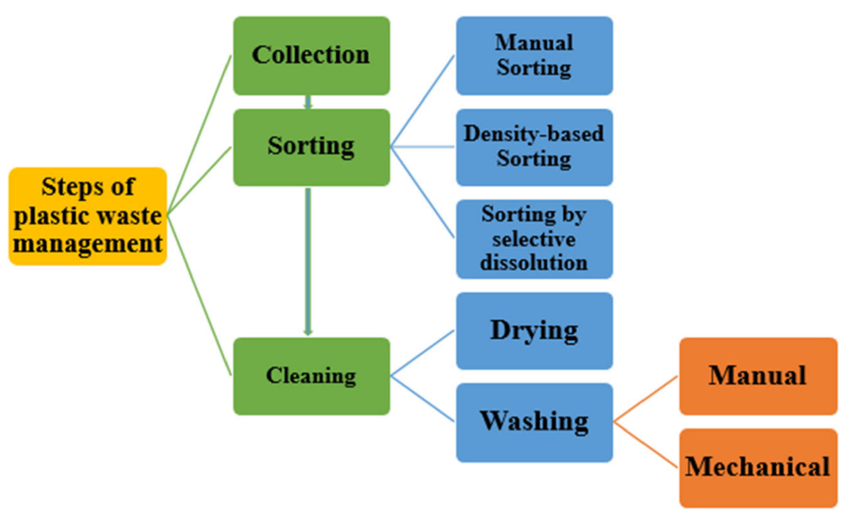


Fig. 15 Sorting of waste plastic in Dhaka (Ruj et al. 2015; Shimo 2014)

Washing

Washing is an important step because waste plastics bring better values and they enrich the condition of the final product if washed properly. Washing can be performed at different stages of the reprocessing like before, after, or even during sorting. Both manual and mechanical washing prevail in Bangladesh. The manual washing is done in specially built basins, in bath tubs or in oil drums that have been cut into half pieces. In order to better cleaning, caustic soda, detergent or hot water with soap is used when the plastic waste is greasy (Ahmed and Lardinois 1995). On the other hand, Blow-plastic is used for mechanical washing. A motor and water filled basin is interlinked in a mechanical washing system, where the motor drives a set of paddles at low speed. Figure 16 represents the available washing procedure of waste plastic (Shimo 2014).

Drying

As there are two types of washing process for waste plastic known as manual and mechanical, drying of this washed output are also different. For manual drying, the plastic is spread out in the sun dry, by hung them on a line. But in the case of Blowplast, a water dryer which is operated on the principle of thermal drying machine at 700 °C is used. Figure 17 represents the drying procedure of waste plastic (Shimo 2014).

Proposed plastic management

Waste plastic material produced from different towns and cities is a part of the municipal solid waste. However disposal of plastic waste is causing many problems such as leaching impact on ground water and land, making land infertile choking of drains, moreover indiscriminate burns causing environmental hazards etc. The waste plastic material is being non-biodegradable, is concerned in most of the cities and towns and thereby giving a bad appearance (Hopewell et al. 2009a, b). It is calculated that approximately 15,342 tons/day (TPD) of waste plastic (on per capita basis) is produced in the country. To overcome these waste plastic disposal problems, Central Pollution Control Board (CPCB) along with M. P. Pollution Control Board has been taken an initiative to use the waste plastic in cement plant at ACC Kymore. For Common harmful Waste Incinerators emission values are observed below the standard set. After getting satisfactory results, many cement plants obtain permission toco-process the hazardous and non-hazardous (including plastic material) waste in their kilns after trial burns from CPCB.

When a plastic material decomposes under the influence of weather effect, first of all, plastic materials break down into smaller pieces of fragmented plastic, since the plastic polymer itself may not inevitably fully degrade within a significant time interval. As a result, significant quantities of plastics are stored in landfills and fragmented plastic in the nature causes both environmental damage and waste-management issue.

In order to overcome these challenges, various approach of waste managements has been adopted such as recycling, landfill, incineration and so on.

Incineration decreases the need for landfill of plastic material waste; Japan and very few European countries like Denmark and Sweden are noteworthy exceptions, with high incinerator (infrastructure) in place for dealing with MSW, including a plastic material. Energy content in the plastic material can be recovered by incineration. Though, it should be remarked that the ability to maintain a residual level of plastic material input, plus the input energy and the result of external impacts on ecosystems will finally decide the ultimate acceptability of the overall system. As a result, we have to find out new technologies of the plastic waste management system. Harmful substances may be released into the atmosphere in this process which may be a great matter of concern. For example, in mixed plastic waste material PVC and halogenated additives is present lead to the risk of dioxins. As a consequence basically of this pollution risk, incineration of plastic material is less harmful than landfill and mechanical recycling as a waste plastic management strategy. The recovered useful energy vary considerably depending on whether it is used for combined heat and power, electricity generation or as solid refuse fuel for co-fuelling of blast furnaces or cement kilns. Liquefaction to diesel fuel or gasification through pyrolysis is also possible and diesel fuel production approach is increasing, due to rising oil prices. Energy-recovery processes are the most suitable way for dealing with highly mixed plastic material like as automotive shredder residue and some electronic and electrical wastes (Siddiqui and Pandey 2013).

The landfill is another successful approach of waste plastic management; however, space for landfills is decreasing in some countries. A well-defined landfill site results in limited environmental harm beyond the harmful effects of collection and transport, though there are risks of contamination of groundwater and soils by some additives and breakdown by plastics material products, which have organic pollutants. A

Fig. 16 **a** Manual washing. **b** Mechanical washing (Shimo 2014)

major disadvantage to landfills is that none of the material resources used to produce the plastic is recovered and the material flow is linear rather than cyclic.

Recycling of plastics is one of the conventional waste methods for decreasing environmental influence and resource exhaustion. Basically, higher levels of recycling, as with a decrease in use, repair and reuse or re manufacturing can permit for a known level of product service with low material inputs than would otherwise be permitted. Recycling of plastic material has many advantages; it helps to save energy and reduce the emission of greenhouse gasses. It also helps to save non-renewable sources like liquid oil, gas etc. Again recycling serves subsistence for a large number of people and families in developing and developed countries, either informal economic activities or formal employment (Hopewell et al. 2009a, b). A typical plastic recycling strategy has been demonstrated in Fig. 18 (Siddiqui and Pandey 2013).

For these drawbacks of conventional waste plastic management, in this paper, we propose a new technology of waste plastic management in the prospect of Bangladesh.

Waste hierarchy concept is based on 3Rs in which they represent reduce, reuse, recycle. For environmentally responsible consumer behavior reduce; reuse and recycle (3R) are the three essential components. But this 3Rs is now replaced by 4Rs, in which the fourth R is added to the three basic R_s, this fourth R represents rethink or recover. Reuse and recycle concept have already explained.

"Reduce" can help to decrease the amount of waste in the environment. For example, we can buy products which have less amount of packaging. Again many products in the market are being wrapped by so many plastic layers which are useless and also there are many products which can be easily produced or do not need a huge amount of resources to produce. These simple products need not be packed. "Reduce" concept can also help by disposing of certain plastic material to a limited number in a certain place.

In many cases, a fourth R is added to the three basic Rs, generally the fourth R stands for either "rethink" or "recover." Rethink means that we have to consider our options and have to think about their impact on the environment. Basically we have to think why we buy any type of plastic material, what type of plastic material we use and how we have to dispose of this type of plastic material. The last R, which is Recover, refers to the practice of putting waste material products to use. After collecting the disposed of plastic material either through landfill or incineration the recyclable plastic material is reproduced or the amount of energy is recovered. For example, methane gas is produced from decomposing garbage products (one of the greenhouse gasses); in which some landfill sites burn and recover for energy rather than dissipate it.

Proposed framework for plastic management in developing countries

There are several options for transforming waste plastic into an asset that has already been practiced in many developed countries can be adopted with some appropriate modification in developing countries. For example, plasma pyrolysis technology, fast pyrolysis, polymer blended bitumen, co-processing in cement kiln are the most potentials ones. Overview of this potential process has been elaborated in the following sections (Medina 1999; Lindell 2012).

Fig. 17 Drying of waste plastic (Shimo 2014)

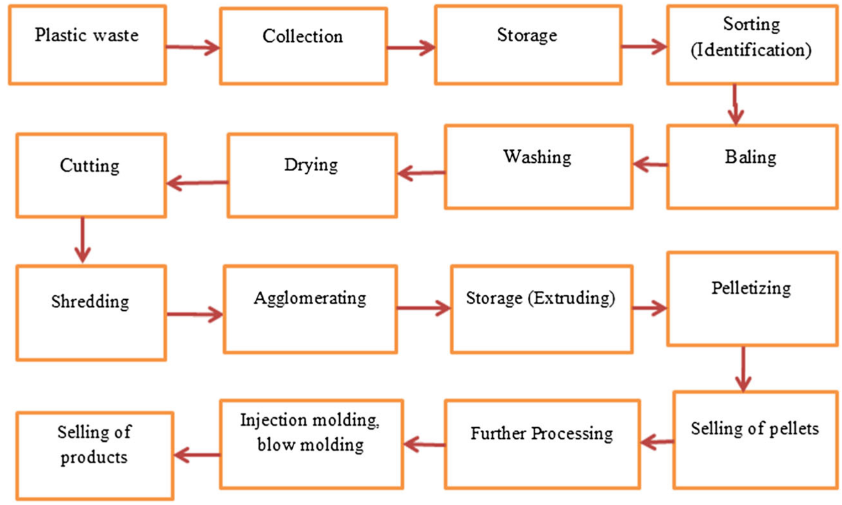


Fig. 18 Simplified scheme of plastic recycling (Siddiqui and Pandey 2013)

Polymer blended bitumen

In many developed countries, the process of the road lying using waste plastic material is designed and the process is being applied successfully for the construction of flexible roads. In this process, after collecting waste plastic, segregating followed by cleaning and drying that plastic. Then shredding the waste plastic into required size of 2 to 4 mm with stone aggregate (granite, ceramic) heated to 160 to 170 °C, shredded polymer waste (5–10%) have to add to heated stone aggregate for 30–40 s and mixed for uniform coating at surface of aggregate, the coated aggregate is then attached with hot bitumen at temperature range of 155 to 163 °C. The mixed composite known as waste plastic-aggregate-bitumen mix is used for road laying at a temperature between 130 and 140 °C as shown in the schematic Fig. 19 (Bhat and Mittal 2016; Tayde 2012; Shedame and Pitale 2014). Again in polymer blended bitumen production waste plastic can be added to hot bitumen to produce plastic aggregate bitumen mix as shown in Fig. 20 (Siddiqui and Pandey 2013; Shedame and Pitale 2014).

A comparative study for 25 mm thickness SDBC (Semi-Dense Bituminous Concrete) – 10 m^2 has been made in India. Three kilograms of bitumen is saved and 3 kg of waste plastic is used. The cost of bitumen is much higher than that of plastics and this process also helps to save the natural resources. There is no maintenance cost for a minimum of 5 years. As a result, the process is less costly and eco-friendly (Tayde 2012; Sreejith 2016).

Recently a researcher from Bangladesh collected waste plastic in shredded form (< 4.50 mm) from old Dhaka (Kashem 2012). Then a total of four modified binders and mixes are prepared with 2.5, 5, 7.5 and 10% waste plastic content to perform the test of penetration, ductility, specific gravity, softening point, flash and fire point, loss on heating etc. At the same time one sample with virgin bitumen and one with 7.5% Pet bottle were also tested. For making this test sample, blending operation was done mechanically. Thermostatically controlled blender prepared by previous researcher was used to perform this study (Al Hossain 2006). However, the above experimentation was done in a small scale but it holds great opportunity for the systematic management of plastic waste through recycling.

Co-processing of plastic waste in cement kiln

Co-processing is the process of using waste plastic or waste material as a source of energy or to replace fossil fuels or natural mineral sources such as gas, coal, petroleum in industry, mainly in energy producing or energy intensive industries like as lime, steel, cement and glass industries etc. Waste plastic materials use for co-processing is referred to as alternative fuels. Co-processing of plastic material completely recovers the energy and for this reason, this process is proposed for waste plastic management.

Waste generation and energy deficiency are the two counteracting phenomenon that the present world facing in a terrible manner. From the very beginning, coal and coke are the conventional energy sources to run the cement industries (Indian Cement 2012). However, the scarcity of high grade coal, price hike and intense emission during of coal insists the cement industries to search for residue waste derived alternative fuels. Moreover, these alternative fuels minimize the greenhouse gas emission by replacing the combustion of conventional fossil fuels as well as the direct incineration of the wastes in open atmosphere. In addition to the reducing greenhouse gas emission features, these types of incineration are advantageous over the dedicated incinerator in terms of derived energy utilization for other mechanical operations and eliminating energy consumption for dedicated incineration process (Indian Cement 2012). Among these types of wastes, plastic has been derived from the crude oil as like the same

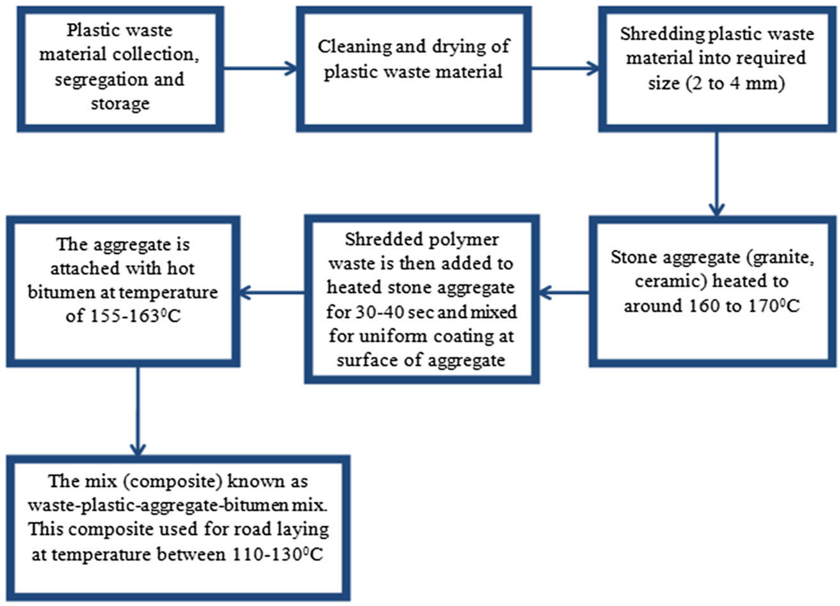


Fig. 19 Simplified scheme of polymer blended bitumen (Bhat and Mittal 2016)

origin of fuels and possesses significant amount of heating values (Poddar and Paranjpe 2015). Some plastic wastes are economically feasible to recycle while the rests find their position in the open dump yard for land filling or direct burning on land. Landfills or open burning left non-degradable materials in the earth which in turn reduces fertility of land. Most of the open burning followed by the partial combustion of the plastic and emits varying quantity of unburned CO, HC, NO_x, SO_x and various toxic gasses depending on the type of plastic wastes (Kim 2015). However, the energy capture from the waste plastics in the form of crude oil extraction through pyrolysis or energy recovery through gasification reduces the demand of fossil fuel for powering engines (Garforth and Ali 2004; Cleetus et al. 2013). The cement industries have been addressed as one of the practical approach to utilize this plastic waste derive energy because the cement kiln has different processing zone with varying temperature modules for the intermittent time period of operations. The operational temperature range for the cement kiln ranging from about 850 to 1800 °C which facilitates different residue drive waste or other fuel to process at different stages. Moreover, the formation clinker is one of the vital steps in the cement kiln that takes place at 1200 to 1500 °C. At this high temperature along with the excess amount of oxygen causes the complete combustion of plastic wastes and does not left traces of harmful pollutants (Indian Cement 2012; Poddar and Paranjpe 2015). Moreover, this type of energy capture enables to use the low end plastic even without separating and cleaning which will rather causes imbalance in ecosystem if it has left without any treatment. Moreover, the counter feeding of the raw materials in the kiln results complete excavation of the exhaust from the kiln by trapping heavy metals, sulfur etc. (Poddar and Paranjpe 2015). Also the emission of fugitive gasses are prevented as the cement kiln works under negative draft pressure. Hence, the operation of cement kiln with the waste plastic as the energy source gets intensified as it utilizes the waste plastic after considering the reuse and recycling options and preventing the reckless open landfill or incineration (Oehlmann et al. 2009). The working principal of co-

Fig. 20 Polymer blended bitumen (Shedame and Pitale 2014; Siddiqui and Pandey 2013)

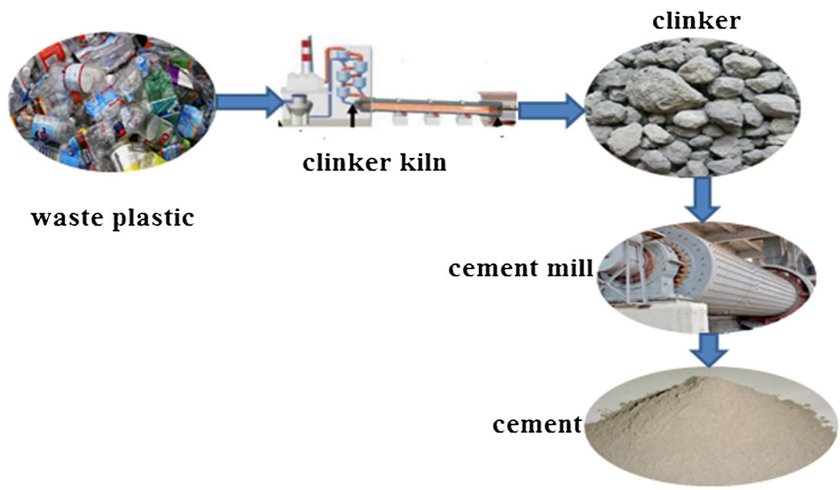


Fig. 21 Working principle of co-processing of Plastic waste in Cement Kiln (Sreejith 2016)

processing of plastic waste in a cement kiln is shown in Fig. 21 (Sreejith 2016).

At 10% replacement rate, 170 cement kilns in India could dispose of the entire plastic waste generated in the country today with the additional benefit of reduction in the use of fossil fuel- coal (Technology 2012).

The energy demand for the global industry is around 45% of the total demand of the energy. Energy intensive industries requirements are 27%. Wastes suitable for co-processing of plastic in cement kiln have an energy potential of 20% of the fossil fuel energy in the present world. By 2030, the thermal decomposition rate of waste could rise to around 30%. The available energy potential in the plastic waste material at present represents nearly 40% of this demand in Europe and expected that to rise to almost 50% by 2030. Around 60% of the waste plastic material that could be re-used for co-processing of plastic waste in a cement kiln is biomass and therefore carbon free (Singh 2014).

Plasma pyrolysis technology

The technology which put together the thermo-chemical properties of plasma with the pyrolysis process is called Plasma Pyrolysis Technology (PPT). The higher heat production ability of (PPT) prefers it to dispose of all types of plastic waste material.

Initially, the plastic waste material is fed into the primary chamber at 850 °C through a feeder in PPT. This waste plastic material decomposes into methane, carbon monoxide, hydrogen, higher hydrocarbons and so on (Pollution and Board 2013). Pyrolysis gasses and the plastic waste product are drained into the secondary chamber by using an induced draft fan. In this chamber, with the presence of excess air, the pyrolysis gasses are combusted the non-flammable gasses catch fire due to high voltage spark. The temperature in the secondary chamber is fixed at 1050 °C. The hydrocarbon, hydrogen, and CO are combusted into the water and harmless carbon dioxide. Conditions are maintained in such a way that it prevents the possibility of formation of toxic gasses. The conversion of organic waste into nontoxic gasses (CO_2, H_2O) is more than around 99%. Stable bacteria are killed by the excessive conditions of plasma such as bacillus stereo thermophiles and bacillus subtilizes right away. Waste plastic material segregation is not necessary, as very high temperatures make sure the treatment of all types of waste without discrimination (Managers et al. 2001). The main parts of the Plasma Pyrolysis system are shown in Fig. 22.

For treatment of waste plastic material, a 20 kg/h capacity plasma arc pyrolyser as well as energy recovery options from waste plastic material has been designed, developed, installed and studied its performance characteristics at the Central Mechanical Engineering Research Institute (CSIR), Durgapur. The performance of the developed plasma pyrolysis has been observed with the plastic waste as feeding material. The major gas components of the product gas are methane, hydrogen, carbon monoxide, acetylene, ethylene and other hydrocarbons, which are combustible in nature. After the experimentation of the pyrolysis, reactor surface is inspected and revealed that it was almost free of residue of waste material; almost no tar was produced in the plasma pyrolysis of plastic waste. This process has advantages over other conventional pyrolysis methods. The product gas from plasma pyrolysis can be applied for syngas applications. It could also be applicable for use in fuel cells after the gas is further cleaned and processed. It can be applied as a fuel gas for turbines or gas engines and so on (Pun et al. 2012). The working principle of the plasma pyrolysis system is shown in Fig. 23 (Pun et al. 2012).

Fast pyrolysis

Fast pyrolysis is a very simple method. However, in the feedstock, a broad range of plastic material can be accepted, including the unwashed, unsorted, or which are hard to recycle.

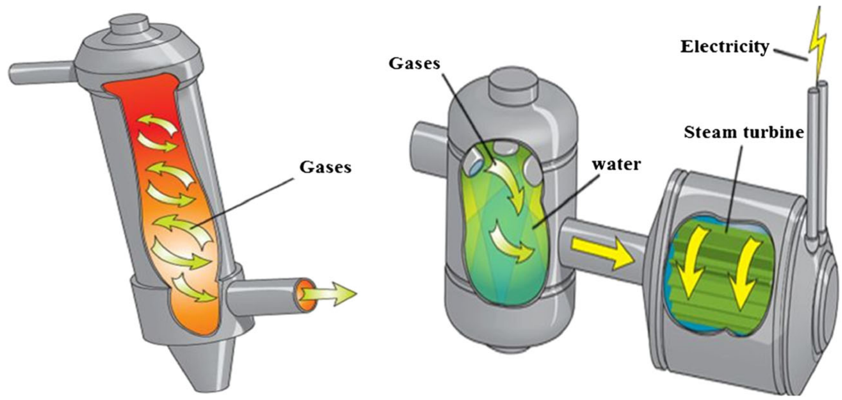


Fig. 22 Parts of the plasma pyrolysis adapted from (Pollution & Board 2016)

Firstly the material is cut up into small sizes prior to its utilization, however, larger pieces of plastic can put directly into the system. To start fast pyrolysis process waste plastic material is laden into a hopper with a forklift. The materials which can be loaded include fuel tanks, plastic car bumpers, component holders, product packaging, agricultural film, and pharmaceutical packaging and so on. To generate heat natural gas is burnt and gets the process started once the hopper is in the reactor. A catalyst helps to break the plastic hydrocarbons into a shorter chain of molecules. The off-gasses that are not collected as fuel are used to produce heat and keep the process going. The fuel oil and diesel are condensed from a gaseous state into a liquid state, which is collected as the process continues. In temporary fuel tanks, they are placed into (Group 2016). The process is controlled by an automated system as shown below Fig. 24 (Wright et al. 2010).

The process of conversion of waste plastic material into liquid fuels is feasible. Also, the rate of fuel does not vary widely along the period (Jones 2009; Wright et al. 2010). In Fig. 25, it is shown that the plastic material is heated rapidly to 450–600 °C in the absence of air (Wright et al. 2010). Under this condition, charcoal, liquid tar, and organic vapors are produced. The vapors then are condensed to oil. The significance of fast pyrolysis is huge due to the reason that a clean liquid is produced in fast pyrolysis which can be used for many applications. In 2003, a researcher from Bangladesh have already performed fast pyrolysis technique utilizing waste plastic (Islam et al. 2004). The lab scale research and pilot plant that have already successfully been accomplished in Bangladesh but it holds substantial prospects for the methodical management of plastic waste.

Among the different propose waste plastic management the polymer blended bitumen can be adopted in developing countries with some modifications. Because the process of polymer blended bitumen can be easily adopted compared to the other processes. Although the polymer blended bitumen process have some technical challenges but the process have already successfully applied in Bangladesh.

In one study conducted in Bangladesh, then a total of 04 (Four) modified binders and mixes are prepared with 2.5, 5, 7.5 and 10% waste plastic content to perform the test of penetration, ductility, specific gravity, softening point, flash and fire point, loss on heating etc. At the same time one sample with virgin bitumen and one with 7.5% Pet bottle were also tested. For making this test sample, blending operation is done by mechanically and thermostatically controlled blender

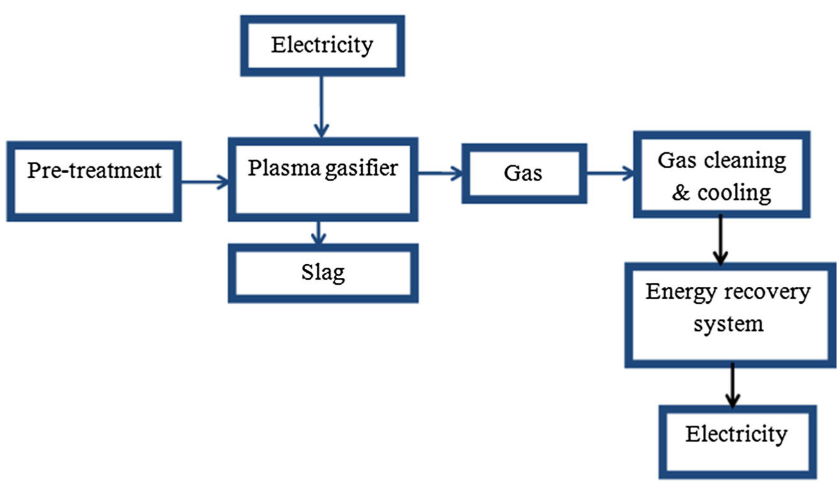


Fig. 23 Working principle of the plasma pyrolysis system (Pun et al. 2012)

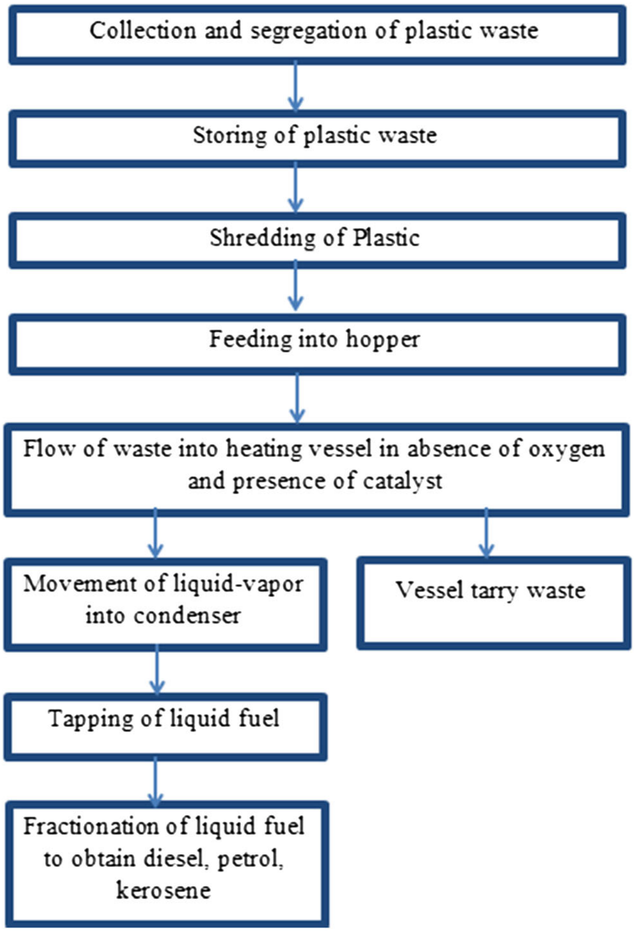


Fig. 24 Working principle of fast pyrolysis (Wright et al. 2010)

prepared by previous researcher is used (Al Hossain 2006). Finally it can be concluded that there is great prospect to utilize waste plastic by adopting the above mentioned proposed technology.

Financial benefits

The financial benefits of waste plastic recycling can be addressed as follows

1. Energy is decreasing day by day, again the fossil fuel also decreasing day by day, so using waste plastic or waste material as a source of energy or to replace fossil fuels or natural mineral sources such as gas, coal, petroleum in industry, mainly in energy producing or energy intensive industries like as lime, steel, cement and glass industries etc. Waste plastic materials use for co-processing are referred to as alternative fuels.
2. By utilizing waste products in a constructive way, we can slowly decrease the size of our landfills. As the population grows, it will become difficult for the landfills to hold so much and trash. When this happens, our cities and beautiful landscapes will face pollution, poisoning and many health problems. The benefits of recycling are that it helps to keep the pollution in check and decrease it little by little.
3. A strong economy is one that is efficient in nature. What drags it down is having to pay for resources that are growing scarce in the country. Every bit of recycling counts when the economy does not have to pay for planting more forests, mining iron ore or purchasing fossil fuels from other countries. When the jobs increase, the economy gets a boost. As the cost of maintaining the current waste disposal system go down, all the money saved is diverted to where it is need the most.
4. Greenhouse gasses are primarily responsible for increase in global warming. It helps to reduce air and water pollution by cutting down the number of pollutants that are released into the environment. A recycling rate of 30% can is almost equivalent of removing 30 million cars from the roads.
5. When recycle aluminum cans, it is possible to save 95% of the energy required to produce those cans from raw materials, energy saved from recycling one glass bottle is enough to light a light bulb for 4 h. This clearly shows how much energy can be saved if recycling is taken on a larger scale. With this, the reliance on foreign oil is reduced which also helps one to save money in long run.

Challenges in waste plastic management in Bangladesh

Implementing of different new techniques to attain a desirable condition of plastic waste in Bangladesh is a challenging task. There are different factors such as lack of economic resources, policy and regulatory, inappropriate technology, lack of

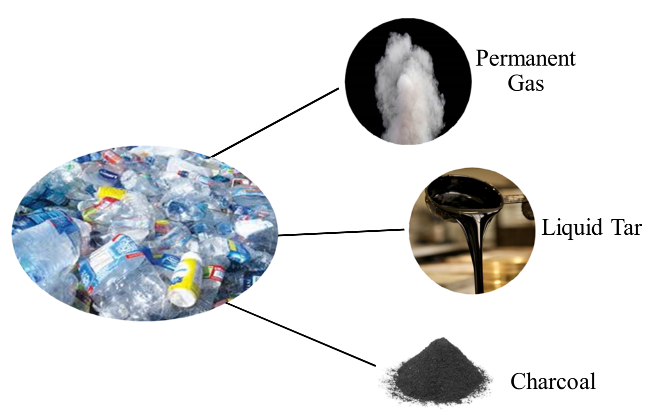


Fig. 25 Outcomes from waste plastics after fast pyrolysis(Wright et al. 2010)

awareness of the mass community people, environmental effect and inadequately trained manpower hindrance to have a green Bangladesh by managing the waste plastic excellently.

Policy-related challenges

The prime challenge in a plastic waste management chain is to reconstruct the rules, supports, and premiums so that the management of waste plastic runs smoothly within the common waste plastic management policy. A summary of policy-related challenges for waste plastic management is given as follows:

- To motivate the members of waste management system a frame work is obvious by which continuous management of waste plastic can be enhanced and ensured. They should have a fixed framework regarding the waste management issue. These management set people in different areas of Bangladesh to increase the awareness of the people not to use plastic shopping bags and give a clear concept of the punishment if anyone use plastic bags. Because in Bangladesh there are many laws regarding against the use of plastic bags.
- Secondly in Bangladesh there are many people who have valuable land but lack of interest to use them for plastic waste management. Policy needs to be developed so that people will be interested to use their land in waste plastic management.

Scarcity of land in the area of the community

Bangladesh was one of the first countries in the world to implement a nationwide ban on plastic shopping bags in 2002, however, due to insufficient enforcement plastic bags remain in the market and the waste stream. MOEF announced that January 1, 2002, shall be the cut-off date for production and use of 20-μm thick polyethylene shopping bag. According to Rule 6 ka of Clause-5 under Section-9, the restriction has been enforced in the production and uses of polythene shopping bag. However the lack of enforcement and a small number of fines have not led to a fruitful result since 2006.

Less that 50% of the waste in Dhaka is collected 380, with estimates as low as 10–15% of plastic waste being managed as part of a formal waste management system 373. The Clean Dhaka Master plan has estimated that as much as 6% of the cities workforce is involved in the informal waste collection and recycling.

- In providing valuable land for landfilling, co-processing in cement kiln and fast pyrolysis. Again less interest was shown by the municipal authority
- The authority of municipal had an assumption that micro-level initiatives could not help to solve the solid waste plastic problem in the cities and towns.
- Source separated waste is hard to get from the household since the community has a poor understanding of the composting process.

In light of the above comprehensive challenges, implementation of the proposed waste plastic management technologies can be adopted in Bangladesh. In addition, "Dhaka Master Plan" also justifies the proposal which is merely discussed as follows:

- The Rajdhani Unnyan Kartripakkha (Rajuk) has to stop promoting plot-based housing in the capital because it encourages massive earth filling of dedicated conservable wetlands by the government and private realtors, recommends a newly proposed master plan for Dhaka city.
- Rajuk instead should support apartment housing and develop urban facilities so that private individuals can build their own houses.
- With the existing master plan mostly unimplemented and its term expiring this year, Rajuk has embarked on drawing up a new one, the Dhaka Structure Plan 2016–2035, under the "City Region Development" project funded by the Asian Development Bank and Bangladesh's government.
- The plan proposes protection of flood flow zones, canals, rivers, ponds and flood water retention areas through land acquisition and proper demarcation to save surface water against contamination, help storm drainage, and ground water percolation.
- The proposed plan outlines long-term development of the city's transportation, housing and utility services, and land use, conservation of floodplains, water retention areas, farmland, open spaces, industrialization, disaster management, heritage and culture. It has divided an updated 1624 sq. km area into six regions.
- The plan recommends construction of three ring roads around Dhaka city, conservation of open spaces and heritage properties, introduction of esthetic urban designing in development, advanced acquisition of land for future road construction.
- Real estate developers have filled wetlands all around leaving Dhaka's storm drainage system clogged.
- The area the plan covers includes four city corporations, five municipalities and 70 Union Parishads of Dhaka, Narayanganj and Gazipur districts with over 15 million people.

- The population is projected to increase to 26 million by 2035 in the proposed plan.
- Gazipur constitutes one-fifth of the master plan area, yet local public representatives were not engaged in the plan preparation process, ignoring local waste management, drainage and disaster management.
- It suggested reclamation of over 2500 acres of flood flow zones and agricultural land from illegal realtors, relocation of 3000 factories and scrapping of 16 development projects.
- Two South Korean consulting firms SAMAN Corporation and Han-A Urban Research Institute and two local firms Sheltech Pvt. Ltd. and DevConsultants Ltd. are preparing the structure plan.

Economical

There are two key economic drivers affect the viability of thermoplastic recycling. These are the price of the recycled polymer compared with fresh polymer and the cost of recycling compared with alternative forms of acceptable disposal. There are additional issues associated with variations in the quantity and quality of supply compared with virgin plastics. Moreover, in many developed and developing country already banned plastic due to cost associated with the plastic bag and due to the environmental problem that created by the plastic bag. For example, in cities Malaysia such as Penang have lead the way followed by other states such as Sarawak and Selangor in case of making shoppers pay 20 Malaysian cents (USD 0.06) per plastic bag (Richards et al. 2016). So the cost of recycling and recycled polymer is a vital key. Additionally, plastic bag tax is a vital concept and the original concept of plastic bag tax is environmental taxation which mainly focused on producer-generated pollution to internalize the external cost of pollution to the environment. The implementation of the plastic bag tax is rather to stimulate consumer behavioral changes, reducing the excessive consumption of plastic (Zen et al. 2013).

A collection of used plastics from households is more economical in suburbs where the population density is sufficiently high to achieve economies of scale. The most efficient collection scheme can vary with locality, type of dwellings (houses or large multi-apartment buildings), socio-economic conditions and the type of sorting facilities available. In rural areas 'bring schemes' where the public deliver their own waste for recycling, for example when they visit a nearby town, are considered more cost-effective than a curbside collection. So the plastics of suburbs and rural areas can be recycled, and some of the materials used to make plastics can be recovered. However, due to difficulties with the collection and sorting of plastic waste, this recycling method is not fully utilized (North and Halden 2013). But the household's willingness to separate the recyclable waste plastic items as the basic requirements is very poor. If curbside recycling facilities are provided respondents indicated positive response towards recycling by showing that 90% of the respondents are willing to separate the recyclable waste plastic (Zen et al. 2014; Zen and Siwar 2015). Again for curbside recycling scheme additional charge is required and gaining respondents support to pay additional charges for the curbside recycling scheme is a vital question. In Kuala Lumpur, Malaysia, the result showed that 41% of the respondents supported the service and agreed to pay extra charges for curbside recycling scheme. It is smaller percentage when compared with the 59% of the respondents that had contrary opinions and refused to pay additional charges for the curbside recycling scheme (Zen et al. 2014; Zen and Siwar 2015). The many local authorities and some supermarkets in the UK operate 'bring banks', or even reverse-vending machines. These latter methods can be a good source of relatively pure recyclables but are ineffective in providing high collection rates of post-consumer waste. In the UK, dramatic increases in the collection of the plastic bottle waste stream were only apparent after the relatively recent implementation of curbside recycling the price of fresh plastic is influenced by the price of oil, which is the principle feedstock for plastic production. As the quality of recovered plastic is typically lower than that of fresh plastics, the price of virgin plastic sets the ceiling for prices of recovered plastic.

So, while over a decade ago recycling of plastics without subsidies was mostly only viable from post-industrial waste, or in locations where the cost of alternative forms of disposal was high, it is increasingly now viable on a much broader geographic scale, and of post-consumer waste.

Technological

In many cases, municipal wastes are not well defined in developing countries and municipalities cannot cope with the rate of waste production. Waste collection rates are often lower than 70% in low-income developed countries. More than 50% of the collected waste is often disposed of through uncontrolled land filling and about 15% is processed through unsafe and informal recycling.

A few of the pressing issues include rapidly increasing quantities and diverse characteristics of the waste, the undesirable consequences of conventional methods of waste management, and failure to tap the resource value of waste.

Experience in developing countries shows that government-led top-down approaches striving to replicate existing models of waste management as used in industrialized countries, focusing on engineered solutions and mechanized technology, or else strict enforcement of policies and regulations, are seldom suitable nor sustainable in low-income urban areas (Wilson et al. 2009).

In addition, to maximize recycling performance labels and adhesive materials are selected. Improvements in sorting/separation within recycling plants give the further potential for both higher recycling volumes, and better eco-efficiency by decreasing waste fractions; energy and water use even, it is unfortunate that there is no hazardous waste collection and disposal scheme is present in Dhaka city.

Technological advances in the recycling can improve the economics in two main ways—by decreasing the cost of recycling (productivity/efficiency improvements) and by closing the gap between the value of recycled resin and virgin resin. The latter point is particularly enhanced by technologies for turning recovered plastic into food grade polymer by removing contamination—supporting closed-loop recycling. This technology has been proven for rPET from clear bottles (WRAP 2008), and more recently rHDPE from milk bottles (WRAP 2006).

Industrial

The plastics industries have been developed widely because of the production of polymers from different chemical and petrochemical sources When a plastic material decomposes under the influence of weather effect, first of all, plastic materials break down into smaller pieces of fragmented plastic, since the plastic polymer itself may not inevitably fully degrade within a significant time interval. As a result, significant quantities of plastics are stored in landfills and fragmented plastic in the nature causes both environmental damage and waste-management issue.

Again due to the use of waste plastic in the industry the quality of the product decreases like as cement production. Again much industry will be hampered due to landfilling and incineration because as compared to the amount of land use, the output of the industry will not be up to the mark.

Environmental

The management of waste plastic material needs to take initiatives in industries in a systematic approach like as handling, storage, and disposal to reduce the risk to environment and health and increase positive measures to an extent that will increase sustainable environmental quality. Because waste plastic now uses in a cement kiln, fast pyrolysis and in polymer blended bitumen. When used in polymer blended bitumen the plastic material creates environmental pollution. In cement industry also due to the use of plastic material, the amount of pollution is increased.

Each year the world goes through some 500 billion plastic bags. They are also at the heart of a battle raging in municipality's worldwide due to the environmental damage caused, polluting waterways and other natural areas.

Unsatisfactory waste management occurs due to low collection coverage, unavailable transport services, and lack of suitable treatment, recycling and disposal facilities, lead to water, land and air pollution, and for putting people and the environment at risk.

Informational

Lack of information about the availability of recycled plastics, its quality, and suitability for specific applications can also act as a disincentive to use recycled material.

Major inhibitors for MSWM for developing countries, includes a low level of technical knowledge, budget allocation MSW management, particularly in collection, transport and disposal mechanism, considering resource recovery, improper MSWM in their respective cities, Human health and biological degradation are affected by improper management of MSW that leads to socio-economic degradation.

The great variety of the different types of plastics that exist renders it difficult to make an unambiguous statement which types of plastic should be avoided at home—additives alone, which give different types of plastic their different properties, and which are also prone to leakage, the number in the hundreds.

Availability

Due to insufficient of integrated solid waste plastic management, most of the plastic waste material is disposed of in an inappropriate manner to avoid its negative impacts on nature and environment and public health and waste plastics are causing chocking and littering of the sewerage system.

Health hazard

These plastic collectors, particularly the children, are vulnerable to infection disease contamination because they do not wear any protective clothing during collection of the waste plastic material which is used in a cement kiln, fast pyrolysis process and polymer blended bitumen. Different types of wastes end up at dumpsites, hospital waste, for example, are mixed with polyethylene bags. Apart from hazardous chemicals including heavy metals; hospital waste may contain pathogens of various infectious diseases, such as tuberculosis, cholera, and typhoid. These diseases are transmitted further by waste collectors when they work in other places without properly washing their hands, for example, women working part-time in the service sector.

Conclusion

Enormous amount of waste plastic is being produced in Bangladesh. Proper management of these waste is indispensable to save the environment from the hazardous effect of plastic waste. However, lack of facilities, infrastructure development, and insufficient budget hinder in management of plastic waste in Bangladesh. Moreover, traditional methods are not effective and adequate in the plastic waste management system in Bangladesh. Several potential waste plastic management systems have been proposed along with the challenges that would be encounterred during the implementation of these strategies. Successful implementation of the proposed management systems would mitigate the plastic waste management-related problems and be the promising source of renewable energy.

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