The Energy and Resources Institute

CHALLENGES AND **OPPORTUNITIES**

Plastic Waste Management in India

CONTENTS

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Introduction

The plastic industry, owing to its use in a wide variety of sectors, such as the automotive, construction, electronics, healthcare, and textiles, is amongst the fastest growing markets. An analysis by Plastindia Foundation suggests that the industry has grown at a compound annual growth rate (CAGR) of 10%, in volume terms, from 8.33 million metric tonne per annum (MMTPA) in FY 10 to 13.4 MMTPA in FY 15 and is expected to grow at 10.5% from FY 15 to FY 20 to reach 22 MMTPA. This growth would be further impelled by various government initiatives, such as Make in India, Skill India, Digital India, and the Swachh Bharat Abhiyan.[1] Figure 1 depicts the consumption of plastic in the various sectors.

[1] 2016. 'Indian Plastic Industry Set to Buck the Global Trend, Set to Grow 12% This Year'; refer to https://www.indiainfoline.com/article/news-top-story/indian-plastics-industry-set-to-buck-the-global-trend-set-to-grow-12-this-year-116091200141_1.html; last accessed on May 30, 2018.

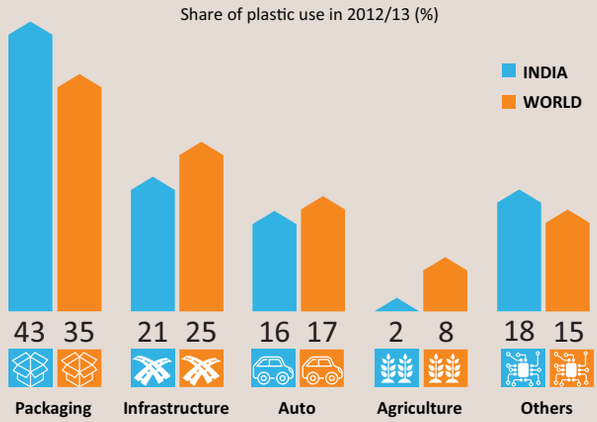

FIGURE 1: Plastic consumption in various sectors
Source: FICCI

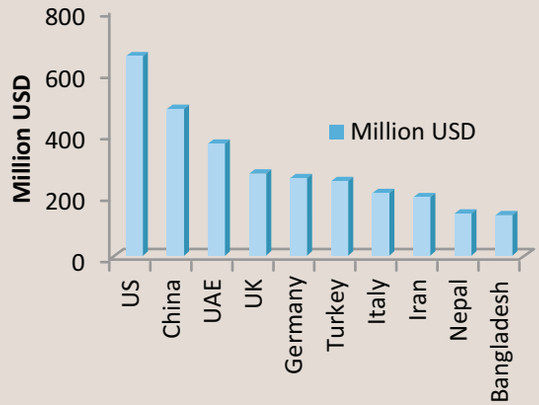

FIGURE 2: Plastic exports in India FY 2015/16
Source: Ministry of Commerce and Industry, Government of India

While the petrochemical sector is regarded as the backbone of plastic production, it is also considered a yardstick for measuring global economic growth, wherein plastic processing and production is of vital importance.[2] Production of plastic (in terms of tonnage) is dominated by polyolefins, such as polyethylenes, polystyrene, and polypropylene. The major polyolefin producers in India include the Reliance Industries, Indian Oil Corporation Limited, Haldia Petrochemicals, Bharat Petroleum Corporation Limited, and Gas Authority of India Limited. Figure 2 depicts the export figures for plastic to the various countries in FY 2015/16.[3] It is expected that in the current financial year (FY

[2] 2018. 'Plastics Industry: Spurring Indians Economic Growth'; refer to http://www.ipfonline.com/news/detailnews/Plastics-industry-Spurring-India-s-economic-growth/Technical%20Articles/8895/9718; last accessed on May 30, 2018.

[3] The Indian Plastic Industry (October 2017); refer to www.ibeb.org/exports/plastic-Industry-India-astex; last accessed on May 29, 2018.

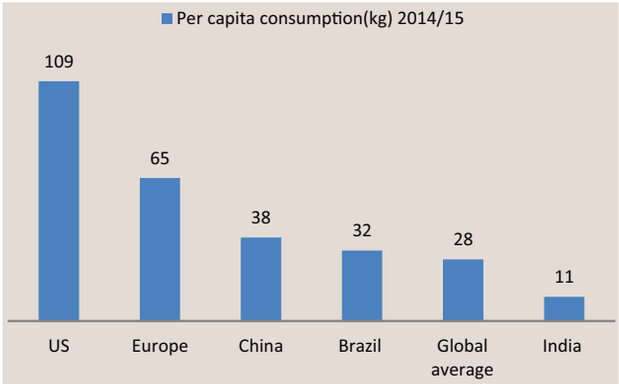

FIGURE 3: Per capita consumption of plastics
Source: FICCI

2018), exports would cross 8 billion USD with an increased growth of 9.5% in the first half of FY 2018 as compared to the past year. It is also envisaged that exports are expected to double in the next 5 years, owing to the growing domestic production.

The average per capita consumption of plastic in India is about 11 kg, which is considerably low as compared to the global average of 28 kg. This is further brought into perspective with a special emphasis on the US where consumption is nearly ten times as has been shown in Figure 3. An estimate by the Ministry of Petroleum and Natural Gas, Government of India suggests that the annual per capita consumption in India would be 20 kg by 2022. Further, the World Economic Forum suggests that the volume of plastic production and consumption would considerably increase, thus leading to large amounts of plastic waste generation and related GHG emissions by 2050. Further, the forum also states that owing to the dependence on petroleum feedstocks, oil consumption will have increased threefold and the carbon budget would register an increase from 1% to 15%.

Although the burgeoning rates of plastic production project positively for Indian businesses, the cause of concern is the lack of an organized mechanism to deal with 15,342 tonnes of plastic waste generated per day. As per the Central Pollution Control Board (CPCB) reports, plastic contributes to 8% of the total solid waste, with Delhi producing the maximum quantity followed by Kolkata and Ahmedabad.[4] Further, the report also suggests that 60% of the total

[4] This is as per the CPCB- CIPET survey conducted for 60 Indian cities.

plastic waste is being recycled. The major challenge, however, is segregation and re-aggregation of plastic waste streams such as packaging waste, including laminated plastic. Although recycling is one of the preferred ways to deal with plastic waste in the waste hierarchy, the concern is the heterogeneous properties of unsegregated and littered waste that remains scattered in the urban landscape. These result in an unpleasant landscape, choking of drains, and release of GHGs from landfills at times leading to fire. The major components of plastic waste (in terms of tonnage) have been expressed in Table 1.

Table 1: Major components of plastic waste with their applications

Plastic	Application
Polyethylene terephthalate (PET)	Water and soft drink bottles, food jar
Polyvinyl chloride (PVC)	Cables, plumbing pipes
High-density polyethylene (HDPE)	Shampoo bottles, packaging
Low-density polyethylene (LDPE)	Grocery bags, packaging
Polypropylene (PP)	Bottle caps, medicine bottles, chips packs
Polystyrene (PS)	Disposal cups, cutlery, packaging foam
Polycarbonate (PC)	Food packaging, electronic goods, and defence gadgets
Nylon	Fishing nets, clothing, ropes

The research and policy fraternity is constantly exploring opportunities to address these problems. Some existing options are:

- One of the sustainable alternatives that could be considered to deal with plastic waste is to develop bio-based and biodegradable plastic which utilize starch, cellulose, and poly lactic acid as raw materials for short-term use products. However, these are more expensive and are presently at a lab scale, which needs to be upscaled. Possible incentive-/subsidy-based strategies for product development and research would assist in facilitating this upscaling. This in turn would increase their usage and enhance the market for these products. Applications of bio-based products extend from the manufacturing of green packaging, disposable cutlery, agricultural mulch films, and manufacturing of superabsorbent materials, that can be used for a sustained release of pesticide/fertilizer in the agricultural sector. Further, these can also be used as eco-friendly alternatives for the removal of toxic dyes and heavy-metal contaminants from water bodies.
- Recycling of plastics is considered the next viable and technically feasible option to tackle plastic waste. The approach utilizes several technologies to produce a second supply chain of raw materials. Recovery of secondary raw materials through recycling is given the highest priority after reuse, according to the waste hierarchy. Recycling options are generally classified into primary and secondary recycling, while tertiary recycling is preferred for multilayered plastics (MLPs) where separating individual layers is difficult and expensive. Recycling requires participation from the public and, therefore, needs citizens to perform separation of waste materials at the source.
- Another potential use of plastic is to generate fuel from waste plastics. The current energy requirements are predominantly met using fossil fuels. Converting waste plastics to fuel is beneficial as it not only allows for waste plastic to be disposed of but also presents the opportunity of developing an alternative to fossil fuel. However, this is still at the research stage. Studies reveal that presently, the 'methane number' of pyrolysis gases is below 65 which is less than the minimum requirement as per the standard for the EU and USA. [5,6]
- Non-recyclable plastic waste finds its application in the co-processing of plastic waste in cement kilns. This refers to the use of wastes in industrial processes from which the energy and material form is recovered.
- Plastic waste is also integrated with bitumen for laying roads. The process of laying roads by utilizing this technique has been well established for the advantages it offers.

This paper seeks to explore and assess all aspects related to plastic waste management and the development of a sustainable alternative to plastics. It also touches upon laws and policy implementation.

[5] Honus, S, Kumagai S, Molnar V Fedoko G, and Yoshioka T. 2018. *Fuel* 221: 361–73.

[6] Honus, S, Kumagai S Fedorko G, Molnary, and YoshiokaT. 2018. *Fuel* 221: 346–60.

Problems Relating to Plastic Waste

Laws and their implementation

In order to address the burgeoning rates of plastic waste disposal and to ensure its scientific management, Plastic Waste Management Rules (PWR), 2011, was introduced under the Environment Protection Act, 1986. The rules established a framework which assigned responsibilities for plastic waste management to the urban local body (ULB)[7] and set-up a state-level monitoring committee. The rules further addressed the issue of carry bags by setting minimum standards for the thickness and a mandate for retailers to charge a fee for each plastic bag made available.

The 2011 rules were succeeded by the Plastic Waste Management Rules 2016[8] which was far more comprehensive and sought to effectively address the issue of plastic waste. This version of the rules extended its purview and applicability to rural areas and plastic importers in the supply chain. Further, the minimum thickness of plastic carry bags was increased from 40 micron to 50 micron. The rationale for doing this was double-edged—that is, not only will the recyclability quotient increase, an increase in the manufacturing cost will deter retailers from supplying bags for free. The rules also mandated the producers and brand owners to devise a plan in consultation with the local bodies to introduce a collect back system. This system known as the Extended Producers Responsibility (EPR) would help assist the municipalities in tackling the plastic waste issue. As a part of the EPR, it also provides for collection of a fee from the producers, importers of plastic carry bags/ multilayered packaging in order to strengthen the financial status of local authorities and, therefore, the plastic waste management systems.

The 2016 rules were revised to be known as the Plastic Waste Management (Amendment) Rules 2018. Three major changes amongst others have been incorporated in the latter. Firstly, the rules notify that under Section 9(3), the term 'non-recyclable multilayered plastic' has been substituted by 'multilayered plastic which is non-recyclable or non-energy recoverable or with no alternate use'. Secondly, Section 15 dealing with the pricing of carry bags has been omitted. The rule earlier required vendors, who made plastic bags available, to register with the respective urban local body and pay a fee of ₹48,000 annually. Thirdly, the new rules attempt to establish a centralized registration system by mandating brand owners and producers operating in more than two states to register with the CPCB. While the rules have been introduced with an attempt to mitigate the plastic menace, some concerns still remain.

The unaddressed expression of EPR

The government and industry must aim at partnering and establishing effective and sustainable EPR implementation models. The idea of the EPR introduced by the 2016 rules was novel but lacked detailing. The EPR for plastic waste management would require similar detailing to that provided by the 'Implementation Guidelines for E-waste' relating to e-waste. There is a need for a real-time assessment and a state-wise mapping of producers, plastic demand and supply, thereby, formulating realistic and accountable EPR targets. Furthermore, pilot EPR models for low-hanging fruits such as the completely recyclable PET must be prioritized and explored. Municipalities may explore some successful models implemented in the state of Goa which includes measures such as the following:[9]

- Tie-ups with local dairies for paying residents a specified amount for returning washed, empty plastic milk bags at the local dairy booths
- Tie-up with Tetra Pak (company) for a buyback of empty packs

Further, India could also seek to explore multiple successful models implemented in other countries where producers take the responsibility of the product's end of life by funding plastic waste management activities.

Sustainability of plastic waste management

As India progresses towards a circular economy, there is need to transition towards improved waste

[7] Press Information Bureau, Plastic Waste (Management and Handling) Rules, 2011; refer tohttp://pib.nic.in/newsite/PrintRelease.aspx?relid=69649; last accessed on May 29, 2018.

[8] Plastic Waste Management Rules, 2016; refer to http://www.moef.gov.in/sites/default/files/PWM%20Rules%2C%202016.pdf; last accessed on May 29, 2018.

[9] The GIZ-CPEEHO manual.

management systems with increased emphasis on information, education, and communication (IEC) amongst its citizens on the issues relating to plastic waste management. Though it is established that solid waste management (SWM) is a state subject with the rules further narrowing down the responsibility to ULBs, there has been little focus and emphasis on ensuring that the service is sustainable financially. Municipalities with a few exceptions are often found grappling for funds to meet expenses related to SWM as The Energy and Resources Institute's (TERI's) article on 'Why Take Away the Cess meant to Clean India's Mess'[10] reemphasizes that there is an impending need for the central government to empower the ULBs financially. Although schemes such as the Swachh Bharat Abhiyan support the local bodies in their efforts by providing viability gap funding or tender document preparation support, there is a need to establish a mechanism to financially sustain this service that operates every day of the year.

Pricing of carry bags

The PWR 2018 amendment has done away with Rule 15 of its predecessor aimed at the pricing of plastic carry bags. It is envisaged that charging users for carry bags would be a key step towards initiating a behavioural change, albeit gradually. Results of a study conducted by the Delhi School of Economics on 'Consumer Responses to Incentives to Reduce Plastic Bag Use'[11] states that in developing countries, a blanket ban may not be the best possible solution and 82% of the consumers would switch from plastic bag use to own bags if the former were priced explicitly. Further, TERI's article on 'Fighting Plastics: Is Ban the Way Forward?'[12] observes that the success behind implementing a fee on plastic bags has been established as an effective strategy in cities around the world.

Enforcement of legislation

Although the government has been proactive in terms of formulating rules, the implementation of a few inclusions has been a challenge. For instance, the PWR 2016 calls for producers and brand owners to work out modalities of the EPR with ULBs within a period of 6 months of the publication of the rules. The implementation of the same may be taken up on a priority basis.

Another instance is the ban on the use of carry bags less than 50 micron in thickness. The effective implementation of this legislation has been a challenge for many municipalities with the use of bags <50 micron persistent with roadside hawkers and vegetable markets owing to cheaper price and continued local manufacturing. Further, the latest CPCB report on the implementation of Plastic Waste Management Rules, 2016, acknowledges that the manufacturing, sale, and stocking of carry bags (<50 micron) has continued in majority of the states/UTs post the implementation of the ban. The situation, therefore, demands for increased monitoring and verification by the ULB staff.

Multilayered plastics (MLPs)

According to the CPCB,[13] an MLP refers to any material used for packaging that has at least one layer of plastic as its main ingredient in combination with one or more layers of paper and aluminium foil either in the form of laminate or a co-extruded structure. Most companies prefer MLPs as they are three times more waterproof, light-weight, reduce shipping volume, and help in increasing the shelf life of products, such as fruit juices and sweets by keeping them fresh for extended periods even at room temperature. However, recycling of this packaging remains expensive and a challenge owing to its multilayered properties. The amendment under the 2018 version of the plastic law allows MLPs to be categorized under either recyclable, energy recoverable, or with some other alternate use.

Indiscriminate littering

Plastic waste, especially carry bags is a major environment and public health problem in India, particularly in urban areas.[14] In India, plastic bags of all

[10] Refer to https://thewire.in/economy/swachh-bharat-cess-budget-2018; last accessed on May 29, 2018.

[11] Consumer responses to incentives to reduce plastic bag use; refer to https://www.isid.ac.in/~pu/conference/dec_11_conf/Papers/KanupriyaGupta.pdf; last accessed on May 29, 2018.

[12] Refer to http://www.teriin.org/article/fighting-plastics-ban-way-ahead; last accessed on May 29, 2018.

[13] Definition of Multilayered Plastics – CPCB.

[14] Tammemagi, H Y. 1999. *The Waste Crisis: Landfills Incinerators and the Search for a Sustainable Future*. New York: Oxford University Press.

sizes and thickness are often found occupying the city landscape due to problems of overuse and littering.[15] In addition to being a visual harassment, plastic bags tend to clog drains, gutters, and rainwater vents, thereby creating a flood-like scenario even for sparse rains. Further, they also pose a danger to stray animals, such as cattle and dogs, who stand a good chance of consuming them. The Solid Waste Management Rules, 2016, provide for a legislation under which ULBs may penalize citizens in the form of spot fines for littering or failing to comply by the provisions of the rules. Strict fines may alone act as a deterrent for individuals indulging in littering.

Effect on the marine environment

The problem of ocean plastic litter is on the rise due to the overflowing effect of plastic waste into the sea. It has been reported that in India, 0.60 million tonnes of plastic waste, out of 5.6 million tonnes, end up in seas annually. The seas near Mumbai, Kerala, and the Andaman and Nicobar Islands are amongst the worst polluted in the world.[16] Both plastic wastes and micro-plastics can enter into the marine environment from land by rivers, drainage or sewage systems, or by wind transport. Some of the most important land-based sources of larger plastic (macroplastics) wastes are from construction, household goods, packaging, coastal tourism along with food and drink packaging. In seas, plastic pollution impacts turtles, whales, seabirds, fish, coral reefs, and countless other marine species and habitats. According to a study by Laist (1997), plastic debris affects at least 267 species worldwide, including 86% of all sea turtle species, 44% of all seabird species, and 43% of all marine mammal species.[17] The main hazard caused by plastic debris to marine life is attributed to ingestion and entanglement, which results in the injury and death of marine animals and birds.[18] Studies have found that 94% of 67 fulmars (marine bird species) had ingested plastics fragments such as styrofoam and candy wrappers.[19,20] An average of 34 pieces of plastic particles were found per bird. The harm from ingestion of plastics is just not restricted to seabirds. According to a study, on an average 1,000 sea turtles die every year due to ingestion of polythene bags that have drifted into the ocean.[21] Further, researchers also found that in Daman and Diu, plastic debris was found in the stomach of a Longman's beaked whale. Studies have shown that, the large amounts of plastic waste in marine environments may also lead to toxic metals entering the food chain.[22] It has been reported that significant amount of toxic heavy metals, such as copper, zinc, lead, and cadmium were recovered from the plastic wastes on sea shores, which again have an adverse effect on coastal ecosystems. Considering these facts, it is of utmost importance to carry out a detailed assessment of the plastic waste issues from the polluting source to the sea. This would help identify problematic areas where urgent interventions are required. Furthermore, public awareness regarding plastic waste disposal and its effects on the marine ecosystem is equally important.

Plastic waste in landfills

Many cities in India lack designed scientific landfills for the disposal of municipal solid waste. Cities choose to dump solid waste in dump yards where waste is either buried or left as it is. In India, dumping is a common practice, particularly due to the lack of awareness and the need for land to discard an enormous amount of wastes generated from our households and surrounding areas. If the solid waste is dumped at the

[15] Koushal, V, Sharma R, Sharma M, Sharma R, Sharma V. 2014. Plastics: Issues Challenges and Remediation. *Int J Waste Resources* 4: 134.

[16] Refer to http://www.downtoearth.org.in/news/mumbai-kerala-most-affected-by-marine-litter-microplastics-are-a-major-threat-57507; last accessed on May 29, 2018.

[17] Laist, D W 1997. 'Impacts of Marine Debris: Entanglement of Marine Life in Marine Debris Including a Comprehensive List of Species with Entanglement and Ingestion Records', J M Coe, D B Rogers (Eds.), Marine Debris—Sources, Impacts and Solutions, pp. 99–139. New York: Springer-Verlag.

[18] Gregory, M R. 2009. 'Environmental Implications of Plastic Debris in Marine Settings: Entanglement, Ingestion, Smothering, Hangers-on, Hitch-hiking and Alien Invasions', *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364: 2013–25.

[19] Ryan, P G, Moore, C J, van Franeker, J A and Moloney, C L. 2009. 'Monitoring the Abundance of Plastic Debris in the Marine Environment'. *Philosophical Transactions of the Royal Society B* 364: 1999–2012.

[20] Thompson, R C, Swan, S H, Moore, C J, and Frederick S. vom Saal. 2009. 'Our Plastic Age'. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 27 (364): 1973–6.

[21] Tomás, J, R Guitart, R Mateo, and J A Raga. 2002. 'Marine Debris Ingestion in Loggerhead Sea Turtles, Caretta caretta, from the Western Mediterranean, *Marine Pollution Bulletin*, 44: 211–16.

[22] Munier, B and Bendell L I. 2018. Macro and Micro Plastics Sorb and Desorb Metals and Act as a Point Source of Trace Metals to Coastal Ecosystems. *PLoS ONE* 13 (2).

current rate, 1,240 hectares of land would be required every year as a landfill site.[23] In India, solid waste generation per capita varies from 0.17 kg/person/day in small towns to roughly 0.62 kg/person/day in mega cities.[24] In landfills, plastic degrades into its smaller components and leaches into the soil and the water table, ultimately making its way towards the food chain and causing massive health hazards. Leachates from landfills contains metals, such as lead, mercury, cadmium along with pesticides, pharmaceutical wastes, disinfectants, organic compounds, chemicals, and so on. Over time, this enters into the soil and finally reaches groundwater. Unmanaged landfills are a chief source of groundwater contamination.[25] A mixture of toxic substances and decaying organic material from a landfill site can affect the soil quality of the adjacent areas. This can exert a direct impact on the biodiversity as the local vegetation may stop growing and may even be permanently transformed.

Several GHG gases are emitted from landfills amongst which carbon dioxide and methane constitute 90% to 98%, respectively. Methane emissions originate due to the decomposition of organic matter in the landfills. GHG gases have the ability to trap solar radiation, thereby leading to global warming. Methane is flammable and can cause landfill fires.

Waste burning

Waste burning is a perennial problem that has been faced by municipalities around the country. Thick black smoke emanating from dumping grounds has become a commonly perceived sight. The practice has been on the rise owing especially to ignorance, lack of awareness about the consequences, and poor prevalent waste collection infrastructure. These practices have been one of the key reasons for the Delhi smog situation and the deterioration of the air quality indices in cities such as Varanasi.

The National Green Tribunal (NGT) declared a ban on the burning of solid waste, announcing a fine of ₹25,000 on every incident of bulk waste burning in open spaces and ₹5,000 in the case of backyard burning. There is a need to ensure the ban on waste burning and the government must take initiatives to combat air pollution at the local level.

Single-use plastics

Single use or disposable plastics are those that are designed to be used only once before being thrown away. These include light-weight plastic bags, disposable utensils, coffee cups and stirrers, soda and water bottles, food packaging, and so on. In India, around 43% of manufactured plastics are used for packaging purpose and most of these are single use.[26]

Substantial quantities of both single-use plastics and MLPs have accumulated in the natural environment and in landfills where it is buried. In the process of breaking down, it releases toxic chemicals which make their way into our food chain and water bodies. The issue of toxicity to humans with regard to single-use plastics and MLPs is primarily due to their use in food packaging.

Furthermore, when these materials are not properly discarded, contaminants leach to water bodies over a prolonged period of time. Due to leaching of phthalates and bisphenol A (BPA), drinking water bottles are often the most common sources of toxicity. Phthalates, have been found to deposit in the fatty tissues of the human body, where they act as antiandrogens. Studies suggest that this leads to diseases and health problems, such as male reproductive dysfunction, breast growth, and testicular cancers.[27] The BPA is known for its harmful effects on human placental tissues. Researchers have found that the BPA even causes premature birth, intrauterine growth retardation, and still birth.[28]

[23] Ilangovan, Ramesh. 'Will India Need a Landfill the Size of Bengaluru By 2030?'; The Wire; refer to www. thewire.in; last accessed on May 29, 2018.

[24] Kumar, S, Bhattacharyya J K, Vaidya A N, Chakrabarti T, Devotta S, and Akolkar A B. 2009. 'Assessment of the Status of Municipal SWM in Metro Cities, State Capitals, Class I Cities, and Class II Towns in India: An Insight'. *Waste Management* 29 (2): 883–95

[25] Environmental Research Foundation: The Basics of Landfills, Smithsonian: Landfills Affect Soil.

[26] FICCI; refer to https://economictimes.indiatimes.com/industry/indl-goods/svs/paper-/-wood-/-glass/-plastic/-marbles/india-wants-to-double-consumption-of-cheap-material-in-5-yrs-what-about-its-plastic-waste/articleshow/59301057.cms; last accessed on May 30, 2018.

[27] Jobling, S et al. 1995. 'A Variety of Environmentally Persistent Chemicals, Including Some Phthalate Plasticizers, are Weakly Estrogenic. *Environmental Health Perspectives*10 (6): 582–7.

[28] Benachour, N and A Aris. 2009. 'Toxic Effects of Low Doses of Bisphenol A on Human Placental Cells. *Toxicology and Applied Pharmacology* 241 (3): 322–8.

FIGURE 4: Price card for recyclables as per the BBMP

Plastic waste management in India

Growth in population, increased urbanization, and the rising average incomes are attributed to problems facing SWM in India. According to the CPCB estimates, urban India generates close to 62 million tonnes of municipal solid waste (MSW) annually with the organic fraction in the range of 40%–60%.[29] Plastic waste forms close to 8% of the generated solid waste in the country.[30] The per capita waste generation has seen a steady rise from 0.44 kg/day in 2001 to 0.5 kg/day and has been estimated to be growing at a rate of 1.33% per annum.[31] .Further, the CPCB has estimated the collection efficiency as 80.28% in 2014, out of which only 28.4% was treated. The remaining quantities were disposed of in landfills or open dumps. A study conducted by the CIPET- CPCB on the 'Assessment and Characterization of Plastic Waste in 60 Major Indian cities' observes a few important findings as has been mentioned below:

- 94% of plastic waste generated is recyclable and belongs to the thermoplastics family, while the rest 6% are non-recyclable thermoset plastics.
- 67% of the plastic waste belonged to the HDPE/ LDPE, 10% to PP, and 8.66% to PET amongst others.

The data indicates that the majority of the plastic waste generated comprised the HDPE/LDPE materials, such as polybags and multilayer pouches used for food packaging, *gutkha*, and so on. Further, the study also observes that households are the biggest source of this plastic waste.

[29] Refer to http://www.cpcb.nic.in/wast/municipalwast/Studies_of_CPCB.pdf; last accessed on May 29, 2018.

[30] Figures from the CPCB 2015 report.

[31] Sharholy, M, Ahmad K, Mahmood G, and Trivedi R C. 2008. 'Municipal Waste Management in Indian Cities: A Review'. *Science Direct Waste Management* 28: 459–67; refer to https://www.unc.edu/courses/2009spring/envr/890/002/readings/SolidWasteIndiaReview2008.pdf; last accessed on May 29, 2018.

Collection and segregation

Source separation of waste coupled with the segregated collection and transportation have been weak links in the waste supply chain. While it is the first and foremost step, it is often neglected. The report by the CIPET-CPCB observes that in the Indian smaller towns, waste is deposited by the residents at the kerbside/community garbage bins which are picked up by municipal trucks and transferred to the disposal site. In larger cities, the house-to-house collection systems have been adapted where residents deposit their waste with the contractual or municipal crew who collect it from the houses using hand carts or tricycles. The report further observes that most of the cities lack a processing plant with a sanitary landfill site and follow crude methods of waste dumping such as landfilling of mixed waste.

The waste management snowballs into bigger issues in larger cities owing to the size and quantity of unsegregated waste. In the absence of source segregation, efficient SWM, especially in large cities, calls for a decentralized approach with segregated collection of dry and wet waste. Municipalities must look into strategies to develop a detailed ward-wise waste collection plan coupled with the IEC outreach activities to sensitize the citizens on waste segregation and its benefits. Modalities, such as separate collection days for dry and wet waste and engagement with self-help groups for the informal sector integration may be explored.

Setting up and empowering material recovery facilities

The Solid Waste Management Rules, 2016, defines the material recovery facilities (MRF) as a facility where non-compostable solid waste can be temporarily stored by local bodies or an agency authorized to facilitate segregation, sorting, and recovery of recyclables by the informal sector before waste is delivered or taken up for processing.[32] The setting up of an MRF remains the next important step towards better management of plastic waste. Waste in a segregated manner must be deposited at the MRF for the separation of its different constituents. The Solid Waste Management Rules, 2016, mandates ULBs to set-up MRF for processing sorted dry waste. However, the on-ground implementation of the same in ULBs has been rather bleak owing to the available land/space concerns.

ULBs could take cue from some of the best practices followed in cities such as Bangaluru where dry waste collection centres have not only been established but also have a self-sustainable business model. Recyclable waste could be deposited at these centres at pre-decided rates notified by the ULB. Figure 4 details a price card prepared by Bruhat Bengaluru Mahanagara Palike (BBMP).

Recycling and associated problems

Effect of toxic additives

The main problems in the homogeneous plastics recycling are only related to the degradative phenomena occurring during recycling processes.[33] These phenomena are generally much more problematic as compared to virgin polymers since the oxygenated groups formed during the processing or during the use remarkably accelerate the degradation of plastic materials. This causes serious deterioration of end properties of the secondary materials. In order to obtain recycled materials with acceptable properties, it is necessary to protect materials from thermo-mechanical degradation occurring during recycling operations. Further, to improve the properties of the secondary materials, benign stabilizers and modifier agents need to be added to make the blends of mixed plastics compatible.

The recycled plastics are more harmful to the environment than the virgin products due to the mixing of additives, colours, stabilizers, halogenated flame retardants, and so on. There is a considerable controversy about the extent to which these additives are released and their adverse effects on the environment. The central issues are the types and quantities of additives present in plastics for the uptake and accumulation in living organisms.[34] Lead and cadmium pigments, commonly used in most of the plastics as additives are hazardous in nature and are known to leach out. Halogenated flame retardants

[32] Solid Waste Management Rules, 2016.

[33] Mantia, F P La. 1996. 'Basic Problems in Plastic Recycling' in *Recycling of PVC and Mixed Plastics*. Toronto: ChernTec Publishing.

[34] Andrady, A L and Neal M A. 2009. 'Applications and Societal Benefits of Plastics'. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* 364 (1526):1977–84.

include chlorinated and brominated products which also have undesirable effects on the environment.[35]

Number of times to be recycled

We can optimize the lifespan of plastics by recycling and reusing them. However, there is often a finite number of times that plastic is recycled before it ends up in a landfill. Some of these plastics have fibres which shorten every time it is recycled. Thus, a plastic can be recycled 7–9 times before it is no longer recyclable.[36] A few polymers can only be recycled 1–2 times before they are down cycled into lesser-value products. The items that are downcycled (such as clothing, fleece, or even lumber) usually cannot be recycled and may eventually end up in a landfill.

Lack of alternatives

The high growth rate of plastic consumption and stringent regulations propel us to explore alternative strategies. Boost for an alternative plastics market may result from the following interventions:

Biodegradable plastics:

- The price of biodegradable plastic products is higher than their synthetic plastic counterparts. Hence, tax exemptions, subsidies, and incentive-based mechanisms are necessary to help boost the market for these products.
- The focus for these plastics should be more on 'bio-based content' rather than biodegradability.
- The quality and performance in terms of strength and thermal stability should be at par or close to that of synthetic polymers. There is no dedicated testing and certification facility which is of vital importance to assess the quality parameters.
- As the market demand increases, there will be a growing need for an adequate supply of biomass feedstock.
- Research funding has to focus on the development of innovative biodegradable products with an emphasis on performance, technology development, shelf life, and related financial aspects.
- Investment, apart from research funding, should also include strategies for market outreach and the development of sustainable business models. Policy aspects also need to be included vis-à-vis framework, promotional measures, and incentives along with the facilitation of testing and certification standards. Biodegradability issues, such as ambient conditions for degradability, also need to be specified; for example, products may be labelled as industry or home compostable, soil or marine degradability, and so on. Investments for the development of bioplastic products would ease the burden on plastic waste management, conserve petrochemical reserves, boost agriculture sector, and thus reduce the environmental impact and carbon footprint.
- On a long-term basis, issues such as different raw materials for developing synthetic polymers can also be investigated. A specific example involves the production of Nylon11 from castor beans. The physical properties may differ from commercial polyamides but then this opens a whole new line of developing sustainable feedstock which need not overlap with those related to livelihood.
- Alternatives to plant sugars, namely, microalgae can also be looked into, wherein the growth can be integrated with CO_2 capture, thereby proving advantageous for both the sectors.[37]

Recycled plastics:

- Manufacturers must consider the end-of-life impact of the product at the design stage itself sometimes known as the 'Design for Environment' concept. It has been envisaged by the plastic zero forum that a decision on the colour of the final product should be made keeping the recycling issues in mind.[38]
- The consumers should also be educated by various forums, including schools to increase the awareness regarding plastics and the ensuing waste disposal issues.

[35] Wagner, M and Oehlmann J. 2009. 'Endocrine Disruptors in Bottled Mineral Water: Total Estrogenic Burden and Migration from Plastic Bottles. *Environmental Science and Pollution Research* 16 (3): 278–86.

[36] Refer to http://ourauckland.aucklandcouncil.govt.nz/articles/news/2016/08/how-many-times-can-it-be-recycled/; last accessed on May 30, 2018.

[37] 2016. For plastics market watch and watching bioplastics; refer to www.plasticsportal.net; last accessed on May 29, 2018.

[38] 2014. 'How to Prepare a Road Map for the Management of Plastic Waste; refer to http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=home.showFile&rep=file&fil=PLASTIC_ZERO_annex_d41b_action1.1_road_map_part_i_final.pdf; last accessed on May 30, 2018.

- There is a lack of testing and certification facility to assess the quality of recycled plastic products.
- Research funding should be directed towards quality, performance, and the inclusion of environmentally benign additives leading to the development of novel products.
- Mapping of waste streams is essential to concentrate on commodity plastics and their tonnage in the recycling streams which may lead to a circular economy.

Plastic waste to fuel:

- The use of catalysts for pyrolysis has to be compared with respect to conversion efficiency. The quantity of catalyst—that is, catalyst/polymer ratio should also be assessed keeping in mind the cost and catalyst reuse capability. These studies are predominantly at the research stage.
- A quality-based decision should be made to assess the methane number and also the quantity of waste plastic oil (in terms of percentage) to be blended with diesel (25%–75%) to ensure optimal engine performance. The emission characteristics should also be quantified.[39] Chintala, et.al. (2018)[40] found that such a solution is feasible although the bottlenecks—that is, hydrocarbon emissions and performance have to be studied in detail.
- As a future strategy, plastic waste to fuel technology may be incorporated as a part of a circular economy.

Sustainable Plastic Waste Management Solutions

Value-added products from plastic waste

In order to manage the plastic waste disposal, some of the alternative options to develop value-added products from post-consumer plastic wastes are as follows:

[39] Geetha, N K, Ragani V, and Sekar P. 2018. 'Mathematical Approach for Selection of Waste Plastic Oil–Diesel Blends. *International Journal of Mechanical and Production Engineering Research and Development* 8: 145–54.

[40] Chintala, V, Godphe P, Phadtare S, Tadpatrikar M, Pandey J K, and Kumar S, 2018. 'A Comparative Assessment of Single-cylinder Diesel Engine Characteristics with Plasto Oils Derived from Municipal Mixed Plastic Waste. *Energy Conversion and Management* 166: 579–89.

Recycled products

Recycled plastics have a great potential and impact on the environment. It helps to address the pre-existing plastic waste problem and saves oil resources (every tonne of plastic waste recycled results in saving approximately 3.8 barrels of petroleum).[41] Some of the key product sectors that contain post-consumer plastics include construction, furniture, landscaping, shipping, soft toys, and so on. Scientists from the National Chemical Laboratory, Pune, have taken steps towards the development of fabric from the recycling of PET bottles. This fabric is being used for making of T-shirts, scarves, denim, and pillows. In fact, the jersey of the Indian cricket team is made out of recycled PET bottles.[42]

Blending of recycled plastics with fillers and additives will enhance the strength and usability leading to value-added products. Blending recycled plastics with fly ash can be used for developing fire-retardant composites with a wide scope of applications. As the separation of individual plastics at waste source is difficult, recycling of commingled plastics and inclusion of non-halogenated fire-retardant additives will to an extent mitigate the problem of segregation while leading to value-added products with adequate strength and fire safety (Figure 5).[43]

Bio-based products

India has a huge potential in producing bioplastics due to the abundant availability of resources. According to a survey by DuPont in India, about 63% of consumers are familiar with bio-based plastics.[44] A study published by Frost & Sullivan suggests that the annual growth rate of the bioplastics market is estimated at 44.8% in 2015.[45] The bioplastics market in India is steadily improving and many industries have explored the manufacturing

[41] Refer to http://greenotechindia.com/plastic-recycling/; last accessed on May 29, 2018.

[42] Marar, Anjali. 2017. 'Recycling Turns Plastic into Pillows, Denims and Team India Gear'. Pune: The Indian Express.

[43] Divya, V C, M Ameen Khan, B Nageshwar Rao, and R R N Sailaja. 2015. 'High-density Polyethylene/Cenosphere Composites Reinforced with Multi-walled Carbon Nanotubes: Mechanical, Thermal and fire Retardancy Studies'. *Materials and Design* 65: 377–86.

[44] Forst & Sullivan; refer to http://www.frost.com/prod/servlet/press-release.pag?docid=193321902; last accessed on May 29, 2018.

[45] DuPont Green Living Survey; refer to http://fhc.biosciences.dupont.com/fileadmin/user_upload/live/fhc/DuPont_Green_Living_Survey_leave_behind_2209.pdf; last accessed on May 29, 2018.

Char formation of neat HDPE | HDPE/fly ash cenospheres | HDPE/PP/Nylon/EPDM

FIGURE 5: Residue after burning composites of recycled HDPE (neat at top) with fly ash cenospheres and recycled commingled plastics (funded by MoEF&CC to TERI)

of bio-based products. The J&K Agro Industries Development Corporation Ltd in collaboration with Earthsoul, launched India's first bioplastics product manufacturing facility with a production capacity of about 960 metric tonnes per year. Companies, such as Ravi Industries Maharashtra, Truegreen Ahmedabad, Ecolife Chennai, and Biotec Bags Tamil Nadu are pioneers in the Indian bioplastics industry. Truegreen manufacturing plant has a capacity to produce around 5,000 tonnes of bioplastics products each year. Many start-up businesses are also venturing into Indian bioplastics market such as Envigreen which started its production in Bengaluru and is capable of producing 1,000 tonnes of bioplastics annually.

Bio-based products can be developed using different techniques and raw materials. One option is using recycled polymeric materials and blending them with biopolymers.[46] Another approach is to develop the composites from only biopolymers without the incorporation of any kind of synthetic polymer.[47] Lab samples of these bio-based plastics developed by TERI have been depicted in Figures 6 and 7.

The performance of bio-based products is about 70%; this is comparable to virgin plastic in terms of mechanical strength and thermal stability. The products developed from these bio-based and biodegradable

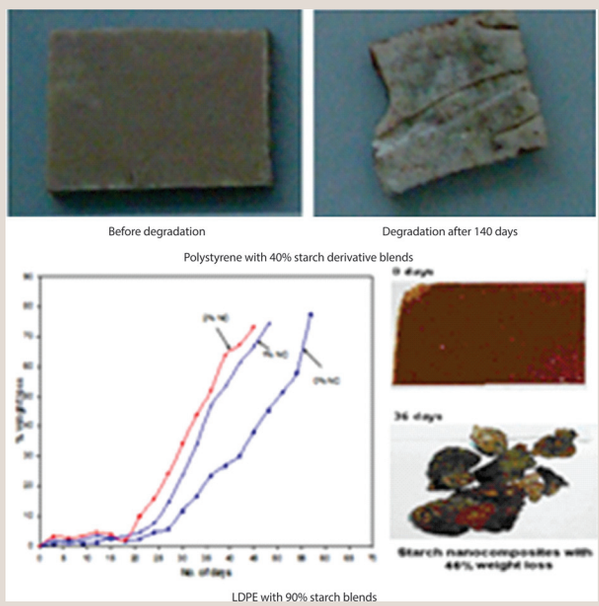

FIGURE 6: Bio-based composites developed by TERI

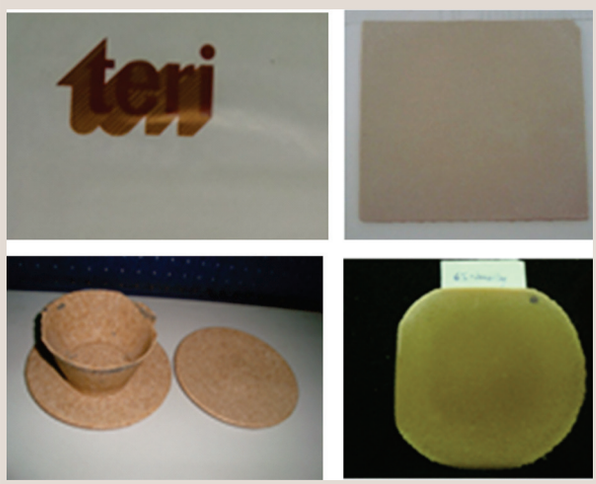

FIGURE 7: Fully biodegradable products developed by TERI (films and sheets)

[46] Manjunath, L, and Sailaja R R N. 2016. 'Starch/Polyethylene Nanocomposites: Mechanical, Thermal, and Biodegradability Characteristics, *Polymer Composites* 37: 1384–95.

[47] Gaurav, Aashish, Ashamol A, Deepthi M V, and Sailaja R R N. 2012. 'Biodegradable Nanocomposites of Cellulose Acetate Phthalate and Chitosan Reinforced with Functionalized Nanoclay: Mechanical, Thermal, and Biodegradability Studies. *Journal of Applied Polymer Science* 125: 16–26.

plastics would be suitable for packaging (food and non-food items) and as mulch films in agriculture. Generally, bio-based products also find applicability in carry bags, super absorbents for diapers, and wastewater treatment. As discussed by Ashter (2016), [48] the market growth of these bio-based and biodegradable plastics is driven by continuous research and developmental activities, increased consumer awareness, consumer preference towards environmental-friendly products, and the implementation of stringent environmental regulations.

Pyrolysis

Pyrolysis is the breaking down of polymers into smaller molecules by thermal decomposition at temperatures close to 300 °C–400 °C in the presence of a catalyst (such as aluminium oxides, fly ash, red mud, and calcium hydroxide) in an inert atmosphere.[49] The kinetic parameters have to be optimized to improve both the quality and yield. Depending upon the process followed, pyrolysis of plastics has an average yield of 45%–50% oil, 35%–40% gases, and 10%–20% tar.[50] The United Nations Environmental Program research report suggests that the yield can be improved (~80%) under controlled reaction conditions.[51] The oil produced in pyrolysis process shows similarity to conventional diesel. Therefore, this may be an effective way to recycle plastic waste into fuels. In comparison with many developed countries, India is yet to generate a business model for the conversion of plastic waste to fuel. The Indian Institute of Petroleum, a Council of Scientific and Industrial Research laboratory, in Dehradun, developed a unique process of converting plastic waste, such as polyethylene and polypropylene to either gasoline or diesel. The technology is capable of converting 1 kg of plastic to 750 ml of automotive grade gasoline.

Rudra Environmental Solutions, Pune, has designed and developed a pyrolysis plant where 1 tonne of plastic waste can be converted to 600–650 litres of fuel with almost 60% conversion rate. M K Aromatics Ltd, has set-up two plants in Goa to convert plastic waste to fuel.

Hydroxy systems Pvt. Ltd. Hyderabad, has adopted a different technique in the production of fuel oil from plastic waste. It has been claimed that the process is safe, controllable, and pollution-free and also holds the approval of the State Pollution Control Board. The facility has the capacity to convert around 13–15 tonnes of plastic waste per month into approximately 500 litres of fuel.

Hence, in order to successfully establish the business model to convert plastic waste to fuel for both industrial and domestic use, it is crucial to develop proper infrastructure and also to create better customer awareness.

Gasification

Gasification of plastic waste has recently gained increased attention as thermo-chemical recycling technique. This process involves partial oxidation of plastic waste at high temperature. The main advantage of this process is the use of air as a gasification agent instead of oxygen alone. This makes gasification a simple technique with reduced operational costs. In this process, hydrocarbon-based materials are oxidized in controlled conditions to produce a gaseous mixture containing carbon monoxide and hydrogen with minor quantities of hydrocarbons.[52,53] This mixture is known as 'syngas' and may be used as a substitute for natural gas. It can be used for heating, lighting, and power generation.

[48] Ashter, Syed Ali. 2016. 'Commercial Applications of Bioplastics', in *Introduction to Bioplastics Engineering*, pp. 227–49; available at http://scitechconnect.elsevier.com/wp-content/uploads/2016/10/Commercial-applications-of-bioplastics.pdf; last accessed on May 30, 2018.

[49] Miandad, Rashid, Mohammad Rehan, Abdul-Sattar Nizami, Mohammad Abou El-Fetouh Barakat, and Iqbal Mohammad Ismail. 2016. 'The Energy and Value-Added Products from Pyrolysis of Waste Plastics', in Karthikeyan O. Heimann K, and Muthu S. (eds) *Recycling of Solid Waste for Biofuels and Bio-chemicals. Environmental Footprints and Eco-design of Products and Processes*, pp 333–55. Singapore: Springer.

[50] Wong, S L, Ngadi N, Abdullah TAT, and Inuw I M. 2015. 'Current State and Future Prospects of Plastic Waste as Source of Fuel: A Review'. *Renewable & Sustainable Energy Reviews* 50: 1167–80.

[51] United Nations Environmental Program. Converting Waste Plastic into a Resource. 2009, refer to http://www.unep.or.jp/; last accessed on May 30, 2018.

[52] Scheirs, J. 1998. *Polymer Recycling*. New York: Wiley.

[53] Vermeulen, I, Van Caneghem J, Block C, Baeyens J, and Vandecasteele C. 2011. 'Automotive Shredder Residue (ASR): Reviewing Its Productions from End-of-Life Vehicles (ELVs) and Its Recycling, Energy and Chemicals Valorization. *Journal of Hazardous Materials* 190: 8–27.

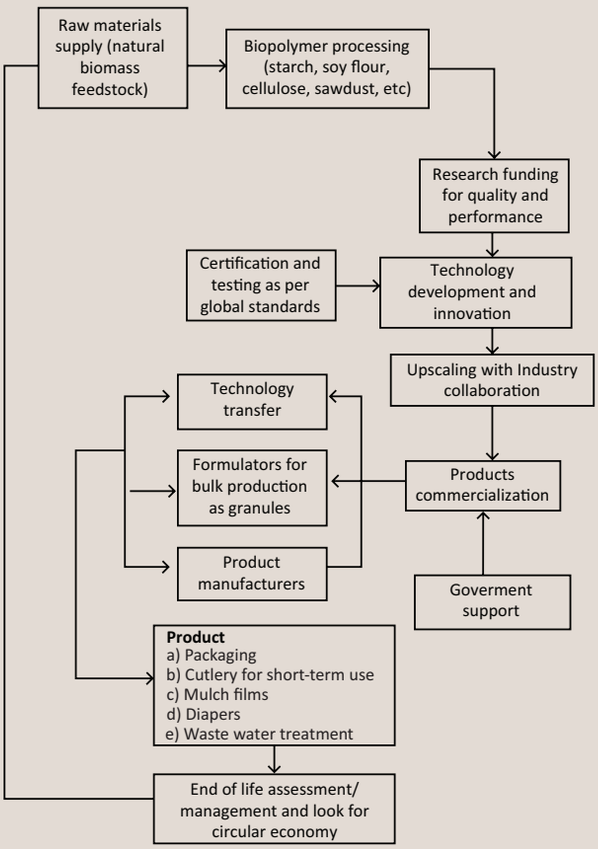

FIGURE 8: Schematic business model for biodegradable/ bio-based products

Plastic waste in road laying

There is a continuous need for enhancing the quality of roads and pavements. Utilization of plastic waste for this purpose is being carried out at various cities in India. The choice of modifier for the road-laying process depends on cost and the expected performance. Modification is attained by two main procedures, namely, dry process and wet process. The waste plastic is blended with aggregates before adding it in bitumen in the dry process, while the wet process involves a simultaneous blending of bitumen and plastic. Better results were observed for a long time with polymer-modified bitumen.[54] [55]Zorrob and Suparama (2004)[56] reported an increased durability and improved fatigue resistance of the roads composed predominantly of PP and LDPE in bituminous-concrete mixtures. The protocol for the road-laying process is simple. Plastic waste is first segregated (except chlorinated/brominated plastic waste) and then shredded to a particular size (2–4 mm). The shredded plastic waste is then added to the aggregate and the bitumen is heated to 160 °C to result in good binding. Jambulingam Street in Chennai was one of India's first plastic roads built in 2002. In 2003/04, the KK Plastic Waste Management Ltd, Bengaluru, signed an MoU with the BBMP to lay 250 km of roads in Karnataka. As time wore on, polymer roads proved to be surprisingly durable with fewer potholes and edge flaws as reported by the CPCB, thus receiving support from scientists and policymakers in India and neighbouring countries.

The ICPE has been supporting the use of waste plastic in making tar roads. In 2015/16, the National Rural Road Development Agency laid around 7,500 km of roads using plastic waste. Today, there are more than 21,000 miles of plastic roads in India and for every km of road (3.75 m width), 1 tonne of plastic (10,00,000 carry bags)[57] is used for every tonne of bitumen that is saved. This serves to mitigate plastic waste management considerably and also ensures petrochemical resource conservation.

Co-processing of plastic

Co-processing refers to the use of waste materials as an alternate fuel or raw material in industrial processes such as cement plants. Waste materials, such as plastic waste, segregated non-recyclable MSW, and select hazardous waste could be utilized as alternate fuel and raw material, thus substituting the use of coal. Cement plants provide an optimum opportunity to balance the act between resource efficiency and waste management. Fossil fuels, such as coal and petroleum coke, have traditionally been used as energy sources in the cement manufacturing industry. However, the use of these energy sources

[54] King, G.N.and H.W. King. 1986. 'Polymer Modified Asphalts: An Overview', *American Society of Civil Engineers*, 240–54.

[55] Isacsson, U and X Lu. 1995. 'Testing and Appraisal of Polymer Modified Road Bitumen. *Materials and Structures* 28 (3): 139–59.

[56] Zorrob, S E and LB Suparama. 2004. 'Laboratory Design and Investigation of Proportion of Bituminous Composite Containing Waste Recycled Plastics Aggregate Replacement (Plastiphalt). *Cement and Concrete Composites* 2000 22 (4): 233–42.

[57] Refer to http://earthuntouched.com/plastic-roads-revolutionary-idea/; last accessed on May 29, 2018.

calls for an assessment of various factors, such as the availability of processing technology, economic viability, potential environmental and health impacts, and CO_2-emission reduction. For instance, basic fuel quality requirements are considered before using waste as an alternative in cement manufacturing. Waste materials cannot always be combusted in the plant, as received, owing to its mixed nature and must be pre-processed to transform the waste to fit the chemical and physical specifications acceptable to kilns. This includes calorific and/or material value, water content, ash content, and concentration of sulphur, chlorine, and heavy metals which can affect the overall performance of the cement plant. The CPCB has prescribed guidelines on the co-processing of plastic waste as an alternate fuel.

Business/Technical Models for Plastic Waste Management

Biodegradable/bio-based products

The schematic business model for biodegradable/bio-based plastics has been shown in Figure 8. The following are the key strategies to be implemented for ensuring sustainable bio-plastics production leading to adequate markets gains.

- There should be sufficient supply of raw material—that is, the natural biopolymer, such as starch, cellulose, and so on without interfering with the food chain. This calls for enhanced crop productivity to sustain the bio-plastic production.
- The need for indigenous technological development and innovation calls for requisite funding. The same can be adopted for technology transfer with industry collaboration or tie-ups.
- The establishment of standard testing and certification facility would further support to improve the quality of the developed products.
- Public awareness, governmental support in the form of subsidies and tax sops, would help promote utilization and the market for biodegradable/bio-based plastics.
- The product stream may cater to various applications, such as:
    - Finished products in the form of packaging, cutlery, single use items, mulch films, and so on.
    - Have a parallel stream for the bulk production of granules, which can be supplied to various retailers.
- End-of-life assessment which would ultimately lead to zero waste or a circular economy.

Adopting the above strategies would ensure innovative business, extended market for agriculture while providing a solution for plastic waste management and lessen the burden on our petroleum resources. Indigenous technology developed would lead to intellectual property rights, integrating technology transfer, and thus production.

Recycled plastics products

The business model for recycled waste products can be efficiently executed by following the key strategies (Figure 9).

- The raw material for this stream is the post-consumer plastic waste. There has to be an organized collection and sorting technology (if possible, based on resin identification codes).[58] The plastic waste processing plant would do the segregation, cleaning, shredding, and palletizing. The palletized granules would serve as the feedstock for developing recycled plastic waste products.
- There is already an existing market for low-cost recycled products, such as flower pots, lids, and toys and sectors such as packaging. Further, to enhance market value, high-performance products from recycled plastic waste need to be developed. Thus, the indigenous research funding for technology development is of paramount importance. Once the innovative products are developed, a centralized facility for testing and certification is essential to meet the global quality standards. Since there is a lack of such testing facilities, the same needs to be set up while engaging in research on product development.
- The commercialization of these products can cater to various sectors, such as the construction industry, non-food packaging, and high-strength furniture and panels with enhanced fire safety.

[58] Chintala, V, Godphe P, Phadtare S, Tadpatrikar M, Pandey J K, Kumar S. 2018. 'A Comparative Assessment of Single-cylinder Diesel Engine Characteristics with Plasto Oils Derived from Municipal Mixed Plastic Waste. *Energy conversion and Management* 166: 579–89.

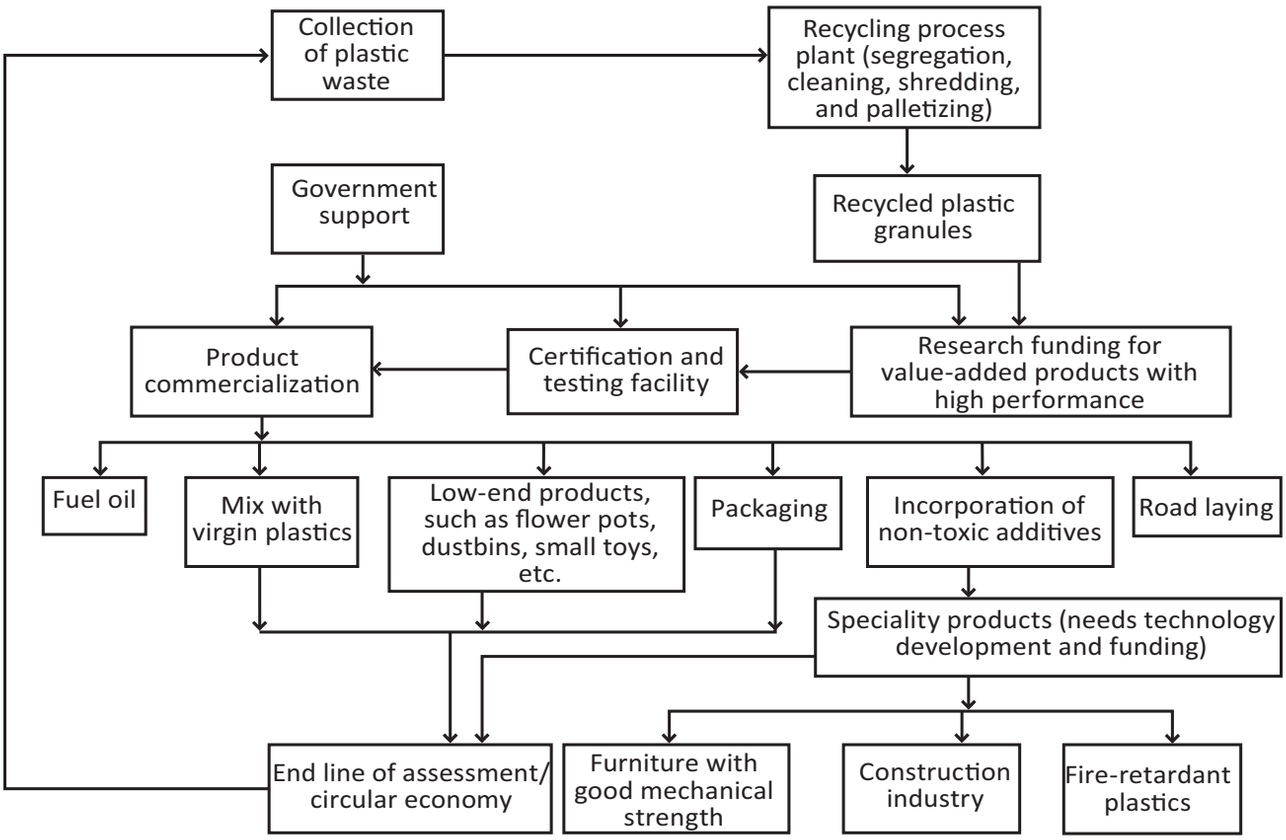

FIGURE 9: A schematic business model for recycled plastics products

This requires industry–academia collaborative tie-ups for technology transfer and for the up scaling of production.

- As a futuristic view, the EPR, promotion of circular economy, and organized implementation of plastic ban in certain sectors (such as short-term usage) would further ease the management of plastic waste. Controlled incineration for plastic waste, particularly so in the case of non-recyclable plastic would be fruitful for waste-to-energy programmes. Conversion of plastic waste to fuel oil (though in the research stage) would be a promising potential, wherein waste plastic would be a high-demand raw material. However, the quality and performance (in terms of strength) have to be indigenously established by promoting research in these areas.

Model for an effective decentralized solid waste management

Figure 10 depicts a model for decentralized waste management with waste-processing options, such as composting, RDF, and co-processing of RDF/plastic waste in cement kilns.

Conclusion

- Plastic consumption is continuously increasing owing to urbanization and the growing global demand. Although the rising rates of plastic production project positively for Indian businesses and the economy, unscientific waste management practices are leading adverse environment effects. This calls for efficient planning, incorporation of "design for environment concept", better end use application and plastic waste management with sustainable solutions and alternatives.
- Municipalities must formulate a plastic waste management plan in accordance with the rules to ensure scientific management of plastic waste. Further, producers and brand owners must partner with municipalities to ensure the devising of an EPR plan and the associated implementation. Furthermore, India may take its cue from the best practices from around the world on the

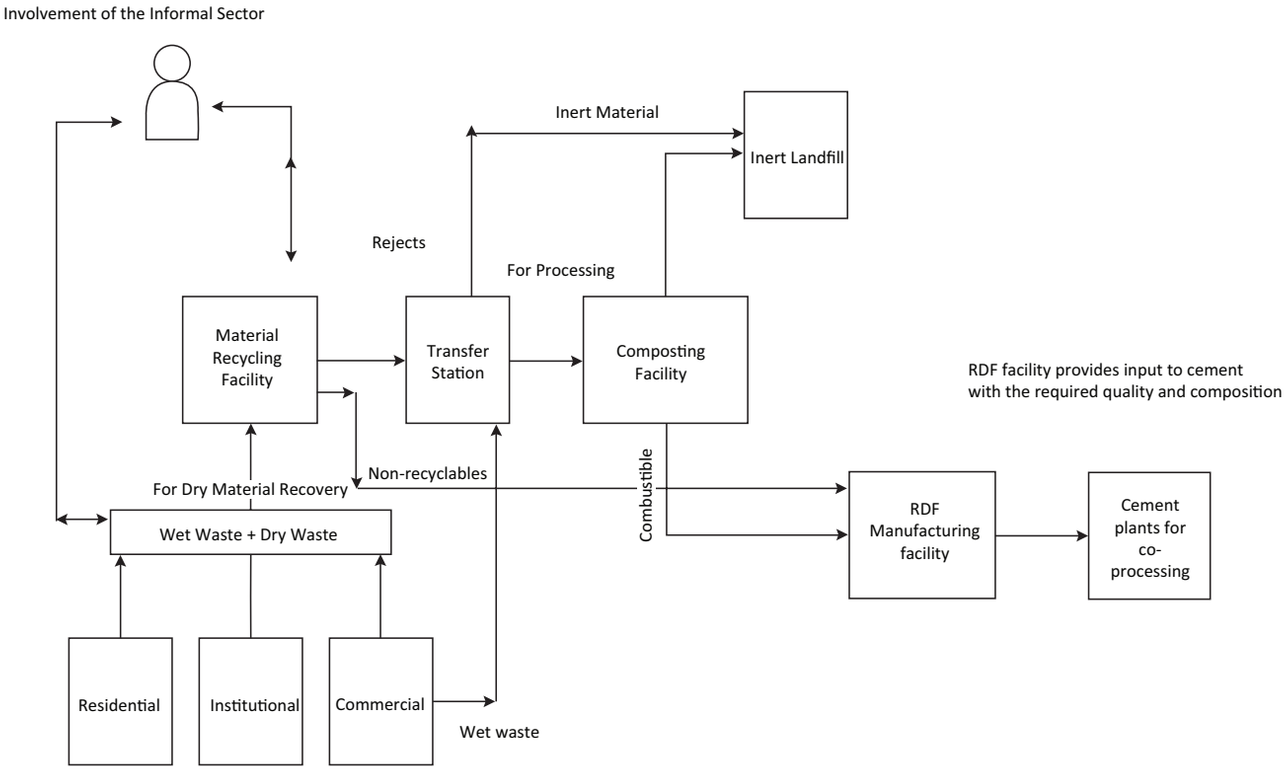

FIGURE 10: A model for decentralized waste management [59]

explicit pricing of carry bags and its role in shaping behavioural change. Although a plastics ban may aim at curtailing manufacture and use, there is a need to visit the economics, applicability and availability of alternatives. However, the consumption of single-use plastics (carry bags, cutlery, etc.) may be lessened with an aim to reduce quantities of disposed plastics into the landfill.

- Though solid and plastic waste management fall under the purview of ULBs, there is a need for ensuring the financial sustainability of a service that operates every day of the year. Novel financial mechanisms may be devised to enhance user-fee / SWM charges collection to ensure better revenue flows for the ULBs.
- To incentivize recycling, innovative economic models may be devised and implemented to encourage citizens to recycle and ensure maximum diversion of plastic waste. This may be in line with the practice, where the *kabadiwallah* incentivizes residents to segregate newspapers and in turn is paid by the dry waste collection centres as per pre-decided prices fixed by the municipality, especially for commodities based out of virgin plastic, such as polyethylenes and styrofoam owing to their high recyclability quotient.
- Bio-based and biodegradable plastics offer sustainable alternatives to curb plastic use and waste minimization. The use of biodegradable plastic must be promoted, especially in large-scale applications, such as manufacturing of agricultural mulch films, superabsorbent composites used for waste water treatment, and sustained release of pesticides. There is a further need for the upscaling and commercialization of these products through a facilitation of research and industry tie-ups. As bio-based plastics is an emerging field, there is substantial scope for research and innovation that could be facilitated either through government/ industry funding or a combination of both.
- While recycling is the most suited model for tackling plastic waste as per the waste hierarchy, the implementation of the same is faced with challenges, such as a lack of source segregation and recovery. The CIPET-CPCB report categorically mentions households as the major generators

[59] TERI-GIZ report on the mapping of RDF around cement kilns within a 100,200,300 km radius.

of polyolefinic waste. Therefore, municipalities must look to improve upon the infrastructure for material recovery centres manned by the informal sector workers and an increased awareness on waste segregation.

- Strengthening of ward-wise material recovery facilities, coupled with the EPR, and integration with the recycled products industry would accelerate India towards a circular economy.
- Development of high-performance and value-added recycled products either commodity wise or with commingled plastics require the development of innovative solutions which focus on increased mechanical properties (at par with virgin plastic) that are tailor-made to meet the special needs, such as recycled fire-retardant plastics, hydrophobic coatings, and so on. These products can cater to the building sector, furniture industry, packaging, and automobile industry.
- Amongst the other sustainable alternatives of plastic waste management, co-processing of plastic in cement kilns offers a sound, environmentally viable mechanism to process non-recyclable, combustible plastic waste and simultaneously address the perennial challenge of waste management. This may help facilitate completing the circular economy loop for such plastic waste. Further, the integration of mixed plastic waste with bitumen is becoming an attractive and accessible option for municipalities owing to the unsegregated nature of waste, improved quality of roads, and pothole filling. Furthermore, though pyrolysis of waste plastic offers an alternative, the same is still at the development stage. The benefits and quality are still to be established and assessed.
- To handhold academia and industry with the development of innovative products, emphasis on the establishment of standardized testing, and certification labs can help better facilitate the assessment of quality and performance of the developed products.

The Way Ahead

- A detailed mapping of waste quantities, generation sources, and the associated characteristics is vital for the implementation of an effective plastic waste management mechanism in cities.
- Devising of a plastic waste management plan and EPR models would lead to effective end use and optimized production. Additionally, ULBs may also explore decentralized (ward wise) waste management models to ensure an enhanced implementation as suggested by the Solid Waste Management Rules, 2016.
- Innovative funding mechanisms, incentives, subsidies for bio-based and recycled plastic product development, and other possible sustainable alternative solutions may help expedite the research and innovation capabilities along with market outreach.
- Plastic waste management has to be assessed on a case-to-case basis in conjunction with climate and geographical location.
- Sustainable plastic waste management solutions and alternatives calls for effective stakeholder engagement and capacity building.

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