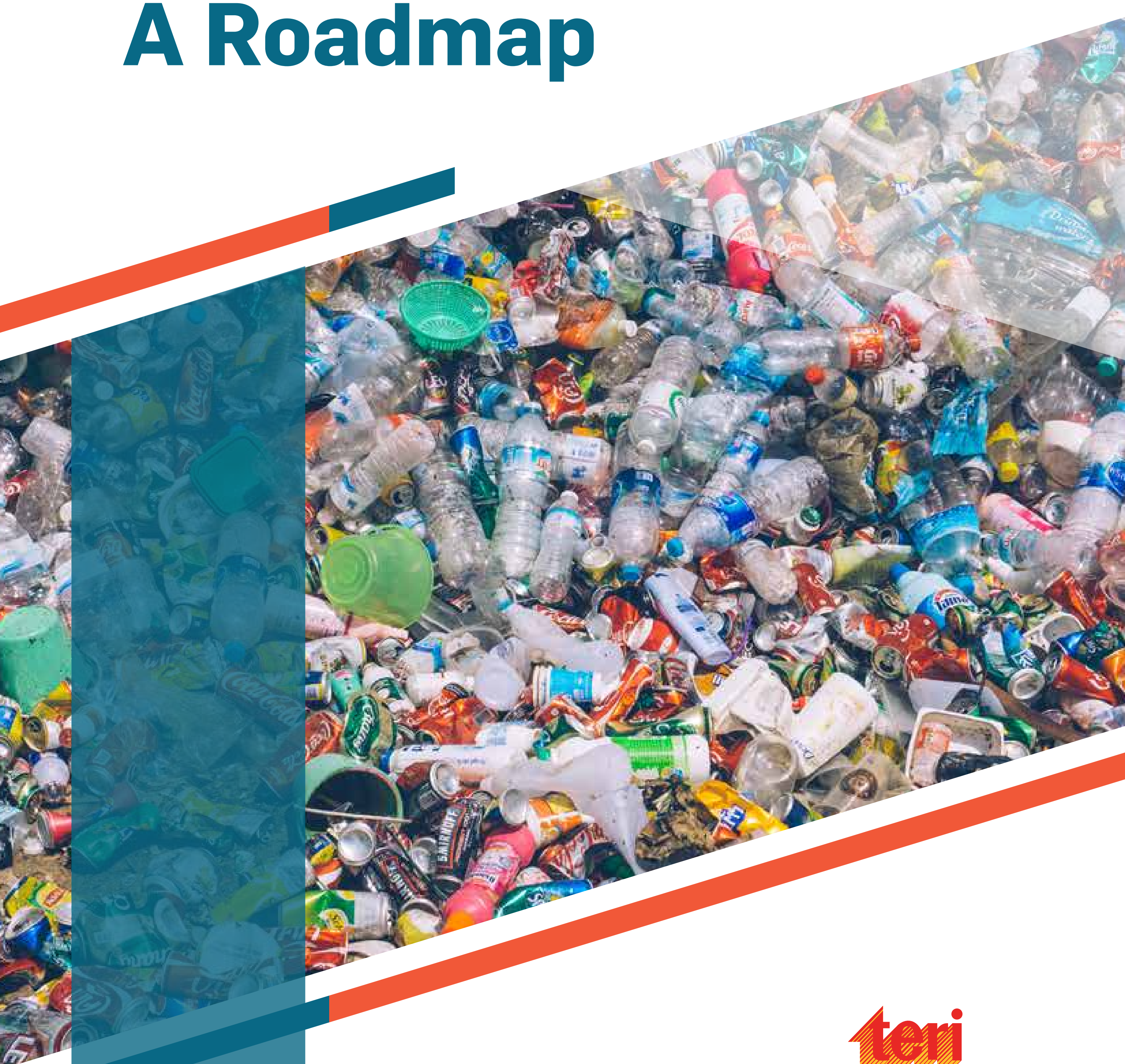
Circular Economy for Plastics in India: A Roadmap



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Authors

Shilpi Kapur Bakshi, Senior Fellow, Environment & Waste Management Division, TERI

Mehar Kaur, Research Associate, Environment & Waste Management Division, TERI

Shweta Gautam, Project Associate, Environment & Waste Management Division, TERI

Advisor

Suneel Pandey, Senior Fellow and Director, Environment & Waste Management Division, TERI

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For more information

Project Monitoring Cell

The Energy and Resources Institute, Darbari Seth Block, IHC Complex, Lodhi Road, New Delhi 110 003, India | Tel.: +91 11 2468 2100 or 2468 2111 | Fax: +91 11 2468 2144 or 2468 2145 Email: pmc@teri.res.in | Web: www.teriin.org

Foreword

Plastics are used in variety of applications including healthcare, automobiles, clean energy from wind turbines to solar panels, and most importantly as packaging material for food and non-food applications. Their benefits range from being lightweight, flexible, durable, to providing long shelf-life and many more, and their use has increased twenty-fold in the past half-century, and is expected to double again in the next 20 years. Further, with the advent of consumerism, growing purchasing power, and higher standard of living, the convenience that plastic-based consumer goods and the packaging provides for both food and non-food applications is invaluable.

However, these benefits are handicapped by the mismanagement of plastic waste which results in the clogging of drains, flooding and breeding of diseases, as well as adversely impacting our river and marine resources. Plastic packaging, much of which is single use and thrown within minutes after unpacking, accounts for nearly half of all the plastic waste globally. These call for a fundamental change in the way plastic products, including packaging, are designed, used, and disposed.

One key solution is to manage plastic waste in an efficient and responsible manner and foster circularity in use of plastics. Circular economy measures/models retain the added value of goods as long as possible, reducing waste and keeping the value of plastics in the economy, without leakage into the natural environment. However, the manner in which most of the plastic products are made, used, and disposed at present does not capture the economic advantages of a more circular approach, and end up with drastic harming of the environment. Also, almost every piece of plastic begins as a fossil fuel, and greenhouse gases are released from its extraction, processing, usage, and end-of-life at each point of the plastic lifecycle.

This Circular Economy Roadmap for Plastics in India, prepared by The Energy and Resources Institute with support from the Children's Investment Fund Foundation, identifies the key demand and supply-side potential across the entire value chain for fostering circularity in plastics and includes a specific focus on the downstream issues on reducing, reusing, and recycling plastics. It aims to decouple plastics production from virgin fossil feedstock, incentivize use of recycled plastics to substitute virgin plastics, encourage responsible design, and strengthen and expand plastic recycling and reutilization. The implementation of the actions suggested in the roadmap will help address the social and environmental challenges due to the mismanagementof plastic waste and the associated economic costs, while also decreasing unnecessary plastic consumption. The roadmap strongly emphasizes that the transition to circular plastics economy in India, requires extensive (financial and regulatory) linkages between key stakeholders, including regulators, policymakers, corporates, and financial institutions, supported by innovative technological and financial solutions.

This roadmap aims at providing a way forward to all stakeholders including industry, policymakers, academicians, administrators and civil society organizations including those working with the informal sector. I am confident that it will enable and generate debates and discussions on plastics use and recycling, and will also generate interest among the business community who might eventually come out with multitude of business models, contributing to promoting a circular plastics economy in India.

Ajay Mathur
Director General, TERI

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The inputs of All India Plastic Manufacturers Association of India (AIPMA), PET Packaging Association for Clean Environment (PACE), and Indian Centre for Plastic in the Environment (ICPE) helped us to reach out to key experts in the plastics sector as well as get feedback on the main issues and challenges facing the industry from a circular economy perspective.

List of Acronyms

ABS	Acrylonitrile Butadiene Styrene
AEPW	Alliance to End Plastic Waste
AFR	Alternate Fuel and Raw Material
AIPMA	All India Plastic Manufacturers Association of India
ASTM	American Society for Testing and Materials
B&C	Building and Construction
B2B	Business-to-Business
BAMB	Building as Material Banks
BAU	Business as Usual
BBMP	Bruhat Benagluru Mahanagara Palike
BIS	Bureau of Indian Standards
BPF	British Plastics Federation
CE	Circular Economy
CEN	European Committee for Standardization
CFRP	Carbon Fibre Reinforced Plastic
CIFF	Children's Investment Fund Foundation
COINDS	Comprehensive Industrial Document
CPCB	Central Pollution Control Board
CPMA	Chemicals & Petrochemicals Manufacturers' Association
CRL	Circular Retrofit Lab
CSR	Corporate Social Responsibility
DIN	German Institute for Standardization
EC	European Commission
EoL	End-of-Life
EPR	Extended Producer Responsibility
FDA	Food and Drug Administration
FMCG	Fast Moving Consumer Goods
GAIL	Gas Authority of India
GHG	Green House Gas
GOI	Government of India

GPP	Green Public Procurement
GPS	Global Positioning System
GRIHA	Green Rating for Integrated Habitat Assessment
GVPs	Garbage Vulnerable Points
HCCBPL	Hindustan Coca Cola Beverages Private Limited
HDPE	High Density Polyethylene
HUL	Hindustan Unilever Limited
HV AC	Heating, Ventilation and Air-Conditioning
IBEF	India Brand Equity Foundation
ICPE	Indian Centre for Plastic in the Environment
ICT	Institute of Chemical Technology
IEC	Information, Education and Communication
ISO	International Standards Organization
JIS	Japanese Institute for Standardization
LDPE	Low Density Polyethylene
LLDPE	Linear Low Density Polyethylene
MLPs	Multi-Layer Packaging
MMP	Multi-Material Packaging
MNCs	Multinational Corporations
MoC&F	Ministry of Chemical and Fertilizers
MoCI	Ministry of Commerce and Industries
MoEFCC	Ministry of Environment, Forest and Climate Change
MoHFW	Ministry of Health and Family Welfare
Mohua	Ministry of Housing and Urban Affairs
MoRTH	Ministry of Road Transport and Highways
MPP	Multi Polymer Packaging
MRFs	Material Recovery Facilities
MSME	Ministry of Micro, Small & Medium Enterprises
MSW	Municipal Solid Waste
MTPA	Million Tonnes Per Annum
OECD	Organisation for Economic Co-operation and Development
ONGC	Oil and Natural Gas Corporation
PACE	Packaging Association for Clean Environment
PBAT	PolyButyrate Adipate Terephthalate
PBS	Polybutylene succinate
PCCPs	Personal Care and Cosmetic Products

PCL	Polycaprolacton
PE	Polyethylene
PET	Polyethylene Terepthalate
PHAs	Polyhydroxyalkanoate
PIB	Press Information Bureau
PLA	Polylactic Acid
PP	Polypropylene
PPE	Personal Protective Equipment
PPP	Public Private Partnership
PS	Polystyrene
PUF	Polyurethane Foam
PVA	Polyvinyl Alcohol
PVC	Polyvinyl Chloride
PVOH	Polyvinyl Alcohol
PWM	Plastic Waste Management
R&D	Research and Development
RDF	Refuse Derived Fuel
RE	Resource Efficiency
RMIT	Royal Melbourne Institute of Technology
SABIC	Saudi Basic Industries Corporation
SBM	Swachh Bharat Mission
SMEs	Samll and Medium Enterprises
SPI	Society of the Plastics Industry
SPP	Single Polymer Packaging
SUPs	Single Use Plastics
TERI	The Energy and Resources Institute
ULBs	Urban Local Bodies
UNDP	United Nations Development Programme
USA	United States of America
VC	Venture Capital
VGF	Viability Gap Funding
WtE	Waste to Energy

Executive Summary

To limit global warming below 2 °C, rapid reduction in global energy consumption is required. The industry has been focusing on reducing the sectoral greenhouse gas (GHG) emissions from production (supply-side) of widely used resources such as steel, cement, plastics. However, this can be achievable only when reduction in supply-side emissions is complemented with demand-side management. Here, circular economy (CE) has an important role to play as it can through better demand management create opportunities to reduce the demand for virgin resources and emissions associated with their production. Globally, in 2019, the GHG emissions from production and incineration of plastic were estimated to be more than 850 million tonne (equal to the emissions from 189 500 MW coal power plants).

Many sectors are using plastics owing to their substantial benefits of being lightweight, flexible, durable, provide long shelf life, which are far greater than their drawbacks. The recent COVID-19 outbreak has seen a significant rise in the use of plastics, particularly in the form of personal protective equipment (PPE) and because of growth in e-commerce packaging, or in light of safety and hygiene aspects of product packaging.

Amongst different applications of plastics, packaging is the key end-use sector accounting for the highest share. Packaging plastics with mostly shorter product lifetimes, compared to plastics used in other applications such as building and construction (B&C) or in automobiles, are considered to have a significant potential in contributing towards CE. Tapping this potential and identifying opportunities along the value chain can help in the transition from the take-make-use-throw linear model.

In the linear model, plastic polymers and raw materials are majorly made from fossil fuels, accounting for 8–9% global oil and gas in its production. In the midstream, manufacturing/design stage, a significant portion of plastics are made for single use, which significantly contributes to waste generation. In the downstream stage, most plastics are consumed for one time use only and become waste after a few minutes of use. Plastic waste is mostly handled by the informal sector. The lack of formal channels, robust technology, economic incentives, business models, and urban local bodies (ULBs) involvement leads to leakages in segregated collection, transport and safe treatment and disposal of plastic waste. In India, 60% of plastics (such as polyethylene terephthalate (PET) bottles, high density polyethylene (HDPE) containers, polyvinyl chloride (PVC) pipes) are recycled. However, these are mostly downcycled in an informal setting. There is high share of plastic waste that ends up in landfills, burnt, or leaked into the environment. Plastics that are difficult or hard to recycle because they are made of mixed materials/multi-polymers or are contaminated or dirty from use, end up mostly as mismanaged waste.

Currently, policies such as ban on single-use plastics are adopted when considering increase research on alternatives and recycling rates. Moving forward, there is a need for developing recyclable, cost-effective plastics as a viable substitute to non-recyclable plastics. It is extremely critical and essential to unlock the market potential of secondary plastics (recycled plastics).

The roadmap for circularity in plastics looks at the entire value chain and aims to decouple plastics production from virgin fossil feedstock, incentivize plastic recycling and reuse, and reduce damage by plastic litter while decreasing unnecessary plastic consumption. Starting from upstream, the material flow of plastics in India shows that out of the total polymer consumption of 16.8 million tonnes per annum (MMTPA) in 2018–19, 90% was for plastic and the remaining 10% was for non-plastic consumption-adhesives, rubbers, cosmetics, etc. Polymers for production of various synthetic fibres, constitutes another 4 MMTPA. Business as usual (BAU) forecasts out to 2035 for plastics consumption across main polymer types show the largest consumption continue to come from polyethylene (PE) and polypropylene (PP). These are the main polymers used for flexible packaging end use, and also constitute a significant part of (mismanaged) plastic waste. Flexible packaging, particularly multi-polymer or multi-material in the form of bags, pouches, shrink films, tubes, sleeves, and carded packaging are mostly non-recyclable, or difficult to collect and, hence, cannot be recycled. For downstream activities, TERI estimates on plastic waste flows for India suggest that out of the total plastic consumption, 42% consumption in current year stays in circulation (lifetime of product greater than 1 year) while 58% comes out as waste. From the total plastic waste generated about 60% is actually recycled, 8.5% reutilized for energy recovery and repurposing, and about 31.5% is mismanaged plastic waste i.e. littered in streets, drains, garbage vulnerable points (GVPs)* , thrown in dumpsites, or openly burnt.

Resource efficiency (RE) and circularity can be integrated through demand and supply-side measures along the value chain. Measures include use of recycled plastics and waste as a substitute for virgin polymers, eco-design to reduce absolute material consumption and ease of disassembly of final product. Incorporating these measures poses challenges linked to biomass availability and land availability for food, biomaterial, or bioenergy production, undeveloped market for recycled plastics/secondary raw material, difficulty in securing high quality supply of recyclable plastic waste, a limited market for post-consumer resin (pellets) and technological limitations for eco-design. The roadmap details the potential impact of these measures from demand and supply sides, under three circularity scenarios for India: BAU, Moderate, and High ambition RE and CE. The roadmap has set three key priorities/objectives, supported by measurable action plan that may be monitored over – short (0–2 years), medium (2–5 years), and long term (>5 years). These objectives are:

» Adopting sustainable material solutions –use of bio-based polymers, substitution of virgin polymer with recycled polymer, and dematerialization of plastic products

» Increase supply of good quality secondary plastics feedstock (recycled plastics); and

» Invent, innovate, and encourage alternative uses of problematic plastics waste

Building on a shared vision, the success of the roadmap requires **cooperation** from all stakeholders including national, state, and city governments, industry, academia, and the informal sector. The **political acceptability** and the **financial viability** of different actions, **enforcement** of the chosen top-down and bottom-up approach will foster the implementation of the roadmap. There will also be required regular, systematic **monitoring** of the action points along with the **collection and analysis** of data in the context to determine the efficacy, and the need for **adjustment** in the actions defining the roadmap.

* GVPs are illegal land disposal sites on unauthorized locations where solid waste is disposed indiscriminately without segregation with little to no regards for pollution controls or aesthetics by individuals or commercial establishments. There are no physical barriers separating these garbage points from humans, animals, and the environment because of which they are a source of surface and ground water pollution and present a health hazard for public and the environment.

Introduction

Across the world, the discussions in the context of sectoral greenhouse gas (GHG) emissions from industry have focused on reducing the emissions from the production (supply side) of widely used resources such as steel, cement, plastics, among others. In 2019, the GHG emissions from global production and incineration of plastic were estimated to be more than 850 million tonne (equal to the emissions from 189 500 MW coal power plants) and by 2050, annual emissions could grow to more than 2.75 billion tonne of CO_2 equivalent if the current patterns of plastic production and use continue (Hamilton, *et al.*, 2019).

Ninety nine per cent of feedstock for plastics is fossil based. For producing plastic products out of plastic polymers, virgin feedstocks account for 90% share, and the remaining 10% is met by recycled polymers. Plastics account for 8–9% of global oil and gas production and its production is projected to double by 2040, with its share of global oil consumption expected to grow to about 20% in 2050 (World Economic Forum;Ellen MacArthur Foundation, 2016). Switching to bio-based plastics has the potential of lowering GHG emissions from plastics production. However, this impact will depend on the source of bio-based feedstock and its direct and indirect impact on land-use change (Borrelle, *et al.,* 2017), (Piemonte & Gironi, 2011).

The reduction of supply-side emissions from the plastics sector will need to be complemented with the management of demand-side emissions. Circular economy can play an important role in creating opportunities for generating demand-side reductions in emissions. This can be achieved through different channels including substitution of virgin resources with secondary raw material/recycled polymers, product design for better resource recovery at end-of-life, improved resource efficiency of production processes, longer use of products to reduce waste generation, and regeneration of natural systems to sequester carbon in soil and products. For example, available estimates note that instead of landfilling (mechanical) recycling lowers GHG emissions by about 0.6 tonne of CO_2 equivalent per tonne of plastic recycled (Bennett, 2016). The circular economy rationale is also increasingly promoted as a means to move from a global plastic waste dilemma to a plastics economy that is aligned with the principles of sustainable development (Gall, *et al.,* 2020).

Of the plastics, packaging plastics, in particular, are considered to have significant potential in contributing towards circular economy (European Commission, 2018; Hahladakis & Iacovidou, 2018; Leslie, *et al.* 2016 ; Plastics Europe, 2018; Eygen, *et al.*, 2018; World Economic Forum; Ellen MacArthur Foundation, 2017). This potential arises majorly from single-use (use and throw) characteristics of packaging plastics and its subsequent mismanagement. A recent study (FICCI, 2020) on packaging in India projects a loss of almost USD133 billion worth of plastic material value in the next 10 years till 2030 due to unsustainable packaging in India. The study also suggests that circular economy-based interventions have the potential of recovering almost 75% of this projected loss value, i.e. USD 100 billion.

There is significant local, national, and global focus on (mismanaged) plastic waste issue and its potential contribution to marine litter (Brooks, Wang, & Jambeck, 2018; Jambeck, *et al.*, 2015; Rochman, *et al.*, 2013; Thompson, *et al.,* 2009). Important to highlight here is that marine plastic pollution contains not only plastic debris/litter but also micro-plastics[1] (an emerging issue of international concern, particularly for the health of oceans and marine biodiversity). In countries like India, with large coastlines and many rivers flowing through the country, the challenges related to plastic use and waste cannot be ignored. The issue of riverine and marine pollution linked with plastics is becoming a topic of wide-spread discussion and stakeholders are coming forward to find a solution to this problem.

This **Circular Economy roadmap for Plastics in India** identifies opportunities across the entire value chain of plastics with specific focus on the downstream issues of avoiding waste and fostering re-use and recycle of plastics. The roadmap draws upon learning from existing best practices across the world. Building on a shared vision, its implementation requires cooperation between all stakeholders including individuals, government, industry, private, public, and informal sectors perspective. The success of the roadmap will depend on the **enforcement** of the chosen top-down and bottom-up approaches, regular, systematic **monitoring** of these approaches along with the **collection and analysis** of needed data in the context to determine its efficacy and the need for adjustment.

1 This is a category of plastic debris termed 'microplastics', which are small pieces of plastic that may enter the ocean as such, or may result from the fragmentation of larger items through the influence of UV radiation

Plastic Industry in India

The plastic value chain (Figure 1)** spans from the extraction of raw material for plastic production over several steps to the end-of-life management and disposal of plastic waste. The plastics sector engages a broad spectrum of stakeholders from the public, private, and civil sector at the national, state, and local levels, as elaborated in Table 1, all of whom have defined roles and responsibilities. The key stakeholders involved across different stages of plastic value chain are plastic producers and processors, consumers, and waste managers. They are supported by connected stakeholders: industry associations, waste management companies, transporters, and importers/exporters. The common stakeholders across the entire value chain include financial institutions, civil society organizations, and regional, national, and international governmental and non-governmental institutions.

Stage		Acitivity	Output
Upstream	Raw Material Production	Oil Exploration and Production	Oil and Gas
		Feedstock production	Monomers
		Polymerization	Polymer Resin
Midstream	Manufacture and Use	Manufacture of Intermediate Plastic Components	Bottle Caps, Multi-layer Films
		Manufacture of Final /Assembled Packaging	Pouches and Cartons
		Manufacture of Consumer Products	FMCG Products
Downstream	Disposal and End-of-Life Treatment	Use of Plastic Products and Packaging	Plastic Waste
		Waste Collection/Sorting	Segregated and Aggregated Plastic Waste
		Recycling	Flakes, Pellets, Films, and Sheets
		Reutilization	Plastones, Roads, Tiles, Lumber, Co processing as fuel

FIGURE 1: Overview of key value chain stages of plastics

** This figure is based on a presentation by Dr. Vijay Habbu, an expert in the plastics sector and currently an Adjunct Professor at ICT, Mumbai

TABLE 1: Stakeholder mapping across the plastic value chain

Category	Level	Stakeholder Group	Plastic Value Chain Stage	Roles & Responsibilities
Government	National/ State	Ministries and Departments	Multiple	Provide policy framework at national and state levels including regulations, market-based instruments, information and voluntary tools; Facilitate capacity building activities
	National/ State	Public Institutions	Downstream	Monitor; Support policy making and ensure compliance; Review of information shared by states
	National/ State	Financing Institutions (banking and non-banking financial institutes)	Multiple	Provide financial resources for waste management infrastructure
	City/Local	Local Government [urban local bodies (ULBs)]	Multiple	Provide policy framework at municipal level; Create bye-laws; Implement waste management activities; Engage with private players supporting waste management activities
Private	National	Monomer (raw materials) and Polymer Producers	Upstream	Perform upstream processes like monomer production and polymer production
	National	Industry Associations	Upstream	
	National/ State	Manufacture and Use (converters/ processors/ plastic producers, importers, brand owners and retailers)	Midstream	Perform midstream processes at state and national levels involving production of plastic components and its use by end-use sectors
	National/ State	Manufacture and Use (product and end-use application industry associations)		
	National/ State	Service Providers (transporters)	Multiple	Contribute to plastic value chain
	National/ State	Service Providers (banks and non-banking financial institutions)	Multiple	Provide financial resources for waste management infrastructure

TABLE 1: Stakeholder mapping across the plastic value chain

Category	Level	Stakeholder Group	Plastic Value Chain Stage	Roles & Responsibilities
Private	City/Local	Disposal & EoL (consumers/ recyclers/ processors/ re-purposers/ collection and recovery centres)	Downstream	Provide downstream processes with regard to plastic waste management
	City/Local	Disposal & EoL (waste industry association/ waste management companies)	Downstream	
	City/Local	Disposal & EoL (informal sector: collectors, aggregators, transporters, recyclers)	Downstream	Support waste management system and perform downstream processes. Collect waste materials from public spaces e.g. waste bins, dumpsters, illegal dumping sites. Sort and collect waste materials at dump/landfill site. Informal plastic recycling sector adds value to the economy by transforming waste into tradeable goods, reducing cost associated with waste management for ULBs
Civil Society Organizations	National/ State research & advocacy, Think tanks	NGOs, Research and Academia (research & advocacy institutions, think tanks and academic institutes)	Multiple	Influence all parts of the plastic value chain (i.e. production, consumption, and EoL) through different measures like research and development; capacity building; raise awareness and initiatives on local issues; support policy making and compliance at national, state, and at local levels
	City/Local research centres	NGOs, Research and Academia (research centres, think tanks, universities, educational centres)	Downstream	

Key Stakeholder	Connected Stakeholders	Common stakeholder

Plastic Waste in India: Challenges and Implications

The existing waste management practices are unable to support the urban waste generated, which is becoming a major issue in India. Post-consumer plastic waste is collected as part of municipal solid waste (MSW). At present, MSW is estimated to have collection efficiency as high as 85–86%. However, source segregation is majorly lacking, which is leading to contamination of potentially recyclable dry waste materials including plastics. Recyclable plastics, such as single polymer packaging (flexible or rigid), if not segregated and instead mixed and contaminated with wet, food waste, will become non-recyclable. Contaminated or low value plastic waste that does not get collected, recycled, or reutilized gets mismanaged. This waste mostly consists of low value, single-use plastics (SUPs) used widely as carry bags or for food and small-sized packaging for FMCG products. Economic incentives do not exist that can capture and prevent the leakage of these low value, contaminated, SUPs at the end of their short life into the environment.

Majority of the post-consumer plastic waste that gets collected mostly end up in open dumpsites and (unscientific)[2] landfills. Landfills occupy a significant area and, given the current rate of population growth and urbanization, there is less land available for landfilling, especially within city limits where land value is high[3]. Landfills also result in an unpleasant landscape, apart from causing leachate and release of GHGs.

Mismanaged plastics also have high chances of becoming part of waterways and marine litter. Such plastic waste is often found littered and thrown in drains and during monsoons lead to drain clogging and increased chances of flooding. Such waste leaked from coastal cities is carried by ocean currents to form gyres, which are garbage patches in the ocean where waste gets collected. It is essential to recycle or safely dispose plastics, as once mismanaged, most plastics do not degrade but fragment into micro-plastics in the environment. Biodegradable plastics[4], contrary to perception or claims do not decompose into the expected benign chemicals (CO_2, CH_4, H_2O) and certainly not overnight, inevitably ending up as litter and microplastics.

Although, CPCB estimates suggest that India has a high recycling of about 60% for the post-consumer plastic waste; however, this is done mostly by the informal sector (which includes waste pickers, aggregators, informal recycling units), with some help from ULBs. There is still a lack of structured integration of the informal sector into formal waste management systems despite the MSWM Rules 2016 mandating it. The ULBs, private sector including the multinational brands, and waste management companies struggle to work effectively with the informal sector despites increasing evidence of economic,

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2 Very few states in India have converted their landfills into sanitary landfills.

3 Estimates suggest the current rate of garbage dumping requiring 1240 ha of land for landfill per year, which is increasingly difficult to achieve (Swati, Thakur, Vijay, & Ghosh, 2018).

4 Biodegradable plastics are plastics which decompose in the environment within a reasonable period of time, but may require biodegradable additives to enhance biodegradation process and some may require a specific environment to disintegrate. Time taken by plastics to decompose depends upon various factors such as raw material used and environmental conditions such as moisture and temperature. These constitute a very small proportion. Examples of such fossil fuel-based biodegradable plastics are poly(butylene succinate) (PBS), poly(butylene succinate-co-adipate) (PBSA), polycaprolactone (PCL), and poly(butylene adipate-co-terephthalate) (PBAT).

environmental, and social benefits of forming mutually beneficial partnerships. The workers are paid low wages, do not have adequate and proper protective equipment, and work long hours without any standard operating procedures (SOPs), in conditions that lack health and occupational safety measures.

The organizational structure and functioning of the informal sector recycling begins with the collection of the recyclables from (open) dumpsites, streets, or directly at the source from households. After collection, the recyclables are passed from the informal waste picker to a local *kabadiwaalas* (who are small scrap aggregators and typically buy[5] different types of waste paper, glass, metal, and plastic, and operate from a shop where they collect, store and minimally process waste materials collected), and then to larger aggregator[6]/ junk yard owners, intermediate dealers, or other middlemen. This trading is done in a rather hierarchical and non-transparent value chain in a market space that is semi-formal and informal with no clear price estimates for different plastic products. Post-recycling, the recycled plastic in the form of pellets and granules is reintroduced into the economy as secondary raw material (Asim, Batool, & Chaudhry, 2012; Ezeah, Fazakerley, & Roberts, 2013).

Lack of technology entails mostly physical or mechanical recycling of plastics by cutting, shredding, or washing into granulates, flakes or pellets of appropriate quality in a crude manner, which can then be blended with virgin material for superior quality. Lack of formal channels, Standard Operating Procedures (SOPs), and rudimentary recycling techniques lead to waste leakages during the recycling process. The final recycled flakes/pellets/granules are not of superior quality and maybe contaminated with other polymers or materials.

Formal recycling is mainly limited to clean, segregated, pre-consumer waste in a few clusters in the country, including those in western Indian states of Gujarat and Maharashtra as they have a robust recycling and transport infrastructure and grid connectivity. These states also recycle pre- and post-consumer plastic waste from far away states of Southern or Eastern India, which involves significant transportation costs. Poor infrastructure and road connectivity in regions, especially like North-East India, make transporting plastic waste over long distances to recycling units a major hurdle. In addition to this, even in locations where recycling infrastructure is available, only about 50–60% of the capacity is utilized due to lack of availability of clean, segregated waste. The capacity is also underutilized due to ban on import of plastic waste[7]. Recyclers were importing clean, segregated, polymer waste, which allowed them to work at capacity while also treating domestic post-consumer plastic waste. However, since the ban, the recyclers are facing shortages in supply of clean waste as large part of the domestic post-consumer plastic waste obtained is contaminated, which makes it less recyclable.

Additives and chemicals in plastic products can leach out during recycling and from the recycled use of pellets/flakes/ granules, thus making the recycled product more toxic for the environment than virgin plastic products (Bhattacharya, *et al.* 2018). This toxicity of recycled material can contaminate the virgin raw material and, hence, their use for food and pharmaceutical applications is restricted.

In addition to reuse and recycling, energy recovery from co-processing and waste-to-energy plants and repurposing plastic waste (for example-use in road construction or lumber making) are other options that define the end state of plastic waste. However, lack of segregated waste, low investments, absence of business models, financial and human resource constraints faced by the ULBs have not allowed these options to achieve scale, and operations are taking place mostly at small scale or pilot level, at times in partnership with the private sector.

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[5] Kabadiwaalas also buy directly from the households and other generators of post-consumer waste by directly going to them.

[6] These larger aggregators also buy waste directly from bulk generators of recyclable waste

[7] In March 2020, changes were made in the country's hazardous waste rules (PIB, 2018) parts of which concern scrap plastic movements stating that 'solid plastic waste has been prohibited from import into the country,' and the exemptions to the existing ban on import of plastic scrap-were abolished.

Existing Policy and Regulatory Framework for Plastic Industry in India

In recent years, the Government of India (GOI) has considered and enacted various forms of environmental legislations and regulations at the national, state, or local levels with respect to plastics, particularly on the end-of-life management and mitigation of plastic waste pollution. But the effectiveness of monitoring and enforcement of these measures is generally weak.

The policy push towards resource efficiency and circular economy in plastics is also relatively new and lacks a systematic approach. Specifically, there is not much emphasis on unlocking the market potential of secondary plastics (recycled plastics).

There is a growing recognition amongst the industry across the value chain to drive change upstream, midstream, and complement the efforts being made downstream. Table 2 summarizes the existing legislative and regulatory framework and its implications on plastics circularity.

TABLE 2: Circularity implications of legislative and regulatory framework for plastics in India

Policy	Year	Government Ministry/ Department	Description
Upstream			
Plastics and recycled plastics manufacture, sale, and usage rules	1999, 2002, 2003	MoEFCC	Rules have laid down provisions for the manufacturing, usage, EoL management, criteria for manufacturing plastic carry bags and containers. Amendments (2002; 2003) provide specifications for virgin and recycled plastic manufacturing, extend definition of vendor, and mandate registration and authorization for manufacturers, production, sale, or trade for plastic packaging
Policy resolution for promotion of petroleum, chemicals, and petrochemical investment regions (PCPIRs)	2007	MoC&F	Provision for specifically delineated investment regions for the manufacturing facilities for domestic- and export-led production in petroleum, chemicals and petrochemicals, along with associated services and infrastructure

TABLE 2: Circularity implications of legislative and regulatory framework for plastics in India

Policy	Year	Government Ministry/ Department	Description
Midstream			
National Design Policy	2007	MoCI	It focuses on 'Design in India' and to enhance the competitiveness of Indian industry
Hazardous and Other Waste (Management, Handling and Transboundary Movement) Rules	2008, 2016	MoEFCC	It has laid down responsibility for handling and storage of hazardous waste. It also deals with the import, export of hazardous waste for recycling, recovery, and reuse. It defines processes generating hazardous waste including plastic production, and where such processes are prohibited. The new (2016) rules banned the import of solid plastic waste, including PET bottles. It also distinguishes hazardous waste from others and recognizes waste as a resource for recycling and reuse supplementing industrial processes
Food Safety and Standards Regulations	2011	MoHFW	It lays down general requirements for packaging and labelling
Notice for withdrawal of producer responsibility organizations	2019	CPCB	Discontinued recognition of PROs with CPCB, and the producers and other stakeholders can plan their EPR implementation as per requirement of PWM Rules, 2018
Downstream			
Guidelines for recycling of plastics	1998	BIS	Describes types of wastes, classification of recycling, and steps involved in the recycling process
Bio-medical waste Rules	1998, 2016	MoEFCC	Earliest policy that addresses the treatment of plastic waste in biomedical area. Focuses on recycling of plastics, sharps and glass to authorized recyclers. Provides colour coding and the type of container for disposal of biomedical wastes containing plastic bags

TABLE 2: Circularity implications of legislative and regulatory framework for plastics in India

Policy	Year	Government Ministry/ Department	Description
Municipal Solid Wastes (Management and Handling) Rules, 2000	2000	MoEFCC	Declared responsibilities of authorities on national, state, and municipal levels
	2016	MoEFCC	New rules have mandated source segregation of waste and event organizers, RWAs, market associations, gated communities, institutions, and SEZ have been assigned the responsibility
Plastic Waste Management (Amendment) Rules	2011	MoEFCC	Rules put ban on use of plastic materials in sachets for storing, packing, or selling gutkha, tobacco and pan masala
	2016, 2018	MoEFCC	Requires producers/brand owners who introduce plastic carry bags, multi-layered plastic sachets, pouches, and packaging into the marketplace to submit an EPR plan. The amended (2018) rules state that only those multi-layered plastics (MLPs) will be phased out which are non-recyclable or non-energy recoverable or have no alternate use. Also there will be a central registration system for the registration of the producer/ importer/brand owner
Guidelines for disposal of thermoset plastic waste including: Sheet Moulding Compound (SMC)/ Fibre Reinforced Plastic (FRP)	2016	CPCB	According to these guidelines, the most preferred option is minimization of use of SMC/FRP/ polycarbonate polymer products and promote the use of alternate material which are easily recyclable/reusable/ degradable
Guidelines for the disposal of non-recyclable fraction (multi-layered) plastic waste	2018	CPCB	Guidelines provide the source of non-recyclable plastic waste and management of non-recyclable plastic waste
Guidelines for co-processing of plastic waste in cement kilns	2016	CPCB	Guidelines provide the protocol to be followed by different stakeholders and description of co-processing plastic waste in cement kilns

TABLE 2: Circularity implications of legislative and regulatory framework for plastics in India

Policy	Year	Government Ministry/ Department	Description
Environment Protection Act (control of non-biodegradable garbage)	2016	MoEFCC	Prevent throwing or depositing non-biodegradable garbage in public drains, roads, and places open to public view and protect the environment from being polluted by such garbage and for matters connected therewith or incidental there to
Consolidated guidelines for segregation, collection, and disposal of plastic waste	2017	CPCB	Guidelines provide roles and responsibilities of different stakeholders in efficient plastic waste management and technologies for disposal of plastic wastes
Prohibition of import of PET flakes	2019	MoEFCC	GOI prohibits the import of PET bottle waste/scraps PET flakes made from used PET bottles, etc.
Guideline Document : Uniform Framework for Extended Producers Responsibility (Under Plastic Waste Management Rules, 2016)	2020	MoEFCC	Mandate manufacturers to take responsibilities over materials used in their products beyond the sale-phase

Material Flow of Plastics

Plastic products are made up of different types of polymer resins (which can be typically identified using resin codes printed on the products) and consumption for these resins is determined through specifications required by the end-use applications/products. The resin codes were adopted by the Society of the Plastics Industry (SPI) in 1988 to provide an industry-wide standard that would make it easier to identify and sort recyclable plastics. These codes were adopted by Bureau of Indian Standards as IS 14534:1998. Table 3 presents the major polymer resins, their common usage, and actual recycling status in India.

TABLE 3: Polymer resins application and actual status of recycling

Resin code	Polymer	Application	Actual status of recycling	Common recycling process and predominant end-products
01 PET	Polyethylene terephthalate (PET/ PETE)	Water and soft drink bottles, food jar, cooking oil, fruit juice container, oven ready meal trays	Very commonly recycled	» Predominant form of recycling is mechanical recycling. Waste converted into flakes (almost 90% of) which are converted into polyester fibres and (the remaining 10%) into bottles; » Chemical recycling is very limited. Waste polymerization and the resulting PET reisin is converted into bottles"
02 PE-HD	High-density polyethylene (HDPE)	Bottles (shampoo and other personal care products), carbouys and cans (milk, edible oil, lube oil), and containers (home care products and personal care products)	Very commonly recycled	» Mechanical recycling. Waste converted into granules which are converted into moulded products (rigid packaging) or sheets/filmc (flexible packaging); » Chemical recycling is being currently researched, yet to even reach the pilot stage"
03 PVC	Polyvinyl chloride (PVC)*	Medical field (blood and urine bags), housing (doors and windows), packaging (cling films, blister packaging, labelling, shrink wrapping), pipes and flexible holdings, rainwear	Commonly recycled	» Mechanical recycling. Waste converted into granules which are converted into moulded products (rigid packaging » Recycling process generates dioxins that are dangerous

TABLE 3: Polymer resins application and actual status of recycling

Resin code	Polymer	Application	Actual status of recycling	Common recycling process and predominant end-products
04 PE-LD	Low-density polyethylene (LDPE)	Grocery bags, wrappings (dry cleaning bags), squeezable bottles, bubble foil	Sometimes recycled	» Mechanical recycling. Waste converted into granules which are converted into flexible packaging; Significant percentage of LDPE plastic waste is mis-managed due to small size and associated difficulties in collection. Contamination of the LDPE plastic waste is also an issue of concern and re-purposing in road construction has significant potential
05 PP	Polypropylene (PP)	Furniture, consumer luggage, bottle caps, medicine bottles, chips packs, drinking straws, ketchup bottles, and hummus/ butter tubs	Commonly recycled	» Mechanical recycling. Waste converted into granules which are converted into rigid packaging or flexible packaging; but these are majorly thrown away (and so get mis-managed)
06 PS	Polystyrene (PS)*	Disposal cups, cutlery, packaging foam, plastic table wear, compact CD jackets	Typically not recycled	» Mostly thrown away (so get mis-managed) and if collected can be used as RDF or landfilled ; 2 types of polystyrene (hard, brittle plastic) and expanded polystyrene (light, insulating, waterproof plastic)
07 O	Others Miscellaneous category and includes Thermoset plastics, Multilayer & Laminated Plastics, PUF Bakelite, Polycarbonate, Melamine, Nylon, fiberglass; acrylonitrile butadiene styrene (ABS)*[8]	Food packaging, electronic goods, and defence gadgets; fishing nets, clothing, ropes	Typically not recycled	» Mechanical recycling. Waste converted into granules and used making lumber or specialized products or can be used for road construction

Important to highlight that SPI points out on its web site, "The code was not intended to be — nor was it ever promoted as — a guarantee to consumers that a given item bearing the code will be accepted for recycling in their community."

Source: Adapted from various sources

[8] The plastics with resin code 7 are more of a miscellaneous category for everything that was not fitted into the other three resin codes. Because this group is miscellaneous, it is difficult to recycle.

There are five major polymers [polyethylene terephthalate (PET), polyethylene (PE),polyvinyl chloride (PVC), PP, polystyrene (PS)] that are commonly used, particularly for consumer/ commodity packaging and non-packaging plastic products. Different combination of dyes and additives are added to these polymers to produce the desired colour, shape, and texture in the final plastic product. PE, which is the most extensively consumed polymer, is made as high-density polyethylene (HDPE), low-density polyethylene (LDPE), and linear low-density polyethylene (LLDPE) in household items, such as plastic containers, bottles, bags, and plastic toys. In terms of consumption share of polymers for making different types of plastic products, estimates for 2020 suggest these to be as follows: PP (38%), LLDPE (11%), LDPE (2%), HDPE (14%), PVC (10%), PS (2%), PET (15%), and others that include other thermoplastics and thermoset plastics (10%)[9]. PP together with the three types of PE accounted for over 50% of India's polymer consumption for plastic products in 2018–19.

Using the relationship between GDP per capita and historical polymer consumption data, a business as usual (BAU) forecasts till 2035 for polymer consumption/demand across main polymer types is depicted in Figure 2[10].

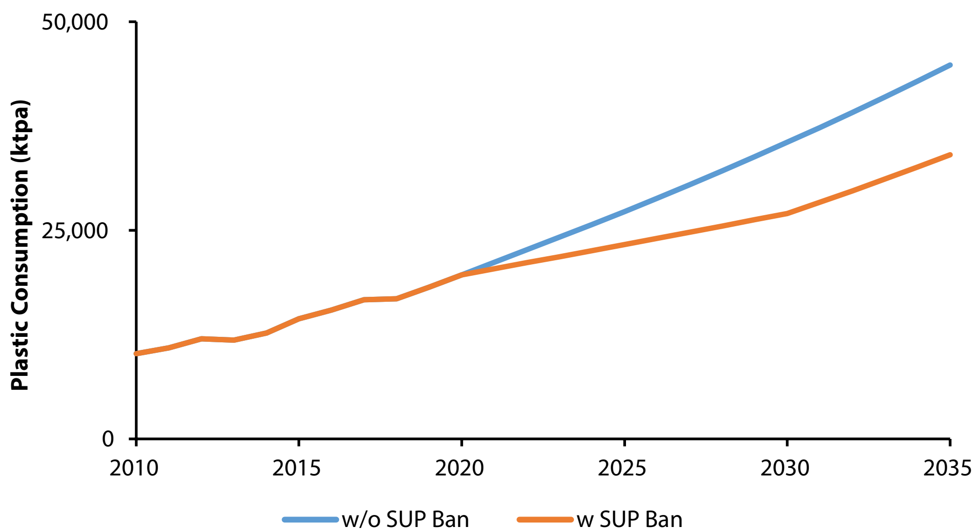

FIGURE 2: Plastic consumption/demand in scenarios without (w/o) and with (w) SUP bans, 2010-35

Source: Own analysis based on (CPMA, 2020; OECD, 2020; Sambyal, 2019)

[9] This is the basis for the CPMA Data for Apparent Demand (CPMA, 2020)

[10] For these forecasts, OECD's long-term baseline projections, assumptions around India's economic and population growth out to 2035 was gathered. It should be noted that these do not take into account the near-term impact of COVID-19, which should have a relatively small overall impact on total plastic consumption over the 2020–2035 time period.

The BAU projections for the respective polymer sub-categories (Figure 3) shows the expected variation in consumption of polymers till 2035, with the largest consumption continuing to come from PE and PP, which are the main polymers used for flexible packaging end use and constitute a significant part of (mismanaged) plastic waste. The BAU projections, however, would change once different circularity interventions are introduced through the use of policy measures. To illustrate, for an SUP ban, though national targets aim 2022, there is likely to be delay both to the implementation and enforcement. It may be more realistic to assume that the relevant policy reaches 100% efficacy by 2030.

Based on these assumptions, by 2035, the implementation of SUP bans in India will reduce plastic consumption by nearly 25%, versus a scenario where no SUP bans were implemented (Figure 4). A breakup of the projection into the respective polymer sub-categories depicts significant increases in

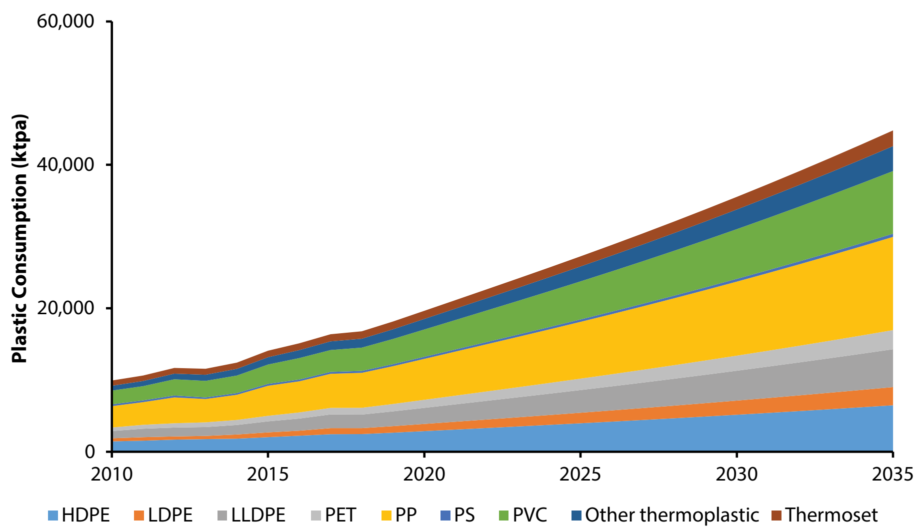

FIGURE 3: Plastic consumption projection by plastic type, 2010–35

Source: Own analysis based on (CPMA, 2020; OECD, 2020; Sambyal, 2019)

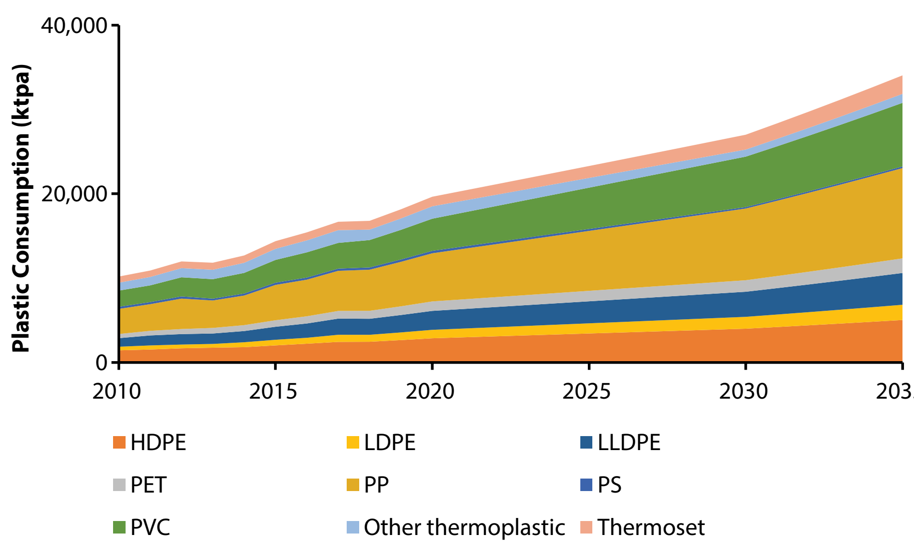

FIGURE 4: Plastic consumption projection by plastic type with sup ban implementation, 2010–35

Source: Own analysis based on (CPMA, 2020; OECD, 2020; Sambyal, 2019) certain plastic polymer types over this period, with the largest consumption still coming from PP, PVC, HDPE, and LDPE.

Limited proven national crude oil reserves that stand in no relation to domestic needs, the country relies majorly on imports of crude oil (measuring 205.3 million tonne with an import dependency ratio of over 80% as per 2018 estimates). The manufacture of monomers (majorly from the oil-refinery by-product naptha[11]) and the production of (plastic) polymers/resins is spread across a small set (17–18) of large industrial groups that have globally competitively sized plants with the state-of-the-art technology. As per 2018–19 estimates (IBEF, 2020), the five companies with the largest market shares together account for over 75% of the plastic polymers market.[12] The supply of polymers for making plastics relies heavily on virgin resins, which are both domestically produced and imported[13]. Midstream processes, include conversion of polymers, specifically resins to manufacture semi-finished products. Local plastic fabrication is done to make finished products for use by the brand owners. Eighty percent of these 'midstream' processes take place in MSME sectors[14].

Durability of plastic products plays an important role in determining consumption patterns and its flow into waste. Short-life plastics end up in the waste stream within a year assuming normal or average rate of physical usage. Long-life plastics give utility over time and do not quickly wear outmay be used repeatedly or continuously (assuming a normal or average rate of physical usage), averaging a lifetime of 3–15 years.

Figure 5 presents the Sankey representation of material flow of plastics in India, basis data for 2018–19. Out of the total polymer consumption of 16.8 million tonnes per annum (MTPA) in 2018–19, 90% (equal to 15.12 MTPA) was for plastic and the remaining 10% was for non-plastic consumption, including adhesives, rubbers, cosmetics, fibres (textiles). Based on TERI's internal calculations[15], the plastic waste flow for India suggests that out of the total plastic consumption, 42% of the plastic consumption in the year remains in use and the remaining 58% comes out as plastic waste. The generation point of plastic waste can be mainly classified into two categories: (a) pre-consumer or industrial plastic waste; and (b) post-consumer plastic waste. These groups of wastes have different qualities and properties and are subjected to different management strategies. Industrial plastic waste contains resin pellets. These are virgin material and mostly used within the plastic manufacturing processes in the same industry or through industrial symbiosis in another industry.

Post-consumer plastic waste comes out as part of the MSW stream, which accounts for the majority of plastic waste. Recent estimates[16] on national-level assessment of plastic waste generation suggest

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[11] The market for bio-polymers (plant)-based feedstock is in its infancy, accounting for a very small share in the production of polymers. More than 95–97% of polymers are derived from fossil fuel feedstock. Also since the prices of crude oil products witness significant volatility, it makes the petrochemicals prices highly volatile.

[12] The five large groups were: Reliance Industries (45%), Indian Oil Corporation Ltd. (16%), ONGC Petro Additions Limited (12%), Haldia Petrochemicals (9%) and Gas Authority of India Limited (GAIL) (8%).

[13] Trade has a central role in India's domestic plastics value chain. Whilst several polymers (raw materials): PP, HDPE, LDPE, are available domestically for the manufacturing/processing industry, plastics also represent the sixth largest imported commodity, and ranks amongst the top 15 export commodities in India (World Bank 2018). Polymers constitute the major form in which plastics are imported by India. These include PE, PVC and the category of polyacetals, other polyethers, and epoxide resins, PC, alkyd resins, polyallyl esters, and other polyesters in primary forms.

[14] Despite the scale of operation at MSME level, the country has the capacity to service both the domestic and the overseas market.

[15] These calculations are part of World Bank supported project on National Assessment of Plastic Waste in Indian cities.

[16] The results of the plastic waste flow are similar to the (CPCB 2015) study on estimating the waste generation in 60 cities of India. However, the study did not factor in re-utilization, which is now becoming an increasingly popular option to deal with contaminated mismanaged waste.

that 60% of the total plastic waste is recycled, and 8.5% is reutilized for energy recovery (in WtE plants or cement kilns) and for repurposing such as in applications of road construction/lumber making. The remaining 31.5% is mismanaged plastic waste, i.e. littered in streets, drains, garbage vulnerable points (GVPs), or thrown in dumpsites or openly burnt leading to high risk of leakage that ends up as marine litter. This mismanaged plastic, regardless of disposal method, represents danger to human health and the environment. For example, whenever plastic is burned, it emits into the environment GHGs, principally CO_2, and hazardous chemicals in the form of additives.

Plastic waste can be flexible type or rigid type and within this categorization, the waste could be packaging or non-packaging type.

Flexible Plastic Waste

Flexible packaging is mainly of three types[17]: single/mono polymer packaging (SPP) (using mainly PET, PE and PP) for manufacturing milk pouches and water poches, multi-polymer packaging (MPP) (using mainly combinations of PE, EVOH, PET, Nylon, PP) for manufacturing edible oil pouches, stand up pouches, and multi-material packaging (MMP) (using mainly a combination of PE, PET, PVC with aluminium) for manufacturing snack food packaging, hair dye, and medicines. Within these three categories, the SPP has the simplest structure and ease of recycling properties, but it has the lowest barrier properties and thus low shelf life. MMP has superior barrier properties (as it controls oxygen, carbon dioxide and moisture level, the key to preserving freshness) and thus longer shelf life but a complex structure, which causes challenges in recycling.

Flexible non-packaging plastic items for SPP include items such as cables and dental floss, for MPP include items such as agricultural mulch films and for MMP include items such as light toys and houseware items.

Discarding different types of plastic products and their littering after use are dependent partly on the weight and size of these plastics products. The collection is very low for flexible SPP and MMP (though recyclability is high for SPP and difficult for MMP) and it is medium for MPP (with medium level of recyclability).

Rigid Plastic Waste

Rigid packaging is also of similar three types: SPP (used for water and beverage packaging, lube oils, and health drinks using PET, PE and PP, respectively), MPP (used for pickles and yogurt pulp packaging, and with PE+EVOH) and MMP using paper, aluminium and polymers such as PE (used for fruit juices, milk packs, blister packs, brick cartons). For rigid packaging too, SPP has the simplest structure (and thus lowest barrier properties) whereas MMP has the complex structure with high barrier properties.

Rigid non-packaging plastic items for SPP include products such as tanks, furniture, crockery, combs, pipes, for MPP include items such as bangles, frames, cutlery, stationery, tooth brushes, white goods, auto parts, and for MMP include items like footwear and razors. Littering is low for all the three types, and their collection is high. Rigid SPP, especially, is easy to recycle (such as PET bottles for beverages and HDPE shampoo bottles) however, challenges in recyclability are associated with rigid MPP and MMP.

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[17] This section describing the different types of flexible and rigid plastics is based on a presentation by Dr. Vijay Habbu, an expert in the plastics sector and currently an Adjunct Professor at ICT, Mumbai.

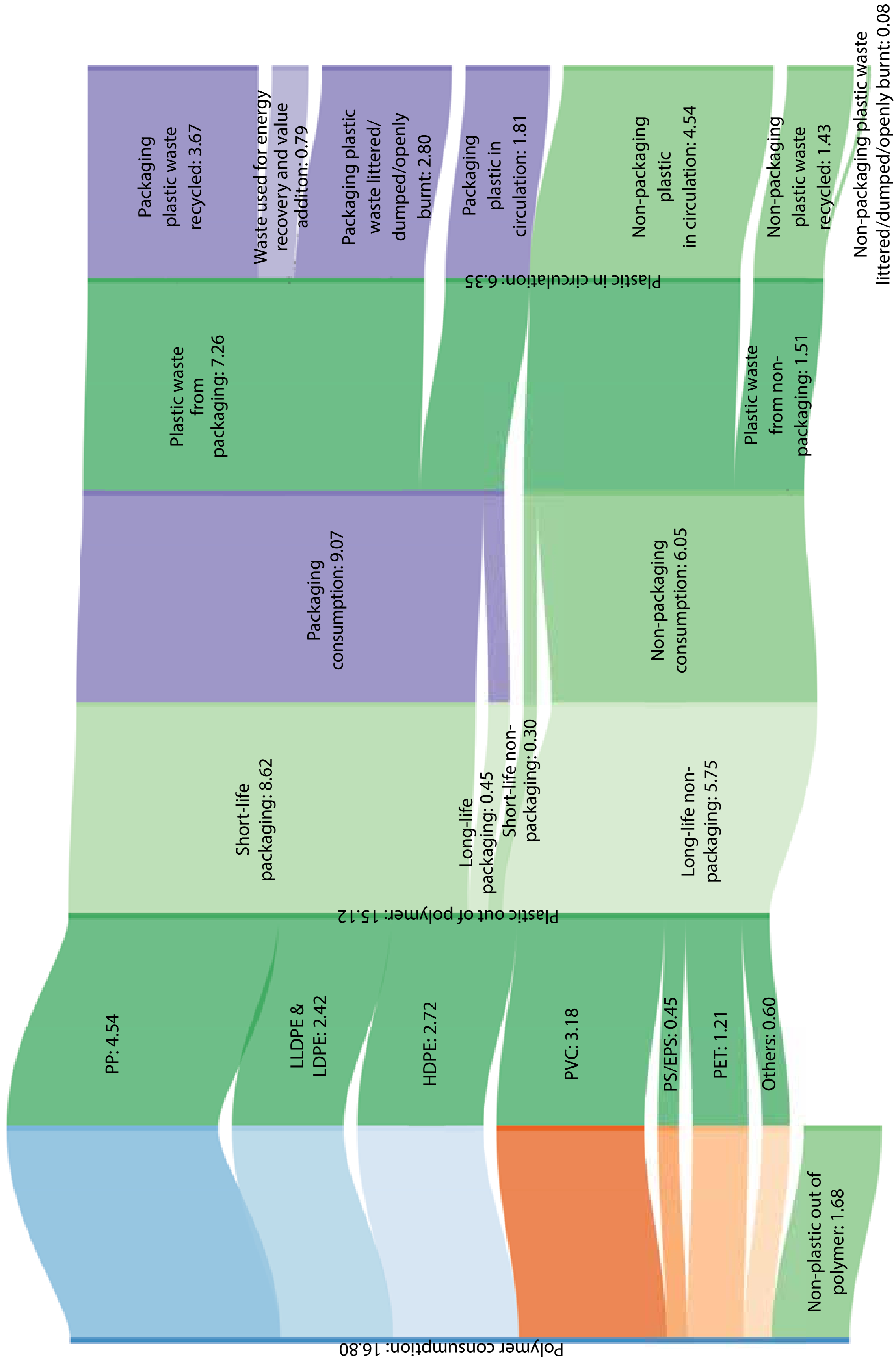


FIGURE 5: Sankey representation of material flow of plastics in india (basis data for 2018–19)

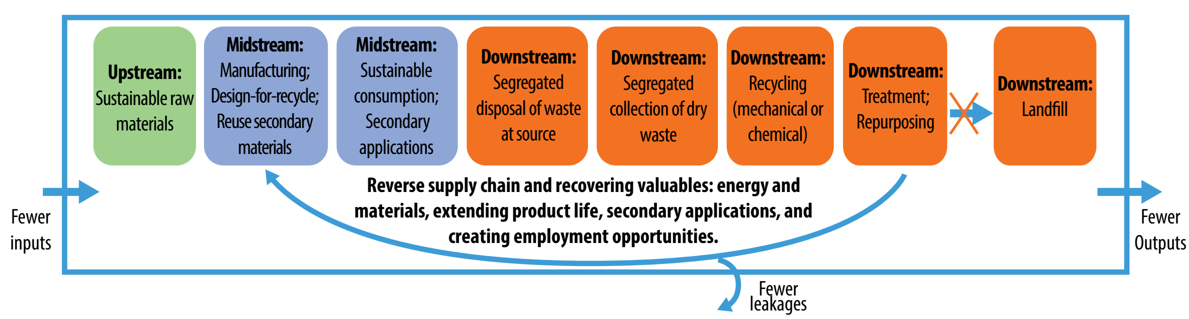
Circular Economy for Plastics in India: Challenges and Opportunities

A resource-efficient circular economy for plastics is one that minimizes wasteful use of plastics, produces plastics from renewable sources, is powered by renewable energy, reuses and recycles plastics within the economy without leakage to the environment, and generates no or minuscule waste or emissions.

To enable this, the GOI through its Plastics Waste Management Rules, 2016 has mandated Extended Producer Responsibility (EPR) that incorporates circularity by making manufacturers of products responsible for collecting and processing their products upon the end of their lifetime. The objective of EPR is to minimize the total environmental impact of waste materials from a product and encourage manufacturers/ brand owners to create markets for reuse or recycling of materials.

Although there have been collaborative initiatives in existence such as the United Nations Development Programme (UNDP) India, in partnership with Hindustan Coca-Cola Beverages Private Limited (HCCBPL), which encourages sustainable plastic waste management practices and fosters a move towards circular economy in 50 cities and towns in India, there are many challenges in adopting circularity of plastics in India, as given in Figure 6.

These challenges, when addressed, can create vast economic, social, and environmental opportunities within the plastics and other industries and allow for synergistic functioning of the public and private sectors.



Existing challenges to foster plastics circular economy in India

- Segregation of waste at source and segregated collection, especially in rural areas, is non-existent
- Unorganized, informal mechanical recycling, with leakages and emissions
- Mixed input streams and 'pure' recyclate types of plastic having large variation in additives
- Chemical recycling requiring large investments
- Occupational and health safety hazards linked with waste collection (for women and children in particular) and in recycling , such as release of dioxins linked to cancer and reproductive problems
- Lack of strict enforcement of waste collection and disposal
- Open dumping and clogging of drains with plastic waste is still prevalent
- Lack of investment and funding to set up proper waste management infrastructure including operational costs of transporting waste for reprocessing
- Lack of market-based instruments and regulatory measures for effective functioning of business models
- Economically challenging to set up standard prices of plastic waste as raw material and market for recycled products
- Most plastic reprocessed only once as plastic resins degrade in quality every time it is re-heated
- Lack of coorporation between stakeholders across the plastics value chain
- Awareness and knowledge gaps
- EPR implementation is more like a CSR initiative

FIGURE 6: Circular economy for plastics in India and challenges

Plastics Circularity Scenarios

Demand-side Potential: Key End-use Sectors

Plastics are used for a variety of different purposes application categories/end-use sectors (Table 4).[18]

Packaging is broadly categorized into rigid packaging and flexible packaging. Flexible packaging, which is the newer form of packaging, has the largest share amongst the key end-uses. It also anticipates a strong growth in the future due to numerous advantages, such as convenience in handling and disposal, price advantage in transportation, as well as its portability, which has traditionally been limited by rigid packaging.

TABLE 4: Share of key end-use sectors of plastic usage

Sectors	Share in 2013–14	Share in 2019
Flexible Packaging	35%	42%
Rigid Packaging	13%	17%
Household	10%	7%
Building and Construction	12%	13%
Agriculture	9%	9%
Electrical and Electronics	14%	2%
Automotive	3%	7%
Others	4%	3%

Household includes FMCG products such as toiletries and cosmetics, furniture, toys, luggage, housewares, and other lifestyle-related goods.

Construction would include water pipes, water tanks, roof shelters, sheets, etc.

Others would include sports and leisure, medical, dental care, and industrial machinery (heterogeneous category)

Source: PlastIndia Foundation (2019); PlastIndia Foundation (2014)

In the automotive sector, usually a car on an average consists of 10–20% plastics in the total weight; there can be variation in this share depending on fuel efficiency standards and performance requirements. Estimates by IHS (Plastics Today, 2016) had suggested that by 2020, an average car will incorporate about 770 pounds of plastic by weight; in 2014 this was 440 pounds. Currently, there are about 30,000 parts in an automobile vehicle, out of which one-third are made up different types of basic plastics and polymers (The Plastics Industry Trade Association, 2016). They are used in the engine, body panels, bumpers, and fascia systems, chasis/suspension, seats/trims, HV AC system, steering wheels, and light panels among other sections in the vehicle.[19] The past few years have seen several advances in plastics technology and a number of conventional metal parts like fuel tanks are being made using plastics. In 2014, plastics used for electrical parts, exterior and interior applications, accounted for 70% in the total automotive plastic consumption (Automoative Products Finder, 2017). More than 70% of the plastic

[18] It is important to note that the use of plastic packaging in other key end-use sectors is considered to be part of the packaging share. Other key end-use sector share only include non-packaging use of plastics.

[19] Comprehensive Industry Document (COINDS) for Automobile Manufacturing Industries

used in the automobiles comes from six polymers:[20] PP, PVC, polyurethane (PU), PE, polycarbonate and polyamide (nylon), (PET), and acrylonitrile butadine styrene (ABS).

Properties of plastics such as being strong yet light weight, durable, cost-effective, low maintenance, non-corrosive makes them an attractive option in the building and construction sector. Plastics are mainly used for seals, cladding, and profiles (windows and doors), pipes[21] (gas, water supply, sewerage, OFD, plumbing, industrial piping), cables, floor coverings, foam insulation, window panels, sealants, floor protective sheets, wall panels, industrial and hospital floorings, bathroom and toilet fittings, submersible pump parts, synthetic tiles and marbles, roto molded water and chemical tanks, buried roto molded/ FRP septic tanks, ducts, wires, and cables (TERI, 2019). Polymers are also the binding materials of paints and lacquerse (such as acrylate co-polymers, epoxy and polyurethane). Piping and conduit in construction are the largest users of polymers using PVC and PE.

Tables 5a, 5b and 5c present the key opportunities[22] for integrating resource efficiency and circularity in the value chains of these key end-use sectors.

TABLE 5A: Plastics circularity in packaging sector

Circularity Aspect	Existing Practices/Scope (International and Indian context)	Opportunities
Use of bio-plastics	» Largest application (60% of total bio-plastic consumption) in India for packaging » Used in bottles, loose-fill, cups, pots, blows, flexible films, etc. » In India, selected FMCG companies aiming for 100% biodegradable plastic for packaging ready-to-eat and cosmetic products	» Use of PBS as alternatives in packaging, including the use in fresh food packaging to enhance lifespan » With bans against SUPs and economic of scale setting in for bio-plastics, their share in packaging sector is expected to increase
Reusable packaging	» Pepsico India, scaling up its non-returnable glass bottles for its packaging » Leadec India provided reusable crating solutions for automotive components made of HDPE which can be folded » Reffin aims to offer restaurants with an alternative means of delivering their foods to consumers by using tiffin carriers, generally made out of stainless steel	» Many reuse opportunities in business-to-business (B2B) applications, which are generally better understood and adopted at scale already » Designing packaging solutions in business-to-consumer (B2C) applications » Potential to meet individual needs, specificities for packaging, improved user experience and create brand loyalty » Replacing existing SUP containers in the growing online food delivery services by using re-usable containers

20 Lightweight materials such as Carbon Fiber Reinforced Plastic (CFRP) are also being increasingly used. Composites help reduce vehicles' impact on the environment because they offer high strength to weight ratio. These materials allow innovative, flexible, and unique design freedoms and aerodynamic shapes normally difficult to achieve with other materials. CFRPs are lighter and stronger and have the potential to reduce vehicle weight by up to 50% while maintaining structural efficiency and enhancing safety of the occupant in the vehicle.

21 Plastic pipes have replaced traditional, Victorian pipes as they have reduced leakages and saved the energy required to process and pump water (British Plastics Federation , 2020). It is also more energy efficient to use plastic pipes instead of iron or concrete pipes due to reduced energy required in the production and transportation of light weight plastic pipes to the building and construction site. Plastic cladding and profile for windows, doors, etc. is increasingly replacing timber for minimum fire risk.

22 This is not an exhaustive list of opportunities

TABLE 5A: Plastics circularity in packaging sector

Circularity Aspect	Existing Practices/Scope (International and Indian context)	Opportunities
Use of recycled plastics[23]	» Commitment by large companies (both Indian and MNCs) will move to 100% recyclable plastic packaging by 2025 » Cargill Oils India, in association with Dow Chemical, reformulated its plastic material, making 90% of its plastic packaging recyclable	» Use recycled plastic in non-food applications » Inclusion of pro-environment message on the packages and to nudge the consumer towards responsible behaviour that includes giving preference to products containing recycled raw material
Re-design of packaging	» Lush, handmade cosmetics have a packaging free line » Cargill's oil business in India has redesigned its packaging by cutting down on the amount of raw plastic used across all products » Cremica Food Industries is reducing lamination in packaging	» Avoid use of extra packaging material or create packaging free line of products » Fewer types of standardized plastics for specific uses in FMCG-reduce plastic waste leakage and improve recycling » Replacing packaging material like shrink wraps with more durable and reusable long lasting alternatives » Stay on tabs for beverages, flip flop caps for FMCG products[24] » Replacing multi-polymer plastic packaging with single polymer plastic packaging[25] » Colour coding and labels for disposing bio-based and/or compostable after use[26]

23 However, ensuring that food safety requirements and rules on food contact materials is followed.

24 Collection and sorting mechanisms find it difficult to capture small package parts such as caps, lids, etc.

25 Stand-up pouches by Dow Chemicals makes use of mono layer of PE which has recycling technologies

26 This can enable its tracking and subsequent segregation can take place and ensure standardization of plastic waste management through its value chain.

TABLE 5B: Plastics circularity in automotive sector

Circularity Aspect	Existing Practices/Scope (International and Indian context)	Opportunities
Use of bio-plastics	» Successful pilot experiments have been completed on the use of bio-based plastics for automotive applications[27] » Most important upcoming market within automotive sector is technical applications. Currently, automotive and transport sectors account for 1% of the bio-plastics market segment	» Bio-based polyesters, bio-based PET and PLA-blends in applications such as headliners, sun visors and floor mats, interior fabrics
Use of recycled plastics	» Currently, recycled plastic account for 15% in vehicles » TATA motors engaged in automotive bumper recycling	» Plastic fibres made from used bottles in sound insulation layers in dashboards » Use of plastics recycled from bumpers to create new bumpers, as well as plastics recycled from bottle caps to make new auto parts » Use of recycled plastic content in vehicles is expected to increase to 70%
Use of eco design practices	» BMW uses hemp as well as natural fibres along with acrylic polymers for manufacturing interior door panels » Ford uses bio-polymers from soyabean along with polyurethane to manufacture head rests in their selected models » Nissan Leaf uses natural fibres from corn along with Sorona (polytrimethylene terephthalate) for manufacturing of rugs and mats	» Natural fibres and/or biopolymers draw significant interest from equipment manufacturers due to their biodegradability, low cost, low relative density, high specific strength, and renewable nature » Eco-design approach gets product design environmental oriented

[27] However, it is important to ensure that the bio-plastic chosen meets the vehicle specifications in terms of safety and the integrity standards.

TABLE 5C: Plastics circularity in building and construction sector

Circularity Aspect	Existing Practices/Scope (International and Indian context)	Opportunities
Use of alternative material	» Bricks and planks made out of plastic waste being used as alternatives to traditional clay and mortar bricks in construction	» Biological nutrients and sustainable, renewable materials can replace materials that are heavily processed and hard to reuse and recycle
Standardized approach	» The utilization of Energy Conservation Building Code and implementation of green rating systems like the Green Rating for Integrated Habitat Assessment (GRIHA) is leading to resource-efficient buildings in India	» Assessing performance of secondary materials in products replaces virgin materials and in the design of construction products » By standardizing technology, construction companies can reduce the cost of their production
Use of recycled plastics	» Royal Melbourne Institute of Technology (RMIT) researchers developed a building material made from cigarette butts mixed with plastic waste, bitumen, and paraffin wax » Corepla along with Waste Free Oceans built the first humanitarian shelter prototype by collecting plastic waste along the river » Benagluru-based non-profit Swachha developed a solution that can convert discarded plastic waste into tiles and irrigation pipes. In association with the Bruhat Bengaluru Mahanagara Palike (BBMP), Swachha developed 'Re-Tile' tiles, which customers can use on pavements	» Recycled plastic blended with virgin plastic lowers the cost » Recycled plastic can save the cost of other materials, such as wood and slate » Recycled plastics can be used to make stronger concrete structures in the form of sidewalks, driveways

Supply-side Potential

Plastic Feedstock

The feedstock for making plastics includes traditional fossil fuels, bio-based plastics, or recycled plastics.

For **fossil fuel based plastics,** monomers are manufactured majorly from naptha and natural gas, the oil-refinery byproduct (Geyer, Jambeck, & Law, 2017). The monomers then become the building blocks for producing (plastic) polymers/resins.[28] This process leads to emissions and their economics also impact the recycling efforts. These types of plastics are mostly non-biodegradable. Polymers such as polybutyrate adipate terephthalate (PBAT), polybutylene succinate (PBS), polycaprolactone (PCL), and polyvinyl alcohol (PVOH, PVA) exist that are biodegradable fossil fuel-based polymers as their chemical structures can be broken down by the action of microorganisms in the presence of light, oxygen, and moisture.

Bio-based plastics are produced from non-fossil-fuel feedstock, usually organic materials such as plant fibres (flax, jute, hemp), wood (reclaimed wood fibres from mills and agricultural waste), and starches; however, like fossil fuel-based plastics, they are available in many grades and in a variety of properties. Bio-based plastic products often have an appearance very similar to conventional plastic products and cannot be easily distinguished by consumers, other than by scientific analysis. If they contain both renewable and fossil-fuel-based carbon, they are then only partially bio-based. The amount of bio-based constituents and the conditions under which these polymers biodegrade vary widely.

By-products of industries that use organic plant materials can be the feedstocks for some bioplastics. Starch can be processed to produce polylactic acid (PLA). Polyhydroxyalkanoate (PHAs) are polyesters produced in nature by numerous microorganisms, including bacterial fermentation of sugars or lipids. Another example is sugar cane, processed to produce ethylene, which can be then used to manufacture polyethylene. However, not all bio-based plastics are bio-degradable (Albertsson & Hakkarainen, 2017) and not all bio-degradable plastics are bio-based plastics. Bioplastics can be as toxic as other plastics. Products based on cellulose and starch contain chemicals which can trigger strong toxic reactions under laboratory conditions.

Though biodegradable plastics break down faster, the speed and nature of biodegradation varies from material to material and depends on environmental conditions. The additives prevent biodegradable plastics from successfully being recycled alongside conventional plastics, and leave behind toxic microplastics in the environment. Despite biodegradable plastics being favoured, the science behind biodegradation, the technology for manufacturing these plastics, and disposal practices indicate that the products will increase the formation of difficult to spot micro-plastics, and hamper existing recycling chain, increase the chance of leaching into the contents of packaging. However, their disposal in the composting environment should result in the formation of natural by-products such as oxygen, nitrogen, carbon dioxide, water, biomass, and inorganic salts. They are also expected to not leave any persistent or toxic residues. But they may end up in posing more harm to the economy, food safety, and human health.

Compostable plastic, on the other hand, means that the polymers get biodegraded within a composting timeframe of about six months, yielding H_2O, CO_2, biomass, and inorganic compounds, and ideally not leaving any visual or toxic residue (Department of Ecology, 2014) . However, they too end up generating

[29] Annexure 2 gives a brief note on production process of ethylene, propylene, and major polymers

micro-plastics. Despite the terms 'biodegradable' and 'compostable' often being used interchangeably, they are not the same. Composting is only one environment where biodegradation occurs. Compostable plastics biodegrade in industrial composting operations at the same rate as other compostable materials.

The current global production capacity of bio based and biodegradable plastics is only about 4 million tonne per year, accounting for about 1% of the total production of plastics, which was estimated at 380 million tonne (Geyer, Jambeck, & Law, 2017) . Companies such as BASF, DuPont, and NatureWorks LLC are among the major players in the bio-plastics domain. It is also the focus of small- and medium-sized companies,[29] and technology providers.

Several worldwide organizations are involved in setting standards for biodegradable and compostable plastics including American Society for Testing and Materials (ASTM), European Committee for Standardization (CEN), International Standards Organization (ISO), German Institute for Standardization (DIN), Japanese Institute for Standardization (JIS), and British Plastics Federation. Standards from these organizations help the industry to create biodegradable and compostable products that meet the increasing worldwide demand for more environmentally friendly plastics. BIS Standard IS/ISO 17088:2008 specifies procedures and requirements for the identification and labelling which has to confirm to any international, regional, national or local regulations and identify products made from plastics suitable for recovery through aerobic composting (CPCB, 2009) .

A third source of feedstock for making plastics is using **recycled plastic**. Each kilogram of plastic that is not reused or recycled is replaced with another kilogram produced from non-renewable, fossil-based raw materials. Recycling is one of the sustainable solutions to treat end-of-life plastics and helps in improving energy and environmental impacts.

A 2018 study (McKinsey & Company, 2018) notes, 'Recycled resins could replace almost a third of virgin plastic by 2030 and nearly 60% by 2050, slashing demand for petrochemicals'. One reason for a growing market demand for high-quality plastic recyclates is the significantly higher voluntary targets, set as part of corporate commitments towards sustainability and mandated targets set by regulations for recycled plastics. This has created a potential for the chemical companies to engage in producing polymers using methods of mechanical recycling, and conducting pyrolysis and chemical recycling of used plastics. The oil major, Shell,[30] has made 'high-end' chemicals using a liquid feedstock made from plastic waste by pyrolysis process that is considered a breakthrough for hard-to-recycle plastics. The initiative is said to advance Shell's ambition to use 1 million tonne of plastic waste a year in its global chemical plants by 2025.

Petrochemical companies are well placed to invest in new feedstock units based on pyrolysis-treated plastic waste from the large volume of newly available waste plastics that could be coming into the market, alongside the fossil fuel-based feeds they have traditionally been using.[29] With consistent supplies of waste plastic, this will also enable petrochemical companies in reducing their vulnerability to virgin fossil fuel prices in the international market.

Increased demand for bio-based feedstock could pose many risks and challenges (Figure 7).

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[29] Some of the large oil and gas companies are becoming more integrated players in plastic production, providing waste processing solutions and supplying bio-based and/or secondary raw materials.

[30] Shell is a founding member of the Alliance to End Plastic Waste (AEPW). This not-for-profit organization is bringing together top minds from across the plastics value chain (chemicals and plastics manufacturers, consumer goods companies, retailers, converters, and waste management companies) and partnering with the financial community, governments, and civil society. The AEPW has committed $1.5 billion over the next five years to help end plastic waste in the environment.

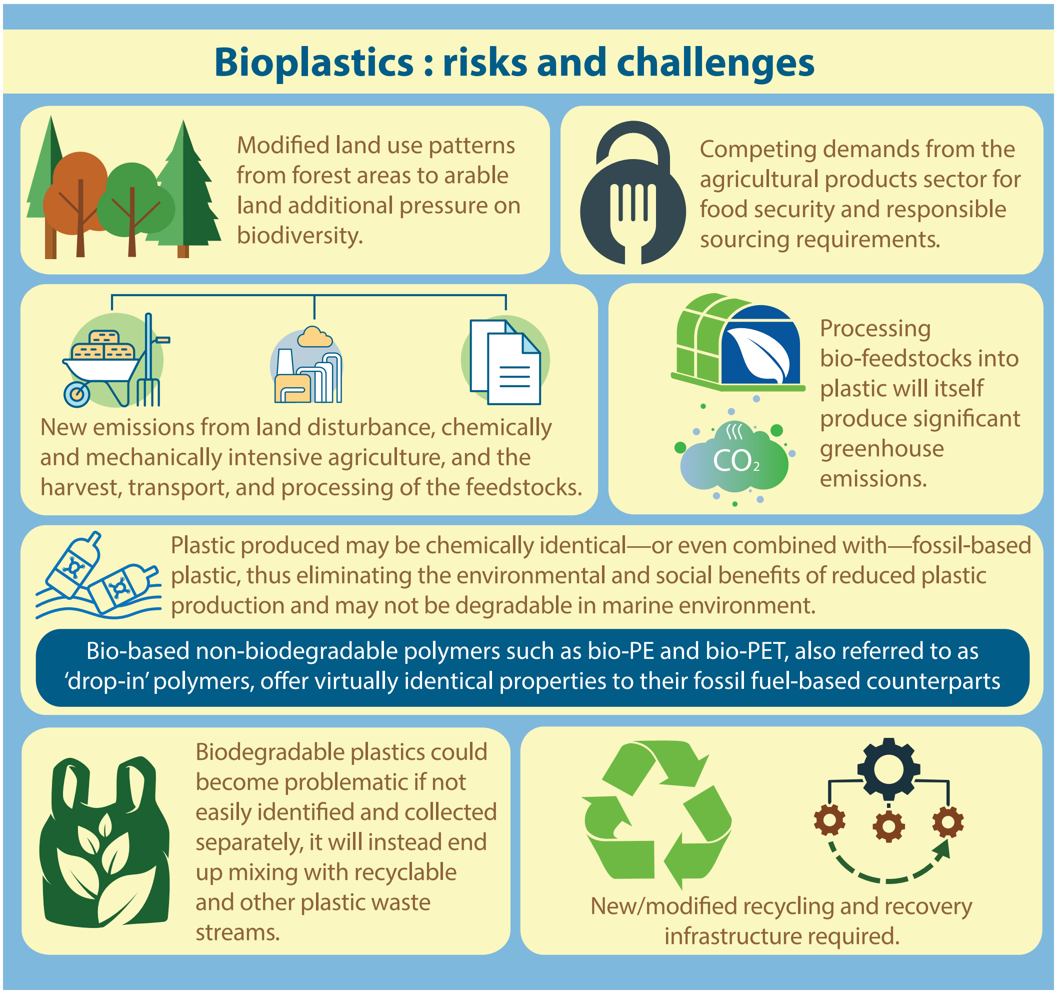

FIGURE 7: Bio-plastics risks and challenges

The development of renewable resource-based bio-plastics and bio-based materials may result in challenges linked to biomass availability and land availability for food, biomaterial, or bioenergy production. An environmental impact assessment (Broeren, *et al.*, 2017) shows a great variation in GHG reduction from starch-based plastics versus their conventional counterparts, from an 85% reduction to an 80% increase depending on the plastics composition. (Broeren, *et al.*, 2017). Further, a cost benefit analysis of petroleum-based HDPE and of PLA resin obtained from cassava root (Case 1) and cassava starch (Case 2) in Thailand showed that the net benefits from PLA are only achieved when cassava meals are sold as another product from cassava root (Chiarakorn, Permpoonwiwat, & Nanthachatchavankul, 2011). A summary of cost benefits is given in Table A3 in Annexure 1.

Currently, with very low levels of production of bio-based plastics, issues of feedstock scarcity and/or land-use competition do not arise; in the longer run, however, as the demand and production increase, these issues may become extremely relevant. This calls for the need to diversify the non-fossil resource base to include bio-waste feedstock and the use of captured carbon dioxide as feedstock.

What will be important is to find ways to use co-product and by-product of one industry and convert it into value-added. Opportunities need to be identified to create value for an undervalued co-product of one industry that can be integrated into a bio-plastic by creating novel bio-based materials for new industrial uses. The co-products from biofuel, pyrolysis, and food processing industries show immense potential as fillers or for reinforcing materials for plastics in creating a range of eco-friendly and sustainable bio-composites.

The cost of production of bio-plastic is currently higher than those of conventional plastics made out of fossil fuel feedstock, owing to absence of adequate infrastructure to make the former compared to the large infrastructure that already exists for the traditional plastics.

There is potential to convert some of the existing infrastructure to process organic feedstock to make bio-plastics. For example, PLA and bio-polyethylene can be produced from already existing manufacturing equipment (those designed and originally used for petrochemical industry plastics). (Babu, O'Connor, & Seeram, 2013).

The biodegradable plastic industry in India is still in its infancy. Several uncertainties exist that prevent its large-scale adoption. As most cities lack adequate number of facilities and infrastructure, the bio-plastics end up on the street posing harm to the environment just like conventional plastics. Continuous research is required in this direction to ensure that these biodegradable plastics are produced from renewable sources and display in-use properties similar to that of conventional plastics (CPCB, 2009).

There is also a need for putting in place adequate infrastructure and generating consumer awareness for end-of-life management of bio-based plastics.

Market for Recycled Plastics/Secondary Raw material

The market for off-take of recycled plastic raw materials can be segmented into two parts: 1) extended recyclers (recyclers who process scrap and convert it to end-product) and 2) plastic product manufacturers (end product manufacturers who purchase recycled plastic resins as raw material).

Formal recyclers face challenges in securing high quality supply of recyclable plastic waste as current supply of this waste id dominated by the informal sector. Further, the cost of processing scrap is high in the formal sector if occupational health and safety conditions are met. These factors make recycled plastic difficult to compete with the low cost of virgin plastic. It is easier to compete in segments that do not currently use plastics as raw material. For example, alternative building materials made out of recycled plastics in the form of plastic bricks and planks can be used instead of conventional materials such as clay and mortar bricks in building construction.

Plastic product manufacturers see only a limited market for post-consumer resin (recycled plastic pellets). This is driven by the low grade of recycled plastic resins produced by most players due to operation in fragmented market. There is a potential to penetrate export markets, such as Europe, where the demand for sustainable products and circular consumption are increasing. But to tap these markets, the manufacturers of post-consumer resin will need to meet the higher quality standards demanded by foreign buyers.

Circularity Scenarios: Integrating Demand-and Supply-side Potentials

In this section, we define three scenarios for India to understand the potential impact of resource efficiency and circular economy (RE&CE) measures from demand and supply side in the plastics sector:

Business as usual scenario: It is assumed that a standard economic growth model exists where the consumption of plastic products and the generation of plastic waste increase at a rate consistent with the international, historical experience. Existing innovations and business models at downstream stage of the value chain focussing on plastic waste management at public and private sector level continue, with new ones coming up. But these innoations and models are majorly localized with no upscaling and replication. Further, no explicit circularity measures/efforts are put in at the upstream stages.

Moderate RE&CE scenario: Moderate reduction (in key end-use sectors) in virgin plastic demand by substituting it with recycled/secondary plastic that is made available from improved plastic waste management. Businesses are working towards complying with the plastic waste management legislations and have initiated the implementation of Extended Producer Responsibilities (EPR), particularly for collection and resource recovery targets. Legislative measures such as ban on SUPs and on certain types of packaging are coming into effect. The GOI is pushing towards developing affordable substitutes/alternatives to SUPs.

High ambition RE&CE scenario: The demand for virgin plastic is drastically reduced through a combination of circularity fostering measures that include increased recycling levels, effective implementation of EPR over entire value chain of plastics (including through measures that aim to reduce plastic consumption and reduce multi-polymer plastic), continued and strengthened push by the GOI in developing affordable substitutes/alternatives to plastics, and improved enforcement of legislative measures such as ban on SUPs and ban on certain types of difficult packaging.

These scenarios have been detailed out in Table 6.

TABLE 6: Potential resource efficiency and circularity scenarios for plastics sector in India

Circularity Interventions and Scenarios	Substitution between Plastic Polymers » Move to a bio-based as alternative feedstock to fossil feedstock » Shift from multi-polymer material to mono-polymer material	Expansion of Segregated Waste Collection » Improved collection and transportation infrastructure » Awareness generation	Increased Recycling or Reprocessing into a Secondary Material[31] » Increase mechanical recycling capacity and efficiency » Scale up chemical recycling capacity	Design for Recycling » Fewer types of plastics to reduce the complexity in plastic waste management [32] » Design to enable easy disassembly at the EoL	Reduction in Plastic Consumption » Use of alternatives to plastics products and reduction in specific uses (across key end use sectors/ applications) » Re-use of end use products » Design to bring in efficiency in plastic raw material use
Business as usual scenario	Bio-based plastics account for less than 1% of the plastics produced Use of multi-polymer material continues to grow (R&D initiated to identify substitutes)	No change in segregation of waste plastic and collection levels Important to note, collection levels in urban India are currently high but the issue is more linked to unsegregated collection and irresponsible dumping and littering post collection	Limited increase in overall recycling of plastics (at rates witnessed over the last 3–5 years) brought by new localized initiatives and business models. Increased awareness generation brought about by IEC activities	Not happening; R&D process initiated	Very limited substitution brought about in specific applications including those related to SUP [33, 34]

31 Maintaining high material quality will remain a challenge and consequently there may continue less than potential demand for recycled material and risk of down-cycling.
32 (Hahladakis & Iacovidou, 2018)
33 There is significant legislative push against SUPs
34 In India, around 43% of manufactured plastics are used for packaging purpose and most are of single use.

TABLE 6: Potential resource efficiency and circularity scenarios for plastics sector in India

Circularity Interventions and Scenarios	Substitution between Plastic Polymers » Move to a bio-based as alternative feedstock to fossil feedstock » Shift from multi-polymer material to mono-polymer material	Expansion of Segregated Waste Collection » Improved collection and transportation infrastructure » Awareness generation	Increased Recycling or Reprocessing into a Secondary Material[31] » Increase mechanical recycling capacity and efficiency » Scale up chemical recycling capacity	Design for Recycling » Fewer types of plastics to reduce the complexity in plastic waste management [32] » Design to enable easy disassembly at the EoL	Reduction in Plastic Consumption » Use of alternatives to plastics products and reduction in specific uses (across key end use sectors/ applications) » Re-use of end use products » Design to bring in efficiency in plastic raw material use
Moderate RE&CE scenario (2035)	Percentage share of bio-based plastics will increase to 10% by 2035 Reason being that the ability of these types of plastics in reducing the accumulation of plastic pollution has been disputed, and their applications are limited	Expansion in infrastructure to support segregated collection and storage (e.g. MRFs and transfer station) has been initiated Improved awareness amongst stakeholders on source segregation	Moderate increase in overall recycling of plastic brought about by improvement in plastic collection, and expansion of recycling capacity in the country by private and public sector; Overall recycling rate increases to 70–75%; the draft National Resource Efficiency policy targets 100% recycling and reuse rate for (PET) plastic by 2025	Pilot experiments around design for recycling	Some substitution brought about in all applications related to SUP[35]; Development of innovative alternative products in a few plastic products, mostly in packaging-related applications; Reducing over packaging; SUP product share decreases to 40% (reduction brought about mainly through reduction in single-use plastic bags and Styrofoam products)

[35] More durable and multi-strip plastic packaging to replace durable and single-strip alternatives.

TABLE 6: Potential resource efficiency and circularity scenarios for plastics sector in India

Circularity Interventions and Scenarios	Substitution between Plastic Polymers » Move to a bio-based as alternative feedstock to fossil feedstock » Shift from multi-polymer material to mono-polymer material	Expansion of Segregated Waste Collection » Improved collection and transportation infrastructure » Awareness generation	Increased Recycling or Reprocessing into a Secondary Material[31] » Increase mechanical recycling capacity and efficiency » Scale up chemical recycling capacity	Design for Recycling » Fewer types of plastics to reduce the complexity in plastic waste management [32] » Design to enable easy disassembly at the EoL	Reduction in Plastic Consumption » Use of alternatives to plastics products and reduction in specific uses (across key end use sectors/ applications) » Re-use of end use products » Design to bring in efficiency in plastic raw material use
High ambition RE&CE scenario (2035)	Percentage share of bio-based plastics reaches 40% [36,37] by 2035	Source segregation is enforced in 90% of the cities in India; Infrastructure to support segregated collection and storage (e.g. MRFs and transfer stations) exist; Deposit refund systems/schemes supported by digital technology are in function that enhance collection of uncontaminated waste	High increase in recycling brought about by significant and step changing improvement in PWM (through full implementation of the best available recycling practices) across the country by private and public sector resulting in an overall recycling rate of plastics as 90-94 percent[38]; Deposit refund systems/ schemes supported by digital technology are in function that enhance supply of uncontaminated plastic waste for recycling	Happens and it positively impacts the recycling rates- by reducing the costs linked to plastics separation from the end-of-life products and also improving the recycling per se due to reduced risk of contamination of mixed plastics	High substitution brought about in all applications related to SUP; Reducing over packaging, and development of innovative alternative products to plastic products in all key end use applications; SUP product share decreases to 20% (reduction brought about mainly through reduction in single-use plastic bags and Styrofoam products)

36 According to PlastIndia, bio-plastics are expected to account for 5% of the plastic market share by 2020 and 40% by 2030. But no concrete evidence on this exists.

37 Literature has indicated that bio-plastics can replace up to 85% of conventional plastics; but no time period for this has been provided.

38 As per (CPCB 2015) 94% of plastic waste generated is recyclable and belongs to the thermoplastics family, while the rest 6% belong to non-recyclable thermoset plastics. Further, 67% of the plastic waste belonged to HDPE/LDPE, 10% to PP, and 8.66% to PET amongst others.

Fostering Circularity of Plastics in India

Need for Special Focus on Difficult-to-Recycle Plastics (Reduce, Redesign or Eliminate)

Difficult or hard to recycle plastics are those contaminated by food waste or combined with other polymers, materials or the low volume SUPs. These plastics face issues linked to collectability and retrievability. The aerodynamic nature of many of the thin plastics in this category such as polyethylene carry bags (particularly those below 50 micron thickness), food wrappers (most commonly chips and biscuit packets) make it the top cause of flyaway litter at landfills and one of the most common components of marine litter (NSW EPA, 2016; Brendelle Group, 2012; Green, et al., 2015). Other examples of thin plastics are food take-away boxes, coffee cups, daily disposable contact lenses, straws, cotton ear swab, cigarette buds, food wrappers. Different types of polymer resins (such as LDPE, HDPE, PET, PP, PS, EPS) are used in manufacturing these products. However, the difficult or hard to recycle plastics can be effectively recycled if:

» Sufficient quantity of clean segregated and mono-material plastic waste is made available. However, majority of difficult-to-recycle plastics become part of MSW that are rarely segregated or very poorly segregated.

» Established value chain for waste products also plays an important role. For example, SUPs made from high value plastic resins such as PET are readily recycled due to a strong post-consumer value chain. In India, more than 90% of PET is recycled and converted into fibre.

» Consumption of some SUPs can be easily reduced. For instance, bulk packaging consumers could switch to reusable containers instead of buying products in multi-layered sachets.

» Consumer and legislative pushback against difficult-to-recycle plastic products/packaging can be given to companies as a CSR/marketing incentive to avoid their use wherever possible. Although substitution to recyclable plastics or other alternatives is not always feasible as alternatives do not have the desired material properties, companies such as Plastic Bank have also come up to help packaging producers transition away from difficult-to-recycle plastics such as MLPs to ethically sourced plastics (Plastic Bank, 2020).

» Researchers and industry groups work on R&D for creating novel processes[39] to recycle MLPs and also develop new recyclable MLPs. Companies such as Borealis are designing recycled plastic materials and offer a range, including multi-layered ones, made from conventional plastic layers such as PE and PP (Borealis, 2020). However, these processes are still at pilot scale and there

[39] MLP recycling has typically been done by dissolving the different layers of MLPs in organic chemicals. However, this method is expensive and releases toxic and flammable chemicals. Novel processes under pilot scale, as created by University of Alicante in Spain, include multilayer film delamination techniques (University of Alicante Research Group). This process creates microscopic holes used to deliver chemicals between different material layers while removing adhesives, ink, etc. and separating the material into different recyclable layers. This can recycle most types of MLPs while using environmentally friendly chemicals.

is a long way before they become commercially available, economically feasible, and scalable. It is also difficult to assess the properties of these new materials and how they may differ from conventional materials.

» Hard to recycle plastics such as contact lenses, cotton ear swabs, etc. have low collectability/retrievability. EPR schemes should be implemented nationally to increase their collection.

» Collection is a problem with low value, hard to recycle plastics. It can be incentivized by establishing and monitoring decentralized recycling units, training low skilled recyclers, partnering with informal sector, and by generating awareness. Customers can also be engaged in strengthening collection systems. Items such as contact lenses are bought regularly and may be returned to the shop through deposit refund scheme that can be applied when the customer returns the old, used contacts for new ones. Formal and strengthened collection systems can be established and strengthened by building infrastructure, capacity, and also by creating customer touch points for the implementation of deposit refund schemes.

Currently, due to lack of commercially available and economically feasible alternatives, phasing out hard to recycle plastics completely will do more harm than good. Here policies such as India's unfolding ban on single-use plastics are essential in considering the nuanced approach needed to increase research on alternatives and recycling rates (Mudur, 2019). However, to have an effective national-level EPR implementation, the SUPs need to have a standard categorization: those that can be banned, those that fall under the EPR obligation, and those that can be exempt.

Existing Practices in India: Scope for Replication and Scaling up

Many good practices exist in India and globally that foster circularity in the plastics sector. Moving forward, enhanced innovation, fostering of partnerships, and building collaboration can help scale up these practices and replicate them from one geography and sector to another. This would help unlock potential mitigation opportunities, including sustainable development benefits through circular business models that redesign the waste supply chain and strengthen the reverse logistics.

It is important to create awareness so that all stakeholders are involved from end to end. Limited customer knowledge on circular opportunities can hinder the scaling up and replication of best practices. Awareness generation creates opportunities of co-creating offerings with individuals, customers, or suppliers by making them part of the value chain. Awareness generation can create demand for more sustainable plastics and alternatives upstream and midstream of the plastics value chain and contribute to improved plastic waste management at the end-of-life, downstream through source segregation and participation in deposit refund schemes.

Table A1 in Annexure 1 summarizes some of the existing good practices/initiatives in India and globally across the plastic value chain that make the plastics sector resource efficient- from upstream sustainable polymer production to midstream impact created by reuse, reduce, recycle plastics in assembly and manufacturing, and finally to improved end-of-life plastic waste management practices at the downstream. These examples emphasize on life-cycle thinking that involves the entire value chain from sourcing to disposal, and to look for circular business opportunities in this flow of goods from end-to-end.

Need for Improved Rural Plastic Waste Management

Most parts of rural India have no waste collection mechanism in place and as a result, the waste including plastic waste is either dumped in the outskirts of the villages or burnt periodically at household level or at the village outskirts. In India where more than 60–70% of its people reside in rural areas, improper rural waste management can pose lot of environmental and health threats. Even in states where there is plastic bag ban in place, plastic bags are still in use. This is especially true in rural areas and smaller towns where enforcement is less strict. In regions like in Delhi, plastic bags are sold not in the open, but in a more clandestine manner. Further, a growth in demand has been witnessed by the rural population for small-sized packaged FMCG and food items (in the form of sachets, pouches, bottles, containers) from an affordability, easy to carry, and use point of view. These small-sized items have enabled meeting of rising consumerism triggered by TV and Internet advertisements.

Most commonly found plastics in rural areas are thermoplastics such as polythene bags, bottles, among others. They are relatively easy to recycle but difficult to collect viably at a scale given the low density in rural areas. In order to deal with the waste generated in rural areas, it is extremely important to first determine the quantity and quality (composition) of household plastic waste and its disposal. Individual house owners should segregate wastes at household level which can be then sold to the local recyclers. Scientific and technological interventions and recycling are essential for sound plastic waste management so it is treated as a resource in rural areas also. States should encourage individual or self-help groups for plastic waste collection and provide them with formal contracts at the village or Gram Panchayat level as well as connect them to plastic aggregation points. This will help in reducing the transportation costs and make collection viable for local entrepreneurs. Ambikapur district in Chhattisgarh successfully implemented the collection and segregation at source which is further segregated at secondary and tertiary segregation solid and liquid resource management centres with the help of SHGs. This requires building infrastructure, providing information, and developing education and communication (IEC) modules for general public. Furthermore, the burden of sourcing of plastic waste for recycling in rural areas should be placed on the producers. States should fix proportionate targets for recycling to be executed by brands and producers within rural areas given the increase of rural penetration of formally produced goods (Ministry of Drinking Water and Sanitation, 2018).

Policy Instruments: Strengthening and Expanding

It is extremely important to strengthen and expand upon the existing regulatory and fiscal measures to mandate and incentivize the use of recycled plastics (including material and products), as well as creating efficient plastic product and packaging design, including designs for disassembly, recyclability and reduction. Further financing solutions can support business innovation around the circular supply chain of plastics.

To support markets for recycled materials, policies must address the supply and demand of recycled materials and products. These policies must account for the dual goal of facilitating consumer acceptance and providing incentives for producers and their suppliers (OECD, 2018). Momentum also exist on plastic bans, fees, and other developments but still much work has to be done to support the implementation and enforcement of these bans and fees.

» Fiscal measures can reduce the use of virgin plastics and increase the use of recycled plastics in production, creating demand for recycled plastic upstream in the supply chain. This in turn expands the incentives for increased collection and the recycling of plastic material downstream.
    - These measures can also stimulate the phasing out of commonly identified problematic packaging or products (Ellen MacArthur Foundation, 2019).
    - Corporate tax credits could be provided to initiatives by the private sector to scale up existing and build new recycling infrastructure.

- Differentiated taxes should be imposed on virgin and recycled plastic, and the cost of externalities linked to the two types of plastics should be internalized.
- Taxes should be levied on the use of known hazardous additives, difficult-to-recycle polymers, or even non-essential single-use plastic products, to discourage their use.[40]
- Penalties could be used to penalize packaging made up of materials that are difficult to separate or recycle, as well as improper waste disposal by industry and individuals.

» A regulatory push that leads to more demand for recycled plastic material and products should be the key focus.

- The push could be recycled content targets for new plastic products to help create a large, reliable demand that the plastic recycling industry can build upon, and that product manufacturers can work towards fulfilling the targets.
- Setting standards, providing certification and labels for quality of recycled material will ensure safety and enable confidence and acceptability by industries using the material as input and consumers utilizing the products made using these materials. Industry associations can play a role in developing and propagating the adoption of these standards and certification. In the absence of formal standards, industry-wide benchmarks could play a similar role. Standards should ensure uniformity in composition at the design stage for products, such as making all bottle caps from the same polymer. For example, in the USA, recycled plastics intended for use with food must comply with the relevant requirements of Chapter 21 of the Code of Federal Regulations. The US Food and Drug Administration (FDA) has prepared a detailed guidance for the use of the recycled plastics in the packaging sector (FDA, 2006).

» Public procurement has been shown to be a powerful tool for promoting and accelerating market entry while simultaneously positively influencing consumers' opinions (Dietrich, *et al.,* 2017). There are examples of public procurement of products made with recycled plastic and/or plastic products designed for easy recycling. The House of Commons (Environment Audit Committee) in the United Kingdom has called for a mandatory requirement of 50% recycled content in the production of new plastic bottles by 2023, which will help create demand and stimulate a circular economy for recycled plastic bottles (BPF, 2018).

» Inclusive and innovative financing solutions beyond fiscal measures for business innovation around a circular supply chain of plastics need to be designed. This could be done through the creation of a dedicated innovation fund, effectively catalysing efficient and equitable use, and the mobilization of domestic and international resources. Venture capital (VC) funds could be one of the key methods for mobilizing resources. Other financing solutions include access to institutional finance to meet working capital requirements, viability gap funding, green bonds, blended finance, risk insurance and impact investing, and risk guarantee funds to enterprises that are engaged in plastic waste collection and management in key 'hotspot' areas.

[40] One such example if that of Ireland where a levy on plastic bags reduced the consumption of plastic bags by 90% (Nielsen, Holmberg, & Stripple, 2019). Ireland's plastic bag tax revenue is earmarked not only to cover administration costs but also to cover environmental fund used to support waste management, litter clean-up, and other environmental initiatives (Anastasia & Nix, n.d) .Other examples include Scotland and Belgium.

Extended Producer Responsibility: Fostering Effective Implementation

Extended Producer Responsibility (EPR) has been recognized by the India's waste management sector since introduction of the Plastic Waste Rules in 2011. However there have been uncertainties and challenges faced in context of its implementation. The PWM Rules of 2016 provided additional impetus and noted that all companies using plastic packaging must register as 'producers' or 'brand owners'. These rules further oblige producers and brand owners to register with SPCBs or the CPCB if active in more than one state and to submit an EPR plan. In June 2020, GOI released the draft Uniform EPR Framework to further guide the implementation of EPR at state and city level.

The Framework aims at implementing EPR along with third-party monitoring mechanisms by roping the private sector including brand manufacturers, producers, recyclers, and integrating the informal sector. It includes a fee-based model, producer responsibility organizations (PROs) based model and a plastic credit model. The new draft framework also has provisions to impose stringent penalties on producers if they fail to meet their targeted collection. However, to foster effective implementation, addressing awareness gaps amongst various stakeholders, creating adequate infrastructure and capacity at ULB level, monitoring enforcement and designing of business models that integrate the informal sector into the formal plastic waste management initiatives will play an important role recognition and need for also taking a more holistic view of EPR and expanding its focus across the entire value chain to include upstream design and material use considerations as well as coming up with innovations such as product delivery related, along the use-phase.

Investment Towards Circular Solutions

There is significant scope to bring about investment to foster circular solutions in India. Under EPR, with producers being made responsible for collecting and processing their manufactured products at the end of their lifetime, there are opportunities to invest and create the required recycling infrastructure and supporting technology. Even the success of the design incentives critically depends on the recycling infrastructure at the implementation locality that translates product design improvements into end-of-life cost reduction. Design infrastructure cost is also a key area which will require investments.

Point 9.3.1 of the draft rules under the Fee-Based Model mentions the following:

The primary responsibility of the collection and segregation and final disposal of the plastic waste is with the ULBs. In the present scenario, the ULBs do not have sufficient funds and expertise to systematically collect the segregated plastic waste and then supply it to the recyclers/cement plants/etc. There is a need to build the capacities of the ULB in terms of infrastructure development and technical expertise so that waste management can happen systematically under the EPR mechanism

» The EPR fees could also provide the funding support to public investment in sanitary landfills. Considering that currently most of the recycling that happens for plastics is mechanical, there is a need to push for chemical recycling. Technologically, advancements in chemical recycling and advanced sorting technologies (e.g. optical sorting) could greatly increase productivity of recycling, while enabling the industry to be able to recycle more complex materials.

» Technology-related investments in digital waste management tools such as GPS-enabled tracking for vehicles or image recognition tools which leverage on the Internet of things and data analytics is another opportunity where investment can play an important role to move towards digital maturity and help improve collection and recycling rates (Ocean Conservancy, 2019).

- Investments into modernizing and integrating the informal recycling sector will not only increase occupational safety and environmental efficiency (water, energy) of the recycling processes these sectors use but reduce leakage of residual plastic waste into the environment.
- Under the Swachh Bharat Abhiyan, recycling sectors/zones should be created with proper infrastructure for pollution control, safe working conditions, and quality check on secondary raw material that is recovered/recycled.
- Some of the key mechanisms to provide the investment support include the provision of grants or low interest loans, modifying collateral requirements to enable small and medium enterprises (SMEs) to access bank finance, viability gap funding, and the use of revolving funds. For example, the European Regional Development Fund Innovations Actions Grant Scheme (Environment) provides grants to SMEs for eco-innovations relating to resource efficiency and waste reduction on a co-financing basis (European Commission, 2015).
- Viability gap funding (VGF), which entails supporting projects till they can be financially self-sustaining, can enable firms to meet high initial costs and address long payback periods and also support scaling up or technology up-gradation. Instruments such as revolving funds can be used specifically to incentivize circularity in business models by allowing business models or specific resource efficiency measures that are seen as potentially risky to obtain funding.
- Local governments can provide seed-funding for circular business models that are suitable to the local context.

Polymer Science Perspective Towards Plastics Circularity

The life cycle analysis of plastics as compared to other alternatives such as glass, wood, or jute bags showed that plastics are more environmentally friendly in terms of lower GHG emissions and energy used. A paper bag, for example, has a higher environmental impact in terms of energy, water, material consumption, and GHG emissions as compared to a plastic bag that is also lighter in terms of weight and alternate options of paper and cloth bags can only compete with plastic if they are reused, which depends on social behaviour and awareness amongst consumers. (Jiang, Fan, & Klemeš, 2020) Therefore, use of plastics is not bad; however, it is the linear plastics economy and the plastic that leaks out at its end-of-life, which causes problems.

In the packaging sector itself, about 70% of plastic packaging products are converted into plastic waste in a short span (Mohua, 2019). These products can have simple structure that are made of single polymers such as a milk pouch or have complex structure with multiple polymers as in edible oil packaging or be multi-material packaging containing laminated layers made of paper, plastic, aluminium, such as in tetrapack. Simple structures made of single polymer are more recyclable than multi-layered plastics; however, they do not offer the same barrier properties and long shelf life as the complex, MLPs like tetrapack. There is a large demand for healthcare products in MLPs-small satches; for e.g. a shampoo satches costs much less than the shampoo bottle of the same brand and the satches are easily transportable as well. However, the satches economy has high costs to the society and economy. It is low value, not collectable/retrievable, and non-recyclable; therefore, it readily leaks out of the plastics waste management system and adds to plastic litter and marine litter.

To stop production of single-use, hard to recycle plastics, brand manufacturers have to work with polymer producers to create plastics that are circular by design and can stay in the circular economy with the end goal of reducing the consumption of virgin polymers upstream and plastic waste generation downstream. As the market demand dictates the type of plastic product needed, brands manufacturers know the market requirements and subsequently create demand for the required resins. Brand manufacturers can, therefore, work backwards with polymer producers to produce sustainable polymers such as recycled polymers instead of virgin polymers.

Some examples of such partnerships are seen globally. For example, Unilever partnered with Clarinet to come up with detectable black plastic shampoo bottles to prevent them from ending up in landfills as they are easily detectable by waste pickers. Globally, such best practices showcasing partnerships between brand manufacturers and petrochemical polymer producers can be seen; however, there is still untapped potential with respect to polymer science.

Roadmap for Circular Economy for Plastics in India

In this section we present the proposed roadmap for circularity in plastics sector in India through a set of three key priorities/objectives, supported by action plan, actions under which can be measured and monitored over a certain timeline: Short Term (ST) and Medium Term (MT) and Long Term (LT), where ST is 0–2 years, MT is 2–5 years and LT is > 5 years. The three key objectives that are identified are:

- Adopting sustainable material solutions –use of bio-based polymers, substitution of virgin polymer with recycled polymer, and dematerialization of plastic products
- Increase supply of good quality secondary plastics feedstock (recycled plastics); and
- Invent, innovate, and encourage alternative uses of problematic plastics waste

The implementation of the roadmap will require stakeholder coordination and collaboration including that between the national government, state governments, city governments, and industry. Further, the political acceptability and the financial viability of the various actions will play a key role in their uptake. To give an example, the local municipalities may be open to MRFs being set up in their cities and may even be willing to allocate land for the same and bear part of the operational costs. However, they would still require the private sector/industry to support the equipment and technology component costs and the remaining operational costs (so need for Public Private Partnership (PPP) mode). Overtime once the MRFs are able to develop the revenue sources based on sales of recyclables, they can become self-sustainable models, which not only builds entrepreneurs but converts waste to wealth. The political acceptability linked to these interventions also increases if the informal sector is integrated in the setup and paid fair dues.

Setting up pilot projects and/or demonstration activities around different circular economy aspects can enhance the transparency which will show in ground results, leading to higher political acceptability and more effective decision-making processes. To identify possible pilot activities, learning from similar countries could be drawn and where required customized.

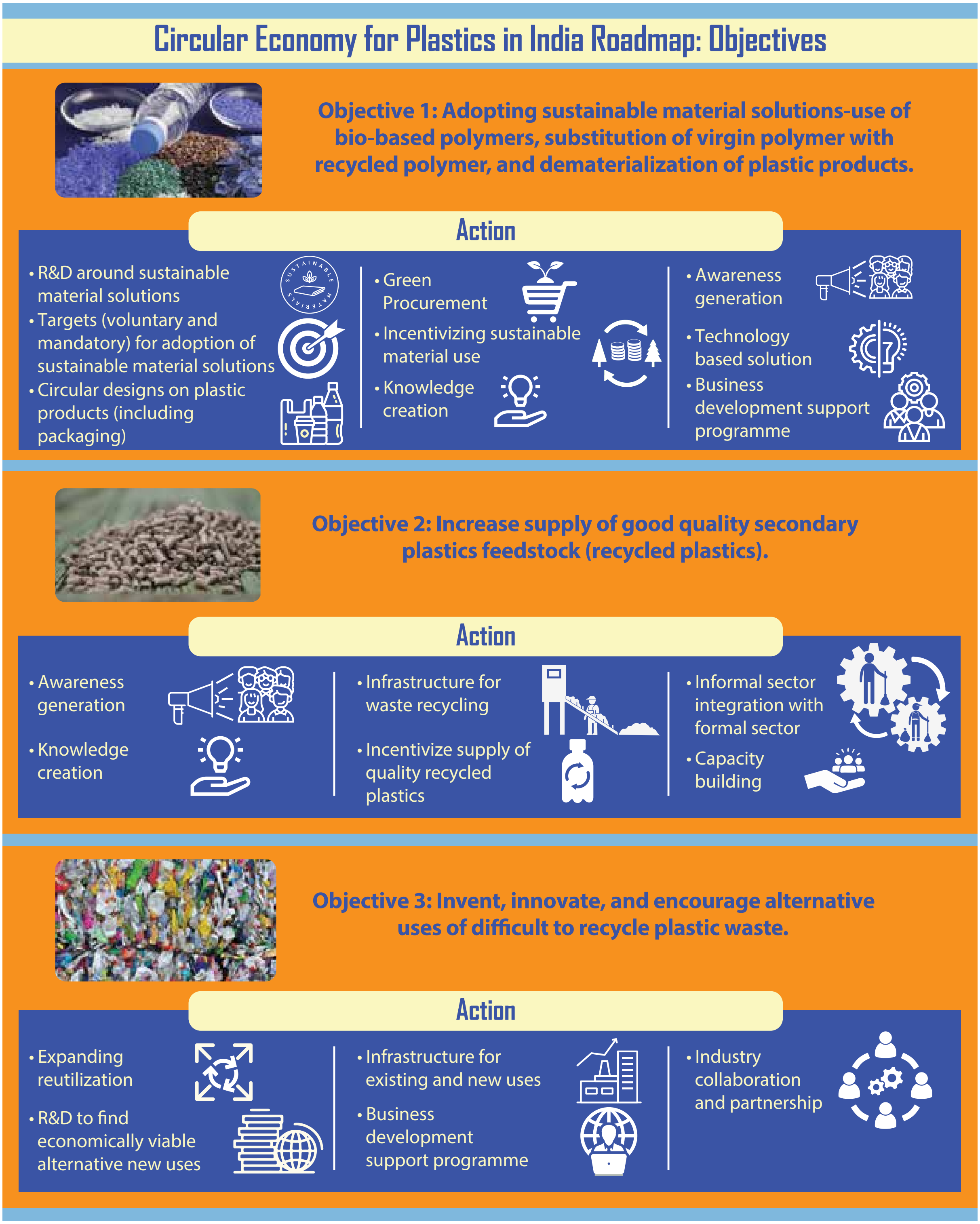

FIGURE 8: Roadmap for circularity in plastics in India: Objectives

Objective 1:

Adopting Sustainable Material Solutions: Use of Bio-based Polymers, Substitution of Virgin Polymer with Recycled Polymer, and Dematerialization of Plastic Products

Focus point in value chain: Midstream/Upstream

R&D around sustainable material solutions (Medium Term)

- Government support - public funding, R&D tax incentive schemes.
- Private sector support -laboratory experiments, technology transfer, collaborative action to promote access to and affordability of sustainable material solutions.
- Key areas:
  - Designing natural alternatives to plastic micro beads in personal care products.
  - Overcoming technical limitations faced by mono-material products as opposed to multi-material products.
  - Developing alternative monomers, polymers and additives using green chemistry approaches.

Incentivizing sustainable material use (Medium Term)

- Differentiated taxes on use of virgin versus recycled materials in production process; penalties (where possible) on products without minimum percentage of recycled polymer content.
- Earmarking of tax revenues for reinvestment in the plastic sector including for enhancing plastic collection, recycling infrastructure, and improving the working conditions of informal sector engaged in plastic end-of-life management.
- Deposit refund system based on digital platforms and use of artificial intelligence to incentivize return of used packaging through specifically for short life plastic packaging.
- Reduction/ discount against obligation within the 'producer responsibility' legislative framework to producers who meet the voluntary and mandatory targets around sustainable material use.

Circular designs on plastic products (particularly packaging) (Medium Term /Long Term)

- Develop and implement design standards for key plastic packaging/products (eliminate unsuitable design choices, reduce quantum of plastics used, design to foster reuse, and improve recycling quality and economics).
- Develop standards, tests, and certification to provide clarity, consistency, transparency on quality of recycled materials.
- Develop plastic products using easier to recycle polymer formats. For example- develop mono material film packaging instead of conventional multi-layer 'difficult-to-recycle' composite films.
- Longer mandatory guarantees for encouraging the production of more durable products.

Targets for adoption of sustainable material solutions (Short Term /Medium Term)

- Voluntary targets (product specific) on reducing the use of virgin plastics and substitution with recycled plastics.
- Mandatory targets (product specific) on use of recycled plastics in making some of the key plastic products such as garbage bags and rigid containers used for non-food applications.
- Reporting by manufacturers and importers of plastic products on the amount of virgin and recycled plastic content in their products.

Knowledge creation (Short Term /Medium Term)

- National (pan-India) classification of SUPs and removal of State-level variations in SUP definition.
- Plastics disclosure to encourage wise and sustainable use of plastics at offices and production facilities; large offices and institutes to conduct audits to determine current plastic usage and identify ways to reduce their plastic consumption and/or increase the proportion of recycled or biodegradable plastic within their set ups.
- Bin audits/maintenance checks across offices and institutions for plastic waste management
- Inventorization studies on waste characterization including share and type of SUPs and polymer type.
- Life cycle assessment of plastics in key end-use sectors to determine GHG emissions from using plastics vs other materials vs bioplastics/ recycled plastics in current scenario and alternative scenarios.

Awareness generation (Short Term)

- Set up local 'no plastic market zones' to engage communities to experience shopping without plastics.
- Industry associations and local government jointly engage with consumers through plastics consumer communications' campaign that promote sustainable purchasing, reuse, and responsible disposal of plastic products.
- Awareness generation on the presence of microplastics in personal care and cosmetic products (PCCPs).
- Focused programme for school and college students to inculcate a measurable behavioural change regarding plastic usage and its disposal (in a manner that minimizes littering and mismanagement) and promote use of alternate materials such a jute and compostable bags.

Green Procurement (Medium Term)

- Large private companies and government to promote procurement of sustainable materials as part of their criteria when tendering projects/ activities.
- Procurers in the retail sector to demand goods in sustainable packaging (containing recycled content and designed for reuse or recycling).
- Offices and institutions to mandate bulk delivery of cleaning and personal care products with refillable plastic containers, thereby eliminating single-use containers.
- Phase-in compulsory reporting to monitor the uptake of Green Public Procurement (GPP).

Technology based solution (Long Term)

- Block chain-supported platforms providing greater supply chain visibility for better decision making-help suppliers, processors, manufacturers, moulders, and brand owners to choose traceable, sustainable, and circular materials.
- R&D and technology support to suppliers and manufacturers to produce traceable and circular materials/products.
- Provide critical information for reversed logistics and take back of products, materials and components:
  - Example: Block chain smart contracts between a supplier of the segregated plastic waste (segregator) and a prospective buyer (example, closed-loop recycler), or between supplier of recycled plastic feedstock and prospective plastic goods manufacturer

Business development support programmes (Short Term /Medium Term)

- Technical and financial support to business models around sharing and leasing of plastic products:
  - Example: Leasing of water dispensers and refillable plastic bottles to households and offices or renting of plastic toys.
- Amplify success stories and exciting ongoing work on sustainable material solutions to attract new entrepreneurs and to encourage the development of new investable ventures.
- Financial support to address the funding gap faced by start-ups that are aiming to design business models around commercial production/use of sustainable materials.

Objective 2:

Increase Supply of Good Quality Secondary Plastics Feedstock (Recycled Plastics)

Focus point in value chain: Downstream

Awareness generation (Short/ Medium Term)

- Targeted messaging with support of the ULBs to influence measurable behaviour change in citizens and encourage them to source segregate, and engage in responsible handing over of waste to waste collector.
- Public awareness campaigns on source segregation, health and environmental hazards linked to plastics mismanagementand the need to recycle plastics.
- Harmonized industry-wide effort to communicate information about chemicals used in plastic and the need for responsible disposal of end-of-life plastic products.
- Standards and labelling of recyclable, bio-degradable, bio-plastics.
- Incorporation of 3Rs of waste management-reduce, reuse and recycle in the education curriculum.
- Extensive community engagement activities involving religious and community leaders to promote reuse, waste minimization, source segregation.

Knowledge creation (Short/ Medium Term)

- Develop best practices document/guidelines in key end-use sectors [for e.g. comprehensive industry document (COINDS)], resource recycling and waste minimization practices.
- Develop best practices document/guidelines of sustainable business models in India and globally that may be scalable and replicable in the key end-use sectors.
- Study to assess the quantity and quality (composition) of household plastic waste in rural areas.
- Assessment of recycling capacity, gaps, and opportunities to identify and increase capacity utilization.
- Information bank on plastic types in different products that will enable tracking of plastic movement in the economy.
- Baseline assessment of quantity and quality of recycled polymers produced through the recycling processes (plastic granules/flakes/pellets).
- This should include state-wise assessment that can be used to determine efficient flows of recycled material and its utilization.
- Inventorization of different types of plastic waste generated, handling practices, storage, and channelization for its reuse, recycling, repurposing, or final disposal.

Infrastructure for waste recycling (Long Term)

- Equipment for source segregation (bins) and collection of the source segregated waste in compartmentalized/separate vehicles:
  - Example: ULBs jointly with private waste management company could one time provide bins for households, bags for commercial establishments, and litter bins at appropriate commercial and public places. Subsequent purchases of bins and bags to be done by the waste generator
- Innovation in infrastructure for collection and separation of plastic waste from MSW.
- Develop decentralized formal recycling clusters including setting up technology for creating better quality recyclates, and treatment infrastructure.
- Develop MRFs, transfer stations to collect, sort, store, transport segregated waste through public-private partnerships with brands/industry; For example, UNDP-Coca-Cola-Unilever initiative, ITC-Pune Municipal Corporation initiative.

Incentivize supply of quality recycled plastics (Medium Term)

- Creating a marketplace to bring in transparency in the demand and supply of recyclates and ensure fair price for the recycler; specifically need to create a market for household waste plastics through procurement and industrial partnerships.
- Fiscal incentives to promote advanced forms of recycling such as chemical recycling.
- Issuance and selling of 'reverse logistics credits' by informal sector (cooperatives) to companies to help them fulfil their EPR responsibility related to collection and disposal of waste in the right manner. These credits make it worthwhile for waste pickers to collect lower-value waste material (difficult to collect otherwise), while also increasing revenue for waste pickers.
- Setting up of a National Plastic Recycling Fund to collect and recycle plastic waste

Informal sector integration with formal sector (Medium Term)

- Integrate informal sector with formal recyclers through contracts and as part of EPR policy and PWM rules to improve collection and sorting efficiency.
- Integration of informal sector by the ULBs could include:
  - Bring in social empowerment programmes for the informal sector, set up cooperatives.
  - Incentivize partnerships between ULBs and waste management companies supporting the ULBs, waste pickers, junkshops, recyclers, and major companies looking to purchase recycled goods.
- Large sorting centres or collection systems with at-the-source separation should employ the informal sector and prevent the possible detrimental effect on such subsectors of new technologies under chemical recycling.
- Capacity building and skill training of the informal sector to increase their technical expertise to upgrade their recovery activities and be able to design their business contracts.
- Partnership between private waste management enterprises and the informal sector to improve the value chains related to materials from waste.

Capacity building (Short Term)

- Improve capacity for enforcement at the local, municipality level, through capacity building workshops with expert organizations.
- Establish cooperatives and unions of independent waste pickers and provide them training, technical support on better sorting, value addition, and responsible waste handling.

Objective 3:

Invent, Innovate, and Encourage Alternative Uses of Difficult-to-Recycle Plastic Waste

Focus point in value chain: Downstream

Expanding reutilization (Short/Medium Term)

» Expand development of plastic roads (plastic substitute for bitumen) through Ministry of Road Transport and Highways (MoRTH), Public Works Department, and National Highway Authorities of India:
  - ULBs to implement the directives of MoRTH.
  - Provision of facilities for aggregation of plastic waste for road construction.

» Use plastic waste for bricks and composites; this will incentivize the informal sector to collect the non-recyclable waste and also reduce the waste going to landfills.

» Expand pilot technology of MLP recycling through tie-ups with key industry partners, ULBs, informal sector by identifying all-India markets including demand for recycled MLP products.

» Conduct scientific studies to understand the safety (toxicity, leachate generation) of recycled MLP-based products.

R&D for economically viable alternative new uses (Medium/ Long Term)

» Develop chemical recycling-based technologies to provide decentralized and broadly applicable recycling systems:
  - Several pyrolysis systems have been initiated, but there is a need for proper scientific data and design of unit and follow up studies to promote up scaling and commercialization.

» Develop techniques and technologies for upcycling of plastic waste:
  - PET plastic waste for energy storage applications.
  - Discarded/ghost fishing gear (nets, ropes, and components) into accessories, clothing, footwear, home ware, recreation.

» Identify new uses and viability of these uses for difficult-to-recycle plastics such as MLPs and non-recyclable plastics.

» Conduct pilot projects to find possible R&D solutions for inadequately sorted industrial waste received for incineration.

» Develop eco-friendly alternative flame retardants which could eliminate the use of some hazardous chemicals in plastics manufacture.

Infrastructure for existing and new uses
(Medium/ Long Term)

- Processing set-ups and technology/equipment for converting plastic waste into alternate fuel and raw material (AFR) in cement kilns and power plants.
- Establish smaller decentralized co-processing facilities near major waste generating cities; this will address the major transport cost related challenge in uptake of dry waste to co-processing facilities.
- Set up/support infrastructure for separate collection, processing, and industrialized composting facilities for compostable plastics.
- Set up units for converting plastic waste into products such as tiles, lumber, bricks.

Business development support programme
(Medium/Long Term)

- Set up incubators and accelerators, through public and private partnership modes that can provide funding, link entrepreneurs with academics and industry professionals for mentoring, training, and provide engagement to start-ups that work on developing business models around alternative uses of plastic waste.
- Amplify success stories and exciting work going on problematic plastics to attract new entrepreneurs and to encourage the development of new investable ventures.
- Successful municipality-led and private partnership based circularity fostering projects to be promoted as case studies.

Industry collaboration and partnership
(Short/Medium Term)

- Country-level plastic pact, like in many other countries, have done to bring industry players together to define a common vision for fostering circularity in plastics sector.
- Regional FMCG brands, their chambers of commerce, and industry in states to come together and define a common vision towards circularity in plastic packaging; tapping significant market strength in their regions of operations.

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Annexure 1

TABLE A1: Some of the existing good resource efficiency and circular economy practices/initiatives in context of plastics in India

Best Practice	Location	Plastic Waste Value Chain: Stakeholders	Waste Management Hierarchy	Description
Taj hotels	India	Downstream; Bulk Consumers	Reduce	Zero SUP hotel in Andamans and have pledged to phase out SUP and eliminate 20 lakh plastic straws in 2019
ITC hotels	India	Downstream; Bulk Consumers	Reduce	Pledge to discontinue SUP in all its hotels since December 2019 including replacing plastic straws with paper or bamboo ones, and replacing plastic drinking bottles with water in glass bottles. Some hotels have also replaced the miniature personal care bottles with permanent dispensers
Hindustan Unilever	India	Downstream; Industry partners, brand manufacturers, recyclers	Reduce/ Recycle	Total waste generated from their factories in 2019 has reduced by 63%. All our factories are also equipped with pre-processing facilities such as waste segregation and waste reduction at source, thus improving recyclability. In 2019, we disposed of more than 39,000MTPA of plastic waste in environment-friendly ways in India
Bizongo	India	Midstream; Brand manufacturers	Reduce and Reuse	Packaging solutions - Elimination of SUP by pushing for alternatives already available, by 2021. They are trying to cut down the cost of alternate material while also promoting by better adaptation and trying to use reusable materials
Zomato	India	Downstream; Bulk Consumer	Reduce	Order without cutlery

TABLE A1: Some of the existing good resource efficiency and circular economy practices/initiatives in context of plastics in India

Best Practice	Location	Plastic Waste Value Chain: Stakeholders	Waste Management Hierarchy	Description
Swiggy	India	Midstream; Bulk Consumer	Reduce	Sustainable packaging
Amazon	India	Downstream; Bulk Consumer	Reduce	Packaging material contains less than 7% SUP and aim for elimination of SUP packaging by June 2020
Flipkart	India	Downstream; Bulk Consumer	Reduce	Reduced the 25% of SUP in 2018- has set deadline of 2021 to make all its packaging recyclable
Walmart	India	Downstream; Bulk Consumer	Reduce	Pledged to phase out SUP shrink wrap from our company's stores across India by the first quarter of 2019
Dabbawalla	Mumabi, MH	Downstream; Waste generators, Bombay Tiffin Box Suppliers Association	Reduce	Deliverymen distributing lunch to 200,000 people throughout the city using washable, durable, and reusable containers that are not made of plastic
Cupable Model	Mumbai, MH; Bangalore, KA; Hyderabad, TE; Chennai, TN; Delhi; Pune, MH	Downstream; Waste generators, collectors	Reuse	Cupable has established a reverse supply chain by partnering with restaurants/ event organizers to install drop off bins that allow only their cups to be dropped-off as no other container fits inside. The model focuses on events with large volume of customers so there potential for scaling and financial flexibility. Waste generators pay directly and are reimbursed part of their deposit back after returning the cup and are also incentivized through discounts on their drinks for using the same cup

TABLE A1: Some of the existing good resource efficiency and circular economy practices/initiatives in context of plastics in India

Best Practice	Location	Plastic Waste Value Chain: Stakeholders	Waste Management Hierarchy	Description
Goa Waste Management Model (GWMC)	Goa	Downstream; ULB, waste generators, collectors, recyclers, treatment providers	Recycle/ Co-processing/ WtE	The GWMC set up by the state government has an integrated solid waste management facility that recycles plastics and dry waste at its MRF and sends its non-recyclable plastics for co-processing to Karnataka whereby the ULB bears the heavy cost of collection and transport to co-processing facility. Through its activities over four years - recycling, substituting coal with RDF, and managing its biodegradable waste the plant has reduced about 35,48243,330tCO_2-eq. emissions
Reliance Plastic road	Raigad, MH	Downstream; National Highway Authority, State governments, ULBs, Waste collectors	Repurposing	As a pilot, RIL has used about 50 MT of plastic waste at its Nagothane Manufacturing Division for construction of 40 km of road by starting its own its own and also outsourcing garbage collection and segregation which enables the collection of sufficient plastic to be shredded to prepare a mixture at its sites

TABLE A1: Some of the existing good resource efficiency and circular economy practices/initiatives in context of plastics in India

Best Practice	Location	Plastic Waste Value Chain: Stakeholders	Waste Management Hierarchy	Description
UNEP - Coca-Cola	Pan India - 28 cities	Downstream; Waste collectors, self help groups, ULBs including RWAs, private operators, institutional and technical partnerships	Recycle	United Nations Development Programme (UNDP) India, in partnership with Hindustan Coca-Cola Beverages Private Limited (HCCBPL) and Hindustan Unilever Limited (HUL) is building on existing systems to reduce the impact of plastic waste on environment in India by promoting collection, segregation and recycling of all kinds of plastics to move towards a socio- technical circular economy model. This includes establishing material recycling facilities. Institutionalizing Swachhta Kendras within governance framework structures and improved socio-economic conditions of waste pickers, developing technology-supported knowledge management: Promote, cloud-based traceability, accountability and digital governance along waste value chain through our technical partner Mindtree through field implementing partners. Impact: The project is currently operational in 28 cities with 22 MRFs (Swachhta Kendras) and since 2018 has collected and processed over 17,000 MT of plastic waste

TABLE A1: Some of the existing good resource efficiency and circular economy practices/initiatives in context of plastics in India

Best Practice	Location	Plastic Waste Value Chain: Stakeholders	Waste Management Hierarchy	Description
Plastic Scrap Trading	West Delhi (Tikri-Kalan)	Downstream; ULB, waste generators, plastic traders	Recycle/ Co-processing	Plastic waste trading 1.4 km_2 area in Delhi, where around 1875 TPD plastic scraps are flowing, 1818 TPD for recycling and 57 TPD to brick-kilns. This is done mainly on an informal scale including backyard mechanical recycling with no integration of informal sector and little to no health & safety measures. Such plastic trading and recycling clusters need to be upgraded and informal sector needs to be integrated for more efficient, leakage proof trading and recycling
Aarohana Ecosocial	Pune, MH and Dadra and Nagar Haveli	Downstream; Industry Partners	Upcycle	Promotes hand weaving of plastic waste into upcycled bags, fabric, and home decor. They are providing employment opportunities to women in remote villages that lack alternative sources of income. Since its inception, Aarohana has salvaged over 776,500 plastic bags, sold about 10,000 bags, and made sales of INR 14 lakhs in their first year. However, their biggest hurdle is lack of segregation as contaminated post-consumer plastic waste cannot be upcycled

TABLE A2: International experience on plastics circularity roadmaps and strategies: key learning

Key Learnings	Institutions / Organizations			
Bring in Innovation	**European Commission (EC): European Strategy for Plastics in a circular Economy (2018)** » Developing innovative solutions • Advanced sorting, chemical recycling • Improved polymer designs in plastics value • Reduce costs of existing solutions • Enhance reuse and recycling of end-of- • life plastics » Proposed new rules for waste management • Obligations for national authorities to expedite separate collection • Encourage investment in recycling capacity	**Saudi Basic Industries Corporation (SABIC): Sustainability Development Goal Roadmap (2019)** » TrueCircleTM Initiative 4 principles: 1. Design for Recyclability 2. Mechanically recycled products 3. Certified Circular Products 4. Certified Renewable Products » Sustainable Material Solutions • Step up circular economy for plastics • Help manufactures to reduce plastic waste	**Hindustan Unilever Limited (HUL) and UNDP: Plastic Waste Management Programme (2018-2024)** » Establish Material Recovery Centres (MRF) • Sustained practises in waste management » Develop technology-supported knowledge management • Enhance segregation, collection and recycling of all kinds of plastic waste along value chain	**Unilever: European Plastics Pact (2020)** » By 2025: • Halve the use of virgin plastic • Ensuring 100% plastic packaging is reusable, recyclable or compostable • Use at least 25% recycled plastic packaging » Clean Future Ambition: • Replace 100% of the carbon derived from fossil fuels in its cleaning by 2030

TABLE A2: International experience on plastics circularity roadmaps and strategies: key learning

Key Learnings	Institutions / Organizations		
Engage Stakeholders	**Commonwealth Scientific and Industrial Research Organisation (Australia):** **National Circular Economy Roadmap (2019)** » Recycle and reduce materials such as plastic papers, glass and tyres » Multi-Stakeholder collaboration on waste management, recycling and resource recovery	**Japan Plastics Federation: Resource Circulation Strategy for Plastics(2018)** » Tripartite Agreement between citizens, business and government • Reduce Plastics Bags	**Malaysia's Roadmap Towards Zero Single-use Plastics (2018–2030)** » Multi Stakeholder Collaboration among federal government, state governments, manufactures, suppliers, business operators, brand owners, general public, and NGOs • Addressing single-use plastics pollution in the country
Identify Opportunities	**UK WRAP:** **UK Plastics Pact – A Roadmap to 2025:** » Eliminate unnecessary single-use packaging • Redesign, innovation, or alternative delivery models » 30% average recycled content across all plastic packaging » 100 % of plastic packaging to be reusable, recyclable or compostable » Published recyclability guidelines in 2019 for rigid plastic packaging (WRAP, 2018)		**Smart Prosperity Institute:** **A Vision for a Circular Economy for Plastics in Canada(2019)** » Assign property rights for end-of-life plastic waste to producers » Set end-of-life performance based regulatory requirements » Set minimum percentage of recycled content in products and packaging » Common definitions, performance standards, and measurement and assessment protocols

TABLE A2: International experience on plastics circularity roadmaps and strategies: key learning

Key Learnings	Institutions / Organizations	
Focussing on R's (Reduce, Reuse, Recycle)	**Japan Industry Federation :** **The Resource Circulation Strategy for Plastics(2018)** » Concept of 3Rs + Renewable • Reduce single-use plastics emission by 2030 • Promote alternatives such as recycled material and recyclable resources • Double use of recycled material • Approximate 2 million tonne of biomass plastics by 2030. (Ministry of Environment, 2019)	**Plastics Roadmap for Finland(2018):** » Reduce and Refuse, Recycle and Replace » Green Deal agreements • Reduce single-use packaging and over packaging Design operating model for businesses using disposable packaging. (Ministry of Enviornment, 2018)
Use of Market Instruments	**The Plastics Roadmap for Finland(2018):** » Introduce tax on single use plastics » Deposit Refund System for recycling of bottles	**Smart Prosperity Institute:** **A Vision for a Circular Economy for Plastics in Canada (2019)** » Use of bans » Tax on single use plastics » Imposing Waste disposal levies

TABLE A2: International experience on plastics circularity roadmaps and strategies: key learning

Key Learnings	Institutions / Organizations	
Regulatory Measures	**European Commission:** **The European Green Deal(2019)** » By 2050, to reach net-zero global warming emissions » By 2030, ensuring packaging in EU market is reusable and recyclable » The European Strategy for Plastics in a Circular Economy emphasized on integrating recycled content in green public procurement (GPP) criteria	**European Commission:** **The Single-Use Plastics Directive (2019)** » From 2021 onwards, bans and restricts the use of single-use plastics • Transition towards making plastics circular (EEA, 2019)
Switch to Alternate Feedstocks	**European Commission:** **The European Strategy for Plastics in a Circular Economy (2018)** » Use alternative feedstock, bio-based feedstock and gaseous effluents such as carbon dioxide or methane » Promote investment and innovation in value chain • Look into lifecycle impacts of alternative feedstock • Supports de-carbonization • Creates opportunities for growth	**Saudi Basic Industries Corporation (SABIC):** **Sustainability Development Goal Roadmap (2019)** » Certified Renewable feedstock: LexanTM Polycarbonate • Develop polymer from renewable feedstock such as oil by products from the pulp and paper industry • Reduce CO_2 emissions and use of fossil feedstock

TABLE A3: Cost benefit analysis of petroleum-based HDPE and of PLA resin obtained from cassava root (Case 1) and cassava starch (Case 2) in Thailand

Variables	HDPE (Million USD)	PLA Resin Obtained from Cassava root (Million USD)	PLA Resin Obtained from Cassava starch (Million USD)
Direct Cost (Production cost + Investment cost)	185.74	555.74	576.74
Indirect Cost (GHG emission + Opportunity cost of land)	143.92	30.92	20.92
Total Cost	329.66	586.66	597.66
Direct Benefit (sales of product)	143	300	300
Indirect Benefit (sales of by product)	NA	294 (Cassava Meals)	NA
Total Benefit	143	594	300
Net Benefit	-186.66	7.34	-297.66

Source: (Chiarakorn, Permpoonwiwat, & Nanthachatchavankul, 2011)

Annexure 2

Brief Production Process of Ethylene, Propylene, and Major Polymers

The production process and the specific energy consumption (SEC) of ethylene, propylene from the feedstock and the monomers to various polymers such as polypropylene, LDPE, HDPE, LLDPE, polyvinyl chloride, PET, and PS are briefed below.

1. Ethylene and Propylene

The production of ethylene and propylene uses steam cracking. The feed material ethane/ propane gas or napththa is fed into pyrolysis furnace in the presence of dilution steam for cracking the feed into ethylene, propylene and other byproducts. In the process, heat is recovered as steam at about 100 ata pressure, which is used for driving steam turbines. The cooled gas is compressed and dried. Ethylene and propylene are separated using cryogenic processes. The production of ethylene and propylene by steam cracking employs two technologies. Stone & Webster accounts for about 57% of total installed capacity in India and Lummus accounts for 43% of installed capacity. The typical SEC of feedstock cracking to produce ethylene and propylene is given in Table A4.

TABLE A4: Typical SEC of ethylene and propylene production

Parameter	Unit	Consumption
Electricity	GJ per tonne	0.3
Fuel	GJ per tonne	13-25
Steam	GJ per tonne	-1.4
Feedstock	GJ per tonne	45

The variations in SEC level may be attributed to type of feedstock and battery limit conditions. The SEC is lower when processing ethane/propane gas (13 GJ/tonne), whereas higher when naphtha is used (25 GJ/tonne)

2. Polypropylene

A number of processes are available for production of polypropylene. The commonly used processes are Loop reactor process and Gas phase process. The solution polymerization process and stirred tank heavy diluent process are obsolete.

2.1 Loop reactor process

The loop reactor process involves a series of loops for carrying out polymerization. It involves a second gas phase reactor for block co-polymer production. The reaction is carried out in liquid propylene medium with 'high yield, high stereospecificity' (HYHS) catalysts at about 75°C and 650 psi pressure. The heat

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[41] This note draws learnings from the TERI's report on developing baseline specific energy consumption in petrochemicals industry in India, Shakti Sustainable Energy Foundation, 2013

of reaction is removed by condensing and recycling propylene to the reactor. The slurry is flashed and volatiles, after purification are recycled. The polymer is purged and dried before pelletization.

For production of block co-polymer, the slurry from the first reactor is transferred to a gas phase reactor wherein ethylene is added in controlled ratio. The reaction is carried out at about 60° C and 240 psi pressure. The block co-polymerization can also be carried out in the loop reactor. The subsequent operations are similar to polymerization.

2.2 Gas phase process

The gas phase process uses either fluidized bed reactor or vertical stirred reactor or horizontal stirred reactor. Polymerization of propylene is carried out in gas phase at 50-105 °C and 350-550 psi pressure with HYHS as catalyst, depending on the polymer grades. The process is suitable for production of both homo-polymers and co-polymers. For the production of block co-polymer, a second gas phase reactor is used in series, wherein ethylene is added. For random co-polymers, ethylene-propylene stream is reacted in the first reactor.

Polypropylene is manufactured by various technologies, notably from Unipol, Innovene, LyondellBasell SPHERIPOL, prevalent in India. The typical SEC of polypropylene production process is given in Table A5.

TABLE A5: Typical SEC of polypropylene production

Parameter	Unit	Consumption
Electricity	GJ per tonne	0.9
Steam	GJ per tonne	1.0

3. Polyethylene

The manufacturing process of PE such as HDPE, LDPE and LLDPE follows addition polymerization kinetics involving catalysis of purified ethylene. Three processes are commonly involved in the production of PE as briefed below.

3.1 High-pressure process

The high-pressure process was developed by ICI, UK for producing yields 'low density polyethylene' (LDPE). It uses peroxide catalyst at 100-300 °C and produces low density randomly oriented polymer, which have a low melting point.

3.2 Intermediate-pressure process

The intermediate-pressure process was developed by Phillips Petroleum Co., USA for preparing high density polymer with increased rigidity, crystallization, tensile strength, and softening point. The process uses MoO_3 and Cr_2O_3 on alumina as catalyst.

3.3 Low-pressure process

The low-pressure process was developed in Germany for preparing HDPE. The catalyst used in this low-pressure Ziegler process consists of aluminium triethyl activated with heavy metal derivatives such as $TiCl_4$. High purity ethylene is prepared through desulphurization and removal of light ends. The ethylene is further treated to remove traces of oxygen. It is pumped into a reactor where it is mixed with catalyst diluents stream. The optimum conditions maintained in the reactor include 70 °C and 7 atm gauge.

The effluent stream follows across a series of flash drums in order to remove the solvent from the catalyst. The residual catalyst is removed by adding water. Thereafter, the flashed solvent is recycled to the catalyst makeup unit after drying and re-distillation. The slurry formed is centrifuged to remove the water, and the water is treated to remove the catalyst before recycling. The final products of PE solids are dried, extruded and given the required final forms. Various types of polyethylenes are made, viz. HDPE, MDPE, LLDPE, LDPE, by deploying various technologies. A few prevalent in India are LyondellBasell Spherilene (LLDPE / MDPE / HDPE), LyondellBasell (Hostalen ACP for HDPE), EniChem (for LDPE), Mitsui CX (for HDPE & MDPE), INEOS Innovene G (Swing LLDPE / HDPE) The typical SEC of LDP, HDPE, and LLDPE production processes are given in Table A6.

TABLE A6: Typical SEC of polyethylene production

Parameter	Unit	LDPE	HDPE	LLDPE
Electricity	GJ per tonne	3.5	0.9	0.4
Steam	GJ per tonne	-2.1	1.0	1.6

4. Polyethylene terephthalate

The conventional production process of PET process includes first the melt phase polymerization to produce co-polymers with an intrinsic viscosity suitable for textile applications, where it is called polyester or for thermoformed PET plastics (such as punnets, collar strips). For making bottle grade (that can be used for water, juices, carbonated soft drinks etc), the polyester needs to have higher molecular weights as reflected in the higher intrinsic viscosity. For achieving this, the molten polyester is extruded and solidified into granules (also referred to as chips, pellets, etc.) which are then transferred to another set of reactors wherein they are subjected to further polymerization in the solid-state. Thus, the polymerization of PET is carried out in stages under mild conditions of less than 300°C with almost zero emissions. Just like the textile grade polyester, PET does not need any phthalates or BPA in their manufacture or further conversion into packaging articles. Due to its unique chemistry, PET is highly recyclable with approximately 90% actual recycling achieved in India. This high degree of recycling is achieved primarily through mechanical recycling in which the PET is converted into polyester fibres. The typical SEC of PET production process is given in Table A7.

TABLE A7: Typical SEC of PET production

Parameter	Unit	Consumption
Electricity	GJ per tonne	0.7
Fuel	GJ per tonne	4.1

5. Polyvinyl chloride

There are a number of processes employed for production of polyvinyl chloride (PVC) based on end application. The polymerization is performed in a batch reactor at about 40–70 °C with the vinyl chloride monomer kept in liquid state under pressure.

5.1 Suspension polymerization

Suspension polymerization is the most commonly used process for PVC production. The vinyl chloride is fed into a sealed reactor under pressure, where it is finely dispersed in water through vigorous agitation.

It is mixed with an in initiator and heated to about 60–70 °C. Upon 90% of monomer is converted to polymer, the reaction is stopped by discharging the slurry into a degasser. The remaining monomer is recycled and the resin is filtered, centrifuged and dried.

5.2 Emulsion polymerization

Emulsion polymerization is performed in an aqueous solution containing water-soluble initiators and emulsifiers. The PVC latex formed has fine particle size suitable for use in the preparation of paints, paper and fabric finishes and printing inks.

5.3 Mass polymerization

In mass polymerization water is not used. The process employs pre-polymerization stage containing liquid vinyl chloride monomer in the presence of an initiator to allow for about 10% conversion. The solution is transferred to an autoclave reactor wherein more initiator and monomer are added and heated. The powder resin formed can be used to produce film with high clarity as well as for other applications.

Generally, the vinyl resin produced is inherently hard and brittle. It requires mixing with additives for converting into useful products. The initial step in producing vinyl compounds involves dry blending. In a closed vessel, dry and liquid additives are mixed. Since the resin particles are porous, liquid additives are absorbed easily, yielding a dry powder compound. In applications like pipe manufacturing, the powder compounds can be processed directly into the final product. Manufacturing of products like wire, cable, rigid profiles, and injection moulded parts will require additional processing. The typical SEC of PVC production process is given in Table A8.

TABLE A8: Typical SEC of PVC production

Parameter	Unit	Consumption
Electricity	GJ per tonne	0.6
Steam	GJ per tonne	0.5
Fuel	GJ per tonne	1.2

6. Polystyrene

The styrene polymerization technology is a one-step batch suspension reaction followed by continuous dewatering, drying and size classification. The styrene monomer, water, initiators, suspending agents, nucleating agents and other minor ingredients are added to the reactor. The mixture is subjected to a time-temperature profile under agitation. The suspending agent and agitation disperse the monomer to form beads. A pre-measured quantity of pentane is added to the reactor and the polymerization is continued to ensure 100% conversion of the monomer. After cooling, the ‘expandable polystyrene’ (EPS) beads and water are discharged to a holding tank. From here, the process becomes continuous. The slurry is centrifuged to remove most of the mother liquor. The beads are transferred to a pneumatic dryer for moisture removal. The dry beads are screened. External lubricants are added for blending to obtain finished products. The typical SEC of EPS production process is given in Table A9.

TABLE A9: Typical SEC of EPS production

Parameter	Unit	Consumption
Electricity	GJ per tonne	0.4
Fuel	GJ per tonne	0.5