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Environmental Management Centre Pvt. Ltd.

6th FRAUNHOFER INNOVATION &TECHNOLOGY PLATFORM (FIT)

Circular Economy – Creating a Sustainable Environment

Knowledge Paper

Circular Economy and Sustainable Solutions in:

- Manufacturing
- Mobility
- Wastewater management focussing on water-energy-food nexus
- Plastic waste management and recycling

Indian and German Scenario and Opportunities for Collaboration

Prepared jointly by
Fraunhofer Office India and Environmental Management Centre Pvt. Ltd.

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Foreword: Embracing the Circular Economy for a Sustainable Tomorrow

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In the pursuit of a harmonious coexistence between progress and preservation, the words of the UN World Commission on Environment and Development resonate profoundly: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." This principle, at the heart of our endeavours, propels us towards a future where prosperity is intertwined with responsibility.

Within this paradigm, the notion of investing in sustainability emerges as a strategic imperative for manufacturers. For instance, the remarkable case of solar panels, which beyond their capacity to slash energy costs by 60%-80%, stand as formidable agents of change, significantly reducing carbon emissions. Such initiatives not only bolster financial resilience but also align seamlessly with the mounting consumer demand for eco-conscious products.

Recycling too emerges as a linchpin in this transformational journey, augmenting profits while staunchly curbing our carbon footprint. This forward-looking investment is a testament to our commitment to embracing an approach that echoes Antoine-Laurent de Lavoisier's wisdom: "Nothing is lost, everything is transformed." This adopted motto of the circular movement redefines growth not as a threat but as a promise – a promise that embodies a harmonious relationship between industry and nature, fostering prosperity in perpetuity.

As we reflect on our interconnectedness with the environment, the ancient wisdom encapsulated in the Atharva Veda reverberates with newfound significance: "mātā bhūmih putruahan pṛthivyā" – an earnest plea to shield our environment, water, and flora. This ethos, deeply rooted in India's rich cultural heritage, beckons us to uphold sustainable practices and safeguard our precious natural resources for generations to come.

Internationally, Germany stands as a beacon of innovation in fostering circular economy. From waste minimization and reuse to recycling and innovative waste-to-energy solutions, its multifaceted approach exemplifies a nation poised for sustainable transformation. Institutions like Fraunhofer, Europe's largest applied research organization, shine as exemplars of this commitment. With an illustrious history and a steadfast dedication to cutting-edge technologies, Fraunhofer serves as a bridge between vision and reality, an embodiment of innovation's boundless potential, serving the needs of the society at large and industry as their immediate clients in order to catapult research outputs from lab to market in the shortest span of time.

The Fraunhofer Cluster of Excellence is a visionary endeavour heralding the shift from linear to circular plastic economies. The combined efforts of Fraunhofer Institutes – UMSICHT, IAP, ICT, IML, and LBF – converge under the banner of "Circular Plastics Economy," an initiative that underscores the gravity of its collective mission. Since its inception in November 2018, this cluster has become a crucible of innovation, fostering a harmonious rapport between technological advancement and environmental stewardship.

Sustainable development beckons us to view the world through a new lens – one that integrates the delicate balance between human endeavours and the intricate ecosystems that sustain us. The Competence Centre Sustainability and Infrastructure Systems embodies this philosophy, wielding a systemic perspective to unravel the complexities of transformation.

This Knowledge Paper on Circular Economy is the basis on which we hope to converge with multiple stakeholders to develop projects, programmes and partnerships. The Fraunhofer Innovation and Technology (FIT) Platform is an exciting initiative and annual flagship event of Fraunhofer in India that focuses on different thematic fields and showcases cutting edge technologies, innovation and solutions. The 6th edition of the FIT Platform focuses on Circular economy, in the areas of Manufacturing, Mobility, Plastic waste management and recycling, and Wastewater management with focus on food-water-energy nexus. We are delighted to present the Indian and German scenario, the opportunities and challenges, and the recommendations for collaboration. This Knowledge Paper draws out the status quo and trends in each sectors and brings into sharp focus the challenges and solutions for sustainability, developing a tapestry of technology interventions that can be further developed and rolled out. The paper brings out many individual recommendations for Indo German collaboration which can be encompassed in a road map for the future.

However, the concept of a circular economy requires a collective revolution, one that engages stakeholders across the value chain, each playing a distinctive role in this symphony of change. It is a systemic, technical, and social transformation, one that demands bold innovation and adaptive networks of value creation. **Hence our key recommendation would be to create an "Indo German Cluster of Excellence for Circular Economy", with stakeholders from Government, Industry, Academia and Research, and accelerate the path to a sustainable future through multistakeholder partnerships and greater value creation.**

Grateful thanks and deep appreciation for our Knowledge Partner- Environment Management Centre Pvt Ltd (EMC) led by the team of Dr. Prasad Modal and Dr. Shilpi Kapur for their partnership and inputs to the Indian scenario in this Knowledge Paper. Deeply grateful to the Fraunhofer team of Aditya Fuke, Sanmati Naik and Marc Beckett, Fraunhofer IGB who have contributed immensely in preparing this paper.

Circular Economy in India – A Transition towards Transformation

Dr. Prasad Modak, Managing Director, Environmental Management Centre Pvt Ltd and Director, Ekonnect Knowledge Foundation

The Context

India is on a development path with rising per capita income. This economic growth has been coupled with consumption of natural resources, raising issues on resource depletion, resource degradation and resource security. The looming threat of climate change has further compounded the situation.

In this context, for India, the circular economy (CE) approach is relevant to decouple economic growth from material consumption and waste generation, making India more resource secure and competitive and thus future ready.

A recent study has estimated that USD 0.5 trillion value could be unlocked by 2030 through circular transition in India[1]. Further, estimates also suggest that a CE path adopted by India could bring in annual benefits of INR 4 million crores (approx. USD 624 billion) in 2050 and would in addition reduce negative externalities[2].

CE is one of the important strategies to meet the Sustainable Development Goals (SDGs). CE has several important co-benefits including promotion of green jobs and entrepreneurship, creation of business models and associated entrepreneurial and livelihood opportunities, building of innovation capital and provision of opportunities for sustainable finance to move towards green growth. As informal sector plays an important role in waste collection, segregation, used product refurbishing and end of life recycling, India's circular economy canvas therefore has to be inclusive. In addition, CE helps in reducing greenhouse gas (GHG) emissions and hence has the potential to contribute to India's decarbonisation journey. GHG emissions, for example, could be 44% lower in 2050 compared to the current development path if India embarked on the circular economy transition[3].

Role of CE in slowing down and eventually halting biodiversity loss, reversing its decline, by restoring ecosystems and rebuilding natural capital is also well known[4]. Biodiversity-based agro-industries are a promising means of ensuring that biodiversity protection is integrated into practices. Biorefineries, for example, can increasingly use various organic materials, like agricultural waste products, as input to make higher-value products such as biochemicals. Concept of circular bioeconomy is also assuming importance as an economic model that is based on the use of these bio-based resources which can act as renewable natural capital and integrates principles of waste to wealth. The model has potential to address the current environmental and associated economic crisis by reducing our dependence on consumption of non-renewable resources such as minerals. India has already undertaken missions and programs in this direction that need some structuring to achieve further impetus towards circular bioeconomy.

India's push towards Circular Economy

In 2015, Ministry of Environment, Forests and Climate Change (MoEFCC) constituted Indian Resources Panel (IRP), as a step to address India's resource security in a strategic perspective. India was the first country in the world to take such an initiative. Following the establishment of IRP, India's apex policy body NITI Aayog came up with an action plan to accelerate Resource Efficiency (RE) and circular economy. In partnership with EU's Resource Efficiency Initiative (REI), several sectoral publications were brought out between 2017-2019, involving dialogue with multiple institutions. Around the same time, Ministry of Finance, Government of India set up a Task Force on Sustainable Public Procurement (SPP). In 2019, MoEFCC established a Resource Efficiency Cell and formulated a draft National Resource Efficiency Policy.

The evolution of CE in India is depicted in Figure 1. This evolution tracks the key initiatives undertaken by the various ministries in the Government of India and the leadership by Ministry of Environment, Forests and Climate Change (MoEFCC) and the NITI Aayog.

The traditional focus of CE policy push in India has been on managing waste at the downstream stage in the life cycle of products. For example, the notifications of various waste management related rules, such as the Plastic Waste Management Rules, e-Waste Management Rules, Hazardous and Other Wastes (Management and Transboundary Movement) Rules, Construction and Demolition

[1] *"Approaches for Measuring India's Circular Economy Transition"*
[2] *"Accelerating India's Circular Economy Shift"*
[3] *"Circular economy in India: Rethinking growth for long-term prosperity"*
[4] *"The role of the circular economy in addressing the global biodiversity crisis"*

(C&D) Waste Management Rules, Battery Waste Management Rules place impetus on strengthening the recycling component of the material and waste streams. However, recent years have seen an increasing emphasis on upstream and midstream stages of the value chain through innovative design, reduction in raw material used and substitution of virgin raw material with secondary materials.

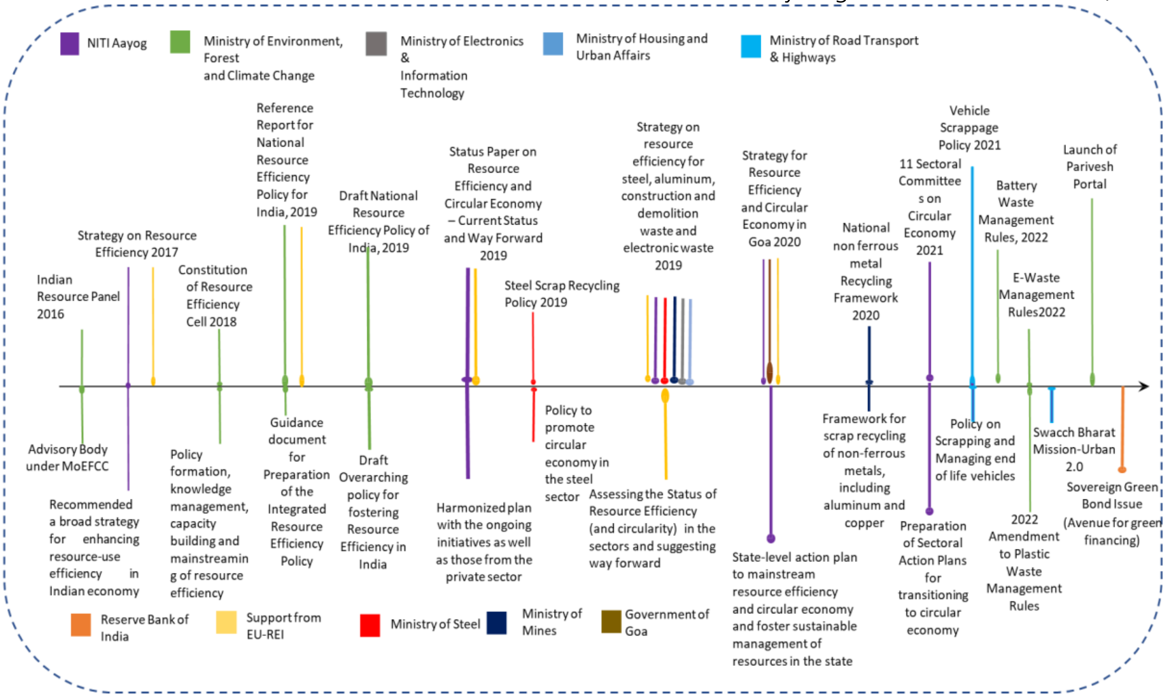


Figure 1: Evolution of Circular Economy in India

To give an example, the Rule 9 of the Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016 has been specifically framed to streamline and encourage the reutilization of hazardous Waste in a scientific and transparent manner following due procedure and adopting necessary safeguards that need to cover more categories of waste. The C& D Waste Management Rules, 2016 also promote C & D waste utilization. Sub-rule (11) notes '*shall make provision for giving incentives for use of material made out of construction and demolition waste in the construction activity including in non-structural concrete, paving blocks, lower layers of road pavements, colony and rural roads.* Fly ash utilization related directive is another example. More importantly, India has framed rules on Extended Producer Responsibility (EPR) covering waste streams such as E-Waste, Plastic Waste, Batteries and Rubber Tyres. The EPR rules will certainly push circularity with greater involvement of the private sector, spurring innovation and connecting with the informal sector with IT based reverse logistics platforms.

On the side of resources, the India's National Water Policy has reemphasized water conservation, reuse and recycling and today more than 8 States in India have developed wastewater recycling policies. Market mechanisms are also under discussion on Wastewater recycling credits. On June 28th, 2023, the Ministry of Power, Government of India, introduced India's first regulated Carbon Credit Trading Scheme through a gazette notification. Notably, on June 26th, 2023, the Ministry of Environment, Forests and Climate Change published a draft notification on Green Credits encouraging going beyond compliance and low carbon and circular practices.

India is also seeing a growing number of "green" certifications and labelling standards, which drive sustainability in production processes and encourage end-users to consume environmentally friendly and socially sound products. The Confederation of Indian Industry (CII) Sohrabji Godrej Green Business Centre (GBC) developed the GreenPro Ecolabel (Type - 1 Ecolabel). GreenPro Ecolabelled products have seen an increase over the last few years crossing more than 5000 products in 2022. Further, CII-GBC developed GreenCo Ratings scheme and this initiative has also witnessed a rising trend reaching to 500 GreenCo companies by 2021. Green building codes such as the Green Rating for Integrated Habitat Assessment (GRIHA) and the Leadership in Energy and Environmental Design (LEED) have also been developed. Estimates suggest that overall projects under LEED stand at 4,304 projects with more than 2.53 billion gross square feet[5]. In case of GRIHA, there are more than 3,571 projects with a footprint of more than 52 million gross square meters[6]. There are CE parameters linked to efficient use of resources like energy and water and use of non-toxic materials in green building certification. However, there are opportunities to integrate CE principles further through bringing in parameters linked to managing the demolition waste e.g. by mandating certain percentage for on-site utilization. These strategies need to be supported and mainstreamed in India's programs on investing in infrastructure.

reduce carbon emissions"[7]. Along these lines, he announced the Mission Circular Economy.

Once again, in March 2022, as a part of one of the post budget webinars, the Honourable Prime Minister of India, Shri Narendra Modi re-emphasized on the importance of CE and encouraged people to make CE mandatory part of their lives by launching Mission LiFE (Lifestyle for Environment).

In February 2021, the NITI Aayog formed 11 Committees to identify the actions for CE in India on various focal sectors[8]. These focus areas were identified considering their volume or scale, associated environmental and social risks that they pose and opportunity areas for enhancing resource use efficiency, recycling and recovery. Further, additional criteria such as potential to reduce imports, generation of green jobs and green enterprises and possibilities to promote innovative business models were also considered. Accordingly, ministries were advised by NITI Aayog to prepare sectoral action plans with KPIs.

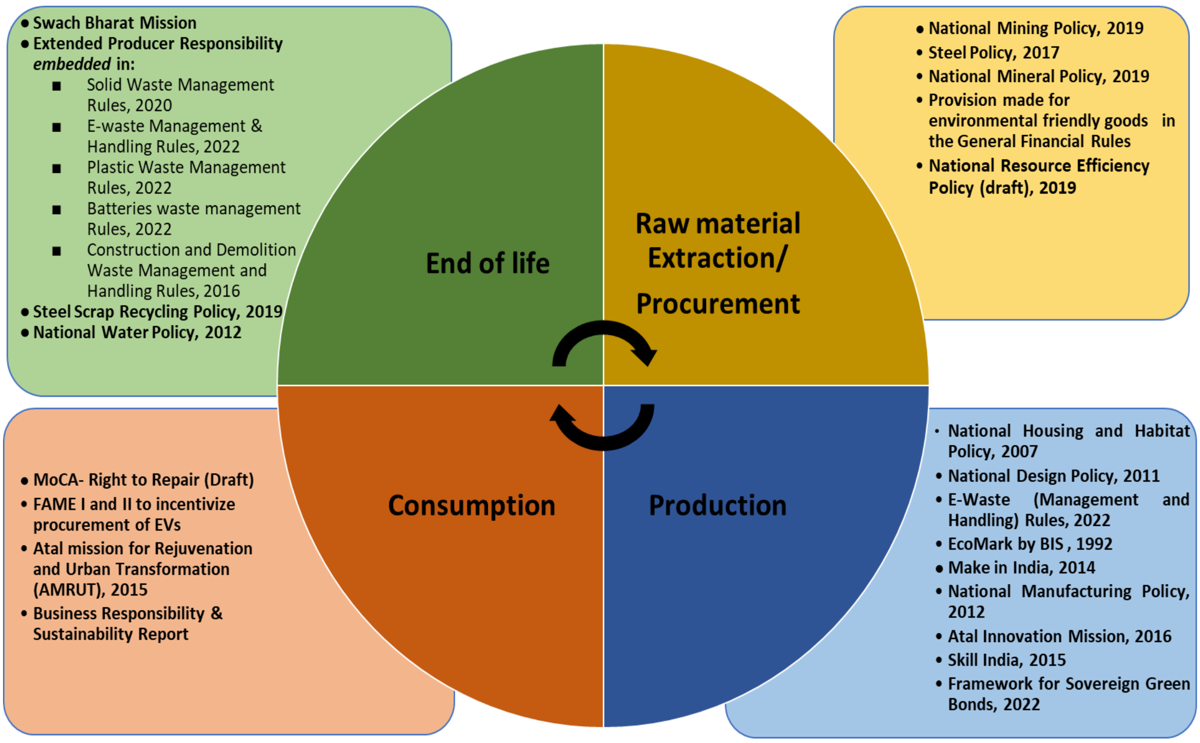


Figure 2: Policy and program push on Circular Economy in India

Figure 2 summarizes the key policy and program push factors in the circular economy on the basis of life cycle.

Way Ahead

In the Independence Day speech on 15th August 2021, honourable Prime Minister emphasized on the need for an "action plan to build a CE so that resources are conserved to improve our economic, natural, and social capital and at the same time

The Union Budgets in recent years have also emphasized on CE and highlighted the role that it can play and the opportunity that it can create. Specifically, the 2022-23 Budget mentioned that the CE transition will support productivity

[5] *"The Top 10 Countries for LEED demonstrate that green building is a truly global movement"*
[6] *"Home: Green Rating for Integrated Habitat Assessment"*
[7] *"The Prime Minister, Shri Narendra Modi addressed the nation from the ramparts of the Red Fort on the 76th Independence Day"*
[8] *"Govt Driving Transition from Linear to Circular Economy"*

enhancement as well as create large opportunities for new businesses and jobs. Further, the Budget had emphasized on the need to focus on addressing important cross-cutting issues of infrastructure, reverse logistics, technology upgradation and integration of the informal sector. Support for active public policies covering regulations, EPR framework and innovation facilitation was also highlighted. The Union Budget of 2023-24 has emphasized on green growth and announced 500 new 'waste to wealth' plants for promoting CE with a total investment of Rs 10,000 crores under the GOBARdhan (Galvanizing Organic Bio-Agro Resources Dhan) scheme. These will include 200 compressed biogas (CBG) plants, including 75 plants in urban areas, and 300 community or cluster-based plants.

India's G20 Presidency has also taken circular economy as a key thematic area to the G20 discussion table with an aim to venture towards co-developing technologies and pilot projects to demonstrate real-world applicability of RE/CE solutions, enabling mechanisms for private sector participation, and mobilising mainstream financing.

There have been 4 key sub-thematic areas that India's G20 Presidency is focussing on under the broader theme of CE. These are: Circular economy in the Steel Sector; Extended Producer Responsibility for Circular Economy; Circular Bioeconomy; and Creation of a Resource Efficiency & Circular Economy Industry Coalition.

To conclude, the CE paradigm has the power to impact the entire value chain of products, by transforming the way products are made upstream (through circular designs, use of recycled content, packaging reduction) and midstream when used (extended product life, ease of repair) thus helping minimize pollution and environmental degradation downstream. Innovation in technology and materials, financing, and building adequate institutional capacities will play a critical role. Transitioning to CE will thus help India towards a transformation achieving ecological modernization in its economic development, especially by altering its consumption and production patterns.

1. Circular Economy in Manufacturing

Introduction

The shift towards a circular economy model is a noticeable trend among companies, driven by resource constraints and environmental concerns. This model replaces the traditional linear "take-make-dispose" approach with a focus on the entire lifecycle of a product and its environmental impact. This transition requires manufacturers to adapt their processes and products to close the loop and achieve sustainability.

The circular economy offers manufacturers several benefits, including stronger value chain relationships and long-tail revenues. However, embracing this model necessitates significant changes. As more companies adopt circular practices, manufacturers must re-evaluate operations and modify their Enterprise resource planning (ERP) solutions to meet the demands of sustainable models.

Four key areas highlight the relevance of the circular economy in manufacturing:

1. **Creating 'Like New' Products with Reverse Logistics:** Remanufacturing, which restores parts to original specifications, gains traction for its economic and environmental benefits. Industries like automotive and electronics embrace this process. However, managing various repair processes and customer agreements poses challenges.
2. **Scale Up and Overhauls:** Larger assets, like heavy manufacturing equipment, can be rejuvenated and upgraded by original manufacturers, offering environmental benefits and adding new technology. Telematics-based services enhance equipment productivity and reduce carbon footprint.
3. **Sustainable Packaging:** The shift to circular value chains introduces re-usable and recyclable packaging. Governments enact regulations to reduce waste, and organizations like Loop promote reusable packaging. Reusable and recyclable packaging trends extend to transport packaging, driven by environmental concerns.
4. **ERP Evolution**: ERP software evolves to manage the entire product lifecycle, including maintenance, recycling, and extended support. Environmental footprint management tools capture lifecycle information, while contract and warranty management ensure proper invoicing and compliance. ERP also supports packaging traceability and reverse logistics, adapting to changing return considerations.

As the circular economy gains momentum, manufacturers must adapt to reap its benefits, requiring changes in operations, products, and ERP solutions. This transition promises a more sustainable and responsible approach to manufacturing, with significant potential for value creation and reduced environmental impact.

German Scenario

The manufacturing industry has been a vital pillar of the German economy for many years. However, mega trends like globalization, individualization, increasing mobility, growing knowledge culture, and urbanization are reshaping the landscape of manufacturing. Germany must adapt to these changes to maintain its position as a technological leader. Globalization has opened up new markets and opportunities for German manufacturers, but it has also increased competition from emerging economies. To stay competitive, German companies must focus on innovation and continuously improve their products and processes.

Individualization and mobility are changing customer demands, leading to a need for more flexible and customizable production methods. Embracing advanced manufacturing technologies like 3D printing and automation has enabled German manufacturers to meet these demands efficiently. The shift towards a knowledge culture demands a highly skilled workforce that can adapt to technological advancements quickly. Investment in education, training, and upskilling and reskilling of workers is essential to keep up with the rapid pace of technological change. Urbanization is also influencing manufacturing, as it drives the need for more sustainable and resource-efficient production processes. Germany's commitment to green manufacturing and sustainable practices can enhance its reputation and attract environmentally conscious consumers and partners.

Addressing the challenges in context of these changing trends and maintaining its technological leadership, a close collaboration between industry and research is crucial. Research institutions can provide valuable insights and breakthrough innovations that can be translated into practical applications by the industry. Partnerships can foster knowledge transfer and accelerate the adoption of cutting-edge technologies in manufacturing. Furthermore, public-private collaborations and government support for research and development initiatives can encourage innovation and help the manufacturing sector remain competitive on the global stage.

In conclusion, the manufacturing industry in Germany must adapt to the changing trends and challenges to secure its leadership position. Embracing innovation, investing in skilled labour, promoting sustainable practices, and fostering collaborations between industry and research will be vital for the continued success of the German manufacturing sector.

Key Policies and Programmes in Germany

Germany has been a leader in implementing circular economy principles in the manufacturing industry. The country has taken a comprehensive approach, combining policy measures, incentives, and initiatives to promote sustainable production and consumption. Some key German policies and strategies to implement the circular economy in the manufacturing industry include:

1. **Resource Efficiency Program (ProgRess):** ProgRess, which is a comprehensive policy framework aimed at promoting resource efficiency and the circular economy in Germany. It sets out specific goals and measures to decouple economic growth from resource consumption and environmental impacts. The program covers various sectors, including manufacturing, and encourages sustainable product design, recycling, and waste reduction.
2. **Closed Substance Cycle and Waste Management Act (KrWG):** The KrWG is a central piece of legislation that focuses on waste prevention, recycling, and sustainable waste management. It promotes the reduction of waste generation, encourages separate collection and recycling of materials, and supports the development of eco-friendly products.
3. **Circular Economy Action Plan:** Germany's Circular Economy Action Plan outlines a range of strategies and initiatives to promote the circular economy across sectors, including manufacturing. It emphasizes sustainable design, eco-innovation, and the reduction of resource use and waste generation. The plan includes measures to enhance recycling and recovery rates, promotes sustainable production processes, and encourage the use of secondary raw materials.
4. **Eco-Design Requirements:** Germany has implemented eco-design requirements for various products, which aim to improve their environmental performance and durability. These requirements encourage manufacturers to design products that are easier to repair, recycle, and upgrade, thereby reducing waste and extending product life cycles.
5. **Extended Producer Responsibility (EPR) Regulations:** Germany has established EPR regulations that hold manufacturers responsible for the end-of-life management of their products. This encourages manufacturers to design products with easier disassembly and recycling in mind, and it also promotes the development of take-back and recycling systems.
6. **Resource-Efficient Circular Economy Policy:** The German Federal Ministry for Economic Affairs and Energy has developed a policy framework that focuses on resource-efficient circular economy strategies. This framework aims to strengthen the competitiveness of German businesses through sustainable production and resource-efficient processes.
7. **Green Public Procurement:** The German government promotes green public procurement, encouraging public institutions and agencies to prioritize the purchase of products that meet certain environmental and circularity criteria. This approach creates market demand for circular products and drives innovation in the manufacturing industry.
8. **Research and Innovation:** Germany invests in research and innovation to support the

development of circular economy technologies and practices. Collaborative research projects, funding programs, and innovation networks focus on advancing sustainable manufacturing processes, materials, and product design.

These policies and strategies reflect Germany's commitment to promoting the circular economy in the manufacturing industry. By integrating circular principles into various aspects of policy and business practices, Germany aims to reduce environmental impacts, enhance resource efficiency, and create a more sustainable manufacturing sector.

Indian Scenario

Traditionally, the Indian society has been focused on frugal living. Consumption and production processes were centric to minimizing wastefulness and maximizing the useful life of products. However, the advent of globalization brought with it some major changes that affected the Indian dynamic. Rising consumerism, growing purchasing powers and higher living standards have made it a challenge to sustain the Indian population, which accounts for 17.76% of the global population today[9]. Additionally, with the ever-increasing emphasis and awareness on sustainable development, multiple stakeholders within the value chain are demanding environmental and social considerations to be an integral part of manufacturing processes. Circular Economy (CE) is an important strategy that can help Indian manufacturing in fulfilling their sustainability goals. CE, spearheaded by the newest technologies and innovative thinking is capable of creating manufacturing practices that are in line with the Indian roots. Efforts are already underway in this regard. Examples from selected industries are presented below:

1. **Renewable Energy Equipment Manufacturing:** India is rapidly expanding its renewable energy capacity, including solar, wind, and bioenergy. The manufacturing of solar panels, wind turbines, and other renewable energy equipment is becoming a key sector in the country. As of July 2023, India's installed non-fossil fuel capacity has increased 396% in the last 8.5 years and stands at more than 179.322 Giga Watts (including large Hydro and nuclear), about 43% of the country's total capacity. Up to 100% FDI is allowed under the automatic route for renewable energy generation and distribution projects subject to provisions of The Electricity Act 2003[10].
2. **Electric Vehicles (EVs) and Components:** With a growing emphasis on clean energy and sustainability, the EV sector in India has been gaining momentum. The manufacturing of electric vehicles, batteries, charging infrastructure, and related components like motors and power electronics was expected to witness substantial growth. The Government of India aims to achieve 100% local production of EVs under its 'Make in India' initiative[11]. Start-ups are also driving innovation and technological advancements in the EV space. For instance, Bengaluru-based GPS Renewables installed an EV charging station in Mumbai that functions on biogas from food waste[12].
3. **Textiles and Apparel:** The textile industry in India is making efforts to adopt sustainable practices, including the use of organic and eco-friendly fibres, water-efficient dyeing processes, and ethical labour practices. Conscious manufacturers are making concerted efforts to introduce sustainability by using innovative materials, using safe dyes, reducing water and energy consumption, treating waste material and ensuring a greater focus on reducing, reusing and recycling[13] [14].
4. **Rail coach manufacturing:** The rail coach manufacturing sector in India is an emerging industry, spurred by government initiatives and investments. With a focus on modernizing railway infrastructure and enhancing passenger experience, the government has encouraged domestic manufacturing and attracted foreign investment through initiatives like "Make in India." Significant investments have been made in expanding manufacturing facilities and developing advanced technologies.
5. **Aerospace and Defense:** The Indian government has been promoting domestic manufacturing in the aerospace and defense sectors. Initiatives like "Make in India" and the opening up of defense production for private players are leading to opportunities in

[9] *https://www.worldometers.info/world-population/india-population/#:~:text=India%202023%20population%20is%20estimated,of%20the%20total%20world%20population.*
[10] *https://www.investindia.gov.in/sector/renewable-energy*
[11] *https://www.livemint.com/news/india/ev-industry-in-india-how-india-accelerates-towards-becoming-next-powerhouse-in-ev-production-11688005217114.html*
[12] *http://gpsrenewables.com/gps-renewables/*
[13] *https://www.fairplanet.org/editors-pick/making-indias-textile-industry-green/*
[14] *https://www.investindia.gov.in/siru/india-goes-green-textile-industry*

manufacturing aircraft, helicopters, defense equipment, and components.

6. **Sustainable Architecture:** India's construction industry has been embracing green building practices, leading to an increased demand for eco-friendly construction materials like low-emission cement, recycled materials, and energy-efficient insulation products. In India, the Leadership in Energy and Environmental Design (LEED) certification and the Green Rating for Integrated Habitat Assessment (GRIHA) certification are widely recognized certification for green building projects.. Various states and central government agencies in India are now more focused on green buildings for promoting energy conservation measures, and states has already started to provide incentives such as tax benefits, loans and fast-track approvals for green certifications. These incentives aim to make LEED-certified building projects more financially viable and to encourage private sector investment in sustainable building practices in India[15].
7. **Green Chemicals and Biofuels:** There is an emerging trend towards the production of green chemicals, which are environmentally friendly and have reduced environmental impacts. Additionally, biofuel production from non-food feedstocks is gaining attention as an alternative to conventional fossil fuels. Over 3,300 startups are now working in the renewable energy sector in India and many of these startups are involved in the green fuel sector to reduce carbon emissions. Such startups are working on innovations in battery composition, new technologies in biofuel production, utilisation of wastes, etc. They are trying to boost the use of clean fuel across the country and promote circularity.

Role of Digital Technologies

Emergence of digital technology is expected to play a major role in circular economy, especially in India, given its strength in the IT sector.

- Attero was launched as India's first integrated end-end electronic waste recycling facility. Founded in 2007, the Noida-based company has developed patented state-of-the art recycling technology to recycle and extract valuable materials viably, even with smaller e-waste volumes. The company offers refurbishment and reconditioning services to extend the useful life of electronics and a digital portal to enable take back from the end consumers. The company has developed a robust reverse logistics network backed by IT with collection centres in 22 states. There are several city-based initiatives too.[16].
- Mahindra's Trringo is India's first of its kind tractor and farm equipment rental and sharing platform, launched to improve asset utilization and address the equipment gap in Indian agriculture. It operates through a dual model, a digital platform based B2B model where tractors are given out to franchisees to set up local hubs and a C2C model where large farmers can rent out underutilized equipment to other farmers. Trringo currently has over 100,000 registered users across 5 states in India.[17]
- Internet of Things (IoT) enabled waste collection and transportation can bring in significant advantages in the overall implementation of waste management solutions. The Urban Local Bodies (ULBs) can check contractor's effectiveness using IoT technologies. Deployment of smart bins, tracking of garbage pickup trucks as well as the sanitation workers, route optimization for trucks, cross-checking of garbage weight etc. can efficiently address the challenges of enforcement and transparency. Similarly, IoT-enabled sensors can also monitor the amount of alternate fuel generated from the processed waste.
- BioEnable in India provides smart waste bin sensor which can be used in any container to monitor any types of waste real- time. It can be used to monitor the fill level of the container. It provides complete solution with manpower that makes waste collection and dispatch operations both efficient and cost-effective. These tools eliminate hours spent on manual routing, maximize productivity, optimize equipment and staff allocations, and allow you to gain better control over your solid waste management operations. BioEnable technology

[15] https://www.gbci.org/government-incentives-green-building-projects-india
[16] Innovative Business Models and Technologies to Create Value in a World without Limits to Growth. (2019). [online] Available at: https://www.accenture.com/t20150523t053139__w__/us-en/_acnmedia/accenture/conversion-assets/dotcom/documents/global/pdf/strategy_6/accenture-circular-advantage-innovative-business-models-technologies-value-growth.pdf
[17] Ellen Macarthur Foundation(2016).CIRCULAR ECONOMY IN INDIA: RETHINKING GROWTH FOR LONG-TERM PROSPERITY Available at: https://www.ellenmacarthurfoundation.org/assets/downloads/publications/Circular-economy-in-India_5-Dec_2016.pdf

has helped Hyderabad and Pune municipal corporations.[18]

Key Policies and Programmes in India

There is significant push by the Indian Government towards circular manufacturing. Some key policies and strategies include:

1. **Make in India[19]:** The Make in India campaign was launched to facilitate investment, foster innovation, enhance skill development, protect intellectual property & build best in class manufacturing infrastructure. To give an example, India's under India's ambitious push for self-sufficiency in mobile phone assembling, it has shipped two billion domestically assembled smartphones and feature phones between 2014 and 2022 through its growing manufacturing infrastructure as part of its Make in India initiative.
2. **Zero Defect, Zero Effect[20]:** In India's pursuit for becoming globally competitive, the 'Make in India' with 'Zero Defect, Zero Effect (ZED)' schemes have been passed with a twin focus- on customers and on society. By zero defect, it is meant that the quality of the products has to be very high and zero effect means that there should be no adverse effect on the environment by manufacturing. This highlights the government's ardent desire to pay particular attention on manufacturing as a means to sustainable growth in order to transform the course of economy. The ZED scheme is also aimed at providing MSMEs with a competitive ecosystem.
3. **Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME)[21]:** FAME is a subsidy scheme which was introduced by the government of India on April 1, 2019, for a period of three years, and later extended for a period of two years up to March 31, 2024. The scheme aims is to promote the adoption of electric and hybrid vehicles in India, with the ultimate goal of reducing the country's dependence on fossil fuels, reducing air pollution, and mitigating the impact of climate change. Incentives are provided to manufacturers and buyers of electric and hybrid vehicles and aims to increase demand for these vehicles by making them more affordable and accessible.
4. **Steel Scrap Recycling Policy[22]:** The Indian government notified the Steel Scrap Recycling Policy in November 2019. The policy provides a framework to facilitate and promote establishment of metal scrapping centres in India for scientific processing and recycling of ferrous scrap generated from various sources. It is within the objectives of the policy to promote a CE in the steel industry of India, coupled with effective management of steel scrap throughout the value chain and production of high-quality ferrous scrap for quality steel production.
5. **National Bioenergy Programme[23]:** The Ministry of New and Renewable Energy of India (MNRE) launched its National Bioenergy Programme in 2022 and extended it until 2025-26 through two phases. The programme has the following sub-schemes:
   a. Waste to Energy Programme supporting the installation of large biogas, bio CNG and power plants.
   b. Biomass Programme for the use of pellets and briquettes in power generation
   c. Biogas Programme supporting installation of family and medium size biogas installations in rural areas.
6. **Initiatives for the textile industry[24]:** The Government of India is taking numerous initiatives and actions to enhance the textile industry. One of the primary schemes that the Ministry of Textiles introduced in 2021 is to set up Mega Investment Textiles Parks (MITRA). This scheme will build a world-class infrastructure with plug-and-play facilities to let global champions in exportation. This project will tender India a hotspot for national and international divers seeking to enter the realm of textiles and garments. The government intends to make seven textile parks over three years. The Production Linked Incentive (PLI) scheme for textiles launched in 2022 intends to boost the domestic textile production and exports, including Man-Made Fibre (MMF), garments, and technical textiles. It aspires to capture a substantial chunk of the market and

[18]18 Smartbin Sensors – BioEnable. (n.d.). Retrieved from https://www.bioenabletech.com/smartbin-sensors
[19] https://www.makeinindia.com/index.php/policy/new-initiatives
[20] https://dcmsme.gov.in/schemes/clcs-tus/Operational_Guidelines_ZED.pdf
[21]https://economictimes.indiatimes.com/industry/renewables/fame-scheme-what-is-it-and-whats-all-the-brouhaha/articleshow/100325140.cms?from=mdr
[22]https://steel.gov.in/sites/default/files/Steel%20Scrap%20Recycling%20Policy%2006.11.2019.pdf
[23] https://prod.iea.org/policies/17413-national-bioenergy-programme
[24] https://www.investindia.gov.in/siru/india-goes-green-textile-industry

elevate India to the top exporter of technical textiles.

7. **Startup India**[25]: Startup India is a flagship initiative of the Government of India and is intended to build a strong eco-system for nurturing innovation and Startups in the country that will drive sustainable economic growth and generate large scale employment opportunities. Government of India has established a Fund of Funds for Startups (FFS) with corpus of Rs. 10,000 crores, to meet the funding needs of startups. The program intends to assist startups by reducing the regulatory burden. In addition to providing funding financial incentives, the Startup India Scheme tries to provide easier compliance, fast tracking of patent applications, legal support and an easier exit process for failed startups. Since 2016,the initiative has rolled out several programs in order to build a robust startup ecosystem by supporting entrepreneurs and ultimately transform India into a country of job creators instead of job seekers. By encouraging the development of sustainable technologies, such as clean energy, waste management, and water conservation, the Startup India Scheme fosters the growth of startups that tackle pressing environmental and resource use challenges.

India is estimated to become the fourth-largest economy in the world in about two decades. This economic growth is however going to come with challenges such as urbanization with increased vulnerability (especially due to climate change), poor resource quality and scarcity and high level of unevenness in the socio-economic matrix due to acute poverty. India, if it makes the right and systemic choices, has the potential to move towards positive, regenerative, and value-creating development. Its young population, growing use of IT, increasing emphasis on social and financial inclusion can make this happen. For this, developing a national policy framework on the Circular Economy makes a strong rationale.

Challenges and Opportunities for Collaboration

Challenges

In Germany, advancing circularity in manufacturing faces several key challenges. Aligning regulations to support circular practices while maintaining a balance between environmental goals and economic considerations is a complex endeavour. Integrating circular design principles into products without compromising performance or aesthetics demands close collaboration among designers, engineers, and stakeholders. Coordinating a network of suppliers, manufacturers, and recyclers to ensure smooth material flow poses logistical challenges. The adoption of advanced technologies like IoT tracking and innovative recycling methods requires careful assessment of feasibility and scalability. Shifting consumer behaviour from disposability to repair and reuse necessitates targeted awareness efforts and incentives. Equipping the workforce with skills for tasks such as remanufacturing is crucial, while establishing efficient collection and recycling systems presents infrastructure challenges. Managing fluctuating demand and pricing for recycled materials alongside economic viability is an ongoing concern. Developing standardized measurement metrics for resource efficiency and waste reduction is complex but necessary. Finally, scaling successful pilot projects across industries and regions requires overcoming funding, regulatory, and resistance-to-change barriers.

In India, there are many key challenges and opportunities that needs to be focussed upon.

(i) Capital Investment: There is uncertainty about the transition costs for companies adopting CE methods, and about its impact on business models and revenues. This creates new risks for investors who are used to investing in linear products and services. And this perceived high level of risk is a constraint on businesses wanting to use capital investment to adopt CE principles. Even where environmental awareness and motivations exist, a lack of access to financial resources can inhibit action.

(ii) Innovative technology solutions: Technology solutions are often available, but their use and scale may be limited due to fewer resources. Overcoming these barriers and providing technologies that can be adopted with minimal effort and a clearly demonstrable business case is a key to reducing and capturing raw materials.

(iii) Technical expertise: A shortage of industry expertise, education and research may be a hinderance to the rollout of circular principles and incentives. The creation of knowledge networks

[25] *https://pib.gov.in/pressreleaseshare.aspx?prid=1703787*

and facilitated capacity building are needed to overcome the significant knowledge barrier.

(iv) Complexity of Green Process and System Design: The complexity of the green processes and system design can make the efficient use of the resources available in the current industry a challenge. Businesses must design green procedures that maximize the use of all available resources.

(v) Planning and Roadmapping: Absence of proactive planning and roadmapping at company level: To successfully integrate sustainable manufacturing practices, a firm needs a good proactive plan and a clear roadmap, which in most cases is missing.

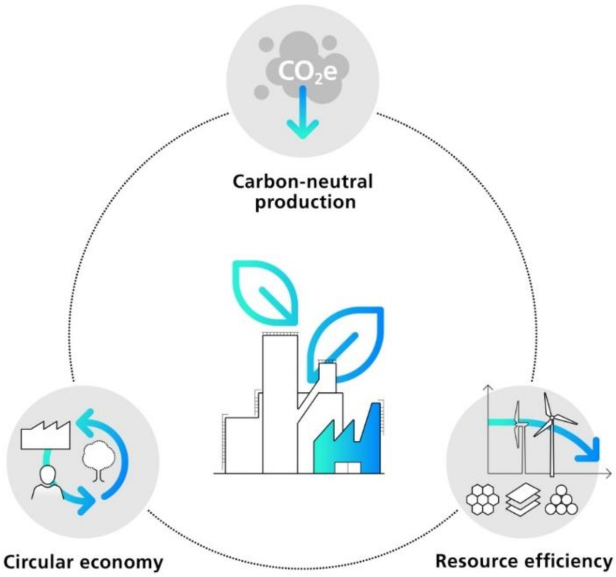
(vi) Stakeholder engagement and synergizing goals and objectives: With multiple stakeholders having varied priorities, there is a lack of trust among stakeholders and high levels of competition between them.

(vii) Lack of commitment and engagement of suppliers: Poor supplier commitment or unwillingness to exchange information due to their lack of trust and the fear of leaking information.

Opportunities for Collaboration

By focusing on long-term outcomes, working collaboratively, and adopting a deliberate and coordinated approach, manufacturers have the capacity to realize significant benefits on the road towards circularity and moving on the path towards sustainable development. These benefits extend from improved competitiveness and efficiency, to reduced costs and risks. By driving measurable circularity focused outcomes, manufacturers also have the power to create lasting social value. Given the complexity of the canvas of circular economy and the interests of diverse stakeholders, a partnership approach is appropriate to implement circular economy projects. Few key areas for partnership and collaboration include – **(i) establishing R&D facilities** for the creation and invention of new goods and processes. This includes establishing research facilities for managing energy use, reducing material use, etc. **(ii) Collaboration with international agencies and industry** organizations to learn about opportunities and processes and systems to make manufacturing green and circular. **(iii) to develop policies** to provide incentives for alternate materials with clear labelling and quality norms as well as provide incentives and tax benefits for alternate materials. **(iv) designing technological upgrades** to machinery and energy sources that are sustainable and can be adopted across sectors. **(v) to share knowledge and experience** on scaling up the use of emerging technologies such as Industry 4.0 and automation, which have the potential to create significant cost and energy savings by an efficient manufacturing process that incorporates remanufacturing and recycling initiatives. **(vi) to create a manufacturing framework** that establishes benchmarks for smaller manufacturers and suppliers to implement green manufacturing practices. The framework should also integrate guidance on technological impetus that can help provide a variable cost structure, enhance agility, and facilitate a shift of resources that allows a focus on sustainable manufacturing. **(vii) Collaboration with different players** in the supply chain through engagement and creating trust and building awareness and capacity to adopt green manufacturing practices and share knowledge. **(viii) to foster innovation to create sustainable and circular designs:** Products need to be redesigned to reduce/eliminate hazardous substances, increase recyclability (and improve safety during recycling) and make remanufacturing possible with most of the components getting reused. This requires innovation, risk appetite and top management commitment. Companies looking to achieve competitive advantage may need to allocate more resources towards product innovation.

Offerings and Activities of Fraunhofer



Closing material loops in industrial manufacturing environments not only offers significant savings potential, but also the possibility of markedly reducing industry's impact on the environment. This opens up opportunities to reduce dependencies on global commodity markets, particularly when it comes to economically strategic commodities. To identify such critical raw materials, Fraunhofer supports the industries by carrying out detailed criticality analyses. In addition, Fraunhofer examines and compares a variety of circular economy strategies to assess their ecological benefits. This results in concrete recommendations for action for the concerned manufacturing industry. The research of Fraunhofer in Sustainable manufacturing focuses on:

1. Circular economy: Maximizing the use of products and raw materials.
2. Resource efficiency: Reconciles climate, energy and material efficiency in manufacturing companies.
3. Carbon-neutral production: Ecological life cycle assessment and resource conservation

Competencies and Range of Services

1. Digitization: Deep competencies in Industry 4.0 to increase profitability of a manufacturing company
2. Conducting raw material criticality analyses
3. Identification and assessment of environmental aspects of circular economy strategies
4. Evaluation of business models in the context of circular value chain
5. Analysis and evaluation of circular economy processes in processing companies
6. Ecological life cycle assessment
7. Develop roadmap to achieve carbon neutrality.
8. Energy Audits: Identification and assessment of energy flexibility potential of industrial systems
9. Simulations for energy optimization

Ready-to-implement Circular Economy Solutions in Manufacturing

1. Additive manufacturing: Wire-based laser metal deposition
2. Cost-efficient and sustainable lightweight materials for the automotive industry
3. Hybrid laser material deposition with wire and powder
4. Wafer-scale series production of glass optics by precision moulding
5. Energy-oriented production control, machine control and monitoring
6. Adaptive robotics
7. Automated wear measurement and process planning for milling.
8. Networked adaptive production with 5G mobile technology.
9. Production and processing of cold-curing fiber composite semi-finished products
10. Substitution of high-energy furnace processes in sheet metal working
11. Low-dust and sensor-supported recovery of technology metals

Offerings to the Industry

1. **Strategic industry 4.0 road mapping and Technology Benchmarking:** Development of step-by-step processes to achieve digital and networked production.
2. **Resource-Efficient Material Flows:** This includes all phases of a product's lifecycle, from production through utilization right up to value-added recycling. To achieve this, Fraunhofer offers tried and trusted methods.
3. **Energy and resource-saving process chains:** Parallel processes and efficient process chains save time, energy and costs. With simulation and digital twins, Fraunhofer ensures that transition to efficient series production with reduced material consumption through process monitoring and AI is achieved successfully by industry.
4. **Energy-efficient plants and machines:** Fraunhofer offers automation, sensor technology and 5G network technology to the industry to optimize control systems and loops so that intelligent consumption control becomes possible.
5. **Life Cycle Assessment in Production:** Fraunhofer analyses the production process according to ecological criteria, taking into account the economic constraints, and accompany the optimization process.
6. **Manufacturing eco-friendly products:** Developing new materials and valuable resources to manufacture climate friendly products.
7. **Management of Hazardous Substances:** Developing strategies to save environmentally harmful materials or replacing by less harmful alternatives in many areas of production. Less use of resources

leads to less waste; problematic dust, chips, coatings or coolants can be avoided through new procedures or optimized processes, components and surface treatments.

8. **Quality Management, Maintenance and Asset Management:** Fraunhofer offers complete planning and optimizing procedures and methods in a consistent quality management system. Fraunhofer optimizes the maintenance of machinery and equipment.
9. **Innovation Network: Online-based quick check to measure company-specific maturity and exchange with other innovative companies.**

Activities of Fraunhofer – some references

Fraunhofer Lighthouse Project »E3 Production« – Efficient, Emissions-Neutral and Ergonomic	The aim of the project is to align the production process, factory and man in an optimum way. An E^3 factory is one that manufactures goods using energy and resources efficiently, integrates man into the production process and has zero emissions. This helps to better plan, implement, and monitor the flow of materials, energy and information in emissions-neutral E^3 factories carrying out ergonomic, energy- and resource-efficient production.
AddRE-Mo	The project aims at value retention scenarios for the urban electromobility of people and goods through additive manufacturing and remanufacturing
KOSEL	The project focuses on developing reusable open-source design kit for electrically powered pool vehicles
LEVmodular	The project focuses on developing Light Electric Vehicle modular – with new mobility for resource-efficient recycling.
MoDeSt	The project focuses on developing circularity of product through modular design and strategies for long-lasting smartphones.
ResmaP	The aim of the project is to achieve resource efficiency through a new process of maintenance and repair and the replacement and recirculation of pumps.
Wear2Share	The project aims to develop innovative circular business models in the textile industry
ARENA2036	The project focuses on developing new methods for producing and assembling lightweight vehicle structures as well as evaluating their suitability for use in practice.
AMBOS-3D	The project focuses on technical support in workshops for people with disabilities through modern optical 3D sensor technology and open-source developments.
Virtual Fort Knox	Virtual Fort Knox is a platform designed for manufacturing companies that offers needs-based manufacturing IT solutions. The platform assists not only large-scale companies but also small and medium-sized enterprises in integrating and operating IT systems to optimize factory planning and factory operations.
Industry 4.0 made easy with Networked Digital Twins	The project focuses on Industry 4.0 even for small and medium-sized enterprises: Devices can be exchanged at random for others with the same production capabilities without the need to change the application code. Its aims at establishing one uniform communication interface and shop floor 4.0.

2. Circular Economy in Mobility

Introduction

The recycled materials for mobility applications market is projected to grow from USD 2.5 billion in 2022 to USD 3.9 billion by 2027, at a CAGR of 8.6% during the forecasted period. The recycled materials for mobility applications market is primarily driven by factors such as growing awareness regarding energy savings and government responses and increasing adoption of lightweight and sustainable materials by the automotive industry. The use of recycled materials eliminates the need to make materials from scratch, which in turn saves a lot of energy. The production of any kind of virgin materials, such as carbon fiber, is an extremely labour-intensive and energy-expensive process consisting of extracting, transporting, and refining natural resources. Thus, the use of recycled materials instead of new resources allows manufacturers to make the same products with much lesser energy requirements. With growing demand for mobility, there will be environmental consequences, given the sector is known to be one of the most significant pollutants of the environment.

Developed countries such as Germany, the US, and Japan are focusing on increasing the use of environment-friendly products instead of petroleum-based products. Automotive manufacturers are increasingly using recycled carbon fiber in various automobile models. Regulatory legislations imposed by the EU and other countries such as the US, India, and Japan are expected to increase the use of recycled carbon fiber, primarily in the automotive & transportation industry. The EU legislation sets mandatory emission reduction targets for new cars for improvements in fuel economy.

German Scenario

The German government is working to create a more supportive regulatory environment for the circular economy in mobility. The circular economy in mobility is a complex and challenging issue, but Germany is prepared to lead the way in its development. With strong government support and a commitment to innovation, Germany can help to create a more sustainable and efficient transport system for the future. This includes measures such as tax breaks for companies that use recycled materials and subsidies for research and development of new technologies.

The German government has set ambitious targets for reducing resource consumption and greenhouse gas emissions in the mobility sector, and circular economy principles are seen as a keyway to achieve these targets.

- Getting 8-10* million electric vehicles on the road by 2030.
- Reducing greenhouse gas emissions from transport by 40% by 2030.
- Making all public transport in Germany emission-free by 2030.

To achieve these goals, Germany is investing heavily in research and development of new technologies and business models for a circular economy in mobility as huge number of used parts end up in the scrap yard for recycling every year. Some of the key areas of focus include:

- **Recycling of end-of-life vehicles:** Germany has a well-established system for recycling end-of-life vehicles, with a recycling rate of over 95%. This system is being further developed to ensure that more materials are recycled and that the recycling process is more energy efficient.

- **Remanufacturing of parts and components**: A growing number of companies in Germany are remanufacturing parts and components for vehicles, rather than simply recycling them. Use of recycled materials in new vehicles, such as recycled plastics and metals. This helps to reduce the environmental impact of vehicle production and reduce the demand for virgin materials and can also save energy.

- **Lightweight materials:** Germany is a global leader in the development of lightweight materials for vehicles, such as carbon fibre and aluminium. These materials can help to reduce the weight of vehicles, which in turn can improve fuel efficiency and reduce emissions.
- **Second-life batteries:** These batteries can be used to store energy in homes and businesses, after they have been removed from vehicles. The recycling of electric car batteries is extremely important in view of the impending shortage of raw materials. Cobalt and nickel, for example, can be recycled at a rate of over 90 percent from a used battery. With lithium, it's a little more difficult, you can realistically recover 70 percent of the original materials.
- **Development of new mobility services**: New mobility services, such as car sharing and ride-hailing, can help to reduce the number of vehicles on the road and the amount of resources they consume. This can lead to a reduction in emissions and congestion. The CE in mobility is to reduces waste, lowers the CO2 footprint and extends the service life of products.
- The German government is providing financial support for circular economy initiatives in the mobility sector, and it is working with businesses and other stakeholders to develop a comprehensive plan for a circular economy in mobility.

Key policies and programmes in Germany

Germany is working to promote a circular economy in the mobility sector. Germany has a number of policies in place to promote a circular economy in the mobility sector. These policies are designed to reduce the amount of waste generated by the mobility sector, increase the use of recycled materials, and extend the lifespan of products. They are also intended to stimulate innovation and investment in new circular economy technologies. These include:

- The Packaging Act, which requires manufacturers to recycle all packaging materials they sell.
- The Waste Electrical and Electronic Equipment (WEEE) Directive, which requires manufacturers to take back and recycle electrical and electronic equipment.
- The End-of-Life Vehicles (ELV) Directive, which requires manufacturers to take back and recycle old vehicles.
- The Battery Directive, which requires manufacturers to take back and recycle batteries.
- The Sustainable Mobility Strategy, which aims to make mobility more sustainable by reducing emissions, increasing efficiency, and promoting alternative fuels.
- The National Innovation Programme for Hydrogen and Fuel Cells, which supports the development and commercialization of hydrogen and fuel cell technologies for transportation and user of hydrogen as a clean energy source.
- The Circular Economy Initiative Deutschland, which brings together stakeholders from industry, academia, and civil society to promote a circular economy in Germany.

In addition to these policies, the German government is also investing in infrastructure to support a circular economy in the mobility sector. This includes the development of charging stations for electric vehicles, the construction of bicycle lanes, and the improvement of public transportation.

- The German government is providing subsidies for the purchase of electric vehicles. This is helping to drive demand for electric vehicles and reduce emissions from the transportation sector.
- The German government is also investing in research and development of new technologies for recycling and reusing materials from vehicles.
- The German government is also working with cities to develop more sustainable transportation systems. This includes investing in public transportation, bicycle lanes, and other infrastructure that can help people to reduce their reliance on cars.

Indian Scenario

India is the world's most populous country with around 1.4 billion people and the fifth largest economy in the world with an average GDP growth rate of 7.2 percent in the year ending March 2023

(PIB June 2023)[26]. The need for safe, secure, fast, comfortable, and sustainable mobility for an ever-increasing and prospering population is also growing exponentially. The growth of the mobility sector led to the socioeconomic development of humanity, be it related to the travel of human capital for various needs or the transportation of goods to various locations. The mobility sector in India is majorly dominated by road-based mobility with the world's second-largest road network followed by rail mobility with the fourth-largest rail network globally, air ranks third in terms of domestic traffic, and ships in India's seaborne foreign trade being 95% by volume and 67% by value. Despite being such an indispensable sector, the mobility sector is also characterized by high use of fossil fuel, greenhouse gas emissions, air, and noise pollution, and environmental degradation. India's transport sector accounted for 14% of the country's GHG emissions in 2019 (IEA Country report 2021)[27]. Road transport contributed 90% of mobility-related emissions due to the dominant use of fossil fuel in both passenger and freight transport highlighting the need to cut its dependency on fossil fuels to reduce the climate impact. The challenge with this sector is that it is already accounting for 50% of the oil demand in the country and rising in parallel with the growing economic growth, rapid urbanization, and heightening aspirations making it critical from an energy use and decarbonization perspective. These challenges could be addressed first by promoting sustainable mobility and secondly by promoting resource efficiency and circular economy measures within these emerging mobility sectors. The attributes of sustainable mobility for ensuring a sustainable future, include safety, affordability, accessibility, efficiency, resilience, and carbon impacts (UN Secretary General's high-level advisory group, 2016)[28].

India, even while contending with issues of high population growth, densely populated metropolitan cities, and insufficient infrastructure to cater to all, is proactively promoting and massively investing in contemporary means of mobility. This includes the modernization and expansion of railways[29], the promotion of Electric Vehicles (EV)[30] and associated infrastructure, as well as the adoption of various other modern mobility solutions such as metro rail in multiple cities, Bicycle renting, Bus Rapid Transit (BRT), Ride-Sharing Apps, Green Fuels, and E-Rickshaws for last mile connectivity. Figure 1 provides a snapshot of the present status and various initiatives in each of the major mobility means used by the people.

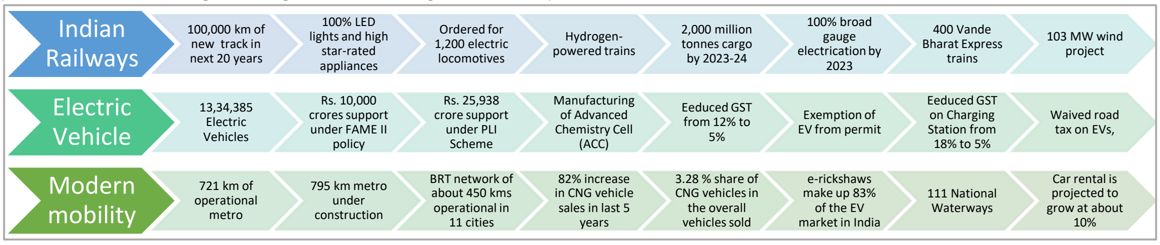


Figure 1: Present status and various initiatives in each of the major mobility modes

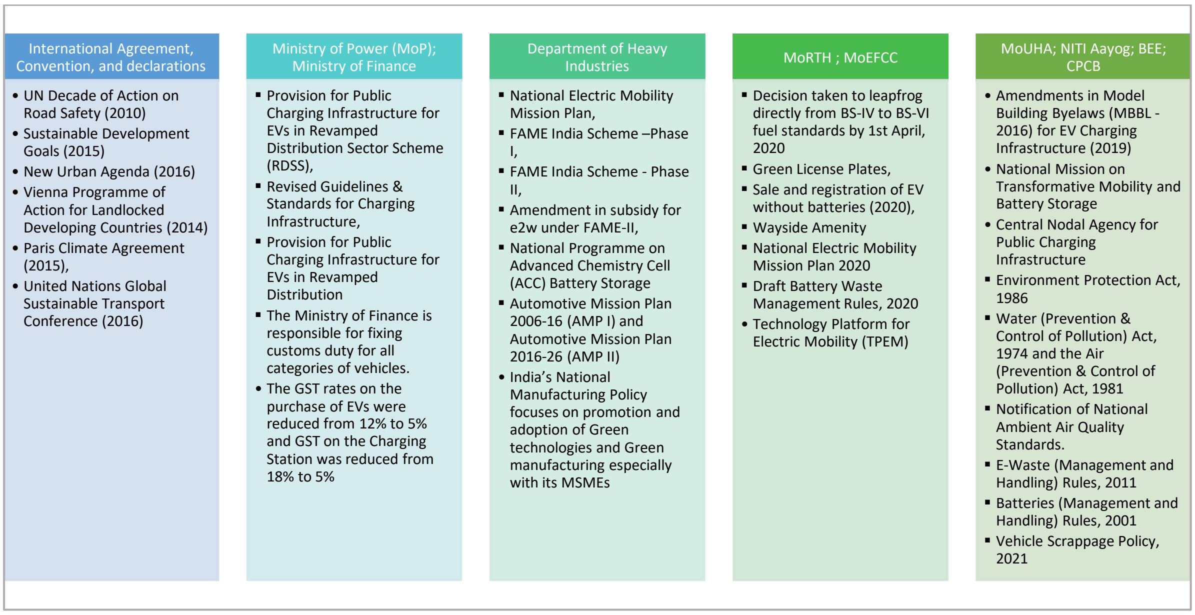
Integrating resource efficiency and circular economic measures in various stages of the life cycle of the emerging mobility sector can play a great role in not only meeting the growing expectations of the Indian population for sustainable mobility means but also supporting GHG emission reduction, decongestion, efficient resource consumption, waste, wastewater, and air emissions. Implementing recyclability, repairability, at the design stage, implementing resource efficiency at the manufacturing stages, End-of-Life vehicle management using a digital passport with reverse logistics infrastructure, and remanufacturing parts and components could go hand in hand in strengthening the circularity in this sector and reducing the loop and emissions.

Key policies and programmes in India

The government of India has formulated many policies for supporting sustainable mobility in India as well as meeting many international agreements, conventions, and declarations that set long-term directions for sustainable mobility. Major international and national policies applicable to the

[26] *India's GDP Growth Exceeds Expectations, Set to Surpass 7.2%: Chief Economic Advisor, https://pib.gov.in/PressReleseDetail.aspx?PRID=1931834*
[27] *https://www.iea.org/reports/air-quality-and-climate-policy-integration-in-india*
[28] *https://sustainabledevelopment.un.org/content/documents/12453HLAG-ST%20brochure%20web.pdf*
[29] *https://indianrailways.gov.in/railwayboard/uploads/directorate/secretary_branches/IR_Reforms/Green%20Railways%20(use%20of%20renewable%20energy).pdf*
[30] *https://pib.gov.in/PressReleasePage.aspx?PRID=1842704*

mobility sector and concerned line ministries are illustrated in Figure 2.



MoRTH: Ministry of Road Transport and Highways; MoUHA: Ministry of Housing and Urban Affairs; BEE: Bureau of Energy Efficiency; CPCB: Central Pollution Control Board; MoEFCC: Ministry of Environment Forest Climate Change

Figure 2: Major international and national policies applicable to the mobility sector

Challenges and Opportunities for Collaboration

Challenges

Remanufacturing, reuse and recycling would become the strategies upon which vehicle manufacturers would base future competitiveness on, leveraging on the benefits of costs saving and, at the same time, guaranteeing environmental benefits and superior performances to customers.

However, there are substantial barriers to the implementation of new business models. The main barrier is the lack of adequate knowledge and capabilities to remanufacture and reuse components and materials in order to provide customers with added value. This is significantly difficult especially from the various technological point of view of applications and may require a fundamental transformation in vehicles design, featuring a substantial evolution in the critical components and materials.

The vehicle industry requires more efficient vehicle production technologies as well as holistic mobility concepts to become climate friendly. The solutions are many and varied, such as alternative drive systems, automated processes, digitization and networking, autonomous driving. The intelligent use of renewable raw materials and multi-material solutions as well as modular smart interiors offers enormous potential for further development and comprehensive use in vehicles.

A huge number of used parts end up in the scrap yard for recycling every year. It is far more resource-efficient, however, to remanufacture alternators, starters and the like as part of a recirculation approach. This reduces waste, lowers the CO2 footprint and extends the service life of products. Also, there is need for the fostering of re-use concepts for used battery systems, modules, cells and components, through product warranty requirements.

The challenges within the mobility sector are twofold. First, there is the imperative to establish sustainable mobility solutions that encompass safe, secure, fast, comfortable, and climate-friendly mobility. This entails reducing dependency on fossil fuels, minimizing greenhouse gas emissions, mitigating air and noise pollution. The second challenge involves ensuring that the manufacturing of sustainable mobility solutions, including Electric Vehicles (EV), CNG vehicles, Fuel-Cell powered vehicles, and conventional internal combustion engine (ICE) vehicles, adheres to environmentally friendly practices, resource efficiency, and follows circular economy principles.

The Electric Vehicle (EV) offers a greener option compared to traditional internal combustion engines (ICE) to reduce our reliance on fossil fuels. However, it faces challenges like limited charging spots, battery worries, and higher initial costs. In vehicle manufacturing, there are challenges too, such as lack of resource efficiency at various stages of production, lack of technological and material innovation, best available technique (BAT), decarbonization roadmap, life cycle thinking, and use of Critical Raw Materials (CRM). The business as usual (BAU) in the mobility sector is often characterized by high consumption of resources such as energy, water, and raw materials; high air pollution emissions and wastewater generation; poor waste management; lack of adequate integration of renewable energy. These limitations make sustainable mobility rather challenging. If these issues are not addressed using a "system based approach" then the BAU scenario could pose significant challenges to India's goal to reach net zero by 2070.

Opportunities for Collaboration

To address these challenges effectively, it's crucial to adopt a holistic approach that encompasses innovation, collaboration, knowledge sharing, life cycle thinking, stakeholder engagement, and facilitates access to finance. By embracing these strategies, most of the challenges can be transformed into opportunities, setting the stage for resource conservation, waste and emission reduction, and the establishment of circular material flows for the sustainable mobility sector. The integration of resource efficiency, circularity and sustainability principles across the value chain will drive the progression towards a more environmentally responsible and economically sustainable mobility model. The key areas for collaboration may include:

- Joint development of circular solutions for improving resource efficiency at each stage of manufacturing including reduced use of toxic and difficult-to-recycle material, designing, manufacturing, assembling, benchmarking, and end-of-life management.
- Incorporating circularity by redesigning components for repairability, and reuse, enhancing the use of secondary raw materials, measuring, and assessing the circularity potential for major components, and developing labelling standards.
- Collaboration for Advanced Chemistry Cell (ACC) Battery Storage and exploring alternatives to Lithium-Ion Batteries.
- Facilitating knowledge exchange and professional development through programs that provide expertise in advanced tools such as Life Cycle Assessment (LCA), Life Cycle Costing (LCC), Material Flow Analysis (MFA), Digital Twin Technology, Design for Environment (DfE), advanced forming technologies, etc.

Fraunhofer's Activities and Offerings

The Fraunhofer Automobile production Alliance is working on all subsectors of plant, mechanical and vehicle engineering face common challenges and must find answers to serious changes in customer behavior and customer requirements, in the shift to a CO2-neutral circular economy and sustainable energy supply in the fight against the climate crisis and resource scarcity, to demographic developments, and to the opportunities and risks of automation and digitization as well as global value chains. In E-Mobility, it offers support in various Drive train technologies, Light weight design, Charging Infrastructure, Battery technologies and System integration.

Fraunhofer has extensive experience in wide varieties of battery technologies from state-of-the-art (Lithium-Ion, Lithium-polymer…) to next gen (lithium Sulphur, metal-air, solid state) battery technologies. Fraunhofer works on battery materials, cells, modules and systems, investigate new material combinations, cell architecture and manufacturing processes, construction and interconnection technology, formation, Lifetime and aging mechanism, Battery management technologies, recycling and reuse of the batteries, battery safety & quality assurance. Fraunhofer's activities in CE of batteries involves energy-efficient recycling of battery materials, to intelligent recycling of traction batteries from electric vehicles to a targeted connection along the entire battery value chain.

Here are some of specific examples of Fraunhofer's activities in mobility sector focusing on circular economy:

Resource-efficient lightweight construction, flexible production and future interior in vehicle construction	The Fraunhofer Center Circular Economy for Mobility (CCEM) is developing new materials, production technologies for a more sustainable automotive industry and digital methods for a circular economy in mobility.
Automated production systems, future interior concepts	Fraunhofer CCEM is working on the goal of developing and evaluating new materials, production technologies and digital methods in an economically and ecologically sustainable manner. To this end, methods for automated disassembly, Re-X processes such as cleaning, remanufacturing, and reuse, as well as for sustainable surface processes along a circular process chain are being developed and near series testing of these technologies is being advanced.
Life cycle engineering and sustainable product design for circular-economy technologies	The Fraunhofer Institutes IST, IFAM, IWU and WKI pool their expertise in the research topics of automated production systems, future interior concepts, life cycle engineering (LCE) and sustainable product design. In addition to automotive engineering, they thereby primarily address aviation, shipping and rail transport.
Turning old into new: A second life for vehicle components	Fraunhofer Institute for Production Systems and Design Technology IPK is developing an AI-based assistance system for semi-automated image-based identification of used parts without QR or bar codes. This will assist the worker with the sorting process so that more used components can be sent for remanufacturing.
Closing the Value Chain In Electromobility - to establish a closed circular economy	Fraunhofer IWKS works at recovering recyclable materials and introducing them into a new product cycle or to substitute valuable materials through sustainable alternatives. It develops innovative processes in the area of functional materials (magnet materials, energy materials, analytics) and functional materials (urban mining, biogenic systems, material flow management). Recovery and processing of functional materials (already synthesized compounds) instead of metallurgical separation into individual elements and Design for Recycling.
Electro-hydraulic fragmentation (EHF)	The separation takes place at macroscopic joints or at microscopic boundaries. The test results are evaluated in detail and the starting and final materials physically and chemically analysed. In the end, the respective process is considered to be economical according to customer requirements and can thus be scaled up to industrial standards.
AutoBatRec2020 (Automotive Battery Recycling 2020)	Fraunhofer IWKS have been working on the intelligent recycling of traction batteries from electric vehicles. The intelligently recycle used batteries from electric vehicles and to identify ecologically and economically advantageous ways of efficiently recycling batteries, including upscaling for industrial application. The entire recycling chain is to be improved in such a way that the valuable raw materials are recovered and reused. Consequently, the end of-life management of traction batteries will be developed in the direction of circular economy and sustainability
Recycling and Green Battery	An economical recycling of battery components in order to avoid losses in the product and material cycle and to reduce negative environmental impacts of batteries as well as geopolitical dependencies. Fraunhofer IKTS is developing various concepts with which material cycles can be closed and raw materials can be fed back into battery cell production. Fraunhofer is investigating the question of how such materials can be reused and what influence this has on the performance of battery cells. Fraunhofer IKTS is developing design guidelines for liquid electrolyte and

	solid-state batteries in order to implement a cycle-oriented design and a recycling-friendly construction. This also includes the consideration of dismantlability and separability. Fraunhofer IKTS is working on the life cycle of lithium-ion batteries from material to electrode pro-duction and assembly, and the future recycling of the materials
Project NEW-BAT	The widespread use of Lithium-ion batteries in EV leads to a high volume of discarded batteries and rechargeable batteries, which are a valuable source of raw materials. It would be more valuable to recover the actual battery materials that have already been produced with great effort from the basic elements, such as high-quality lithium metal oxides and carbon compounds that were previously not recyclable. This would save energy and costs and sustainably secure valuable resources such as lithium. The aim of the NEW-BAT project is to develop a robust, energy-efficient and cost-effective process that can be widely used.
StaTrak – Second Life of Lithium-ion Traction Batteries in Mobile and Stationary Applications	The objective of ISE's Statrak project is the investigation of aged energy storage devices with a now lower energy density, not usable anymore for mobile applications, and to check their suitability for other applications.
Project ECO COM'BAT (Ecological Composites for High-Efficient Li-Ion Batteries)	The project addressed the demand for better materials and technology solutions for sustainable mobility and the reduction of critical raw materials in batteries. The aim of the ECO COM'BAT project is to combine the latest developments in green and high-performance materials into new composite materials for the next generation of lithium-ion batteries, high-voltage batteries
ecoLEPuS – Second Life Batteries for Use in High-Performance Applications Using the Example of Buffer Storage in Charging Infrastructure	At the end of their life in the vehicle, the batteries can continue to be used in stationary storage before being recycled. Even though this significantly minimizes the CO2 footprint and makes the recycling economy more effective, many new questions arise, e.g. about the qualification of the cells, cooling and the integration of stationary storage into the infrastructure. These issues are being investigated in detail in the ecoLEPuS project.
PIONEER – Airport Sustainability Second Life Battery Storage	The project aims to support the Leonardo da Vinci international Airport in Rome Fiumicino on its way toward net zero emission airport. A 30 MWp photovoltaic system is planned for this purpose, which will be supplemented by a 2nd Life energy storage system consisting of used vehicle batteries with a total output of 5 MW and a capacity of 10 MWh. The main objectives of the project include the development and construction of a mobile test bench for the characterization and qualification of battery systems, and the integration of 2nd life batteries from several car manufacturers with inhomogeneous key characteristics into a safe and reliable power system.
Reducing batteries' environmental footprint – RecyLIB project aims to save resources and energy	As the number of traction batteries increases, the question of environmentally friendly manufacturing and recycling processes is also becoming louder. One key aspect is the function-preserving recycling of lithium-ion batteries. The "RecyLIB" project - aims to set an example with new processes for battery electrode production, direct recycling and integrated functional material cycles.

Support by Fraunhofer

With its research expertise, the Fraunhofer CCEM supports the manufacturers and suppliers of the respective industries in developing sustainable solutions and bringing them to market: from sustainable raw materials, through resource-efficient manufacturing and on to the most complete recycling possible.

- New, environmentally compatible and automated cleaning and preparation processes
- Functional and smart surfaces for innovative and sustainable product systems
- Reduction of the CO2 footprint through the use of bio-based and secondary materials
- Development of future interior concepts
- Competitive advantages through LCE and sustainable product design

- Development of sustainable production lines
- Sustainable material and surface systems for future vehicle concepts
- Design for Recycling" and "Design for Disassembly" of the batteries by unification of the Characterization of (resynthesized) active materials for lithium-ion batteries
- Digitization and automation of battery disassembly as far as possible as well as development of alternative disassembly solutions through innovative fragmentation technologies
- Material selective fragmentation of battery cells in liquid medium for passivation of pollutants and efficient separation of material composites
- Enrichment of recyclable materials - especially active materials - through innovative separation and sorting processes in the first stage of recycling
- Recovery and processing of functional materials (already synthesized compounds) instead of metallurgical separation into individual elements.
- Second life of batteries - Battery cell design suitable for recycling.

3. Circular Economy in Wastewater Management focusing on Water-Energy-Food Nexus

Introduction

The 21st century has witnessed an explosion in global population, environmental changes, agricultural land disintegration, hunger, and geopolitical instabilities. It is difficult to manage these conditions or standardize improvement systems without thinking of the three main subsystems that are necessary for any meaningful development—namely water, energy and food. These key elements form what is globally agreed upon as the "Water-Energy-Food (WEF) Nexus." The WEF Nexus represents a framework to ensure environmental protection and should be seen as an ethical and socioeconomic obligation. Connections between water, energy, and food are at the centre of long-term economic and environmental development and protection. The adoption of water management policies and technologies that support the sustainable use of resources while promoting economic growth is becoming an important concern, particularly in countries where water and food scarcity are critical. The global community has been faced with a water quality crisis emanating from rapid population growth, poor wastewater treatment, etc. Approximately 25% of the global population has access to quality drinking water, and <30% has access to essential sanitation services. Some of the major challenges that are preventing the achievement of circular economy in wastewater treatment globally include (i) Improper Sewerage Systems (ii) Unimproved onsite sanitation systems (iii) Improper domestic / industrial wastewater treatment (iv) Diseases caused by contaminated water (v) Agricultural wastewater challenges (Sediment runoff, Nutrient runoff, Microbial runoff, Chemical runoff) (vi) Sludge disposal challenges (on land, in ocean, incineration) (vi) Energy Challenges (Increased operational costs for wastewater treatment, inefficient use of waste-to-energy technologies). Wastewater treatment is an important part of circular economy due to integration of energy production and resource recovery during clean water production. A number of major drivers emphasize the need of the recovery of resources available in the wastewater. The main drivers for developing wastewater industry are global nutrient needs and recovery of water and energy from wastewater.

Nutrient recovery is one of the key drivers promoting sustainability in wastewater management and the circular economy. Wastewater contains, among other substances, phosphorus and nitrogen, which are vital nutrients for food production. Current practices in wastewater management lead to inefficient recovery and reuse of wastewater-based nutrients and can result in environmental problems such as eutrophication, contribute to climate change, and undermine global food security in most of the under-developed and developing countries. Thus, implementation of water-energy-food nexus becomes a daunting task and further leads to socio-economic problems including poverty, conflicts and diseases.

German Scenario

Germany has the highest rate of wastewater reprocessing and recycling in the European Union. Germany is also one of the leading countries for wastewater treatment along with the United States, Mexico, China, and Japan among the top five countries. Germany's wastewater treatment market has been valued at EUR13,158.0 million in 2021, with 10,723.8 million cubic meters of wastewater treated during the same period. The country's wastewater treatment market grew at compounded annual growth rate (CAGR) 0f 0.5% between 2017 and 2021, while the underlying market volume grew at a CAGR of 0.2% during the same period.

More than 96% of the wastewater from private households or public facilities in Germany is discharged into nearby sewage treatment plants for processing. More than five billion cubic metres of sewage water are generated each year by private households, industry and trade. Approximately three billion cubic metres of rainwater from paved surfaces and roads are also discharged into the sewage treatment plants with a considerable additional amount of infiltration water entering the sewer system through leaks.

In Germany, it is not permitted to discharge untreated wastewater into rivers and lakes, regardless of whether it originates from private households, trade or large-scale industry. The Federal Water Act (WHG) stipulates that pollutants contained in drainage water must be reduced in line with the best available technology.

More than 96% of the German population is connected to the public sewage system. Wastewater from private households is collected in the public sewage system covering 540,723 kilometres of sewers. Wastewater is treated in more than 10,000 sewage treatment plants. 10.07 billion cubic meter of waste water are annually treated in public wastewater treatment facilities. In general, municipalities are responsible for wastewater treatment facilities. There are, however, also privately owned sewage treatment plants in industry**.** Almost 100 percent of the wastewater is treated in sewage works with three purification stages:

- a mechanical stage
- a biological stage without elimination of nutrients such as nitrogen and phosphates,
- an additional biological purification stage with specific nutrient elimination.

According to Urban Wastewater Treatment Directive (UWWTD), Germany must apply biological treatment with nitrogen and phosphorus so that at least 75% of the total nitrogen and at least 75% of the total phosphorus are removed from the wastewater generated.

Key Policies and Programmes in Germany

1. **In order to achieve Circular Economy through recovery of nutrients,** the new German Sewage Sludge Regulation requires sewage plant operators to recycle phosphates.
2. Pursuant to the new German Sewage Sludge Regulation in force since 3rd October 2017, sewage sludge must now be recycled to recover phosphorus. The aim is to gradually close the phosphorus cycle and reduce Germany's dependence on phosphorus imports, thus saving phosphorus resources and reducing soil contamination.
3. **Directive 91/271/EC:** requires the collection of wastewater from households and small plants and reduction of the organic load. Moreover, it makes the removal of not less than 75% of phosphorus and nitrogen a requirement of wastewater treatment in urban wastewater treatment plants.
4. **Circular Economy Act:** This Act promotes circular economy and the environmentally compatible management of waste. It aims to conserve natural resources and to ensure the protection of human health and the environment in the generation and management of waste. It applies to the waste prevention, recovery, disposal other activities of waste management.
5. **Standardization Roadmap Circular Economy of BMUV:** More sustainable business practices through circular economy: To keep materials and natural resources in the economic cycle, ideally without consuming new ones – fully in keeping with the European Green Deal and the Federal Climate Change Act 2021.

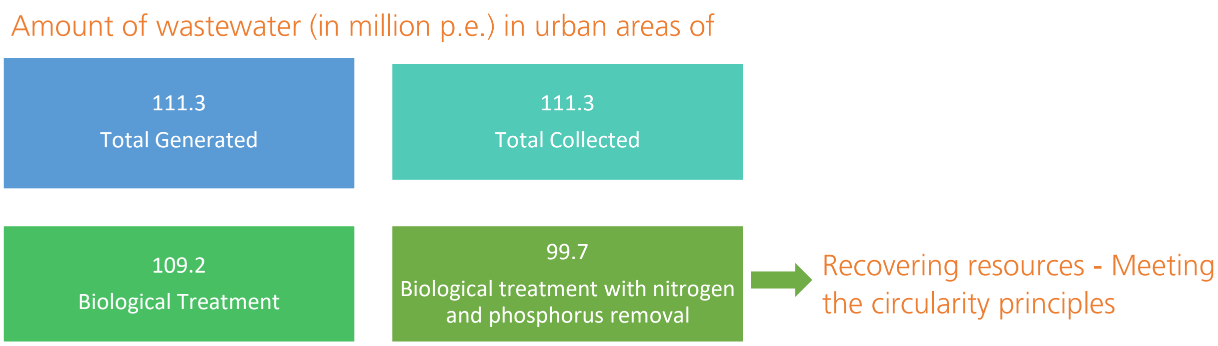


Figure 3: Amount of urban wastewater which is required to be collected and treated according to the Urban Wastewater Treatment Directive (UWWTD)

Indian Scenario

India is grappling with a pressing and intricate water contamination crisis, as an overwhelming 70% of the nation's water sources stand tainted. This alarming reality comes into stark focus when observing India's disheartening placement at 120th out of 122 countries on the global water quality index. The multifaceted challenges stemming from this dire scenario encompass a range of issues, spanning from the generation and treatment of wastewater to the repercussions of rapid urbanization on public health and the environment. The origins of India's water contamination crisis are rooted in a variety of factors, including the rapid pace of urbanization, the insufficient infrastructure for wastewater treatment, and a host of wastewater mismanagement practices. The sheer scale of wastewater produced is staggering- rural regions generated a colossal 39,604 million litres per day (MLD) during 2020-21, while urban centres contributed an even more staggering 72,368 MLD. This substantial surge in wastewater production is an outcome of the burgeoning urban landscape, where cities now house over half of the world's population, a number that is projected to surge to 70% by 2050. The predominant source of water pollution in India arises from the disposal of domestic sewage in cities and towns. Collectively, all Class I cities and Class II towns churn out a staggering 29,129 MLD of sewage (based on the 2001 census population data). In stark contrast, the installed capacity for sewage treatment merely stands at 6,190 MLD, creating a gaping shortfall of 22,939 MLD, constituting a staggering 78.7% deficit. Despite some silver linings, including an additional 1,742.6 MLD of sewage treatment capacity in the pipeline, even when combined with the existing capacity, a substantial gap of 21,196 MLD (equivalent to 72.7%) in sewage treatment capacity remains (CPCB 2021). This imbalance underscores the urgency of addressing India's wastewater treatment infrastructure, which is pivotal in curbing the water contamination crisis that poses a grave threat to public health and the environment.

The Indian government has taken proactive measures to tackle critical issues, demonstrating its commitment to addressing environmental concerns. Through the National River Conservation Plan (NRCP), a budget of Rs. 5961.75 crore has been allocated to effectively combat pollution in 34 stretches of rivers across 77 towns in 16 states. This endeavour has led to the successful establishment of sewage treatment capacity, reaching 2677 MLD. Simultaneously, under the Namami Gange program, a total of 353 projects have been sanctioned, encompassing 157 sewage treatment projects capable of handling 4952 MLD. These projects, accompanied by an extensive sewer network spanning 5212 kilometres, require an investment of Rs. 30458 crores.

Additionally, the Ministry of Housing & Urban Affairs has taken significant strides by initiating 883 sewerage and septage management projects through the Atal Mission for Rejuvenation and Urban Transformation (AMRUT) program. The total investment for these projects stands at INR 34,081 crore, out of which 370 projects worth INR 8,258 crore have already been successfully completed. Furthermore, the Swachh Bharat Mission (Urban) 2.0, launched in October 2021, has earmarked INR 15883 crore for wastewater and used water management. This funding will support vital initiatives, including the establishment of Sewage Treatment Plants (STPs) and Faecal Sludge Treatment Plants (FSTPs) across States and Union Territories.

Amount of wastewater (in MLD) in urban areas of India

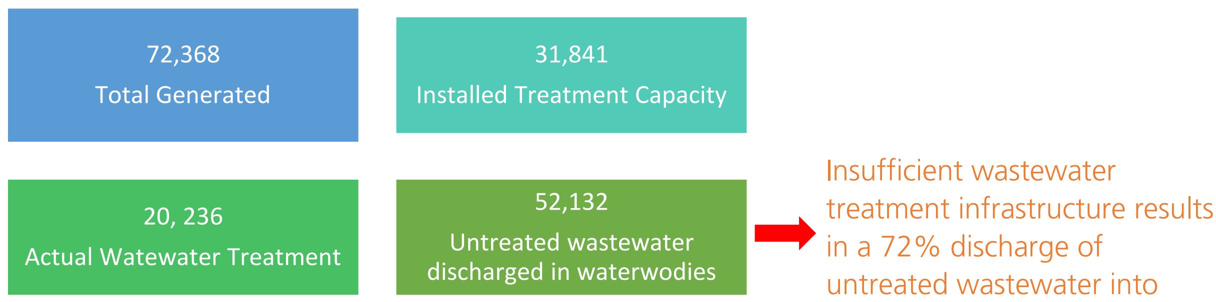


Figure 2: Amount of urban wastewater generation and treatment according to the CPCB

Policies and Programmes in India

To address the pressing issue of water contamination, the Indian government has initiated various policies and measures aimed at improving water quality and promoting sustainable water management. These initiatives include:

1. **National Water Policy:** Introduced in 1987 and updated in 2002 and 2012, this policy emphasizes integrated water resource management, efficient water use, and enhanced water quality through pollution control measures.
2. **National Water Mission:** Part of the National Action Plan on Climate Change, this mission strives to increase water efficiency by 20% through regulations, innovative technologies, and basin-level strategies, including rainwater harvesting and improved irrigation practices.
3. **Bureau of Water Use Efficiency (BWUE):** Established under the National Water Mission in 2022, BWUE focuses on a comprehensive nationwide program to enhance efficient water utilization across sectors such as irrigation, domestic supply, municipalities, and industries. It involves formulating regulations, guidelines, standards, incentivizing efficient practices, and fostering research and collaboration.
4. **Clean Ganga Mission (Namami Gange):** Launched in 2014, this mission aims to rejuvenate the Ganges River by addressing wastewater treatment, solid waste management, and afforestation to restore ecological balance.
5. **Atal Mission for Rejuvenation and Urban Transformation (AMRUT):** Introduced in 2015, AMRUT focuses on improving urban infrastructure, including water supply and sewage management, to enhance the quality of life in urban areas.
6. **AMRUT 2.0:** Launched in October 2021 for a five-year period, this extension of the AMRUT mission aims to provide every household with access to clean water through guaranteed water supply and sewer connections.
7. **Swachh Bharat Mission:** A nationwide initiative targeting proper sanitation and waste management, indirectly contributing to the reduction of water contamination.
8. **Zero Liquid Discharge (ZLD) Policy:** Encourages industries to treat and reuse wastewater, thereby reducing the industrial pollution load on water bodies.
9. **Standards for Water Neutrality/Water Positivity for Industry:** A foundational document for establishing definitive standards to evaluate and implement water neutrality and water positivity concepts within India's industrial landscape.
10. **State-Level Wastewater Reuse Policies:** Several states, including Assam, Jharkhand, Kerala, Madhya Pradesh, Maharashtra, Gujarat, Karnataka, Punjab and Rajasthan, have introduced policies to encourage recycling of treated wastewater for non-potable purposes, such as gardening and toilet flushing in residential complexes.

Challenges and Opportunities for Collaboration

Challenges

In Germany, a major challenge for the future will be the elimination of pollutants in wastewater which, to date have not been taken into account. These pollutants include pharmaceutical residues, antibiotics from animal husbandry or chemicals displaying hormone-like effects even in minute quantities. Current treatment technologies are not able to remove these trace substances. A "trace substance strategy" is currently being developed under the auspices of the BMU (Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection). There are first tentative technologies such as **special membranes or oxidization processes** which make a removal possible. However, to date there are no legal thresholds which could serve as a guidance for sewage plant operators.

Studies on nutrient recovery potential and life cycle impacts of source separation systems are mainly limited to small systems (for example a few households) while the impacts of upscaling source separation to a regional level have hardly been studied, especially in sparsely populated areas where the cost of the connection to a main treatment plant is higher.

In India, despite numerous initiatives, there are substantial challenges in the realm of wastewater treatment and recycling. These challenges encompass: **(i) Inadequate Treatment Capacity:** The existing sewage treatment infrastructure falls woefully short of accommodating the rapidly escalating volume of wastewater generated. Consequently, untreated wastewater is consistently released into water bodies, exacerbating environmental contamination. **(ii) Urbanization Pressures:** The rapid pace of urbanization places immense stress on water resources, exacerbating pollution due to inadequate sanitation facilities. This intensification of urbanization further strains an already burdened ecosystem. **(iii) Infrastructure Deficiency:** A stark disparity between the volume of sewage generated and the capacity of collection networks highlights a critical need for the expansion of sewage systems. Urgent action is required to bridge this infrastructure gap and prevent further environmental degradation. **(iv) Water Quality Monitoring:** While monitoring initiatives are in effect, a multitude of river segments continue to suffer from severe pollution, signifying persistent threats to aquatic ecosystems. The efficacy of these monitoring efforts must be enhanced to ensure meaningful impact. **(v) Institutional Hurdles:** Urban Local Bodies face formidable challenges in effectively planning and executing projects, evident in manpower shortages and operational deficiencies. For instance, audits in Tamil Nadu exposed issues related to revenue and service delivery due to inadequate staffing, while in Jharkhand, absent sewage networks led to untreated wastewater discharge. **(vi) Economic Impediments:** The substantial capital investment required deters meaningful private sector involvement, and the revenue generated from Sewage Treatment Plants (STPs) scarcely covers operational expenses. Challenges associated with land acquisition for Centralized Wastewater Treatment facilities add to the struggle, resulting in the adoption of less efficient technologies. **(vii) Technological Obstacles:** Outdated wastewater treatment methodologies persist, despite the pressing need for modern, efficient approaches. Lack of awareness and expertise contributes to inadequate oversight of STP operations. The adaptation and scaling of advanced technologies to align with India's distinct context poses a central technological barrier. **(viii) NGT's directives:** The NGT's stringent directives on NP, BOD, COD, and TSS have left industrial wastewater treatment plants struggling to meet standards. Existing infrastructure falls short, necessitating state-of-the-art technology integration for compliance. **(ix) Social challenges:** Widespread public resistance to embracing recycled water endures due to concerns regarding health, aesthetics, and cultural beliefs. Educating citizens about the benefits of recycled water usage remains an ongoing challenge.

Opportunities for Collaboration

SWOT analysis of the wastewater sector in India regarding the implementation of circular economy for recovery of nutrients, energy and water.

STRENGTHS	WEAKNESSES
▪ Obtain benefits from something that has always been considered a waste ▪ Reduce/eliminate energy consumption. ▪ Large number of alternative technologies ▪ Constant availability of wastewater ▪ Decrease of pressure over natural resources ▪ Net water savings and increased availability for other purposes ▪ Better carbon and sustainability footprint	▪ Considerable initial financial outlay ▪ Little experience in large-scale implementation ▪ Technical complexity
OPPORTUNITIES	**THREATS**
▪ Nation-wide trend to promote greener processes ▪ Due to freshwater scarcity, wastewater reclamation and reuse plays a fundamental role ▪ Quick development of new technologies ▪ Supply chain security of valuable resources ▪ Independence from imports ▪ Cost savings	▪ Political changes ▪ General distrust towards the use of reclaimed water ▪ Recovery costs for some substances might end up being higher than their synthesis or extraction

The major opportunities of collaboration in developing sustainable and circular-economy-based wastewater treatment systems would be to (a) innovate and integrate energy and resource-efficient wastewater treatment systems, (b) practice resource recovery processes and (c) enhance carbon capture to be diverted to energy recovery schemes.

Wastewater circularity offers a transformative path forward, encompassing three pivotal avenues:

1. **Municipality-to-Municipality:** Promoting the utilization of treated wastewater for purposes like gardening, maintaining parks, and non-potable uses is a key aspect. This practice can significantly reduce the demand for freshwater resources in these activities. To enable and enhance this exchange, it is imperative to invest in modern and efficient infrastructure.
2. **Municipality-to-Industry Integration:** Establishing symbiotic relationships between municipalities and industries, wherein treated municipal wastewater becomes a resource for industrial processes, can lead to both water conservation and reduced pollution. This requires innovative partnerships and technology adoption.
3. **Industry-to-Industry Synergy:** Encouraging industries to recycle and reuse treated wastewater for similar processes, thereby creating a closed-loop system, not only conserves water but also minimizes the release of pollutants into the environment.

Industries such as pharmaceuticals and semiconductors exemplify the need for high-quality water, pushing the boundaries of wastewater treatment. The extraction of ultrapure water from industrial wastewater necessitates cutting-edge techniques like membrane and advanced oxidation processes. However, key wastewater treatment technologies are still in their nascent stages in India. This is where collaborative efforts, especially drawing from Germany's well-established expertise in wastewater management, can play a transformative role. Leveraging Germany's advanced technology and experience could catalyse the development and adoption of efficient and ecologically sound wastewater treatment practices in India.

Offerings and Activities of Fraunhofer

Fraunhofer is a partner for research and development of concepts on resource efficiency, bioeconomy, circular economy as well as sovereignty of value-added cycles. It specializes in developing biotechnological, process engineering, circular and systemic solutions for the responsible management of natural resources and their application. This includes raw material and energy supply, the protection of the climate and environment as well as securing sufficient food supply and health. Fraunhofer drives innovation in environmental technology and the industrial transformation towards a sustainable and circular bioeconomy. The competence lies in: (i) Technologies for efficient and sustainable application of resources (ii) Water and Waste treatment (iii) Waste -to- Energy Solutions (TCR Technology / Agri-waste -to- Hydrogen) (iv) Bioeconomy (v) Circular Economy.

Competencies and Range of Services

The innovations developed by the Fraunhofer cover the entire water value chain:

- Recovery and recycling of nutrients and metals - Solutions that recover and reclaim nutrients from wastewater, organic waste and residues.
- Recycling of energy, nutrients and other compounds from wastewater and sludge.
- Sustainable Management of Catchment Areas
- Water Distribution Systems
- Processes for municipal and industrial wastewater treatment
- Water Monitoring Solutions
- Complex water management systems solutions
- Developing sustainable, regenerative infrastructure systems
- Developing integrated urban concepts for water, energy and waste
- Analyzing water infrastructures and adapting these to climate/population changes – flood protection
- Socio-economic studies
- Status Analyses and Demand Forecasts
- Financing Concepts

Ready-to-implement Technologies to achieve Circular Economy in Wastewater Management

- ePhos – Electrochemical phosphorus recovery (TRL7)
- Solar Desalination (TRL8)
- Diamond electrodes for disinfection, antifouling, pollutant removal and pest control (TRL7-8)
- Semiconductor based UVC-Disinfection (UVC-LED) (TRL8-9)
- Superheated Steam Drying and Torrefaction of Biomass Residues (TRL7)
- Solar enhanced micropollutant removal (TRL6)
- Two-stage high-load digestion (TRL8)

▪ HydroDyn: Dynamic Calculation of Water and Gas distribution Networks (TRL8) ▪ Advanced Oxidation Processes (TRL6) ▪ Treatment of complex process wastewater with bifunctional biobased flocculant (TRL4) ▪ Plasma process for water purification (TRL4)
Offerings to the industry
▪ Solutions for Urban/periurban water management systems ▪ Development of Processes and systems for the supply with drinking and service water ▪ Consulting and piloting Wastewater treatment processes and systems ▪ Support in developing Integrated water resource management (IWRM) ▪ Analysis and evaluation of water-economic systems ▪ Advanced solutions in Industrial Wastewater Treatment

Activities of Fraunhofer – some references

Fraunhofer Innovation Platform for the Water-Energy-Food Nexus	The aim of "Fraunhofer Innovation Platform for the Water-Energy-Food Nexus is to bring together know-how and technologies in the field of water treatment and water utilization and to develop solutions for South Africa and the sub-Saharan countries through joint research and development.
MGI – Morgenstadt Global Smart Cities – global approach, local solutions	Supports cities in India, Mexico and Peru in development and implementation of sustainable transformation processes in developing circular nature-based approach for water treatment, sustainable energy approaches and green building concepts.
Smart Water Future India	Intelligent Water Management for India's Cities, which resulted in: ▪ Semi-centralized, integrated municipal water management (also considering the energy and food sectors) ▪ Establishment of water quality monitoring system (Technologies to monitor the quality of treated industrial effluents, surface waters and groundwater and to visualize the results)
AQUA-Hub	Water Innovation Hubs for fostered Indo-German cooperation in India to contribute to the sustainable development in the water sector and demonstrate the potential of technology transfer using the example of smart water monitoring.
EVOBIO project	Feasibility of a bio-based circular economy. The projects makes integrative use of material flows to produce optimized materials for innovative products in bioeconomic process cycles.
PhosKa-Demo	Further development of a sustainable process for phosphorus and potassium recovery from liquid waste through to market maturity
HypoWave+	Implementation of a hydroponic system as a sustainable innovation for resource-efficient agricultural water reuse
GOBi	Increasing operational, material, energy and ecological efficiency of biogas plants with special consideration of the production of a natural customer-specific fertilizer
FERTINNOWA	Transfer of innovative techniques for sustainable water use in fertigated crops
BioEcoSIM	An innovative bio-economy solution to valorise livestock manure into a range of stabilised soil improving materials for environmental sustainability and economic benefit for European agriculture
InBiRa – the insect biorefinery	An insect biorefinery is being built, which uses organic residues and biowaste to convert into usable higher-quality products; insect biotechnology has potential to make good use of Europe's 88 million tons/year of biowaste.

4. Circular Economy in Plastic Waste Management and Recycling

Introduction

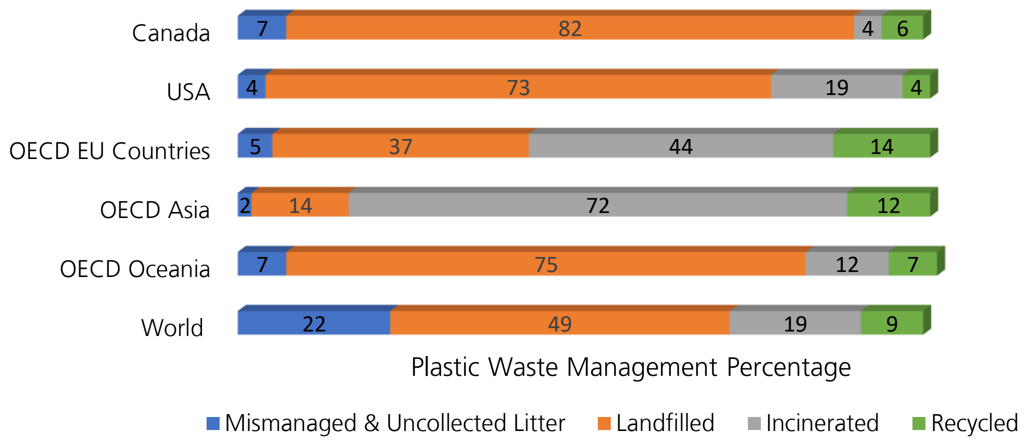
Plastic is the material of our present and future. It is light, functional and inexpensive. It is used in cars, electronics, cosmetics and furniture, and in almost all areas of medicine. At the same time, however, this polymer all-rounder is regarded as disposable item and environmental pollutant – an image that overshadows its enormous potential. Without plastics, many achievements of our modern society would be inconceivable. They make our food last longer (airtight), their low weight as transport packaging for goods and as vehicle components saves fuel and thus CO_2, or in their application as fiber-reinforced composite materials in wind turbine rotors they enable the generation of CO_2-neutral energy.

The production of plastics consumes fossil resources and energy; 4 to 6% of today's oil production is needed for plastics. This share is expected to increase to 20% by 2050. Significant CO_2 emissions are generated along the production chain, and at the end of the product life cycle, the volume and diverse types and compositions of plastics pose a recycling challenge. If disposed of improperly, they also damage ecosystems, e.g. as microplastics in the ocean.

Almost half of all plastic waste is generated in OECD countries. The world generated 353 million tonnes of plastic waste in 2020, a number which has more than doubled since 2000.

Out of this, only 9% was recycled while almost 50% was landfilled, 19% incinerated, and 22% was discarded in uncontrolled sites or in the environment.

Share of plastics treated by waste management category, after disposal of recycling residues and collected litter



Ref: OECD.org

Due to the plastics production process, other environmental impacts through the plastics lifecycle are also projected to increase, including greenhouse gas (GHG) emissions, ozone formation, acidification, and human toxicity, all of which are projected to more than double.

German Scenario

Europe produces around 60 million metric tonnes of plastic every year, but only around 30% of this is eventually recycled. Waste management varies by country, with Germany leading the way by recycling 99.6% of plastic packaging in 2020. **Germany is**

known to be a world leader in recycling. Its waste management system and sorting policies have paved the way for other countries to implement greener practices when it comes to trash disposal and collection. Circular economy, waste minimization and plastic recycling are hot topics for the country's legislation, manufacturers, and consumers.

The overall waste management landscape of Germany is characterized by a strong legislative drive towards resource efficiency, sustainability, and conserving natural resources.

In 2020, approximately 12.1 million tons of plastics were consumed in Germany, and 6.23 million tons were generated as post-consumer or post-industrial waste. Of these 6.23 million tons, 2.93 million tons (46.6%) were recovered as input in recycling plants. Their rejects and the remaining 3.31 million tons (52.8%) were recovered for energy, i.e., used in waste-to-energy plants or as refuse-derived fuel.

During energy recovery, e.g. in the form of incineration, the carbon bound in the plastics is released in the form of heat and CO_2. The average fuel utilization efficiency, i.e. the proportion of the energy content of the waste that can be converted into usable electricity and heat, in the current recycling path of waste incineration plants and RDF power plants is only about 45% (waste incineration plants) to 52% (RDF power plants) on average throughout Germany.

Key Policies and Programmes in Germany

Germany is considered a leader in recycling and waste management and its success story comes down to two factors: strong government policies and high public awareness in recycling.

1. The Packaging Ordinance (1991): Through the Packaging Ordinance, Germany was the first country to introduce binding requirements to manufacturers for the recycling and recovery of sales packaging. In 2019, the Ordinance was replaced by the Packaging Act, which contains new, more ambitious recycling rates and targets and further important regulations for a more transparent and economic competition.
2. The Green Dot System (1991): Another milestone was reached after the German government adopted the Green Dot System, forcing manufacturers to place a green label outside of packaging indicating it must be accepted by recycling facilities. The strategy is considered the frontrunner of the European Green Dot Scheme, which has since been adopted by more than 130,000 companies across 23 European countries with overwhelmingly positive results. Today, over 460 billion packages are labelled with the Green Dot.
3. Closed Substance Cycle and Waste Management Act (1996): The Act comprehensively extended the policies enclosed in the Packaging Ordinance, requiring whoever produces, markets, and consumes goods to be responsible for the avoidance, reuse, recycling, and environmentally compatible disposal of waste that arises. It encouraged businesses to radically rethink their production system; making sure that most products are produced with recyclable materials as well as promote low-waste products and displace waste in an environmentally sound way. The Act was amended in 2012, when Germany adopted the Circular Economy Act, which set legally binding measures on the part of manufacturers and distributors to promote producer responsibility.
4. Ban on Single-Use Plastics and Plastic Bags: At the end of 2019, the German Federal Government introduced a ban on plastic bags and in the context of the EU's Circular Economy Action Plan, the country also implemented stricter rules on single-use plastics, prohibiting manufacturers to produce as well as import these types of plastics.

Indian Scenario

In the financial year 2021-2022, the total demand for major plastics (excluding engineering plastics and thermosets) across India was approximately 15 million tons[31]. The per capita consumption of plastic has increased from 11 kg in 2014 to 15–20 kg in 2022. The rising plastic consumption is attributed to growing population, rising consumerism and increasing trends

[31] *https://www.statista.com/statistics/1154447/common-plastic-consumed-india-by-type/*

towards e-commerce, expanding industries, and rapid urbanisation.

The key sectors consuming plastics are- packaging, agriculture, infrastructure, home and office furnishings, personal care products, surface coats, transport, electrical and electronics, industrial machinery, biomedical applications, food and beverages, and textiles (ibid). Packaging materials account for 24% of the total domestic consumption of plastic, followed by agriculture at 23%, and household items at 10%.

In terms of the size of the plastic industry in India, there are approximately 2,000 exporting companies, 150 plastic processing machinery producers, and over 30,000 processing units.

According to the Central Pollution Control Board (CPCB), India generates close to 26,000 tonnes of plastic a day and over 10,000 tonnes a day of plastic waste remains uncollected. India does better in the aspect of recycling compared to the developed countries due to a large informal sector workforce (comprised of individual waste pickers and waste traders) making a living by collecting, sorting, recycling, and selling valuable plastic materials recovered. Approximately 60% of plastic waste gets collected for recycling and recovery in India, which is much higher than in developed countries.

The mis-managed plastic waste poses significant social and environmental challenges and at the same time provides an opportunity to design solutions that not only address these challenges, but also foster the economic sustainability of the sector.

Key Policies and Programmes in India

Recent years have seen a significant policy push by the Government of India (GoI) through various environmental legislations and regulations at the national, state, or local levels for improving plastic waste management and fostering circularity in plastics sector.

The Plastic Waste Management (PWM) Rules were notified in 2016 and its subsequent amendments have tried to bring a holistic approach for waste management, clearly delineating the responsibilities of different stakeholders especially the Producers, Brand Owners and Importers (PIBOs). The rules focussed on minimization of plastic waste generation, source segregation of various types of waste and aims to follow a waste to-wealth pathway via recovery, reuse and recycling.

In context of the SUP bans, the PWM Rules, 2016, mandated the minimum thickness of plastic carry bags to be increased from 40 microns to 50 microns. To encourage reuse, the allowed thickness of plastic carry bags was increased from 50 to 75 microns from September 30, 2021, and to 120 microns from December 31, 2022. The PWM (Amendment) Rules, 2018, phased out the multilayered plastic (MLP), which is "non-recyclable, or non-energy recoverable, or with no alternate use." The PWM (Amendment) Rules, 2021, prohibited the manufacture, import, stocking, distribution, sale, and use of SUP, including polystyrene and expanded polystyrene, commodities from July 1, 2022. The SUP products list includes earbuds with plastic sticks, plastic sticks for balloons, plastic flags, candy sticks, and others. There is a blanket ban already in place on sachets using plastic material for packing, storing, or selling pan masala, gutkha, and tobacco. The GoI has also taken several measures to promote effective enforcement of the SUP ban. For instance, enforcement teams have been formed to check illegal manufacture, import, stocking, distribution, sale, and use of banned SUPs. The various States and Union Territories have set up control rooms for better enforcement and border check points to stop inter-state movement of banned SUP. Efforts to raise awareness and wider public engagement to curb SUPs have been pursued.

In context of the EPR, the GoI notified the Guidelines on Extended Producer Responsibility for Plastic Packaging through the PWM (Amendment) Rules, 2022 stipulating mandatory targets on EPR, recycling of plastic packaging waste, reuse of rigid plastic packaging and use of recycled plastic content. Obligations for different entities- Producers, Importers, Brand Owners (PIMBOs) have set under the rule. For the producers and importers, these obligations include - EPR Target, Obligation for recycling, End of life disposal and Obligation for use of recycled content, and for the brand owners, besides these obligations, there is the additional obligation for reuse.

EPR is applicable on both pre and post-consumer plastic packaging waste which are further categorised into four categories -Category I (Rigid Plastic packaging), Category II (Flexible Plastic packaging), Category III (Multi-layered Plastic packaging), Category IV (Compostable plastic packaging & carry bags). A Centralized online EPR portal for the registration, which is mandate to all the EPR obligators has been created. Category wise EPR targets have been set to enable better tacking of waste and increase recycling rate. Some of the recent targets are as follows:

EPR targets for plastic

Year	EPR Targets
2021-22	25%
2022-2023	70%
2023-24 and onwards	100%

In addition, there exist minimum level of recycling (excluding end of life disposal) of plastic packaging waste collected under EPR targets. The table below shows the percentage of plastic waste to be collected under EPR targets shown in the table below:

Percentage of recycling of plastic waste collected under EPR targets

Plastic packaging category	2024-25	2025-26	2026-27	2027-28 and onwards
Category I	50	60	70	80
Category II	30	40	50	60
Category III	30	40	50	60
Category IV	50	60	70	80

The focus of the GoI to close the circularity loop is clearly reflected in the targets on mandatory use of recycled plastic in plastic packaging. The table below shows the percentage of recycled content used in plastic packaging.

Percentage of recycled content used in packaging

Plastic packaging category	2025-26	2026-27	2027-28	2028-29 and onwards
Category I	30	40	50	60
Category II	10	10	20	20
Category III	5	5	10	10

EPR Obligations can be met by the mechanism of exchange of EPR credits wherein, surplus certificates are purchased by the Obligators under the same category. Such transaction shall be recorded and submitted during the filing of Annual Returns under EPR framework.

Under Swachh Bharat Mission-Urban (SBM-U) 2.0, the MoHUA has made efforts towards source segregation, collection, transportation, and processing of plastic waste. Material Recovery Facility (MRF) has been set up in all urban local bodies (ULBs), and awareness generation initiatives have been taken up for reducing SUP products and encouraging the use of substitute products.

The 'Swachh Survekshan' (an annual survey of cleanliness, hygiene and sanitation in villages, cities and towns) and 'Star Rating Protocol' (aimed to institutionalize a mechanism for cities to achieve garbage-free status and sustainable cleanliness) have been aligned with Plastic Waste Management (Amendment) Rules, 2021 to encourage cities to phase out SUPs.

However, despite the many policy push measures discussed here, it is important to recognize the need for a systematic approach and improving the effectiveness of monitoring and enforcement of the levied measures. There is also a need to build capacity of the stakeholders and create awareness to unlock the market potential of secondary plastics (recycled plastics).

Industry Initiatives

Circular economy initiatives undertaken by the industry with respect to plastics, are primarily driven by EPR. Upstream actions are seen in the form of banning SUPs use in their offices, reduction in use of virgin plastics particularly in packaging of their products and increasing commitments to the use of recycled plastics. The downstream actions focus has been in the form of material recovery by supporting/setting up take-back systems and financing the setting up of material recovery facilities. Industries are also putting efforts towards building awareness, conducting R&D to come up with circular solutions, and financing start-ups in the space of circular solutions to the plastics problem.

Industry associations such as Confederation of Indian Industry (CII), Federation of India Chambers of Commerce and Industry (FICCI) and All India Plastics Manufacturers Association (AIPMA) are facilitating information sharing and collaboration amongst the industry.

Emerging circular business models in India in the plastic circularity space mainly relate to substitution of plastic materials (such as plant-based fibres for cutlery[32] bio-based plastics and natural alternatives for packaging), recycling and technology platforms to facilitate extended producer responsibility (EPR) schemes. Kapur-Bakshi et al. (2021)[33] have proposed a preliminary roadmap for a circular economy for plastics in India and have included several enabling actions to facilitate circular business models as part of the roadmap. These enabling actions include:

- Using revolving funds to incentivise circular business models.
- Provision of seed funding by the local governments for circular business models that are locally suitable.
- Developing incubators and accelerators to provide funding and linkages for mentoring and training to set up circular business models.

Community led initiatives

In India, the community-led initiatives, led by non-governmental organisations (NGOs), religious groups, community-based groups, and research groups have been playing a strong role in engaging citizens and building awareness on the need and approaches to foster plastics circularity. Strong focus has been on the end of life, particularly recycling, recovering and repurposing of collected plastics, along with awareness generation for inculcating the values of 'refusing' or avoiding plastics. Most initiatives are undertaken as partnerships or collaborations including collaborations with waste pickers, government agencies, social entrepreneurs, municipalities, educational institutions and NGOs. A research study[34] under the India – Australia Industry and Research Collaboration for Reducing Plastic Waste, presents a detailed overview of these initiatives.

Challenges and Opportunities for Collaboration

Challenges

In Germany, which a great example of running an effective and efficient waste management system; despite being a leader in recycling and having a solid waste management system, the country is also one of Europe's biggest producers of packaging waste, **especially plastics.** Between 2005 and 2020, the average amount of waste produced in other EU-states declined whereas in Germany, it grew by almost one-tenth.

Germany exports around one million tons of plastic waste worth around 254 million euros every year. This is more than any other country in the EU. In 2020, the first year of the COVID-19 pandemic, nearly 6.5 million tonnes of packaging waste were collected, and per capita packaging waste was up by 6 kilograms from 2019. For decades Germany had to rely on third countries like China to manage its waste. With China's import ban, it highlighted a hidden side to Germany's waste situation; as important it is to have a strong recycling system in place, it is more so to avoid plastic waste piling up in the first place, and this is where Germany still has much work to do.

It is important to note that waste incineration remains one of the main pillars of waste management in Germany. Waste burning can be used to generate electricity and heating. In Germany, this share is equivalent to approximately 1.5% of the total annual primary energy consumption. Considering the environmental hazards and with studies pointing out that incinerators emit more toxins and pollutants than landfills, adds a significant negative contribution to air quality. There is still a lot of room for improvement when it comes to recycling: only a fraction of the garbage collected in Germany is intended for incineration and recovery. Accordingly, a total of 38 million tons of waste were collected from private households in 2019-20 - an average of 457 kilograms of household waste per capita. Only a third of it is recycled or incinerated.

In India, despite the multiple efforts made by the government and the private sector, plastic waste management in India remains a significant challenge.

The limited success of SUP bans has been due to issues related to the lack of enforcement authorities and penalties, support for suppliers, plastic alternatives, and gaps in informing and guiding behaviour change. Despite the ban, numerous

[32] Many companies are also working on fully compostable natural alternatives for manufacturing of disposable cutlery/plates/bowls with materials such as sugarcane bagasse/waste (Ecoware, Paapco Greenware), using areca-nut leaves (Ecotopia) or bamboo (Bamboo India).

[33] Kapur-Bakshi, S., Kaur, M. and Gautam, S. (2021) Circular Economy for Plastics in India: A Roadmap. Available at: https://www.teriin.org/sites/default/files/2021-03/CircularEconomy-Plastics-India-Roadmap_0.pdf

[34] Tyagi, A., et al (2021) Towards a circular economy for plastics in India A review of community, industry and public sector initiatives Available at https://research.csiro.au/rpwi/wp-content/uploads/sites/412/2021/12/Community-Industry-Initiatives-Report-Final-2021-1.pdf

banned items are still widely available in Indian related to the lack of effective implementation strategies and weak and insufficient enforcement authorities, especially in rural and remote areas (Krishnan, 2022[35]; Zaffar, 2022[36]).

The implementation of the EPR too has been limited due to a lack of clarity regarding, roles, responsibilities, and guidelines for those involved and a lack of monitoring and mapping of the producers, importers and brand owners (Hossain et al., 2022[37]; Talwar et al., 2021[38]). Additionally, the option to buy EPR recycling credits if companies fail to meet their targets might increase lax implementation (Deshpande, 2022)[39].

As of today, India employs a wide range of technologies for recycling, reutilization and recovery as well as different instruments for funding waste management services throughout the country. Mechanical recycling is by far the most dominant technology applied to manage plastic waste in India, where the chemical structure of the polymer is unchanged but is physically. Well-established recycling markets and value chains exist for mechanically recycled PET and, to a minor extent, also for HDPE. Chemical recycling, on the other hand can break down the polymers into their raw materials for conversion back into new polymers and can help eliminate downcycling. It is often heralded as the penultimate solution for dealing with mixed polymers and difficult-to-recycle wastes. But despite these advantages, it remains in its infancy and faces various challenges, such as high capital expenditures, need for deployment at large scale and low demand for recyclates.

There is lack of necessary infrastructure to ensure an effective collection of plastic waste, such as transfer stations and material recycling facilities (MRFs), tend to generate more mismanaged waste. The situation is broadly uniform across many Indian cities and the absence of simple collection infrastructure components such as community bins contribute to high shares of mismanaged plastic waste.

The consistent supply of high quality recyclates and recycled polymers cannot be guaranteed by most recyclers in India due to a lack of harmonized standards across India. Although the BIS published IS 14534-1998 (Guidelines for Recycling of Plastics) more than 20 years ago, there has been little progress in standardizing processes for plastic waste and the standard lacks specific requirements for the quality of output recyclates for different uses.

Another challenge that is faced is that linked to upscaling the use of bioplastics. The handling and treatment of bioplastics, require further regulatory guidance as they are still in early stages of development of marketization and have the potential to substitute petrochemical polymers on a medium- to long-term basis.

Opportunities for Collaboration

Building a circular economy involves building a system with a wide range of players including corporates, government, R&D centres non-profit groups and consumers. These players are a key part of the plastic ecosystem and can play an instrumental role in reducing plastic waste and pollution and fostering circularity in the sector. Following key collaborations will play an important role: (i) **to rethink product and packaging design** to reduce plastic material use, design reusable packaging solutions, and create products and packaging that is recyclable and have a longer lifespan. The Indian plastic manufacturers should be encouraged to collaborate with leading research institutions (CSIR, CIPET, DRDO, IITs) to develop indigenous technology for biodegradable materials for a wide range of applications, including those with functional properties for a level playing field and to actualize the Make in India vision[40]. **(ii) across the value chain** to set up a robust reverse logistic system for collection, sorting and recycling of post-consumer plastic waste and its

[35] *Krishnan, M. (2022). Why is India's single-use plastic ban failing? DW. Retrieved from https://www.dw.com/en/why-is-indias-single-use-plastic-ban-failing/a-63625217*

[36] *Zaffar, H. (2022). India bans single-use plastics, but provides no alternatives. FairPlanet. Retrieved 1 February 2023 from https://www.fairplanet.org/editors-pick/india-bans-single-use-plastics-butprovides-no-alternatives*

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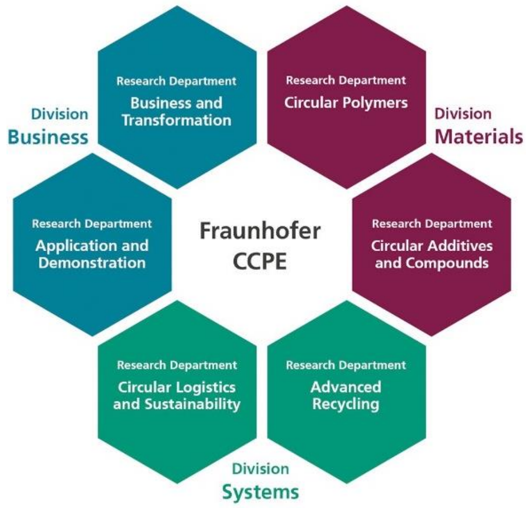
[39] *Deshpande, T. (2022). Extended producer responsibility: Why the rules do little to eliminate plastic pollution. IndiaSpend. Available at https://www.indiaspend.com/pollution/extended-producer-responsibility-why-the-rules-do-little-toeliminate-plastic-pollution-839270*

[40] *https://www.niti.gov.in/sites/default/files/2022-07/Plastics%20Alternative%20Study_Final_Report_compressed.pdf*

channelization for use to substitute virgin plastics. **(iii) Innovation and Research** to develop new technologies and processes that enhance plastic recycling and promote circularity. This can include investments in research and development, pilot projects and the adoption of state-of-the-art recycling technologies. This R&D development can be supported through programs such as the EU Research and Innovation Programme. **(iv) to develop tech-based solutions** that allow improving the coverage of EPR and its effective monitoring and implementation. (v) t**o identify and provide research funding and R&D infrastructure** for the development of innovative biodegradable products with an emphasis on performance, technology development, shelf life, and related financial aspects. **(vi) to foster creation of scientific knowledge, sharing of best practices, and partnerships** to work together are essential to address the common and emerging challenges. **(vii) Managing plastic waste from flexible and multi-layered materials-based packaging** that is rarely recycled due to being time-consuming to collect and costly to recycle with available technologies, is a key challenge that the country faces. Here developing EPR implementation models and schemes that involve active participation of informal recycling workers can increase the collection of multi-layered plastics whilst also supporting livelihoods in the informal sector.[41] **(viii) To ensure the availability of recyclates of consistently high quality** and create sufficient demand in high-end applications (e.g. electronics, automotive sectors), the development of up-to-date standards on recycled plastics and secondary raw materials under the Bureau of Indian Standards (BIS) is extremely important. These standards could be developed so they are brought in line with international best practices and existing environmental regulations is encouraged. Collaboration with international standard setting agencies like the European Committee for Standardization, CENELEC and ETSI would be valuable. **(ix) The product certification** can further facilitate the increase of supply for circular and resource efficient products. BIS could update and further refine the Guidelines for Recycling of Plastics in line with industry standards and create labelling and certification for recyclates.

Offerings and Activities of Fraunhofer

The circular economy of plastics concerns their entire life cycle — from product design, material selection and additives, the circular business model and traceability to added value for customers. The transformation from a linear to a circular plastics economy can only succeed with a multi-stakeholder approach. For this, Fraunhofer has formed **Fraunhofer Cluster of Excellence Circular**



Plastics Economy CCPE (Fraunhofer CCPE), which combines the expertise of six institutes of the Fraunhofer-Gesellschaft and cooperates closely with partners from industry to work on systemic, technical and social innovations, focusing on the entire life cycle of plastic products. This includes product design, material development, recycling and prototype construction to life cycle assessment and business models. The research focuses on creating a circular value chain:

1. Sustainable plastics materials: (i) Bio-based plastics (ii) Biodegradable polymers (ii) Recyclable plastics
2. System innovations: (i) Smart sorting technologies (ii) Material recycling (iii) Chemical recycling (iv) Circularity assessment
3. Circular business models and holistic product design

[41] *This has been effectively demonstrated under the SWaCH model in Pune.*

Competencies and Range of Services
Fraunhofer has expertise in developing economically relevant technologies and services to achieve circular plastics economy. They are: 1. **Circular Polymers:** Development of synthesis techniques of bio-based polymers and the qualification of monomeric building blocks from renewable carbon, Optimization of plastics with regard to degradation behaviour in the environment and Investigation of the processing behaviour of bio-based plastics using different forming technologies (injection moulding, film, staple fibres, extrusion blow moulding). 2. **Circular Additives and Compounds:** Designing precisely tailored plastic additives and compositions to improve the quality of recyclates, Odour improvement of recyclates through additives, and testing the degradation and lifetime of polycondensed products and develop new bio-additives from renewable raw materials. 3. **Advanced Recycling:** Advanced recycling technologies such as physical recycling technology, solvolysis and pyrolysis to recover polymers and monomers from the industry-specific life cycles of the plastic, and analysis of technical, economic and ecological parameters of waste streams and recycling processes as well as the recovery of problem plastics and composite materials. 4. **Circular Logistics and Sustainability:** Material flow analysis and development of logistics systems for product returns and Assessment of products and systems using Circular Readiness Level Tool. 5. **Application and Demonstration:** Support in development and rapid implementation of circular prototypes and products and applying suitable circularity strategies, and holistic system analysis and simulation from linear to circular products. 6. **Business and Transformation:** Analysis of regulatory issues, market trends, material flows, stakeholders and acceptance for current/future plastic products and commercialization of recycling technology as well as support in the transformation from linear to circular business models.
Ready-to-implement Technologies to achieve Circular Economy in Plastic Waste Management
1. **The CreaSolv® Process:** Efficient separation of plastic composites and contaminated post-consumer waste. Odorous substances and contaminants (PBDE, HBCD, etc.) can be efficiently removed and high purity materials from complex mixture of waste can be recovered. 2. **The iCycle® Process:** The iCycle® process is a thermo-chemical technology able to separate many different materials. In the process, plastics and further organic materials are thermally decomposed in an oxygen-free atmosphere. Not only contained metals and fibres are gently disintegrated, but also high-calorific fuels can be gained as oil and gas. The iCycle® process is able to fully separate and eliminate pollutants such as halogens or dioxins in order to win products of a unique quality. 3. **Chemical recycling:** From waste materials to valuable chemical compounds ▪ Solvolysis: (i) Alcoholysis, (ii) Glycolysis (iii) Hydrolysis ▪ Thermochemical Conversion: (i) Pyrolysis (ii) Gasification 4. **Preparation and purification processes:** (i) Dehalogenation (ii) Extraction (iii) Distillation 5. **Recyclable, fiber-reinforced material made from 100% bio-based polylactic acid for packaging:** Bio-based solutions for the automotive and textile industries. 6. **Injection and Compression Moulding for reusing odour-contaminated plastics:** Using this technology, high-quality applications using odour-contaminated recyclates are achievable, making an important contribution to resource conservation. The technology can also be transferred to other odorous materials such as plastics containing natural fillers.
Offerings to the industry
1. **Assessment check by using Circular Readiness Level (CRL®):** Tools and methods developed by Fraunhofer for companies to evaluate products and systems at various levels of circularity details. 2. **Improving products:** Support in improving products, expand the performance and also developing completely new ones with circular practices. 3. **Product developments up to the small-scale series:** Implementing processes and products in collaboration with industry up to small series production. 4. **Market analysis and innovation consulting:** Conducting feasibility studies, profitability calculations and information on funding to analyze technological trends and market developments. 5. **Deployment of new technologies:** Transforming new technologies into products and conceptualization of lab-scale ideas and translating into pilot plants. 6. **Optimization of existing processes:** Analysing the existing technical and organizational processes and suggesting measures for optimization with resource efficiency. 7. **License acquisitions:** Transferring the preliminary research into market-relevant results and inventions that can be exploited by companies under license.

Activities of Fraunhofer – some references

CIRCONOMY® Hub	Fraunhofer has built a network of CIRCONOMY® Hubs across Germany: These hubs are a new, agile instrument for cooperation on the basis of a shared mission and a reliable data space. They create added value regionally, nationally and internationally. In each hub, Fraunhofer institutes work with their partners in industry, science, politics and society on a mission not just to contribute to the circular economy, but to develop innovations for sovereign value cycles, climate neutrality, circularity and bioeconomy.
Waste4Future	The aim of the Fraunhofer lighthouse project "Waste4Future" is to increase energy and resource efficiency in the use of plastics. New possibilities for recycling are created, from which high-quality raw materials are produced. The resulting solutions make it possible to circulate the carbon contained in the plastic. Instead of contributing to global warming in the form of CO_2 or polluting the environment as plastic waste, it is available as a "green" resource for the chemical industry.
Pilot Plant Process Development for Plastic Recycling	The project includes setting up CreaSolv® pilot line, which is efficient separation of plastic composites and contaminated post-consumer waste, and recovery of high-value materials.
Recycling of multilayer packaging	In this project, Fraunhofer has developed a customized, sustainable, and process-oriented approach for recycling thermoplastic multilayer materials. The objective is for plastics to retain their excellent material properties even after several life cycles.
Carbon2Chem® – A Key Building Block for the Climate Protection	The purpose of the project Carbon2Chem® is to turn industry process gases such as smelting gases from steel production into a valuable source of carbon for the chemical industry.
Recycling of Large-Scale Composite Components – Rotor Blades	In this project, Fraunhofer is developing an economically feasible disposal strategy that achieves the highest possible recycling rate of rotor blades up to 80%, thus enabling a sustainable circular economy in plastics.

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- Fraunhofer Gesellschaft
- Fraunhofer Cluster Circular Plastics Economy CCPE
- Fraunhofer Energy Alliance
- Fraunhofer Battery Alliance
- Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB
- Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT
- Fraunhofer Institute for Solar Energy Systems ISE
- Fraunhofer Institute for Machine Tools and Forming Technology IWU
- Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM
- Fraunhofer Institute for Structural Durability and System Reliability LBF
- Fraunhofer Institute for Chemical Technology ICT
- Fraunhofer Institute for Process Engineering and Packaging IVV
- Fraunhofer Institute for Manufacturing Engineering and Automation IPA
- Fraunhofer Institute for Production Technology IPT
- Fraunhofer Institute for Material Flow and Logistics IML
- Fraunhofer Institute for Microstructure of Materials and Systems IMWS
- The Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV)
- The Federal Ministry for Economic Affairs and Climate Action abbreviated (BMWK)

Fraunhofer Gesellschaft - *Founded in 1949, the* ***Fraunhofer-Gesellschaft*** *based in Germany is the world's leading applied research organization. It provides contract-based R&D services for specific industry demand, application-oriented technology development from proof-of-principle up to market-readiness across the value chain and offer technical consultancy and feasibility studies to nearly all the industry sectors. Prioritizing key future-relevant technologies and commercializing its findings in business and industry, it plays a major role in the innovation process. A trailblazer and trendsetter in innovative developments and research excellence, it is helping shape our society and our future. Founded in 1949, the Fraunhofer-Gesellschaft currently operates 76 institutes and research units throughout Germany. Over 30,800 employees, predominantly scientists and engineers, work with an annual research budget of €3 billion. Fraunhofer generates €2.6 billion of this from contract research. Our global footprint is very strong, with offices and research centres in the USA, Europe and Asia. Some of our renowned innovations are the MP3 software, white LED's and the smallest of cameras. Fraunhofer has been a long-time trusted innovation partner in India, collaborating with some of the major players in the field of Material Science, Energy, Environment, Automotive, Electro-mobility, Production Technology, Microelectronics and Smart Cities, working with Industry, Government and Public Sector.*

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Environmental Management Centre Pvt. Ltd. – *Environmental Management Centre (EMC) was established in 1996. EMC's consulting services are essentially strategic, knowledge driven and supported through research and training. In all the consulting assignments, EMC's expertise lies in harmonizing economic, environmental and social considerations (often called triple bottom line) in the business logic, development plans and policy frameworks. Over the past 27 years, EMC has conceived, developed and executed a number of national, regional and international assignments that have set several "firsts". Many of these assignments have stimulated action leading to policy reforms, sustainable investments and led to long term capacity building. EMC has since its inception completed more than 700 assignments for clients in India as well as overseas. Clients represent Governments, UN Agencies, Corporates, Industries, Financing Institutions as well as Research & Community Based Organizations. EMC is one of the few Indian owned environmental management consultancy with significant international business.*

EMC is more of a policy, planning and strategizing group that brings in multi-disciplinary knowledge and skills. EMC blends its international experience with national context and governance to provide solutions that are rounded and robust. The team at EMC comprises of economists, engineers, urban planners, LCA experts and policy researchers supported by senior associates with sectoral and domain expertise.

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