Resource Efficiency and Circular Economy Industry Coalition

Hindustan Unilever Limited

FICCI Centre for SUSTAINABILITY LEADERSHIP

TRANSITIONING THE CHEMICAL INDUSTRY TO A NET ZERO PATHWAY

THE CRITICAL NEED FOR A MATERIAL TRANSITION

CSIR-NCL

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Authors

Dr. Venkataraghavan R
Platform Leader – Bright Future, Unilever R&D Bangalore
https://www.linkedin.com/in/venkataraghavanr/

Dr. Paresh L Dhepe
Senior Principal Scientist,
CSIR-National Chemical Laboratory
http://academic.ncl.res.in/pl.dhepe

Dr. Rajeev K Sukumaran
Senior Principal Scientist at the CSIR-National Institute for Interdisciplinary Science and Technology
www.niist.res.in/rajeev-kumar-sukumaran-msc-phd

Dr. Rajat Verma
Associate Fellow,
Centre for Social & Economic Progress
www.linkedin.com/in/rajat-verma-a8263a57/

Shifali Goyal
Research Associate,
Centre for Social & Economic Progress
www.linkedin.com/in/shifaligoyal/

Alak Desai
Senior Manager – Public Policy,
Chase India
www.linkedin.com/in/alak-desai-873abaa5/

Saptarshi Lahiri
Manager – Public Policy,
Chase India
www.linkedin.com/in/saptarshi-lahiri/

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MESSAGE FROM RECEIC CHAIR

The need for a material transition in the chemical industry is both urgent and undeniable. As one of the fastest-growing sectors in India, the chemical industry plays a pivotal role in the country's economic aspirations. However, its heavy dependence on fossil feedstocks presents critical challenges—ranging from high greenhouse gas emissions to resource security concerns. The transition towards bio-based alternatives is no longer an option but a necessity, aligning with India's net-zero commitments and global sustainability imperatives.

I extend my sincere appreciation to the members of the working group for their dedicated efforts in compiling this comprehensive report. Their insights and in-depth analysis have not only highlighted the challenges but also provided a clear roadmap for advancing bio-based solutions, fostering sustainable supply chains, and driving technological innovation. This report offers strategic recommendations that will serve as a catalyst for policy interventions and industry-led action.

We strongly believe that these recommendations will be instrumental in shaping the future of the chemical industry, not just in India but globally. At RECEIC, we are committed to translating these insights into tangible action by implementing lighthouse projects that demonstrate real-world impact. By showcasing successful models of sustainable material transition, we aim to accelerate large-scale adoption and drive meaningful change across the sector.

This is a defining moment for the industry to reimagine its future. With collaborative action, innovative policy frameworks, and industry commitment, we can transform challenges into opportunities and position India as a global leader in sustainable chemistry.

Mr. Manish Sharma
Chair, RECEIC

PREFACE

Material Transition
A Transformational Opportunity for the Chemical Industry

The Resource Efficiency and Circular Economy Industry Coalition (RECEIC), set up during India's G20 Presidency in 2023, has a mission to foster industry collaboration, build cross-sectoral capabilities and value chains, enhance resource efficiency and accelerate circular economy transition. Within this coalition, the Material Transition Working Group is focused on a sustainability transformation for the chemical industry, through developing actionable strategies, and bringing together diverse stakeholders from industry, academia and research institutions.

The chemical industry's reliance on fossil feedstock leads to dual challenge of substantial greenhouse gas emissions and import dependency, raising concerns about resource security and sustainability. To achieve India's net-zero emissions by 2070 along with other Panchamrit goals, the sector must transform its raw material sourcing and processing. This includes reducing emissions during production and end-of-life (e.g. biodegradation), focusing on both Energy and Material Transitions.

In this remit, the working group has steered the publication of this knowledge paper, 'Transitioning the Chemical Industry to a Net-Zero Pathway: The Critical Need for a Material Transition'. It captures challenges in transitioning from fossil-based to bio-based feedstocks, a key element of the material transition, and offers strategic solutions addressing multiple objectives and unlocking new opportunities. It also provides technical and policy insights to accelerate the transition, specifically focusing on key technology areas with industry collaboration. Additionally, the paper emphasises on the need of strong governmental support through favourable policies, streamlined regulations, and financial incentivisation for adoption of bio-based chemicals.

This knowledge paper marks a significant milestone in our journey toward sustainable material transition. The recommendations presented in this report aim to provide a roadmap for stakeholders across government, industry, and academia to collaborate effectively in driving this transformation.

The working group extends its sincere gratitude to the authors, subject matter experts and industry colleagues, who have contributed their valuable insights and experiences to build the paper.

Mr. Rajat Arora
Chair, Material Transition Working Group, RECEIC
Vice President - Home Care R&D India, Hindustan Unilever Limited

Ex utiv
u ry

India's chemical industry, currently valued at USD 220 billion and growing at ~8.1% CAGR (vis-a-vis global 5.5%), stands at a critical crossroads. While the sector is vital to India's manufacturing ambitions and serves as an essential input to numerous industries, its heavy reliance on fossil feedstocks poses dual challenges - significant greenhouse gas emissions (~ 0.14 giga tonnes CO_2e) and high import dependence (~ 0.23 giga tonnes). This transition moment, marked by India's COP26 commitments including being net-zero by 2070 and the Panchamrit goals, presents a strategic opportunity to reimagine the sector's future through bio- based alternatives.

Biomass emerges as a strategic solution, offering not only a renewable energy source, but also as a chemical feedstock alternative, contributing to greenhouse gas (GHG) emissions reduction, and economic growth potential. In fact, recent life cycle studies show that bio-based chemicals could be more sustainable than biofuels (e.g., bioethanol) and have significantly lower climate impacts than their fossil-based analogues. However, the transition must incorporate environmental guardrails, ensuring sustainable sourcing, and value chain scrutinised through a life cycle assessment, to ascertain that the transition from fossil resources will indeed positively benefit the planet. With an estimated biomass availability of ~500 million tonnes per annum, the shift presents multiple strategic advantages for India including enhanced energy security, reduced imports, and rural employment opportunities. For example, the ethanol blending programme alone cumulatively saved ~ USD 14 billion in crude imports, and generated ~ USD 28 billion revenue for distillers, farmers.

Through other opportunities, such as taking advantage of being a net exporter of ethylene and benzene, India can maintain competitiveness through sustainable value chain transition amid evolving global sustainable practices and stringent net-zero targets. Transitioning to bio-based feedstock requires establishing resilient and sustainable biomass supply chains, providing a potential leadership opportunity in the global bioeconomy.

While the transition is crucial from an economic and environmental point of view, it is not without challenges, including high initial costs (e.g., bio-based materials cost ~ 1.2 to 4.2 times over fossil counterparts), technology gaps, supply chain complexities, and financing barriers. Research and development investments for building technology platforms, scaling supply chains, and de-risking innovation require substantial capital. While India has policy frameworks supporting bio-based fuels and energy through initiatives like the National Biofuel Policy and PM JI-VAN Yojana, targeted policy action supporting bio-based chemicals remains crucial. The recently announced BioE3 policy is a right step towards accelerating this transition.

While the use of biomass to make chemicals is in nascent stages, there are many emerging examples from India, such as the production of furfural, acetic acid, bioethanol, and green energy from bamboo by Chempolis, with Numaligarh Refinery Limited (NRL), Assam and National Thermal Power Corporation (NTPC). Praj Industries has demonstrated the production of bioethanol from various crop wastes, and Indian Oil has initiated bioethanol and sustainable aviation fuel production at scale.

Technology Development Support

- Dedicated bio- based chemicals technology fund
- Support for technology and scale up of bio-based materials

Industry & Economic Competitiveness

- Modified PLI scheme for bio- based chemicals
- Industry incentive to develop domestic manufacturing capabilities at scale, global competitiveness

Supply Chain Development

- Building biomass infrastructure, value chain
- Coordinated and Certified value chains
- Skill development and FPO integration

Risk Financing

- Green bonds
- Duty exemption/ subsidies for biomaterials
- Sustainable finance/ Capital support

Green Public Procurement & Consumer Awareness

- Targets for green public procurement
- Product certification
- Consumer awareness for sustainable product labelling

This report recommends a comprehensive policy framework centred on five key pillars, to bring specificity to the required actions for a sustainable material transition.

1. **Technology Development Support:** Establish dedicated bio-based chemicals technology funds, support industry-academia partnerships, and provide viability gap funding for commercialisation. This includes creating startup incubation centres and matching grants to enhance Technology Readiness Levels (TRLs). Some of the specific technology interventions desired include, developing research and technology pathways, especially for feedstocks such as used cooking oil (UCO), waste biomass and scaling capabilities for chemical intermediates, such as ethoxylates, BTX, long chain hydrocarbons and process capacity building in biofermentation and thermocatalytic processes.
2. **Industry and Economic Competitiveness:** IIncentives for chemical industry across scales, ranging from large chemical producers, Micro, Small, and Medium Enterprises (MSME) and start-ups, to drive innovation and encourage competition, along with tax benefits to attract investments. The focus is on developing domestic manufacturing capabilities at scale that enables global competitiveness.
3. **Supply Chain Development:** Developing biomass collection infrastructure, integrating Farmer & Community collectives, and building rural entrepreneurship capacity is critical. Additionally, building cogent and cooperative supply chains for aviation fuel and chemicals is necessary, and UCO maybe a strategic and scalable starting point for this. This also includes creating strategic biomass collection hubs by 2030 and establishing quality standards and efficient market mechanisms. Avoiding resource competition while fostering cooperation for biomass

from energy, materials and GHG reduction mandates, as well as an internationally recognised, but local and inexpensive solution to sustainability certification is also desired.

4. **Risk Financing:** Create innovative financial instruments such as green bonds. Provide duty exemptions and subsidies for the sourcing of bio-based feedstock to ease capital investment burdens.
5. **Green Public Procurement and Consumer Awareness:** Implement mandatory public procurement targets, develop product certification frameworks, and launch consumer awareness initiatives (market development) through national campaigns and curriculum integration.

By implementing these recommendations, India can revolutionise its chemical sector, meet climate goals, boost energy security, and unlock economic opportunities. This strategic shift aligns with India's vision for sustainable industrial leadership and self-reliance, potentially positioning the country as a global leader in sustainable chemical production while supporting both environmental and economic objectives.

01 Intr u ti n

Chemicals are ubiquitous and essential for everyday life, reflected by their impact through a variety of products, such as, pharmaceuticals, fertilisers, plastics, adhesives, binders, paints, polymers, surfactants etc. Currently, the global chemical industry is expected to grow from USD 6,182 billion in 2024 to USD 6,324 billion by 2025 at a year-over-year (YoY) increase of 2.3%[1]. While the growth of the chemical sector presents significant economic opportunities, it also raises concerns about increased associated greenhouse gas (GHG) emissions. The chemical sector is responsible for approximately 5% of the global emissions[2], alongside other major contributors like energy (34%), agriculture (22%), and transportation (15%)[2].

1.1. Chemical Industry - Priority Sector for India

As the 6th largest chemical producer globally and 4th in Asia, it is poised to grow at an approximate rate of 7-8% CAGR and is expected to reach USD 300 billion by 2030 and USD 1 trillion by 2040[3]. At the global stage, India currently accounts for ~3% of global chemical sales[4], is the largest producer of chemical dyes and intermediates, and 4th largest producer of agrochemicals in the world[5]. The sector contributes to 12% of India's exports[6], approximately 7% to India's GDP[7], and supports nearly 100,000 products[8], making it integral to various dependent sectors such as agriculture, automotive, pharmaceuticals, and consumer goods, underscoring its importance in the overall economic framework of the country. Additionally, the sector is poised to grow further in the tailwind created by future growth drivers, as below.

Rising Domestic Demand:
Rise in demand from end-user industries such as food processing, personal care and home care is driving development of different segments in India's chemicals market coupled with strong GDP growth and growing incomes.

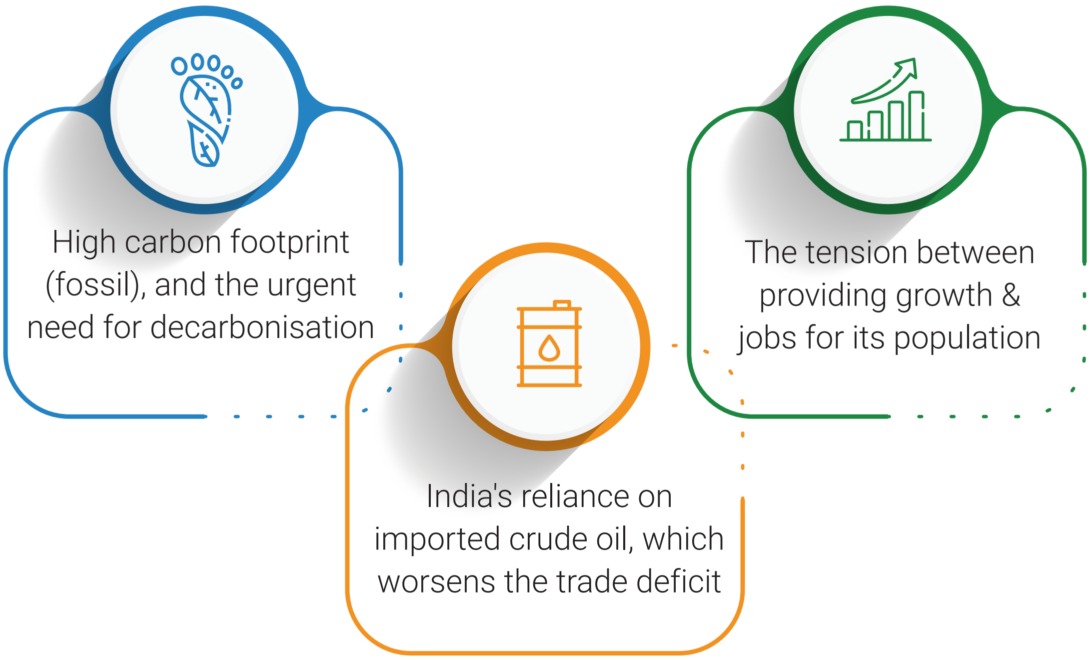
De-risking Global Supply Chains
With global companies seeking to de-risk their supply chains, the chemical sector in India has the opportunity for significant growth.

Growing Government Policy Support
Push for 'Make in India' and 'Atmanirbhar Bharat' through PLI schemes with local value addition (LVA), 100% FDI through automatic route, specialised investment zones and parks for attracting investments in chemical manufacturing.

1 Chemical Industry Outlook worth $6,324 billion by 2025 - Exclusive Report by MarketsandMarkets™; https://finance.yahoo.com/news/chemical-industry-outlook-worth-6-113000322.html
2 U.S. Environmental Protection Agency. (2023). Global greenhouse gas emission overview. Retrieved October 24, 2024, from https://www.epa.gov/ghgemissions/global-greenhouse-gas-overview
3 CII & Kearney. (2022). Mission Net Zero: A Roadmap for the Indian Chemicals Industry
4 Invest India. Chemicals sector. Retrieved October 29, 2024, from https://www.investindia.gov.in/sector/chemicals
5 Ministry of Commerce & Industry. (2022, April 27). Exports of Indian chemicals register growth of 106% in 2021-22 over 2013-14. Press Information Bureau. https://pib.gov.in/PressReleasePage.aspx?PRID=1820478
6 Department of Chemicals & Petrochemicals, Ministry of Chemicals & Fertilisers. (2023). Chemical & petrochemical statistics at a glance (2022-23).
7 India Brand Equity Foundation. Chemical industry in India. Retrieved October 29, 2024, from https://www.ibef.org/industry/chemical-industry-india
8 The Royal Society. (2024). Catalysing change: Defossilising the chemical industry – policy briefing (DES8815). ISBN: 978-1-78252-705-3.

Another contrasting facet of this growth opportunity is that the global GHG emissions from the chemicals industry reached ~58-59 gigatons of CO2 equivalent (GtCO2e) in 2020. These have grown at an average of 1.4% per annum since 2010. The contribution from the Indian chemicals industry is roughly ~ 0.14 GtCO2e, though modest now, needs to be seen in the context of the expected growth[3].

In an era marked by growing environmental concerns, the chemical industry is currently lagging other sectors in its journey to transition to net-zero emissions. A vast majority of these chemicals are derived from fossil resources, and the chemical sector in India today faces a trifecta of challenges:



In this context, India's aspirations of becoming a developed economy by 2047 (Viksit Bharat), essentially backed by a thriving chemical manufacturing sector while committing to climate agreements and net-zero emissions, appear to be in conflict. Considering this, it becomes increasingly clear that the shift towards sustainability in the chemical sector is not just an environmental imperative but also a strategic necessity for India's economic goals.

02

h ll n with u f F il R ur n th N f r Tr n iti n

The chemical industry has co-developed alongside the oil & gas industry over the last century and is closely integrated with the fossil-fuels value chain. Petroleum crude is the key feedstock for petrochemicals. Petrochemicals account for approximately 10-12% of India's total petroleum products consumption, making it one of a major consumer of fossil resources[9]. With robust growth projections and substantial government support, the sector is poised for expansion, highlighting both its importance in the economy and its reliance on fossil fuels as feedstock.

GHG emissions associated with materials occur during the production and from the energy consumed in the process, as in sectors such as steel and cement primarily, and are referred to as production emissions. For many chemicals, GHG emissions occur during production, and are also released during biodegradation. The latter is often a significant portion, embedded in the feedstocks, and released at the end of the product's life cycle[10] (see Figure 1). For the Indian chemicals industry, emissions are roughly similar during the production (0.07 $GtCO_2e$) and end of life (e.g. biodegradation) (0.065 $GtCO_2e$). The particular concern with the high reliance on fossil resources (as feedstock) for chemicals (petrochemical) is the release of previously sequestered fossil carbon (over 2 million years ago) as GHG emissions[3].

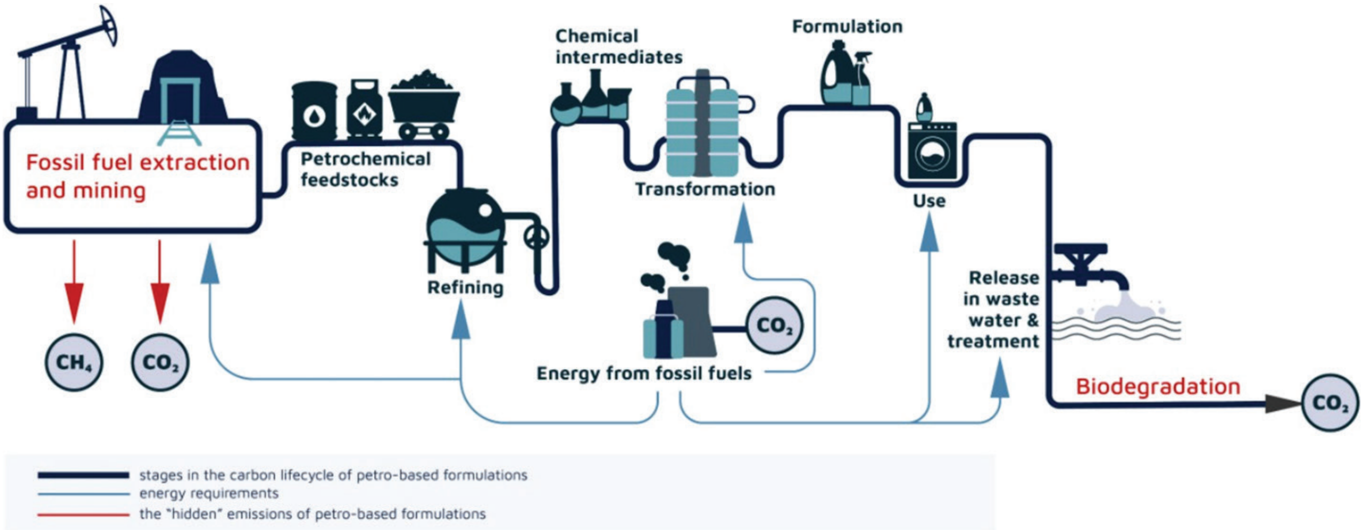


Figure 1 Carbon life cycle for a chemical (as manifested in a laundry detergent) showing emissions across extraction, production and end of life emissions (biodegradation).

2.1. Argument for an Energy & Material Transition

Decarbonisation of the chemicals industry requires the adoption of renewable sources of energy and renewable materials, for addressing production and biodegradation emissions. This requires switching out of fossil energy and fossil material resources. This transition is referred to as 'energy transition' and 'material transition' respectively.

Although both energy and material transitions are necessary, leading an energy and material transition can often be at conflict, and need to be managed. For example, the transition to renewable energy will increase the need for solar panels, windmills, etc., putting a higher demand on materials such as epoxies, polymers, etc., all derived from fossil-based chemicals. Further, the varying adoption of renewable energy globally, driven by technology access, commitment and

9 India Brand Equity Foundation. Oil and gas industry in India. Retrieved October 29, 2024, from https://www.ibef.org/industry/oil-gas-india
10 Collett, K. A. et al., 2023. Cleaning up Cleaning: policy and stakeholder interventions to put household formulations on a pathway to net zero., s.l.: Oxford Smith School Working Paper 23-07.

regulations, consumer demand and acceptance, creates large uncertainties with supply and demand for resources (both fossil and renewable). This can reduce the demand for fossil fuels, making current supply chains for petrochemicals unviable, as fuels and chemicals are produced in the same value chain, with a very high tilt to fossil energy versus chemicals (about 2% of the crude barrel). Resolving this conflict therefore needs energy and material transition in chemicals to be co-planned and executed, alongside other sectors. The renewable energy transition is well underway primarily in transport, power sectors, etc., and there is an urgent need to accelerate material transition for the chemicals industry.

2.2. Biomass Feedstocks as an Alternative for Material Transition

To produce renewable energy, leading alternatives to fossil feedstocks (i.e., oil, coal, gas) are wind, solar, biomass, geo-thermal, nuclear, hydro etc. However, for chemicals, with linked feedstock for the energy and material transition, using biomass for energy is an affordable alternative, and can also be a source for primary chemical building blocks, such as ethylene, propylene, ammonia, and methanol. Further, biomass is naturally carbon neutral, sequestered from the atmosphere via photosynthesis, fixing carbon, hydrogen, and oxygen naturally, and released back into the atmosphere on biodegradation (renewable and circular). It contains key hydrocarbon classes, lignocelluloses – cellulose (polysaccharides), lignin; starches – polysaccharide and nitrogen containing polysaccharides from marine sources. Therefore, renewable biomass, which can produce biofuels (ethanol, biodiesel, synthetic/ sustainable aviation fuel (SAF), transportation fuels), biopower (heat and electricity), and bioproducts (chemicals), remains a key to a sustainable energy & material transition (see Figure 2[11]).

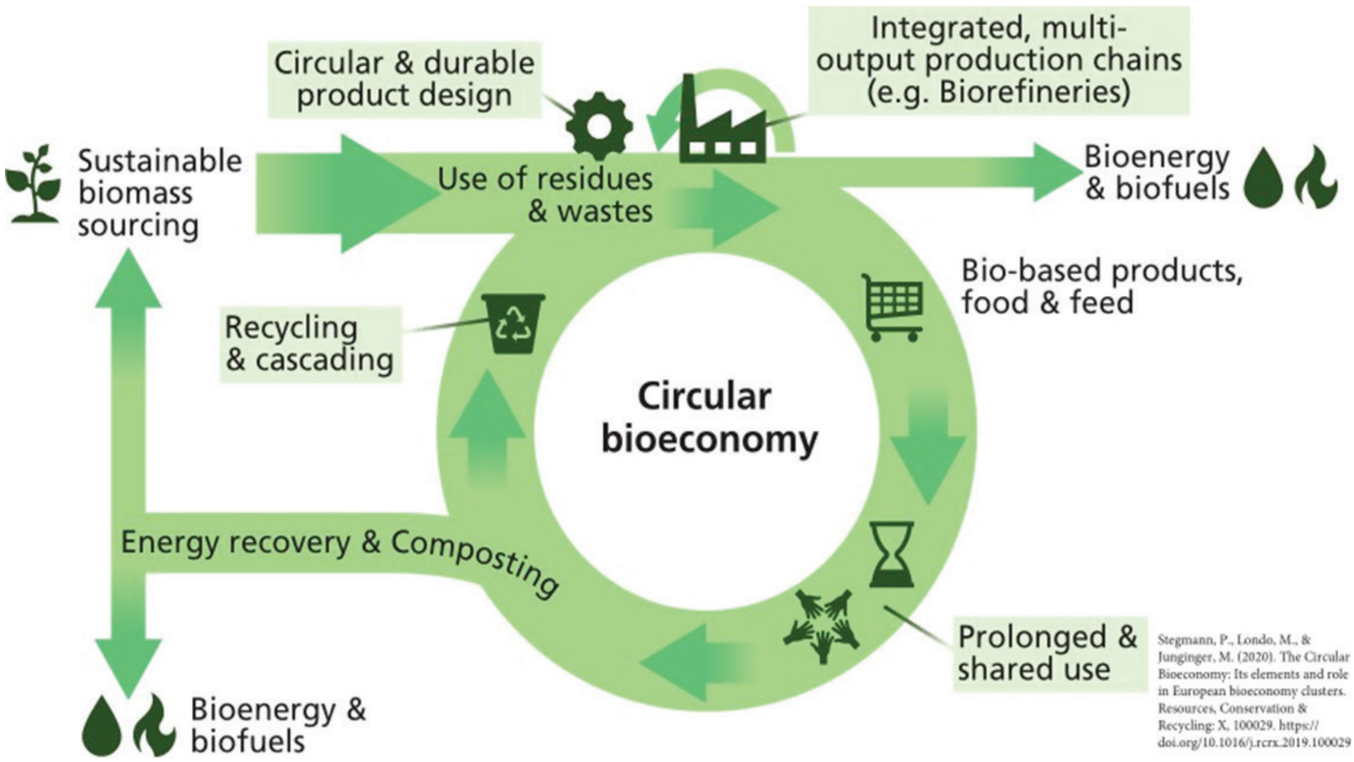


Figure 2 Sustainable sourcing and use of biomass: resource efficiency and optimising use

[11] Stegmann, P., Londo, M., & Junginger, M. (2020). The circular bioeconomy: Its elements and role in European bioeconomy clusters. Resources, Conservation & Recycling: X, 6, 100029. https://doi.org/10.1016/j.rcrx.2019.100029

While various feedstocks and technologies are available for decarbonising industry sectors, the choice depends on specific contexts and goals. These are referred to as first generation (1G), food crops like corn and sugarcane; second generation (2G), non-food biomass like agricultural residues; third generation (3G), like algae, and fourth generation (4G), involving genetically modified organisms designed for high yield and sustainability[12]. For the chemical industry, with both production and biodegradation emissions, overall GHG reduction can only be achieved by using biogenic carbon from biomass or CCU (Carbon Capture and Utilisation) with direct air capture (over point source CCU or Carbon Capture and Storage, CCS). We therefore believe that biomass as the feedstock for material transition, enabling significant GHG reductions, needs prioritisation due to its current technological readiness and economic advantages.

Integrating precision logistics, decentralised storage, and efficient feedstock management can replace fossil materials and lower greenhouse gas emissions, if supported by an effective supply chain, robust collection networks, optimized transport, and improved processing capacity. Investment in technology, infrastructure, and logistics, alongside advancements in traceability, blockchain, and AI-driven analytics are needed to ensure seamless integration with industrial processes.

Lt Col Monish Ahuja (Retd)
Chairman & Managing Director,
Punjab Renewable Energy Systems Private Limited (PRESPL),

2.3. GHG Emissions & Environmental Guardrails

The key outcome of this transition would be to stop the GHG emissions from non-renewable (fossil) carbon into the atmosphere, that would otherwise add to the existing GHG in the atmosphere. The transition would abate both the production and biodegradation emissions being from fossil resources. Given the large volumes of fossil energy and material resources currently deployed, the transition would make a large positive contribution to the reduction of GHG from the chemical industry. The exact impact on GHG reduction will depend on the chemical, chosen process pathway, nature and source of feedstocks and energy, and the linked supply chain from feedstock to product, and is to be confirmed through a life cycle assessment (LCA).

However, the transition to biomass as sources for chemicals must incorporate environmental guardrails. Therefore, sustainable sourcing of biomass that includes environmentally sustainable choice, substantial/verifiable benefits, aspects of land use change (LUC), deforestation, biodiversity loss and choosing residues over virgin biomass, are highly relevant and crucial to the transition. With technological progress, waste bio-resources like wood, agricultural waste, municipal waste, used cooking oil (UCO) and non-edible oils could become amenable for production of sustainable

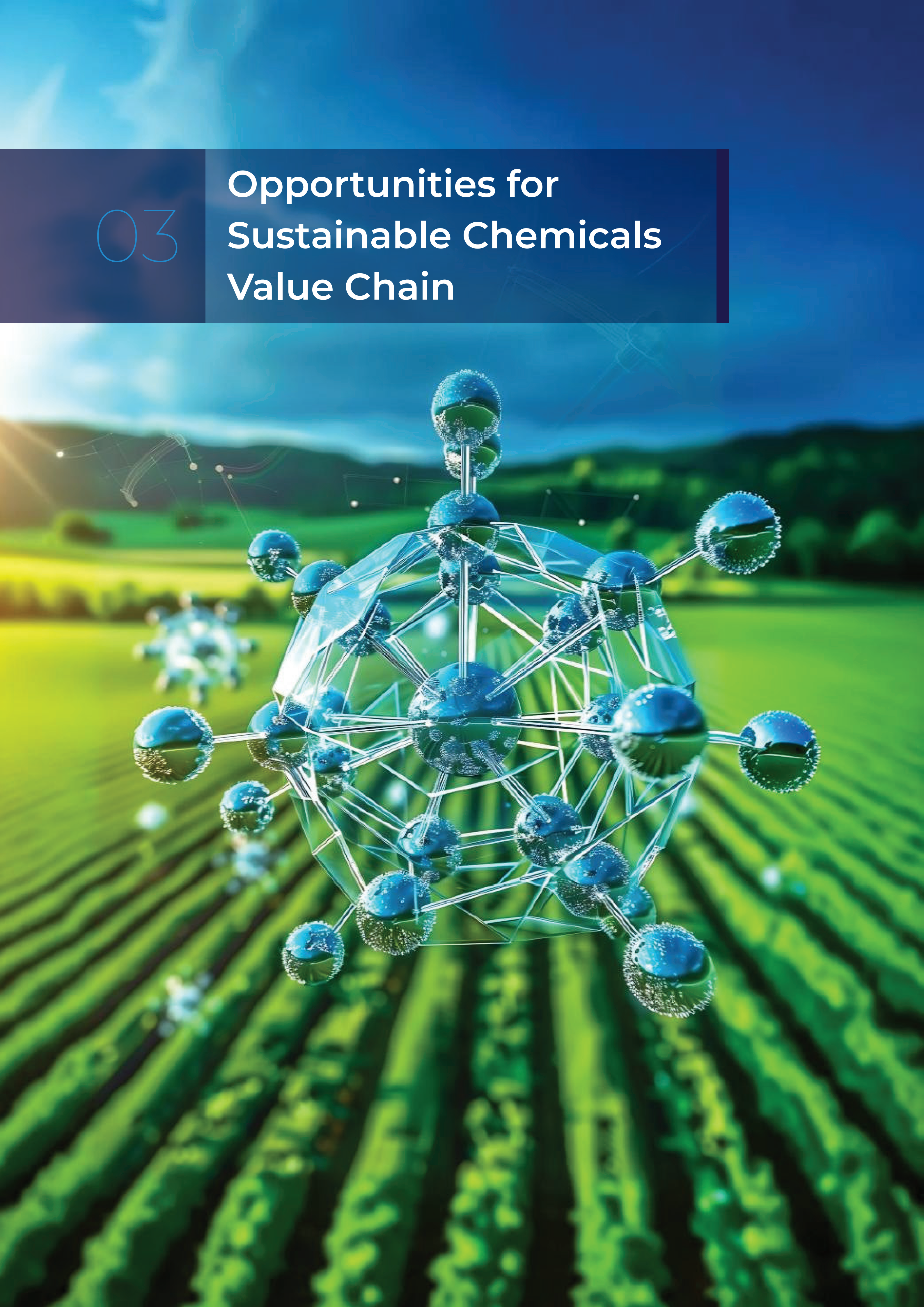
[12] Kumar, B., Bhardwaj, N., Agrawal, K., Verma, P. (2020). Bioethanol Production: Generation-Based Comparative Status Measurements. In: Srivastava, N., Srivastava, M., Mishra, P., Gupta, V. (eds) Biofuel Production Technologies: Critical Analysis for Sustainability. Clean Energy Production Technologies. Springer, Singapore. https://doi.org/10.1007/978-981-13-8637-4_7

chemicals, limiting food security impacts. Similarly, processes across the supply/value chains from feedstock extraction/sourcing, production and disposal must be included in scope and be scrutinised through a full LCA, to ascertain that the transition from fossil resources will indeed positively benefit the planet.

There is also further guidance and a unique opportunity to learn from prior work already done/ underway in other regions. For example, the European Chemical Industry Council (CEFIC) has developed a "Safe and Sustainable by Design" (SSbD) framework to guide the innovation and market placement of chemicals, materials, products, processes, and services. The framework aligns with the European Green Deal and the Chemicals Strategy for Sustainability, aiming to support a circular economy and a climate-neutral society. It includes guiding design principles that address safety and sustainability considerations throughout the entire lifecycle of products. The framework emphasises the need for supportive policies and practical methodologies that encourage innovation and are easy to implement. This approach aims to ensure that chemical innovations are not only safe for human health and the environment but also contribute positively to society and the economy.

Similarly, the organisations for Economic Co-operation and Development (OECD's) "Safe and Sustainable by Design" (SSbD) framework aims to ensure that technological innovations, such as nanotechnology and biotechnology, are developed in a way that prioritises both safety and sustainability. Various other organisations are taking a lead as well. Select examples include the United Nations Environment Programme's (UNEP) Global Alliance for Circular Economy & Resource Efficiency (GACARE) and World Business Council for Sustainable Development's initiative on Planet Positive Chemicals.

03 Opportunities for Sustainable Chemicals Value Chain



3.1. Potential for Biomass across Energy & Chemical Intermediates

The Indian economy is largely agrarian, with major cultivation of rice, wheat, cereals, pulses, oil crops, sugar cane, and cotton. This leads to abundant biomass sources, such as vegetable oils, starches, municipal solid waste, garden waste, crop and forest residues, etc. The total dry biomass, across the principal crops and in the three growing seasons, is estimated to be around 670 million metric tonnes[13]. After different usage by farmers, a surplus biomass of ~170 million metric tonnes per annum is estimated. Across sources, this estimate varies from 50-750 million metric tonnes. Biomass is made up of a variety of chemical material classes, like triglycerides, fatty acids, esters, starches, cellulose, hemicellulose, lignin, polysaccharide, etc., and has the molecular level base to many chemical classes of industry interest; and can be derived through suitable processes. Biomass, which is mainly plant-derived lignocelluloses, could yield a variety of vital chemicals.

Biomass is a relevant dual-purpose feedstock for energy and production of chemicals, although biomass valorisation to chemicals often returns higher value than valorisation to fuels (energy). Biomass is arguably the most important renewable feedstock in the Indian context, being an agrarian economy, and it also has the added advantages of social and environmental benefits, besides opportunities for decentralised development and creation of employment[14]. One of the key steps is the preparation of biomass for valorisation, i.e., collection, sorting, and pre-treatment to separate components.

While the hypothesis for the pivotal role of biomass in the energy and material transition is indeed proven, it lacks the planned and consolidated drive required for the development of a viable supply chain. Three important factors are to be considered while shifting from fossil to renewables – economic viability, technology readiness, and environmental impact.

"India, with its extensive agricultural and animal husbandry sectors, possesses significant potential to become a global leader in the development of bio feedstock and food biochemistry. The foundation of this material transition lies in the advancement of fermentation techniques, the discovery of new pathways and the development of technology for scaling up manufacturing processes. This includes the formulation of new standards for quality and carbon content within the field."

Mr. R. G. Krishnan
Jt President & Head -Safety Sustainability and Tech Academy,
Aditya Birla Group Chemicals Business

3.2. Biomass Valorisation to Fuel, Energy & Chemicals

Biomass can be valorised to energy, via multi-centric approach in the country with urban, industrial, agricultural wastes/residues, food wastes and municipal solid waste (MSW) being utilised for energy recovery in the form of power, biogas, bioCNG (compressed natural gas), bioethanol, biodiesel and SAF, via several catalytic processes, and hydrogen via reforming processes.

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[13] TIFAC-IARI. (2018). Estimation of surplus crop residues in India for biofuel production. October 2018. Accessed from: https://www.tifac.org.in/index.php/reports-publications/recent-publications/2-uncategorised/1062-estimation-of-surplus-crop-residues-in-india-for-biofuel-production

[14] Ministry of New & Renewable Energy. Bioenergy overview. Accessed on October 29, 2024, from https://mnre.gov.in/bio-energy-overview/

There are four main technology pathways to valorising biomass to chemicals, viz., physical (mechanical), thermochemical (pyrolysis, gasification, liquefaction), chemical (hydrolysis, solvent extraction, supercritical extraction) and biological (fermentation, digestion, enzymatic).

Historically, thermochemical methods, such as pyrolysis and gasification have been used to get gases carbon dioxide, dihydrogen, carbon dioxide, methane, etc., which are the elementary building blocks for hydrocarbons. The reaction conditions are harsher and yield a mix of products, where an additional process for separation is required.

Biological pathways use a biorefinery concept, mirroring the petrochemical analogies, except petro-crude, which is substituted by oils and fats generated from plants, seed oils, and animal fats. The operations are performed under milder conditions requiring lower energy, avoiding waste of carbon, hydrogen and oxygen in undesired products, and more in the required hydrocarbon ranges. Lignocellulosic (biomass) feedstock can also be converted to fuels and chemicals following a similar biorefinery concept, where the biomass to product conversion follows a hybrid thermochemical and biochemical conversion. The former can involve thermochemical or catalytic routes in addition to the fermentative, to generate ethanol and quite often platform chemicals.

While the use of biomass to make chemicals is in nascent stages, there are many emerging examples, such as the production of furfural, acetic acid, bioethanol, and sustainable energy from bamboo by Chempolis, with Numaligarh Refinery Limited (NRL), Assam and National Thermal Power Corporation (NTPC)[15].

Praj Industries has demonstrated the production of 2G bioethanol from various crop wastes. India's key oil marketing companies will start bioethanol production at scale as mandated by the government. Other chemicals of value, such as sorbitol (sugar alcohol) via glucose hydrogenation, vanillin from lignin, lactic acid via biotechnology and butadiene, p-xylene via thermochemical pathways, have shown promise. In fact, some recent LCA studies have shown that the development of chemicals, starting from bio-based hydrocarbons as described above, could be more sustainable than biofuels (e.g., bioethanol) and with much better positive climate impact over fossil fuels [16].

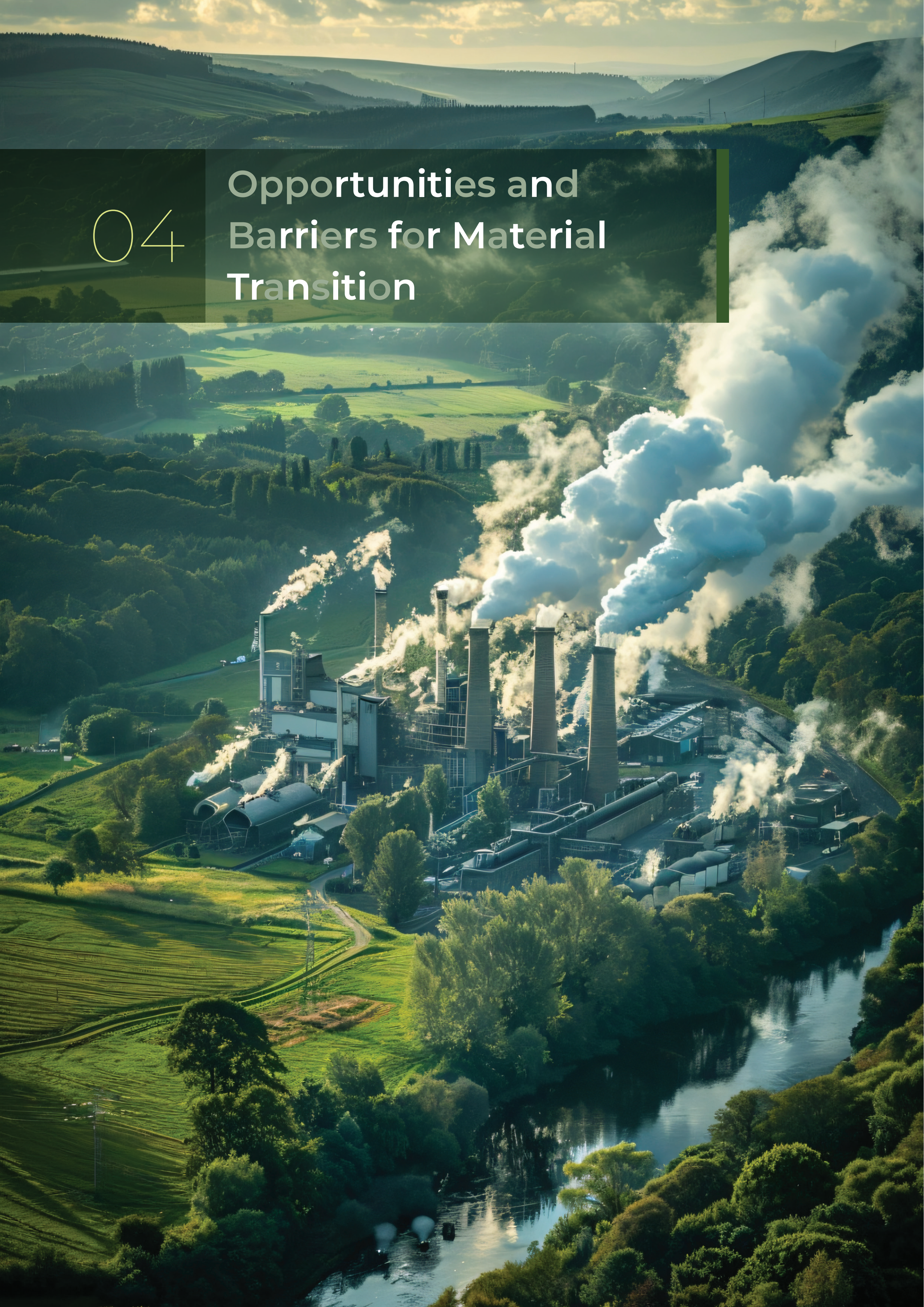
We need to commit to developing a robust technology value chain that accelerates the transition to sustainable materials. By leveraging innovation, bio-based solutions, and strategic partnerships, industries can adopt eco-friendly alternatives, ensuring resilience, efficiency, and sustainability in the evolving global supply chain.

Dr. Pramod Kumbhar
President and Chief Technology Officer (CTO),
Praj Matrix, the R&D Center of Praj Industries Ltd.

[15] Chempolis. (2018, May 2). Chempolis seals deal for Indian biorefinery. Chempolis. Accessed from: https://chempolis.com/chempolis-seals-deal-for-indian-biorefinery/

[16] Winter B, Meys R, Sternberg A, Bardow A. 2022. Sugar-to-What? An Environmental Merit Order Curve for Biobased Chemcials and Plastics. ACS Sustainable Chem. Eng. 10: 15648-59. https://doi.org/10.1021/acssuschemeng.2c03275

04 Opportunities and Barriers for Material Transition



4.1. Transitioning the Chemical Industry

Table 1 provides a comprehensive view of the chemical intermediates involved in the production processes across various industry sectors that rely on the (petro)chemical value chain. As can be seen, a variety of organic chemical intermediates, such as ethylene, styrene, BTX (Benzene, Toluene, Xylene) and long chain hydrocarbons have an opportunity to be derived from biomass; and the transition to non-fossil feedstock can positively impact GHG emissions from various industry sectors. The table also emphasises the current deep integration of the chemicals value chain with petrochemicals/fossil resources, and sets up the context, highlighting the opportunities and barriers in steering the material transition.

Industry Sector	Key Chemical Building Blocks	Chemical Intermediates	Products
Petrochemicals	Ethylene, Propylene, Benzene, Toluene, Xylene, Butadiene, Propane, Naphtha, Ethanol, Methanol	Ethylene Oxide, Propylene Oxide, Cumene, Styrene, Cyclohexane, Alpha olefin, Acetic acid, Acrylic acid, butanol, Polyolefins, Epichlorohydrin, Epoxy resins, Acrylonitrile, Crotonaldehyde	Plastics, Synthetic fibers, Rubber, Solvents, BioLPG, Detergent polymers
Consumer Products	Surfactants, Fragrances, Polymers, Preservatives, Colorants, UV filters	Sodium Lauryl Sulphate, Benzyl Alcohol, Polyethylene Glycol, Parabens, Fatty alcohol ethoxylates, fatty amine, Fatty acid ethoxylates, UV filters-Lignin, Sinapoyl malate, p-Hydroxy cinnamic acids and benzaldehydes	Detergents, Cosmetics, Personal care products
Agricultural Chemicals	Ammonia, Urea, Potassium Chloride, Phosphate Rock, Glyphosate, Silica, Ethylene oxide	Ammonium Phosphate, Potassium Nitrate, Diethyl Phosphite, Ethoxylates	Fertilisers, Pesticides, Herbicides
Specialty Chemicals	Surfactants, Fragrances, Polymers, Catalysts, Adhesives, Sealants, Succinic acid, 1,4-Butan-diolC2, C3, C4, C5, C6 compounds	Ethoxylates, Silicones, Polyurethanes, Epoxies, Acrylates, Gamma butyrolactone, Polyglycols, EO-PO Block copolymers, PAGs, Allyl PEG, Isoprene, Ethyl lactate	Paints, Coatings, Adhesives, Sealants, Catalysts, Deicers, Plasticisers, Detergents, Binders, Car industry-Tyre, Rubber gloves, tailored solvents

Industry Sector	Key Chemical Building Blocks	Chemical Intermediates	Products
Pharmaceuticals	Acetone, Ethanol, Methanol, Sodium Hydroxide, Hydrochloric Acid, Ethylene oxide	Benzyl Chloride, Acetyl Chloride, Ethyl Acetate, Methylamine, malonic acid, Succinic acid, Polyethylene glycols, Sorbitol Esters	Medicines, Vaccines, Biologics, Excipients
Inorganic Chemicals	Sulfuric Acid, Chlorine, Sodium Hydroxide, Ammonia, Nitric Acid	Sodium Carbonate, Calcium Hypochlorite, Ammonium Nitrate, Phosphoric Acid	Acids, Alkalis, Fertilisers, Glass, Cement
Construction chemicals	Adhesives, Hardeners, Curing agents, Polymers, water repellents, admixtures	Wood products- tannin, lignins, Phytic acid-Diamino decane, Bioplastic, Bio polymers, Modified fatty oils, Preservatives	PU coatings, all types of constructions- concrete, paints
Foods	Polymers, Preservatives	Polylactic acid, Polyhydroxy butyrate, Ethyl acrylate, Starch-LDPE Polymers, Polyhydroxyalkanoates, PAG	High durable, water repellent, antimicrobial food packaging
Industrial Lubricants	Base oils, Lubricants, Surfactants, Preservatives, corrosion inhibitors, Anti wear, Antioxidant	Estolides, Polyalkylene glycols, Ethoxylates, Chitosans	Cutting oils., Hydraulic oil, Greases, transformer oil, engine oil

The chemical industry through feedstock evolution must address climate change and resource scarcity. In India, biomass and CO2 represent an important element of the future circular economy. Stakeholders across the value chain need to adopt low-carbon alternatives and invest in technologies to achieve net zero and Mission Viksit Bharat@2047.

Mr. Nitin Sharma
CEO & General Manager,
Clariant IGL Specialty Chemicals Pvt. Ltd.

4.2. Opportunities

4.2.1. Reduction in Dependence on Imported Fossil Fuels

As the world's third-largest importer of crude oil and petroleum products, India met around 87% of its crude oil requirements through imports in 2022-23[17]. Promoting biofuels such as bioethanol has allowed India to reduce its crude oil imports, resulting in significant foreign exchange savings (estimated at ~ USD 14 billion over the last 11 years), with the ethanol blending rate increased significantly from 1.53% to 13%, enhancing India's economic resilience[18]. It also promotes diversification by creating climate-resilient income sources. For instance, ethanol blended petrol (EBP) has generated substantial revenues for distillers and farmers, with distillers earning approximately USD 16.7 billion and farmers around USD 10 billion[19].

Further, the global trend towards decarbonisation and growing consumer preference for sustainable products is reshaping the industry. As a net exporter of key petrochemicals like ethylene, benzene, toluene, xylene, etc., India must adapt to this shift to maintain its competitive position in the global chemical market and sustain its exports.

Similarly, India has a significant opportunity to deepen its integration with global value chains in the renewable chemicals sector, increasing self-reliance, working towards 'Atmanirbhar Bharat' and positioning itself as a leading producer and export hub.

4.2.2. Growing Global Market for Bio-Based Chemicals

The global market for bio-based chemicals is projected to expand substantially, increasing from USD 47 billion in 2023 to USD 142 billion by 2033, offering India a promising chance to secure an early-mover advantage by establishing itself as a key player in this rapidly expanding sector[20]. This growth reflects a robust compound annual growth rate (CAGR) of 11.6%. This growth is driven by increasing demand for sustainable products across various industries, including packaging, automotive, and personal care. As consumers become more environmentally conscious, there is a growing preference for eco-friendly products. Several studies show that nearly ~45-73% of consumers worldwide are willing to modify their consumption habits to lessen their environmental impact[21,22]. This shift presents a lucrative opportunity for Indian manufacturers of bio-based chemicals.

4.2.3. Attracting Investments for Sustainable Chemicals & Export Opportunities

Foreign Direct Investment (FDI) in India's chemical sector has steadily increased in recent years. With 100% FDI permitted under the automatic route, the sector (excluding fertilisers) attracted inflows totalling USD 22.14 billion between April 2000 and March 2024[23] Further FDI inflows will be

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17 Ministry of Petroleum and Natural Gas. (2023). Review of policy on import of crude oil (Twenty-third report). Standing Committee on Petroleum & Natural Gas. https://sansad.in/getFile/lsscommittee/Petroleum%20&%20Natural%20Gas/17_Petroleum_And_Natural_ Gas_23.pdf?source=loksabhadocs

18 Press Information Bureau Releases, Ministry of Petroleum & Natural Gas https://pib.gov.in/PressNoteDetails.aspx?NoteId=153363&ModuleId=3&reg=3&lang=1

19 ANI. (2024, September 3). Union Minister Hardeep Puri assures industry of the stability in the price of ethanol. Economic Times Auto. Accessed from: https://auto.economictimes.indiatimes.com/news/oil-and- lubes

20 Global Market Analysis, https://market.us/report/bio-based-chemicals-market/

21 https://www.pwc.com/gx/en/news-room/press-releases/2024/pwc-2024-voice-of-consumer-survey.html

22 https://nielseniq.com/global/en/insights/analysis/2019/a-natural-rise-in-sustainability-around-the-world/

23 Invest India Analysis, https://www.investindia.gov.in/sector/chemicals

crucial for India's transition to a low-carbon economy. With climate change at the forefront of global development discussions, investments are increasingly flowing toward countries prioritising and implementing sustainable practices. According to FDI Markets, green FDI has tripled in the last decade, now representing the largest category of foreign investment. Fostering a conducive environment for the growth of the renewable chemicals industry will help the country position itself as an attractive destination for FDI.

4.2.4. Potential for Employment Creation in Agri-allied Sectors

In deepening its integration with global value chains in the renewable chemicals sector (section 4.2.1), India has a massive opportunity in employment creation. The growing biofuels industry is already a substantial source of employment worldwide. For instance, in 2021-2022, the liquid biofuels sector generated approximately 35,000 direct and indirect jobs in India alone, around 856,000 in Brazil and 360,000 in the USA[24]. Further, by aligning agricultural practices with the growing demand for bio-based products, India can harness this momentum to create new employment opportunities and promote economic diversification in agri-allied sectors.

4.2.5. Transform India as a Research & Development (R&D) Hub

India's bioeconomy has experienced significant growth, expanding from USD 10 billion in 2014 to over USD 130 billion in 2024, and is expected to reach around USD 300 billion by 2030[25]. This growth underscores India's potential to lead the production of bio-based chemicals. However, the current R&D spending in India's chemical sector remains relatively low, at just 2-3% of total turnover, compared to 9-10% by multinational corporations abroad[26]. Closing the research funding gap and channelling investments in R&D and innovations around sustainable chemicals and ingredients can help India emerge as a global player in the renewable chemicals sector. This must be driven by strategic initiatives and innovation in the chemical industry.

Although the focus is currently on bioenergy, the parallel transition to manufacturing bio-based chemicals is equally essential. The introduction of the BioE3 policy, emphasising the importance of indigenous R&D-focused entrepreneurship across key sectors, including high-value bio-based chemicals, biopolymers, enzymes, and Carbon Capture and Utilisation (CCU) and approaches via thermochemical technology are pivotal in this transformation. By promoting biomanufacturing hubs and supporting the commercialisation of bio-based products, among others, the policy aims to accelerate the growth of India's bioeconomy. From parallels with the current chemical industry, it can be estimated that the valorisation to speciality chemicals, and commodity chemicals would be higher than fuels, making this an attractive opportunity for sustainable chemicals.

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[24] IRENA and ILO (2023). Renewable energy and jobs: Annual review 2023, International Renewable Energy Agency, Abu Dhabi and International Labour Organization, Geneva. https://www.irena.org/Publications/2023/Sep/Renewable-energy-and-jobs-Annual-review-2023

[25] Ministry of Science and Technology. (2024, August 26). New bioeconomy policy rolled out by the Modi Government is set to place India as a global leader in the years to come, says Union Minister Dr. Jitendra Singh. Press Information Bureau. Accessed from: https://pib.gov.in/PressReleasePage.aspx?PRID=2048873

[26] Chemical and Petroleum Statistics at a Glance - 2022, Ministry of Chemicals and Fertilizers, https://chemicals.gov.in/sites/default/files/Reports/Chemical_%26_PC_Statistics_at_a_Glance-2022.pdf

4.3. Barriers

4.3.1. High cost for Material Transition

The transition to bio-based inputs in chemical production presents significant cost challenges. Bio-feedstocks, except for ethanol, are generally more expensive than their fossil-based counterparts, ranging from 1.2 to 4.2 times their cost. For example, bio-naphtha is estimated to be at USD 3,500 per tonne, over its fossil analogue at USD 750 per tonne[10]. As another example, the production of bio-ethylene in India from bioethanol is estimated to cost around USD 1,220 per tonne, while the global average price of chemical-based ethylene is around USD 1,100 per tonne (ranging between USD 600-1,300/t)[27]. The higher production costs associated with sustainable chemicals can be a major barrier to their widespread adoption, reflecting the need for government support in promoting R&D and substantial incentivisation of the production of bio-based inputs.

4.3.2. Responsible and Reliable Sourcing of Biomass

The growth and wider adoption of bio-based chemical feedstocks are constrained by numerous challenges, viz., sourcing and collecting biomass, appropriate sourcing to avoid conflicting with food and consequent inflation, seasonality, storage (dry). Further, the need for a reliable biomass supply throughout the year, requires managing the seasonal and scattered nature of biomass production. Additionally, biomass is a heterogeneous feedstock, and usage depends on the condition as well as the source material and composition, affecting the calorific value, specific chemical constituents etc.

Some of these procurement-related challenges may be overcome by developing an efficient storage and transportation infrastructure for biomass, which requires substantial investment, further increasing the cost of transition from fossil-based to bio-based chemical feedstocks. In addition, the government imposes restrictions on the usage of certain feedstocks like rice, cane juice and B-heavy molasses due to concerns over inflation in cereal and sugar markets, which further adds to uncertainty in terms of the availability of bio-based feedstocks. Considerations (technical/ R&D as well as supply chain) must also be made to develop biomass as a consistent and reliable feedstock for the chemical industry. Specific opportunities like the development of supply chain for 2G feedstocks, and allied technologies for converting lignocellulosic biomass, can also alleviate challenges from stubble burning.

While seeking to manage the emerging supply and demand for biomass via policy interventions, this can also be considered an opportunity for cooperation, as the direct usage scenarios could include thermochemical and biochemical intermediates like syngas, bio-oil, etc., to power the energy transition in the chemical industry. The same processes can also yield biogas, bioethanol, biomethane, and liquid hydrocarbon cocktails (bio-oils, biodiesel), which are starting points for many chemical intermediates.

Further, with multiple use cases for biomass (energy, fuels, aviation fuels and chemicals), some of the transition schemes compete for the same biomass resource. In direct competition is the need to decarbonise India's transport sector, which is the third largest GHG emitting sector and accounts

[27] EA-ETSAP & IRENA. (2013). Production of bio-ethylene: Technology brief. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2013/IRENA-ETSAP-Tech-Brief-I13- Production_of_Bio-ethylene.pdf/1000

for about 14% of our energy-related CO_2 emissions[28]. The growing demand for the generation/supply and diversion of biomass for biofuels, SAF and for chemicals can lead to undesired competition, market and price distortion, unmanaged overall environmental outcomes, and needs to be managed by policy incentivisation and/or regulation. While the National Biofuels Policy has partly managed this for the biofuels, a more comprehensive set of guidelines needs to be developed. In its absence, market forces are likely to drive the destination of biomass and will beat the desired outcome of the material transition for decarbonisation.

4.2.5. Technology Readiness at Scale

In India, the production of bio-based chemical feedstocks is still in its early stages and requires significant investments in capital assets, logistics and innovative technologies. The government needs to incentivise the production and usage of bio-based feedstocks across various industries beyond ethanol blended petrol (EBP) through appropriate policies. Investment needs may be met through capital and R&D investment from both industry and government (as in the case of bio-refineries in India), financial backing through green bonds, dedicated technology funds, capital subsidies, etc. This financial support is essential to develop sustainable and resilient supply chains for bio-based chemicals.

To exemplify challenges in the chemical transition, some of the supply chain challenges in bioethanol production are indicated below:

Competing uses for biomass (high demand from EBP program)	Restrictions to access certain feedstocks based on concerns over inflation in cereal and sugar markets	Higher cost of producing 2G bioethanol- scaling up requires government support

The case of ethanol in India underscores the broader challenges the chemical sector faces during the material transition. Addressing these challenges will require coordinated efforts across government, industry, and supply chain stakeholders to develop sustainable supply chains for bio-based feedstocks. Achieving the material transition through availing opportunities and overcoming challenges, requires strong policy support and regulatory interventions. Some of the existing policy support and the need for more strong policies are discussed in following sections.

[28] Sinha, S., & Sharma, M. (2021, June 24). Decarbonising transport: Redefining mobility policies in India. The Indian Express. NITI AAYOG. Accessed from: https://www.niti.gov.in/decarbonising-transport- redefining-mobility-policies-india

05 Policy & Regulatory Framework

5.1. Existing Policies & Regulations

The government has implemented several regulations and policies aimed at promoting bio- based feedstock for energy generation, as well as addressing the emissions from fossil fuels. Some of the major policy initiatives and measures are:

1. **SAF Production:** India is actively working towards integrating SAF into its aviation sector, with a specific mandate for blending SAF with conventional aviation turbine fuel (ATF).
   a. Initial mandate for 1% blending by 2025 – 1% mandate for domestic airlines with an ambition to achieve 5% blending in coming years.
   b. The SAF produced will primarily come from sustainable sources such as agricultural residues, municipal solid waste, and forestry residues. This approach supports waste management and contributes to significant reductions in greenhouse gas emissions[29], up to 80% compared to traditional jet fuels.
2. **Anusandhan National Research Fund:** This fund primarily aims to seed, grow and promote research and development (R&D) and foster a culture of research and innovation throughout India's universities, colleges, research institutions, and R&D laboratories. It is administered by the Anusandhan National Research Foundation (ANRF), acting as an apex body which:
   a. Provides high-level strategic direction of scientific research in the country in accordance with the National Education Policy.
   b. Fosters a culture of research and innovation in universities, colleges, research institutions, and R&D laboratories.
   c. Enables India's research and innovation ecosystem.

The ANRF has received a significant boost in the 2025 Union Budget. The allocation for ANRF has been increased to USD 230 million (INR 2,000 crore) for the fiscal year 2025-26, compared to USD 23 million (INR 200 crore) in 2024-25. This scheme is perhaps ideally placed to upscale technologies that lie in the "high technological risk - high market risk" quadrant with industry-academia collaborations. This increase is part of a broader effort to enhance domestic research, development, and innovation in India.

3. **BioE3 (Biotechnology for Economy, Environment and Employment) Policy:** BioE3 is a major initiative approved by the Indian Government in August 2024 to accelerate the country's biomanufacturing capabilities and position it as a global leader in biotechnology innovation. The bio-based processes and technology routes being promoted under this policy are well aligned to some of the material transition approaches. Key features of the policy are-
   a. Innovation-driven support for R&D and entrepreneurship across thematic sectors like bio-based chemicals, carbon capture, etc.
   b. Shift from chemical-based industries to bio-based models, promoting a circular bioeconomy and working towards net-zero carbon emissions.
   c. Enhance India's competitiveness in the global biotechnology market while ensuring responsible and safe development of biotechnologies.

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[29] Net zero 2050: sustainable aviation fuels – December 2024 https://www.iata.org/en/iata-repository/pressroom/fact-sheets/fact-sheet-sustainable-aviation-fuels/

4. **Eco Mark Scheme:** The initiative is aimed at promoting environmentally friendly products through a certification and labelling system. It was first introduced in 1991, with the Ministry of Environment, Forest and Climate Change notifying the rules in September 2024, which officially came into effect in October 2024.
   a. Promote Eco-Friendly Products: The primary goal is to encourage consumers to choose products with a lesser adverse environmental impact.
   b. Support Manufacturers: The scheme motivates manufacturers to adopt environment-friendly practices in their production processes.
   c. Consumer Awareness: By providing clear labelling, the Eco Mark Scheme aims to enhance consumer awareness regarding the environmental impacts of products.

Some of the more recent/ related initiatives have also been implemented to specifically focus on promoting bio-based feedstocks and alternatives in the chemical sector (as captured in Figure 3).

Figure 3 Government policies and regulations aimed at promoting decarbonisation through biomass use, CCUS.

It's important to note that while these policies and regulations provide a framework for bio-based fuels and, to some extent, bio-based chemicals, there is still a need for more specific policies targeting bio-based chemicals and there is room for expansion to cover a broader range of bio-based products.

Additionally, looking to internationally developing policies, CEFIC's Safe and Sustainable by Design framework and OECD's Safe and Sustainable by Design framework, can also enable building relevant standards and certification schemes, that may be developed in the indigenous context and are globally acceptable. This will help India emerge as a top-ranking player in the global sustainable chemicals sector.

A clear policy and regulatory framework promoting bio-based feedstock and reducing fossil dependency is key for sustainable materials in the chemicals industry. Directional initiatives include SAF in ATF, ANRF support, BioE3, Eco Mark labelling. Additionally, a mix of mitigation and adaptation options, and adopting global standards, implemented in a participatory and integrated manner, can enable rapid, systemic transitions necessary for an accelerated material transition within chemicals, consistent with limiting global warming to under 1.5°C.

Mr. Debojit Chakrabarty
Senior Vice President – Research & Development,
Jyothy Labs Limited

5.2. Need for Long-term Policy Vision for Material Transition

Transitioning from fossil-based chemicals to bio-based chemicals presents a significant opportunity for India. It is essential for achieving sustainability goals, reducing greenhouse gas emissions, and fostering a circular economy. However, this transition is complex and requires a long-term policy vision to address multiple aspects of the biomass-based chemicals value chain and maximise the potential benefits of bio-based alternatives.

Further, more than 90% of material needs currently depend on fossil resources. While there is an imminent need for a transition, this will likely take decades. For a significant time in the future, fossil and renewable resources will coexist and need to be co-deployed. Therefore, during this transition, approaches such as mass balance and relevant certification schemes will have to be adopted, and regulations to support them will have to be made available. Several key aspects that drive the need for a robust policy framework –

Addressing Market Uncertainties

A long-term vision will be needed to provide stability and predictability in the face of the fluctuations of fossil-fuel prices and their impact on bio- based alternatives. It will provide clear direction to help mitigate technological risks associated with developing new bio-based processes, by providing a stable environment for innovation and investment.

Aligning with Climate Goals & International Commitments

India's commitments under the COP21 Paris Agreement will be amply supported by the transition to bio-based chemicals. India has also set targets under its Panchamrit goals and envisions to achieve net-zero emissions by 2070. The outcome of the material transition can effectively support this commitment.

Ensuring Economic Competitiveness

Bio-based chemicals need support to compete with established fossil-based alternatives, which have decades of infra development and economies of scale. Large-scale investments in bio-based chemical production will require assurance of policy stability. A long-term vision can help bio-based alternatives achieve scale, efficiency and attract investments.

Promoting Technological Innovations

The development of new bio-based processes often takes many years, and a long-term policy vision will provide the necessary support. Bridging the gap between lab-scale discoveries and commercial production and facilitating technology transfer requires sustained policy support, which a long-term vision can provide.

Building Resilient Supply Chain

Developing reliable biomass supply chains will need a long-term policy vision for the gradual development and restructuring of the existing supply chain. New infrastructure development for biomass collection and processing needs to be built at an extensive level and it can contribute significantly to the rural economies. A long- term vision will allow for the integration of economic goals with the chemical industry’s transition.

The transition from fossil-based to bio-based chemicals is complex and involves economic, environmental, social, and technological factors. A long-term policy vision is essential for stability and support. Policy recommendations should be prioritised based on industry needs, resource availability, and potential impacts, ensuring alignment with sustainability goals and fostering innovation and competitiveness.

> *Chemical Industry is an important stakeholder in decarbonising our world & making it safe for generations to come. Green House Gas reduction, green chemistry, sustainable feedstocks, waste circularity etc are critical pillars in moving towards sustainable chemical industry.*
>
> **Mr. Avinash Nandanwar**
> *Head – Sourcing & Sustainability, Galaxy Surfactants Limited*

06 Policy Recommendations

India's transition to bio-based feedstock in the chemicals sector needs comprehensive policy support to incentivise sustainable practices, considering economic and social impacts. With competition from other sectors like energy and aviation, a holistic policy framework is crucial to address shared challenges and opportunities, ensuring all sectors contribute to net-zero goals without hindering each other. Some of the coordinated policy interventions necessary to overcome market barriers, drive innovation, and create a level playing field for bio-based alternatives are provided as key policy recommendations below.

Technology Development Support

- Dedicated bio- based chemicals technology fund
- Support for technology and scale up of biobased materials

Industry & Economic Competitiveness

- Modified PLI scheme for bio- based chemicals
- Industry incentive to develop domestic manufacturing capabilities at scale, global competitiveness

Supply Chain Development

- Building biomass infrastructure, value chain
- Coordinated and Certified value chains
- Skill development and FPO integration

Risk Financing

- Green bonds
- Duty exemption/ subsidies for biomaterials
- Sustainable finance/ Capital support

Green Public Procurement & Consumer Awareness

- Targets for green public procurement
- Product certification
- Consumer awareness for sustainable product labelling

Figure 4: Policy interventions needed to address market barriers, drive innovation, and create a level playing field for bio-based alternatives

6.1. Technology Development Support

Accelerating the development and commercialisation of bio-based chemical technologies requires sustained investment and risk-sharing mechanisms that can be achieved through strategic public-private partnerships (PPPs), complemented by targeted grant programs and viability gap funding. It will create a robust innovation ecosystem that bridges the critical gap between laboratory breakthroughs and commercial deployment. Key policy ask is:

- Financial grants for supporting industry-academia partnerships for the development of technologies in bio-based chemicals bridging TRLs across 3-7 and bridging the gap between foundational research and commercialisation. Neither the academia/R&D institutions nor the industry is appropriately structured to bridge the TRL 4/5 - 7/8 'Valley of Death' for various reasons. Like in other countries, a newly created different set of institutions are needed whose primary goal is to upscale technologies and de-risk them beyond the lab-scale proof of concept/mini-pilots.

- Grants could support the establishment and operational costs of industry chairs in universities, encouraging long-term collaboration, and enhancing the relevance of research outcomes while creating a talent pipeline with expertise tailored to industry requirements.
- Additionally, this nature of financial support enabling industry-academia partnerships creates opportunities for incubation centres tied to universities where industries can provide the necessary infrastructure and mentorship to foster early-stage startups and spin-offs in the bio-based chemicals and bio-fermentation sector.

> *Innovation towards bio-based chemicals is essential for a sustainable future. By leveraging bio-solutions, we can unlock new value streams for producers and reduce the reliance on fossil fuels. Strategic support for technology development will help accelerate breakthroughs, enabling reach commercial scale, balancing environmental upliftment and industry competitiveness.*
>
> **Mr. Krishna Mohan Puvvada**
> *Regional President, Middle East, India and Africa, Novonesis*

To achieve these objectives in a relevant timeline, the following interventions are required:

- Research and technology pathways for chemical intermediates decoupled from fossil resources; especially for feedstocks such as UCO, waste biomass (2025)
- Low carbon pilot process for bio-based thermochemical & biotechnology routes (2026)
- Investments in scale manufacturing through established pathways as above (2026 onwards)
- Focussed support for key platform chemicals (prioritised by feasibility, volume demand, potential GHG reduction and economic viability) (2027-2030)

Some of the suggested areas that would positively impact the chemicals industry are:

- Extension of the biofuels value chain to further extend the bio-based ethanol value chains to ethoxylated products
- Building capability and ecosystem of valorised bio-lignocellulosic intermediates to BTX, long chain hydrocarbon value chain and relevant biomaterials
- Building expertise in bio-fermentation outside the pharmaceutical sector, particularly in areas like lignin and ethanol di-acetic acid fermentation
- Exploration of alcohol to aviation fuel routes to a variety of other aromatic and linear hydrocarbons

There is an opportunity for this specific policy intervention to be achieved by extending the ambit of ANRF (detailed above in Section 5.1) and supporting a mission on the material transition, as was under its Mission for Advancement in High-impact Areas (MAHA) program for the EV industry.

However, heralding this material transition requires specific, targeted and sustained effort to reduce GHG emissions, dependence on fossil resources and help climate action goals. This will also require support to industry through specific technology missions via government institutes, like those under Council of Scientific & Industrial Research (CSIR). A centralised portal to bring together funding sources and sustainable innovations seeking capital, across Department of Science and Technology (DST), Department of Biotechnology (DBT) etc., could further aid this.

6.2. Industry & Economic Competitiveness

The transition to bio-based chemical production presents a strategic opportunity to strengthen domestic manufacturing capabilities and establish leadership in the growing global bioeconomy. As international markets increasingly prioritise sustainable products and major economies implement carbon pricing mechanisms, early movers in bio-based manufacturing will gain significant competitive advantages. Key policy measure to accelerate transition at the industry level:

- Special incentives are needed for the chemical industry across scales, ranging from large chemical producers, MSMEs and start-ups, to operate to accelerate the transition. MSMEs and start-ups play a crucial role in driving innovation and fostering competition. Given their agility and capacity for niche innovation, they can significantly contribute to the acceleration of the transition from fossil-based to bio-based chemicals. Policy interventions offering tailored incentives such as grants, subsidies, low-interest loans, access to shared facilities and capacity building can unlock their potential while addressing systemic challenges in the industry.

The Union Budget 2025 has laid a strong foundation for a transformative leap in India's startup and MSME ecosystem. At a time when entrepreneurship is fuelling economic growth and job creation, the government has introduced a series of strategic measures aimed at fostering financial inclusion, innovation, and global competitiveness. A new fund-of-fund has been proposed with an allocation of ~ USD 1.1 billion (INR 10,000 crore) to expand the existing scope of startups eligible for funding. There is potential for earmarking a certain amount from this fund to specifically enable material transition in the chemical sector. Additionally, grants can be provided to MSMEs working in the sector for setting up pilot projects within their existing facilities to commence the transition.

A policy like Faster Adoption & Manufacturing of Electric Vehicles (FAME) could be an exemplar catalyst for such a transformation. e.g., industry support and upfront incentive to stimulate faster adoption of finished products.

6.3. Supply Chain & Environment Impact Management

6.3.1 Supply Chain Development

Establishing reliable, cost-competitive, and sustainable biomass supply chains is fundamental to scaling bio-based chemical production. The transition from concentrated fossil feedstock sources to distributed biomass resources requires new supply chain networks, quality standards, and market mechanisms to efficiently collect, process, and deliver feedstock. A systematic approach to supply chain development, supported by appropriate policy frameworks, will be essential to provide manufacturers with the confidence to invest in bio-based production capacity.

- A robust infrastructure for biomass collection, processing, and marketplace creation is essential to ensure a stable supply chain, reduce wastage, and enhance the economic viability of bio-based industries. This can be achieved by infrastructure development for biomass collection and processing independently or through Farmer Producer Organisations (FPOs) integration, marketplace creation and eventual digitisation, skill development and capacity building for farmers and the workforce.
- Investment in developing end-to-end feedstock and product management systems using blockchain-AI/ML platforms for operationalising best in class supply chain management.
- This policy intervention should also address skill development and capacity building for farmers and the workforce to maximise participation and benefits across the value chain.

6.3.2 Impact assessment, LCA, & Certification

Managing the transition to bio-based chemicals also requires support in terms of environmental impact assessment, and relevant validation and certification from competent bodies. Currently, the proliferation of certification schemes (e.g., Bonscuro, Roundtable on Sustainable Biomaterials (RSB), International Sustainability and Carbon Certification (ISCC), REDcert, Roundtable on Sustainable Palm Oil (RSPO) etc.,) requires complex compliance procedures. Establishing domestic certification options through premier national laboratories like those under CSIR and relevant private sector players could lower costs, ease market entry, and reduce bottlenecks in bio-based production and fermentation processes.

Prioritising environmental and social responsibility in the supply chain brings value to the people and communities. Reducing costs, improving efficiencies, and enhancing performance is fundamental to scaling chemical production from bio-sources. Further, health and well-being of the locals are important areas which will need to be addressed by appropriate framework. While we make our journey towards sustainable future and create a robust infrastructure, we will need to ensure that the carbon footprint is kept low through the entire life cycle of alternate feedstock and develop end-to-end traceability by using IoT based technologies.

Mr. Sumanda Bandyopadhyay

Senior Manager, Applications for Rest of Asia (APAC excl GC), SABIC

6.4. Financing

Financing the transition to bio-based chemical production requires innovative financial instruments and risk-sharing mechanisms that address the unique challenges of this emerging sector. To mobilise the substantial capital required for this transformation, a comprehensive risk financing framework is needed – one that combines public guarantees, green bonds, sustainable finance, and dedicated credit facilities. Following are examples of such financing mechanism:

- Green bonds for bio-based chemical projects.
- Economic policy interventions on a governmental level which will enable the transition to bio-based chemical production.
- Availability of duty exemptions or subsidies on the import or purchase of sustainable feedstock to support the capital-intensive transition to sustainable chemical production.

6.5. Green Public Procurement and Consumer Awareness

Strategic public procurement policies, coupled with enhanced consumer awareness initiatives, can create powerful demand-side drivers for bio-based chemicals and materials. As one of the largest buyers in the economy, governments can leverage their purchasing power to provide assured markets for sustainable bio-based products, helping manufacturers achieve economies of scale and stimulate market development. Some of the measures which may be undertaken are:

- Mandatory public procurement targets of bio-based chemical products by 2030 and green public procurement policy for bio-based chemicals.
- Product labelling and certification frameworks for products made from bio-based chemicals.
- Consumer education and awareness programs through national campaigns, digital platforms, and education curriculum integration.

A 'green chemical industry' also provides an opportunity to amplify Mission LiFE and drive widespread consumer awareness and behavioural change. This will support the economic viability of the transition, since apart from scaling up the supply, it is equally important that consumers be inclined towards products that are made with components that are environmentally friendly and safe for humans. A case can be made for supporting and accelerating renewable chemicals for the cleaning industry, a product category that can impact through high volume/ scale, great potential for positive environmental impact and a product category with great consumer engagement. Bio-based surfactants, for example, have great potential to help reduce the cleaning industry's carbon impact as it's fully biodegradable with a low-impact lifecycle.

07 Summary & Conclusions

India’s chemical industry, valued at USD 220 billion and growing at 8.1% CAGR, faces challenges like high GHG emissions and import dependence. Material transition, to bio-based alternatives using abundant biomass, alongside energy transition, is imperative for achieving India's net zero ambitions, and can also enhance energy security, reduce imports, and create jobs. Policy support and industry collaboration are crucial for overcoming high costs and technology gaps. A policy framework with five pillars is recommended, viz., support for bio-based technology development & specific technology interventions, industry competitiveness incentives, supply chain development, innovative risk financing, and green public procurement with consumer awareness initiatives. These measures aim to drive a sustainable material transition in India’s chemical industry.

Accelerating the transition to net-zero emissions from the chemical industry through innovation is crucial to minimising environmental impact, saving lives and creating new jobs. Bridging the 'Valley of Death' needs new institutions & investments to upscale technologies and derisk them beyond mini-pilots. The 2025 budgeted RDI scheme is perhaps ideally placed to address this.

Dr. Ashish Lele
Director,
CSIR – National Chemical Laboratory

Other Contributors

Rajat Arora, Jonathan Hague, Florian Verney, Nimish Shah, Isha Singh, Ian Howell, Rupert Posner, Tina Parker, Roberto Ferro, Babita Baruwati, Seema Yadav

Suryaprabha Sadasivan, Nikhil Rathi, Shubhangi Narayan

Materials Task Force

R G Krishnan (Aditya Birla Group Chemicals Business), Nitin Sharma (Clariant IGL Specialty Chemicals Pvt. Ltd), Esha Sar (International Finance Corporation), Debojit Chakrabarty (Jyothy Labs Limited), Manvir Saggoo (Novonesis), Phani Rao (Praj Industries Ltd.), Monish Ahuja (Punjab Renewable Energy Systems Private Limited), Sumanda Bandyopadhyay (SABIC)

Contact
Mr. Mritunjay Kumar
Director, FICCI & In-charge, RECEIC Secretariat,
mritunjay.kumar@ficci.com; receicsec@ficci.com

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RECEIC Address -
FICCI, 1 Federation House, Tansen Marg, Near Mandi House, New Delhi – 110002

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