1. Bio-Based Chemicals and Enzymes – S & T

India is promoting bio-based chemicals and enzymes as key pillars of a green bioeconomy, linking climate action, industrial growth, and rural income diversification

1. Conceptual Understanding

Bio-Based Chemicals

Definition- Industrial chemicals derived from renewable biological feedstocks such as sugarcane, corn, starch, lignocellulosic biomass, algae, agricultural residues, and industrial organic waste.

Production Pathways

1. Microbial fermentation (e.g., ethanol, lactic acid)
2. Enzymatic catalysis
3. Synthetic biology–driven metabolic engineering
4. Biorefinery models integrating multiple value streams

Core Principle- Replace fossil carbon (petroleum, natural gas) with biological carbon in chemical production.

Major Categories-

1. Organic acids (lactic acid, citric acid, acetic acid)
2. Bio-alcohols (ethanol, butanol)
3. Bio-based solvents and surfactants
4. Platform chemicals (succinic acid, 1,3-propanediol)
5. Biopolymers and intermediates (PLA, bio-based PET)
6. Specialty chemicals for pharma and cosmetics

Industrial Applications-

1. Bioplastics and packaging
2. Personal care products
3. Pharmaceutical intermediates
4. Agrochemicals
5. Adhesives and coatings

Strategic Importance- Forms the backbone of a circular bioeconomy and low-carbon industrial transformation.

Enzymes

Definition- Protein-based biological catalysts that accelerate biochemical reactions under mild operating conditions.

Functional Characteristics-

1. High specificity for substrates
2. Operate at low temperature and pressure
3. Reduce need for harsh chemicals
4. Improve process efficiency and yield

Industrial Applications-

1. Detergents (proteases, lipases)
2. Food and beverages (amylases, invertases)
3. Textile and leather processing
4. Pulp and paper bleaching
5. Pharmaceuticals and vaccines
6. Biofuel production
7. Advanced biomanufacturing

Technological Advancement-

1. Enzyme engineering
2. Directed evolution
3. AI-assisted protein design
4. Immobilised enzyme systems

Environmental Benefit-

1. Lower energy consumption
2. Reduced greenhouse gas emissions
3. Reduced chemical waste

2. Why India Needs Bio-Based Chemicals

Reducing Import Dependence

India imports several petrochemical intermediates, exposing industries to global price volatility.

Example- Approximately $479.8 million worth of acetic acid imported in 2023.

Bio-based domestic production reduces

1. Foreign exchange outflow
2. Supply chain vulnerability
3. Geopolitical risk exposure

Leveraging Agricultural Strength- India's large agricultural base generates abundant biomass, including

1. Sugarcane molasses
2. Rice husk
3. Wheat straw
4. Corn residues

Opportunities

1. Diversified farmer income
2. Monetisation of crop residues
3. Reduction in stubble burning
4. Creation of rural bio-industrial clusters

Supports agro-industrial integration and rural industrialisation.

Strengthening Climate Commitments

Bio-based chemicals generally have-

1. Lower lifecycle carbon emissions
2. Reduced fossil carbon intensity
3. Greater recyclability potential

Aligns with

1. Net Zero 2070 commitment
2. Nationally Determined Contributions (NDCs)
3. Circular economy objectives

Facilitates decarbonisation of hard-to-abate industrial sectors.

Enhancing Industrial Competitiveness- India's pharmaceutical and vaccine ecosystem has strong fermentation expertise. Skilled workforce in biotechnology and life sciences.

Potential to

1. Become a global supplier of sustainable intermediates
2. Capture emerging green chemistry markets
3. Integrate with global value chains

3. Policy Framework in India

BioE3 Policy (Biotechnology for Economy, Environment and Employment)

Focus Areas

1. Biomanufacturing infrastructure
2. Technology translation from lab to industry
3. Skill development
4. Employment generation

Emphasis on

1. Sustainable chemicals
2. Enzymes

3. Bio-based materials

Bio-RIDE Scheme

Outlay- ₹9,197 crore

Objectives

1. Support biotech R&D
2. Promote industrial scale-up
3. Develop biofoundries
4. Strengthen translational research

Dedicated support for biomanufacturing ecosystem development.

Infrastructure Development

Establishment of-

1. Biomanufacturing hubs
2. Pilot plants
3. Demonstration facilities
4. Bio-AI hubs

Goal- Reduce "valley of death" between research and commercialization.

4. Global Best Practices

European Union

EU Bioeconomy Strategy integrates-

1. Climate targets
2. Waste valorisation
3. Circular industrial policy

Coordinated funding, certification systems, and regulatory harmonisation.

United States

USDA BioPreferred Program

1. Mandates federal procurement preference
2. Creates assured early demand
3. Reduces market risk for producers

Strong venture capital ecosystem in synthetic biology.

China

Strategic national plans prioritise-

1. High-value bio-based chemicals
2. Enzyme engineering
3. Industrial biotechnology

Strong state-backed scale-up mechanisms.

Japan

METI/NARO programs integrate-

1. Research institutions
2. Industry readiness
3. Manufacturing scale transition

Focus on process optimisation and industrial integration.

5. Risks and Constraints

Cost Competitiveness

Bio-based chemicals often face-

1. Higher capital expenditure
2. Smaller economies of scale
3. Feedstock cost volatility

Petrochemical incumbents benefit from-

1. Established infrastructure
2. Scale advantage

3. Integrated refineries

Feedstock Availability

Constraints

1. Seasonal supply
2. Competing uses (food, feed, bioenergy)
3. Logistics and storage challenges

Risk of food vs fuel debate if poorly managed.

Market Adoption

Downstream industries may hesitate due to-

1. Switching costs
2. Process compatibility concerns
3. Certification and performance validation

Requires standardisation and demonstration of equivalence.

Technological Gaps

Need for

1. Advanced strain development
2. Improved yield and productivity
3. Reduced downstream processing cost

6. Way Forward- Strategic Recommendations

Infrastructure Development

Create shared

1. Biofoundries
2. Pilot-scale fermentation plants
3. Demonstration facilities

Reduce capital risk for startups and SMEs.

Standards and Certification

Develop

1. Bio-based content standards
2. Carbon accounting frameworks
3. Sustainability certification systems

Enhance market confidence and export readiness.

Promote R&D and Innovation

Invest in

1. Synthetic biology
2. Enzyme engineering
3. Metabolic pathway optimisation
4. AI-driven strain design

Strengthen academia–industry collaboration.

Demand-Side Policy Support

Introduce

1. Public procurement mandates
2. Green labelling
3. Fiscal incentives or carbon pricing

Create predictable early-stage demand.

Sustainable Feedstock Strategy

Encourage

1. Use of agricultural residues
2. Waste biomass valorisation
3. Integrated biorefinery models

Avoid diversion of food crops.

Conclusion- Bio-based chemicals and enzymes represent a structural shift from fossil-carbon industrial chemistry to renewable-carbon biomanufacturing. For India, the sector is not merely an environmental initiative but a strategic industrial opportunity — combining import substitution, rural development, climate commitments, and high-value manufacturing leadership.
Source- https-//www.thehindu.com/sci-tech/science/what-are-bio-based-chemicals-and-enzymes-explained/article70636267.ece