GREEN CHEMISTRY AND LABOUR LAW: TOWARDS SUSTAINABLE AND SAFE WORKPLACES

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ABSTRACT

The intersection of green chemistry concepts and labour legislation in developing safe and sustainable workplaces. Green chemistry focuses on safer chemical design and use, as well as the implementation of safer processes that minimise or eliminate harmful chemicals, thereby directly impacting employee health by limiting toxic exposure. Labour legislation serves as the legislative base that implements health and safety regulations to ensure workers are entitled to safe working environments. Combining these two methods presents a synergistic approach that promotes environmental sustainability, labour safety, and social justice. By embracing green chemistry technologies with proper labour protection, workplaces will be able to better mitigate chemical risks, minimise workplace injuries and diseases, and ensure fair treatment of employees. This convergence fosters an active safety culture centred on preventing hazards, rather than relying on reactive control practices, which in turn promotes healthier workers and a more sustainable industry. The paper is written to call attention to the responsibility and actions of employers, workers, and policymakers in making this shift, showing policy, science, and practice combining to realise safer, more sustainable industrial workplaces. This captures the fundamental connection between green chemistry and labour legislation towards safer, sustainable workplace growth.

INTRODUCTION

GREEN CHEMISTRY

Green chemistry is the research strategy dedicated to creating chemical products and processes that minimise or eliminate the use and formation of hazardous substances, with a goal to have little or no effect on the environment and to enhance human and ecosystem safety.

Key Features

- Averts pollution at the point of origin, instead of cleaning up waste after its creation. Encourages the use of renewable resources and energy-efficient processes.
- Promotes the design of safer chemicals and minimises the production of hazardous materials.
- The 12 Principles of Green Chemistry, which include waste prevention, atom economy, energy efficiency, and designing for degradation, guide these efforts.
- Green chemistry contributes to sustainable development through the safer, cleaner, and more environmentally friendly processes of chemicals.

LABOUR LAW MEETS GREEN CHEMISTRY

Labour legislation, on the other hand, mandates employers to provide safe working conditions and to comply with safety standards and legislation. By implementing green chemistry, employers are tackling these regulations at their most powerful level: eliminating or replacing dangerous chemicals is the most powerful hazard control methodology under the NIOSH (The National Institute for Occupational Safety and Health) hierarchy of controls and is accepted as such. The alignment of labour law and green chemistry allows the workplace to shift toward preventive accident prevention, enhanced compliance, and enhanced worker health, where workers' safety is secured not only through mitigation, but by refocusing on chemical risks fundamentally and reducing them at their origin.

OBJECTIVE:

The goal is to illustrate how green chemistry, through reduction or avoidance of harmful

chemicals at the point of origin, promotes workplace health and safety directly through safer chemical design and processes. Labour law can then be a feasible enforcement tool, compelling employers to adopt these best practices by requiring hazard elimination, controlling exposure, and enforcing employees' rights to a healthy workplace. In combination, green chemistry and labour law represent a holistic strategy for protecting workers through prevention of accidents, minimising toxic exposures, and instilling safety into the very fabric of industrial processes.

CONCEPT OF GREEN CHEMISTRY

Overview of the 12 Principles of Green Chemistry:

I) Prevent Waste: Avoiding the generation of waste is preferable to cleaning up or treating waste after it has been formed. Chemical processes should be designed to minimise waste generation at their source.

II) Maximise Atom Economy: Synthetic strategies should be developed so that the final product holds the maximum amount of the initial materials. This minimises waste through the efficient use of all atoms in the process.

III) Design Less Hazardous Chemical Syntheses: Chemical syntheses should be designed to utilise and produce substances of lower toxicity to human health and the environment.

IV) Design Safer Chemicals and Products: Chemical products must function safely with their intended purpose, with as little toxicity to humans and the environment as possible.

V) Use Safer Solvents and Auxiliaries: The solvents and auxiliary materials must be minimised or avoided. If unavoidable, safer solvents must be selected to minimise harmful effects.

VI) Enhance Energy Efficiency: Minimise energy usage by performing chemical reactions at room temperature and pressure whenever feasible to reduce environmental and economic effects.

VII) Employ Renewable Feedstocks: Renewable starting materials must be employed instead of depletable starting materials, prioritising resources such as crops or waste materials over fossil fuels.

VIII) Eliminate Chemical Derivatives: Prevent unnecessary use of blocking or protecting

groups or temporary transformations since they involve additional reagents and generate more waste.

IX) Use Catalysts, Not Stoichiometric Reagents: Catalysts are to be used due to their ability to catalyse a reaction repeatedly in small quantities, thus minimising waste compared to the stoichiometric reagents utilised in excess and consumed in one process.

X) Design Chemicals to Degrade After Use: Chemical products must be designed to decompose into harmless materials after being utilised, avoiding accumulation in the environment.

XI)Real-time Analysis to Prevent Pollution: Incorporate in-process, real-time monitoring and control in synthesis to avoid or reduce the creation of harmful byproducts.

XII) Reduce the Likelihood of Accidents: Chemicals and physical states should be designed to reduce the possibility of accidents involving explosions, fires, or releases to the environment.

These values are what direct chemists to design safer, more effective, and environmentally friendly chemical processes, improving sustainability as well as lessening harmful effects on health and the world.

Consumer Education and Research Centre v. Union of India (1995).

In this case, the Supreme Court of India itself expressed clearly that workers' health is upheld under Article 21 of the Constitution[1], particularly underscoring the fact that the State and management are bound by duty to protect the health of workers, particularly in the presence of harmful substances and environments common in the chemical and manufacturing industries. The Court ordered the formulation of policies for the safety of workers, insisted on routine medical check-ups, and emphasised compulsory compliance with applicable environmental and occupational safety legislation.[2]

This ruling is in line with several green chemistry principles—e.g., designing safer chemicals and processes, increasing energy efficiency, real-time monitoring, and minimising risk of

[1] INDIA CONST. art. 21.
[2] Consumer Education & Research Centre v. Union of India, 1995 S.C.C. (3) (India).

accidents—by reinforcing the legal requirement to reduce hazardous exposure and maintain worker welfare in industrial operations.

IMPORTANCE OF GREEN CHEMISTRY IN INDUSTRIES

Green chemistry is very significant in several industries, such as pharmaceuticals, textiles, agriculture, and chemicals, based on its emphasis on environmental responsibility, safety, and sustainability:

Pharmaceuticals

Green chemistry in drugs cuts back on dangerous solvents and reagents, decreases waste formation, and enhances the efficiency of reactions. This decreases environmental contamination and operating expenses and meets regulatory requirements for safer production. It favours safer drug designs and environmentally friendly synthesis pathways, improving public health and minimising exposure to toxins during manufacturing.

Textiles

In textiles, green chemistry facilitates the substitution of toxic dyes and chemicals with sustainable alternatives, lowering water pollution and toxic effluent. It encourages energy-efficient operations and waste reduction, resulting in healthier work environments for workers and a lower environmental footprint from textile production.

Agriculture

Green chemistry is involved in the creation of safer pesticides and fertilisers with reduced toxicity and enhanced biodegradability. This minimises soil and water contamination and maximises sustainable soil health and crop protection. It also promotes the use of renewable raw materials and bio-based agrichemicals, which benefits ecosystems and farm workers.

Chemicals Industry

For the larger chemicals community, green chemistry allows the production of environmentally friendly products and processes, minimising hazardous waste and emissions. It favours the utilisation of renewable feedstocks, energy-saving synthesis, and catalytic processes, enhancing safety, sustainability, and economic attractiveness.

Overall, green chemistry encourages a smaller environmental footprint, greater worker safety, compliance with regulations, and creativity, making industries more sustainable and socially responsible.

LABOR LAW AND GREEN CHEMISTRY: A SAFETY PARTNERSHIP

The 6th and 12th green chemistry principles—accident prevention and energy efficiency—are highly congruent with labour law by encouraging safer, healthier, and more sustainable working conditions in chemical and manufacturing sectors. Their incorporation facilitates not only environmental objectives but also the larger goals of labour law: protecting workers' welfare, reducing health hazards, and providing safety in workplaces.

6th Principle: Design for Energy Efficiency

The 6th principle commands chemical processes to be as low in energy demand as possible, preferably at ambient pressure and temperature. It sees both economic and environmental consequences of high energy consumption, calling for reactions and production methods that reduce the consumption of resources and pollution.[3]

Applied to labour law:

- Worker Health and Safety: Such high-energy processes place workers in contact with extremely high temperatures, pressures, and unsafe conditions, increasing the potential for burns, explosions, or heat-related sickness. By implementing energy-efficient process alternatives—mandated by green chemistry—the workplace inherently becomes safer, as mandated by labour law requirements for risk minimisation and protection of workers.

- Occupational Stress Reduction: Reducing process temperatures and pressures minimises the rate of equipment malfunction and emergency interventions, which lowers physical and psychological strain for employees. This complements labour codes stipulating reasonable workloads and secure operating conditions.

[3] G.A. Res. 70/1, annex, Transforming our world: the 2030 Agenda for Sustainable Development, at 15, U.N. Doc. A/RES/70/1 (Sept. 25, 2015).

- Sustainable Employment: Environmentally friendly technology tends to enable modernisation and upskilling of workers, serving the labour law purpose of safeguarding jobs as well as skills growth during technological changes.

12th Principle: Inherently Safer Chemistry for Accident Prevention

The 12th principle requires chemical and process design to avoid the potential for accidents—such as fires, explosions, and toxic releases. It encourages manufacturers to select chemicals and forms with inherent risk reduction.[4]

Relevance to labour law:

- Legal Duty of Care: Labour laws across the globe mandate employers to ensure a duty of care to ensure safe workspaces. The 12th principle facilitates compliance by reducing the root causes of hazards at the workplace—prevention instead of incident response.

- Accident Rate Minimisation: When chemical reactions are planned in such a manner that catastrophic accidents will not occur, the possibilities of acute harm, chronic disease, or death diminish considerably. Labour standards on accident reporting, emergency response, and compensation find support through green chemistry's accident minimisation philosophy.

- Worker Empowerment and Participation: Adoption of more secure chemical processes generally entails worker training, consultation, and feedback—core demands under contemporary labour law. Green chemistry's participatory philosophy adds to the overall safety culture.

- Prevention and Mandate Synergy: Green chemistry and labour law both have a prevention philosophy. The 6th principle's emphasis on minimising excessive energy handling serves to reinforce requirements of labour law to minimise workplace hazards, and the 12th principle directly satisfies statutory demands for prevention against accidents and worker security.

- Holistic Well-being: Through the integration of these principles, industrial businesses

[4] G.A. Res. 70/1, annex, Transforming our world: the 2030 Agenda for Sustainable Development, at 19, U.N. Doc. A/RES/70/1 (Sept. 25, 2015).

promote both social and environmental responsibility, decent work (according to ILO conventions[5] and SDG 8[6]), and a sustainable future for labourers, the community, and the environment.

Concisely, green chemistry's 6th and 12th principles not only propel sustainability in industry but also enhance labour law goals through a direct elimination of workplace hazards as well as promotion of long-term worker well-being.

The Bhopal Gas Tragedy is a landmark experience demonstrating the essential collaboration required between labour law and green chemistry to ensure industrial safety. Between December 2-3, 1984, a methyl isocyanate (MIC) gas leak from the Union Carbide India Limited pesticide factory at Bhopal caused thousands of fatalities and long-term, devastating health consequences for the affected population.

Labour Law Failures Highlighted

The tragedy exposed a poor occupational health and safety level, where there were inadequate regulations, a weak safety culture, failure to train employees, and low levels of emergency preparedness.

Post the tragedy, the Factories Act was amended (Provisions related to Hazardous Process) Sec.41A to Sec.41H to cope with chemical industry risks and workplace safety[7], while new legislation, such as the Environment Protection Act (1986)[8] and the Public Liability Insurance Act (1991)[9], was passed to improve safety guidelines, corporate responsibility, and compensation to victims.

Green Chemistry Principles and Bhopal

Several green chemistry principles, like "prevent waste", "design less hazardous chemical syntheses", "use safer chemicals and processes", "maximise the use of renewable materials and energies", and "reduce the likelihood of accidents," were violated straight away in Bhopal.

[5] Int'l Lab. Org., Declaration on Social Justice for a Fair Globalization, Res. I, 97th Sess., U.N. Doc. ILO/ILC/Res/2008/00 (June 10, 2008).
[6] G.A. Res. 70/**1**, Annex, ¶ 21, U.N. Doc. A/RES/70/1 (Sept. 25, 2015).
[7] The Factories (Amendment) Act, No. 20 of 1987, India Code (1987).
[8] The Environment (Protection) Act, No. 29 of 1986, India Code (1986).
[9] The Public Liability Insurance Act, No. 6 of 1991, India Code (1991).

Employment and storage of highly toxic MIC in bulk quantities, bad process design, and disregard for safer alternatives or catalysts maximised risk and disaster extent.

Lack of installing strong monitoring systems (real-time analysis), backup safety measures, and observing best safety practices resulted in disastrous consequences that could have been prevented if green chemistry principles were adopted.

The Safety Partnership:

Lessons from Bhopal illustrate the integral interconnection between labour law (workers' rights, health, and safety protection) and green chemistry (using safer processes and products)

Successful prevention of such catastrophes requires both vigorous legal requirements for workplace safety and a science-based commitment in industry to safer design, reduction of toxins, and lifecycle management of chemicals

The fallout resulted in companies being held more accountable for worker and community safety, echoing the necessity for sustained enforcement and cooperation between regulation and scientific ingenuity to avoid future disasters.

The Bhopal disaster is a strong argument that sound labour legislation, strict regulatory monitoring, and the ethical use of green chemistry are all essential to make the workplace safe, the environment protected, and the public good preserved.[10]

One very important Indian case that most epitomises the symbiosis of labour law and green chemistry ethos—particularly on the issue of safety in risky industries—is Consumer Education and Research Centre v. Union of India (1995) 3 SCC 42. In this Supreme Court case, workers' health and safety in the face of exposure to dangerous chemicals (e.g., those in the chemical and manufacturing sectors) were deemed to be safeguarded under Article 21 (the right to life) of the Constitution[11].

Major Legal Principles of the Case

The Supreme Court held that the State and employers both have a shared responsibility to

[10] Union Carbide Corp. v. Union of India, A.I.R. 1990 S.C. 273 (India).
[11] INDIA CONST. art. 21.

provide secure work environments and to put in place mechanisms preventing occupational injury by means of scientific and regulatory measures.

The Court emphasised that a healthy environment is a constituent of the right to life and dignity of man, and that it demands stringent health checks, proper environmental waste disposal, strict enforcement of safety measures, and adherence to environmental laws.

The ruling provides the groundwork for combining labour law's safety concerns with green chemistry's preventive, non-toxic, and life-cycle oriented approach, encouraging process design and operation that protects workers as a prerequisite of environmental safety.[12]

Why This Case Represents the Safety Partnership

The law closely supports green chemistry aspirations: reducing toxic exposure ("design less hazardous chemical syntheses"), preventing accidents, employing safer processes, and ensuring that workplace innovation promotes, not threatens, labour safety.

It specifically enables courts, legislatures, and administrators to apply statutory regimes (such as the Environmental Protection Act, Factories Act, and related rules) to the protection of both workers and the environment, showing effective law-science collaboration.

LABOUR LAW AND WORKER PROTECTION

Indian Legal Framework:

The Factories Act 1948 is still the bedrock of occupational safety in India, setting out detailed provisions for worker health, safety, and welfare:

Health Provisions (Sections 11-20):

Hygiene and ventilation standards in the workplace,

Provisions of adequate lighting and noise controls,

Supply of clean drinking water and toilet facilities,

[12] Consumer Education & Research Ctr. v. Union of India, (1995) 3 S.C.C. 42 (India)

Temperature control and dustproof measures.[13]

Safety Provisions (Sections 21-41):

Compulsory fencing of machines and protective equipment,

Prohibition on women and children's employment with hazardous machinery,

Appointment of safety officers for hazardous industries,

Emergency response measures and fire protection provisions.[14]

Welfare Measures:

First-aid amenities and occupational health units,

Restrooms, wash facilities, and canteens,

Medical testing requirements for workers with hazardous chemicals.

OSH Code 2020: Contemporary Labour Protection

The Occupational Safety, Health, and Working Conditions Code 2020 merges 13 current labour laws, introducing consistency to India's regulation of the work framework:

Key Features:

Comes into force for all establishments employing 10+ persons, mines, and docks,

Sets up Occupational Safety and Health Advisory Boards at the central and state levels,

[13] *The Factories Act, 1948*, No. 63, Acts of Parliament, 1948 (India), § 11.
1. *Id.* § 12.
2. *Id.* § 13.
3. *Id.* § 14.
4. *Id.* § 15.
5. *Id.* § 16.
6. *Id.* § 17.
7. *Id.* § 18.
8. *Id.* § 19.
9. *Id.* § 20.

[14] Factories Act, 1948, § 21-41 (India)

Makes the employer responsible for sanitary work conditions,

Asks for permission to work overtime and limits working hours to 48 hours a week,

Greater penalties: up to ₹5,00,000 in fines or 2 years' imprisonment for occupational negligence causing death.

Obligations of the Employer:

Supplying protective gear up to national standards,

Regular health check-up and medical monitoring,

Emergency preparedness planning and worker training initiatives,

Reporting workplace accidents and occupational illnesses immediately.[15]

Essential OSH Conventions:

Convention 155 (1981): Occupational Safety and Health Convention setting out basic safety principles[16],

Convention 187 (2006): Promotional Framework for OSH, calling for national policy formulation[17],

Convention 161 (1985): Occupational Health Services Convention calling for occupational health services in workplaces[18].

These conventions call for prevention, employee participation, and ongoing improvement in workplace safety standards.

Bhopal Gas Tragedy (Union Carbide Corporation v. Union of India) is not only an environmental catastrophe case but also a bleak example of profound failures of labour law

[15] The Occupational Safety, Health and Working Conditions Code, 2020, No. 37, Acts of Parliament, 2020 (India).
[16] Occupational Safety and Health Convention, 1981 (No. 155), art. [Article #], June 22, 1981, 1522 U.N.T.S. 456.
[17] Promotional Framework for Occupational Safety and Health Convention (No. 187) art. 2, June 15, 2006, 2695 U.N.T.S. 273.
[18] Occupational Health Services Convention, 1985 (No. 161), June 25, 1985, 1498 U.N.T.S. 397.

and protection of workers in India. On 2-3 December 1984, the leakage of hazardous methyl isocyanate gas from the Union Carbide factory resulted in thousands of fatalities and permanent disability to tens of thousands of people, including employees both inside and outside the factory.

Labour Law and Worker Protection Failures

Weak Occupational Safety Enforcement: The Factories Act, 1948[19], and subsequent progressive legislations protecting worker health and safety notwithstanding, the tragedy revealed sloppy enforcement, inadequately manned inspection, and ineffective risk management in risky industries.

Trade Union Inaction: Employees within the Bhopal factory had protested unsafe working conditions and pollution. Trade unions did not mobilise well either before or after the accident; however, this reflected systemic vulnerabilities in protecting worker rights and safety.

Compensation and Legal Issues: The Supreme Court imposed the doctrine of absolute liability on Union Carbide, making it liable for the harm on a strict liability basis due to the noxious industrial activity. However, the compensation that was given was widely regarded as insufficient by victims and advocates, revealing loopholes in laws and mechanisms for effective worker protection.

Impact on Labour Law Reforms

Enactment of New Legislation:

In turn, India passed legislation like the Public Liability Insurance Act, 1991, and enhanced Factories Act regulations to protect workers and public health in risky industries.

Emphasis on Workplace Safety: The tragedy pushed the realisation that workplace safety, health surveillance, risk identification, and emergency planning for workers are central principles of good labour law, not corporate obligations.

Current Challenges: Even after policy reforms, gaps in enforcement, lack of resources for oversight, and business opposition persist, making worker safety and protection a perennial

[19] The Factories Act, 1948, No. 63, Acts of Parliament, 1948 (India)

struggle decades after the tragedy.

The Bhopal Gas Tragedy, therefore, stands as a benchmark case illustrating why strong labour legislation and active enforcement are inextricably connected to worker safety and protection in risky sectors, and why their absence can mean disastrous human costs.

Occupational Health and Safety Association v. Union of India (2014) 3 SCC 547

Here, the Supreme Court of India reaffirmed the basic right of workers to a healthy and safe workplace under Article 21 of the Constitution.

The Court directed the Ministry of Labour and the concerned authorities to ensure adherence to labour legislation governing the safety and health of work and occupational health, highlighting the responsibility of the government to safeguard workers from health hazards from hazardous and unhygienic conditions of work.

The verdict emphasised the importance of medical check-ups, giving protective gear, ongoing health monitoring, and enforcement of prevention policies that conform to internationally accepted OSH conventions[20].

INTERSECTION OF GREEN CHEMISTRY AND LABOUR LAW

Safer chemicals lower accidents in the workplace by reducing the inherent risks of chemical compounds directly, thus contributing to a safer workplace.

Lower Toxicity: Safer chemicals are less toxic or even non-toxic to workers, minimising health hazards from exposure like poisoning, respiratory complications, or skin sensitisation.

Reduced Flammability and Reactivity: Less flammable, explosive, or reactive chemicals ensure safety against fire and explosion accidents.

Reduced Exposure: Green chemistry encourages the replacement of toxic chemicals with safer substitutes, thus keeping the amount of hazardous material low in the workplace. This minimises the likelihood of accidental spilling, leakage, or airborne exposure causing injury or

[20] Occupational Health & Safety Ass'n v. Union of India, (2014) 3 SCC 547 (India)

long-term health impacts.

Safer Handling and Processes: Safer chemicals tend to need less stringent control systems, with lower chances for human mistakes while handling, storing, and disposing of chemicals. Such ease brings down risks of accidents associated with intricate safety procedures or protective gear malfunction.

Environmental and Health Compatibility: If chemicals break down into innocuous products and leave fewer toxic waste byproducts, the danger of secondary accidents from environmental damage or toxic waste handling is reduced.

Alignment With Safety Management: Incorporating safer chemicals into workplace safety systems is aligned with models such as OSHA's hazard controls, where emphasis is laid on eliminating or substituting hazards as the most effective safety practice, which green chemistry upholds fully.

Safer chemical design and utilisation under green chemistry principles avoid accidents by removing or minimising chemical hazards, thus safeguarding worker health, reducing potential fire or explosion risks, and streamlining safe workplace procedures.

Protecting workers – the role of labour law

Labour legislation can insist on the phase-out or substitution of toxic chemicals and demand that employers incorporate green chemistry values into workplace practices, ensuring worker protection at the product and process design phase. Regulatory regulations like the EU's REACH regulation and India's OSH Code mandate the use, disclosure, and safe management of chemicals, including reporting and restricting highly hazardous substances and supply chain risk communication. Legislation may insist on frequent training of workers in safe chemical handling, demand safer technologies and equipment, and require transparent reporting and emergency preparedness for chemical-related emergencies. Enforcement mechanisms include penalties for non-compliance, regular safety audits, and rights for workers to refuse unsafe work or request safer alternatives according to green chemistry values and recognised occupational safety standards. Green chemistry is incentivised in some jurisdictions through fast-tracked regulatory approval, public recognition schemes, and legal protection for innovations that phase out toxins.

M.C. Mehta v. Union of India (1986)

This historic Supreme Court ruling brought in the doctrine of absolute liability over dangerous industries that inflict harm on workers and the environment.

The case spurred a move toward greater regulation of chemical production to enable safe process design and to shield workers against dangerous exposure, in the preventive vein of green chemistry, and in addition to labour law protection.

Broader Context

Principles of green chemistry, emphasising reduction of toxicity, safer materials use, and prevention of pollution, meet labour law objectives of occupational safety, monitoring of health, and prevention of accidents.

Indian courts increasingly believe that the protection of the right to life entails enforcing ecologically sustainable processes that prevent workers from exposure to dangerous conditions, in effect inserting green chemistry into labour law jurisprudence[21].

Case examples for the use of safer solvents and minimising pesticide toxicity:

1. Substitution of Hazardous Solvents

An R&D chemistry department in an industrial setting was able to cut the use of seven harmful solvents by half in two years by embracing green chemistry principles. Toxic solvents such as chloroform and dichloromethane (DCM) were replaced with safer substitutes, ethyl acetate, acetone, and bio-based alternatives such as dihydrolevoglucosenone (Cyrene). Hazardous waste was reduced, laboratory safety was enhanced, and sustainability was increased without the sacrifice of chemical performance.

Examples of past pharmaceutical industry applications include substituting conventional toxic solvents used in drug production with less harmful ones, such as water and renewable bio-solvents. In the synthesis of sertraline hydrochloride, for example, heavy metal catalysts and toxic solvents were avoided, leading to a greener and more selective process. In paroxetine

[21] *M.C. Mehta v. Union of India*, (1987) 1 SCC 395, AIR 1987 SC 1086 (India).

manufacture, production was also optimised to provide greater yield through greener and safer means that minimise hazardous solvent use and waste.

2. Reduction in Pesticide Toxicity

Green chemistry promotes the creation of less hazardous pesticides through designing molecules that are less toxic and more biodegradable. This shift minimises environmental pollution and health hazards to farm workers and communities. Less hazardous pesticide formulations also reduce occupational exposure and injury caused by working with dangerous chemicals in agriculture.

3. Substitution-based strategies

This involves substituting persistent, bioaccumulative chemicals with less toxic alternatives, such as biodegradable ones and natural product-based or bio-pesticides. This strategy ensures sustainable crop protection with lower toxic effects on non-target organisms and ecosystems.

CHALLENGES AND STRATEGIES IN IMPLEMENTATION

Firms can overcome the challenge of implementing green chemistry by addressing incentives, collaboration, and education, with cost-effective innovation and policy assistance facilitating sustainable transitions.

Major Barriers to Implementation

- Economic: Initial high capital investment requirements, ambiguity over long-term advantages, and resistance to replacement of current facilities are major barriers.
- Technical: Unavailability of green alternatives to some processes and challenges in scaling up from laboratory to industrial levels.
- Regulatory: Current regulations usually benefit conventional practices, posing barriers to approving greener counterparts and a lack of incentive schemes.
- Cultural: Lack of awareness and adverse attitudes towards green chemistry can hamper demand and take-up.

- Organisational: Absence of cross-functional backing from firms and inability to incorporate new technologies into existing processes.

- Definitions and Metrics: Uncertainty in what "green chemistry" is and the absence of standardised measures pose challenges to benchmarking and recognition.

Effective Solutions & Strategies

- Government Incentives: Monetary incentives such as grants, low-cost loans, or tax credits for green chemistry investments can reduce barriers to adoption.

- Policy Shift: Shifting regulation to emphasise hazard reduction (and not only exposure management) and simplifying approvals for green products spur innovation.

- Collaborative Networks: Support connections between solution providers, researchers, and industry to bridge technology transfer and develop scalable solutions.

- Education and Training: Create specialised programs and knowledge-sharing programs to educate chemists and engineers in green chemistry techniques.

- Public Awareness: Educate consumers and stakeholders on the advantages of green chemistry to create demand and reduce negative attitudes.

- Research and Innovation: Fund research into new technologies and processes based on renewable materials and energy-efficient processes; encourage pilot projects and case studies for replication.

- Metrics and Standards: Establish universal standards and metrics to assess and compare green chemistry solutions for various sectors.

Industry-Specific Approaches

- Pharmaceutical: Employ enzymatic catalysis for greener syntheses, minimising hazardous waste.

- Manufacturing: Incorporate biodegradable materials, enhance energy efficiency, and minimise hazardous emissions.

- Chemical Processing: Transition to solvent-free or green solvent systems to minimise VOC emissions and health hazards.

With a combination of financial incentives, collaboration, education, targeted research, and regulatory support, industries can overcome barriers and speed up the adoption of green chemistry for sustainable development.

CONCLUSION

Encouraging Worker Safety Labour legislation imposes requirements for health and safety conditions, whereas green chemistry proactively designs out chemical hazards at the source by substitution or safer process design. This is consistent with the occupational health "hierarchy of controls" principle, beginning with elimination or substitution of hazards, then engineering and administrative controls, followed by personal protective equipment as a last option. The coordination of labour laws with green chemistry offers holistic risk reduction that actively forestalls workplace injuries and occupational disease due to chemical exposure. Improving Social Justice. Social justice in this scenario is achieved by providing equal, just protection to all workers, particularly those who are vulnerable and are disproportionately exposed to toxic chemicals and hazardous workplaces. Labour legislation ensures workers' entitlements to safe working conditions and just treatment, while green chemistry minimises environmental health inequities through controlling hazardous exposures among marginalised groups. This holistic strategy adds to environmental justice, which enables the same access to healthy environments and decision-making participation regarding workplace safety and chemical usage.

WAY FORWARD

Stronger integration of green chemistry principles in labour safety laws.

Deeper incorporation of green chemistry concepts into worker safety legislation entails integrating green chemistry concepts—such as designing less hazardous chemicals and processes for avoiding hazards—into workplace safety policies. This strategy targets removing or minimising chemical dangers at the source, making the workplace safer and healthier. It supports best practices in safety by avoiding accidents, reducing toxic exposures, enhancing efficiency, and reducing costs to the benefit of workers and the environment.

Government incentives for industries adopting safer practices.

The government rewards grant industries that adopt greener practices through grant incentives, tax credit incentives, and subsidies that incentivise firms to invest in the creation of safer chemical processes and products. Individual incentives lower the cost of research and innovation in green chemistry and drive industries towards greener and safer production processes. Alongside, regulatory systems having explicit norms enable the adoption of such safer practices and education programs and campaigns for raising public awareness, enhancing a culture of sustainability and safety across sectors. Multi-stakeholder collaboration between government, industry, and academia also eases the transition towards green chemistry, resulting in enhanced workplace safety, lower environmental footprints, and financial gain for companies.

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