BIOSYNTHESIS IN GREEN CHEMISTRY

Biosynthesis is a core element of green chemistry, leveraging biological systems to produce chemicals, materials, and energy in a sustainable manner. This approach aligns with the twelve principles of green chemistry, prioritizing waste prevention, atom economy, and the use of safer, renewable feedstocks and catalysts.

Core principles of biosynthesis in green chemistry

Biosynthesis is fundamentally a "green" process because it operates under conditions that are mild, non-toxic, and energy-efficient.

- **Renewable resources:** It uses natural, often waste, materials (biomass) as feedstocks rather than non-renewable petrochemicals.
- **Reduced toxicity:** The process avoids or minimizes the use of hazardous reagents, volatile organic solvents, and toxic by-products that are common in traditional chemical synthesis.
- **Energy efficiency:** Biosynthesis typically occurs at ambient temperatures and pressures within living cells, requiring far less energy than high-temperature, high-pressure chemical reactions.
- **Waste prevention:** It is designed by nature to be highly efficient, with metabolic pathways that prevent the formation of waste. Any "waste" products are often non-toxic and biodegradable.
- **Catalysis:** The use of enzymes as catalysts offers high selectivity and efficiency. Enzymes function under mild conditions and are recyclable within the organism, avoiding the need for heavy metal or toxic chemical catalysts.

Applications and examples

1. Green synthesis of nanoparticles

Biological methods, including the use of bacteria, fungi, algae, and plant extracts, are used to create metal nanoparticles such as silver (Ag) and gold (Au).

- **Mechanism:** Biomolecules like enzymes, proteins, flavonoids, and other metabolites act as natural reducing and capping agents. For example, plant extracts can reduce metal ions to stable metal nanoparticles in a single, eco-friendly step.
- **Advantage:** This method is safer, more cost-effective, and more sustainable than traditional physical and chemical approaches that often use hazardous chemicals and high energy.

2. Bioproduction of industrial chemicals

Microorganisms can be engineered to biosynthesize platform chemicals and polymers.

- **Sitagliptin synthesis:** The pharmaceutical company Merck developed a greener, enzymatic process to synthesize the active ingredient in its diabetes drug, Januvia. The new method resulted in a 10–13% increase in overall yield while reducing waste.
- **Adipic acid production:** Researchers have demonstrated an integrated electrosynthesis and biosynthesis method for producing adipic acid, a precursor for Nylon, from lignin-derived feedstocks.

3. Cell-free biosynthesis

In this approach, enzymes are isolated from organisms and used *in vitro* to carry

out specific reactions. This offers a high degree of control over the process, but the challenge lies in making it cost-effective and scalable.

- **Challenge:** The high cost of enzymes and cofactors remains a significant hurdle for industrial-scale adoption. However, ongoing research aims to develop sustainable and economically feasible cell-free systems.

4. Engineered biosynthesis

Genetic engineering allows scientists to manipulate the metabolic pathways of microorganisms to increase the production of target compounds. This process enables the creation of new enzymes and pathways for synthesizing novel materials.

Challenges and future outlook

Despite its promise, the widespread adoption of biosynthesis in green chemistry faces challenges. These include the economic feasibility and scalability of large-scale production, particularly for cell-free systems that require costly enzymes and cofactors. However, continued advancements in metabolic engineering, synthetic biology, and cell-free technology are paving the way for more economically viable and sustainable biosynthetic processes. The integration of biotechnology with chemical synthesis is expected to become an increasingly important part of the transition toward a greener chemical industry.