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# Biocatalysts in Green Chemistry: Enzymes as Sustainable Reaction Tools

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**Abstract:**

Biocatalysis is the application of natural enzymes to perform chemical reactions. It forms a significant component of green chemistry since it minimizes pollution and makes chemical reactions safer and environmentally friendly. Unlike conventional chemical processes that frequently incorporate poisonous metals or harsh acids and bases, biocatalysis employs enzymes that operate under mild conditions such as regular temperature and pressure. These enzymes are derived from living organisms and can be reused, so they are eco-friendly. Examples of some of the most common biocatalysts are transaminases, hydrolases, and oxidases. These enzymes are responsible for specific kinds of reactions like preparing amines, hydrolyzing esters, or oxidizing. Biocatalysis has numerous advantages like high selectivity, low energy consumption, and fewer toxic by-products. It is already being applied in industries such as pharmaceuticals, food, and biofuels. In the future, improved understanding and application of enzymes can make chemical production cleaner and more efficient. This paper discusses the types of enzymes utilized in biocatalysis, how they work, and the role they play in making chemistry sustainable.

**Keywords:** Biocatalysis, Green Chemistry, Enzymes, Transaminases, Hydrolases, Oxidases, Sustainable Reactions.

## 1. Introduction

Green chemistry is a chemistry that is centered on designing products and processes that minimize or eliminate the use and generation of harmful substances. It seeks to render chemical practices safe for both humans and the environment. Green chemistry is founded on 12 core principles. They involve the use of safer solvents, designing energetically efficient processes, employing renewable feedstocks, minimizing waste, and maximizing atom economy. These principles assist in guiding researchers in developing more sustainable and less harmful chemical processes. One significant method that is favorable to green chemistry is biocatalysis. Biocatalysis employs enzymes, which are biological proteins, to conduct chemical reactions. Enzymes function as catalysts that accelerate reactions without being destroyed. Since enzymes operate under gentle conditions such as room temperature and neutral pH, they consume less energy and form fewer toxic by-products. Thus, they are a clean and environmentally friendly substitute for conventional chemical catalysts. Conventional catalysis tends to use strong bases, acids, or metal-containing compounds, which are toxic, corrosive, and difficult to dispose of. Biocatalysis, on the other

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hand, is selective, biodegradable, and safer to work with. This is why biocatalysis promises to be an effective tool for safer and greener chemical manufacturing [1].

## 2. Types of Enzymes in Green Reactions

Enzymes are strong weapons in green chemistry due to their high selectivity for reaction and mild, environmentally friendly conditions. Of the numerous enzyme types, transaminases, hydrolases, and oxidases/dehydrogenases are well employed in green chemical processes. These enzymes assist in minimizing waste, conserving energy, and evading toxic chemicals. The following are the primary types along with their applications in green chemistry.

### A. Transaminases

Transaminases are enzymes that transfer an amino group from one molecule to another. They are primarily utilized for the generation of chiral amines, which are essential for the generation of pharmaceutical drugs. Sitagliptin, a drug for the treatment of type 2 diabetes, is a significant utilization of transaminases.

In the conventional method, heavy metal catalysts and aggressive conditions were employed. However, employing a transaminase enzyme enabled the same reaction under mild temperatures and in water without toxic waste. The reaction is converted into sitagliptin from a ketone intermediate by an amine donor, with the enzyme conferring stereo-selectivity [2].

#### Balanced Reaction

Ketone + Amine donor → (Transaminase) → Chiral Amine (Sitagliptin) + By-product

This technique also provides higher yield and decreases the requirement for multiple purification steps. Figure 1 can be included here to represent the transaminase-catalyzed synthesis of sitagliptin.

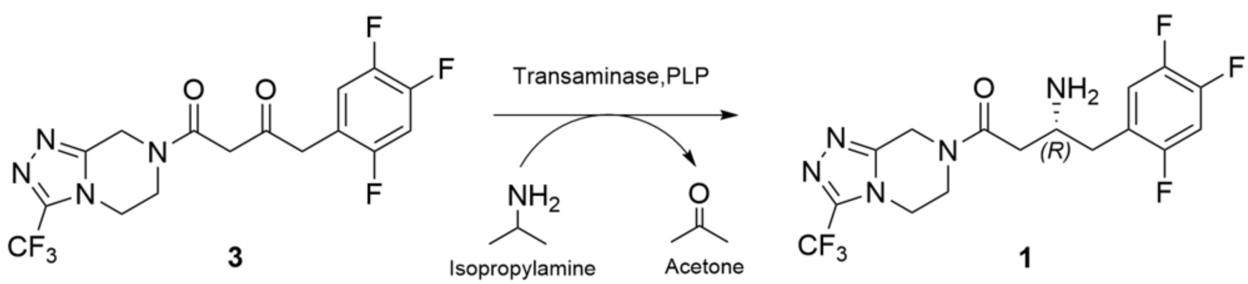


**Fig 1: Enzymatic synthesis of sitagliptin using transaminase [4]**

### B. Hydrolases

Hydrolases are a large category of enzymes comprising esterases, lipases, and proteases. Hydrolases are used to catalyze the cleavage of chemical bonds with the help of water. Hydrolases have various green applications, particularly in biodiesel and ester hydrolysis processes. For instance, lipases are used to hydrolyze fats to glycerol and fatty acid esters, which are subsequently converted to biodiesel. This is achieved through mild aqueous conditions without requiring toxic acids or extreme heat [3].

#### Example Reaction

Triglyceride + Methanol → (Lipase) → Biodiesel (Fatty acid methyl esters) + Glycerol

This is a fine application of enzymes in the manufacture of renewable fuels. The process is easy, safe, and free from pollution because of the use of lipase. Hydrolases are also utilized in the food and detergent industries because of their mild and selective action.

### C. Oxidases and Dehydrogenases

Oxidases and dehydrogenases are enzymes which assist in oxidation-reduction reactions. They find widespread application in the conversion of alcohol into ketones, an important step towards the manufacture of fine chemicals and pharmaceutical intermediates. For example, alcohol dehydrogenase (ADH) can oxidize alcohol to ketones with the assistance of NAD+ as a coenzyme. NADH is recycled in the system in the reduced form. Unlike other chemical oxidants such as chromium or permanganate, the reaction occurs under water or ethanol as green solvents.

**Example Reaction**

$$\text{Alcohol} + NAD^{+} \rightarrow (\text{Alcohol Dehydrogenase}) \rightarrow \text{Ketone} + NADH + H^{+}$$

This process eliminates the employment of toxic metal oxidants and minimizes hazardous waste. Such biocatalytic oxidations are increasingly being used in laboratory and industry settings because they are safe and environmentally friendly.

## 3. Enzyme Mechanisms and Conditions

Enzymes are biological compounds that serve as catalysts. They accelerate chemical reactions without being used up. Enzymes are employed in green chemistry because they operate under gentle conditions and provide very specific outcomes. Two primary models, the lock-and-key model and the induced fit model, describe how enzymes function. In the lock-and-key model, the enzyme contains a precise shape that is identical to its substrate's shape, as if a key fits into a lock. This implies only specific molecules can enter the enzyme and react. In the induced fit model, the enzyme slightly adjusts its shape upon binding of the substrate. The flexible accommodation allows the enzyme to hold the substrate more firmly and facilitate the reaction more quickly [6][7].

Enzymes are of great advantage. They possess a high selectivity, i.e., they form only one desirable product and not unwanted side products. These include enantioselectivity (selecting one enantiomer), chemo selectivity (selecting between varying functional groups), and regioselectivity (selecting one site on a molecule). The other benefit is that enzymes function under gentle conditions, i.e., room temperature, ambient pressure, and close to neutral pH. This conserves energy and prevents the use of corrosive acids, bases, or high temperatures. It also renders the process safer and more environmentally friendly. These characteristics render enzymes an excellent option for green reactions in pharmaceuticals, food processing, and biofuel manufacturing industries. Enzymatic reactions tend to occur in a cycle involving the binding of substrate, conversion, and release of products Fig.2.

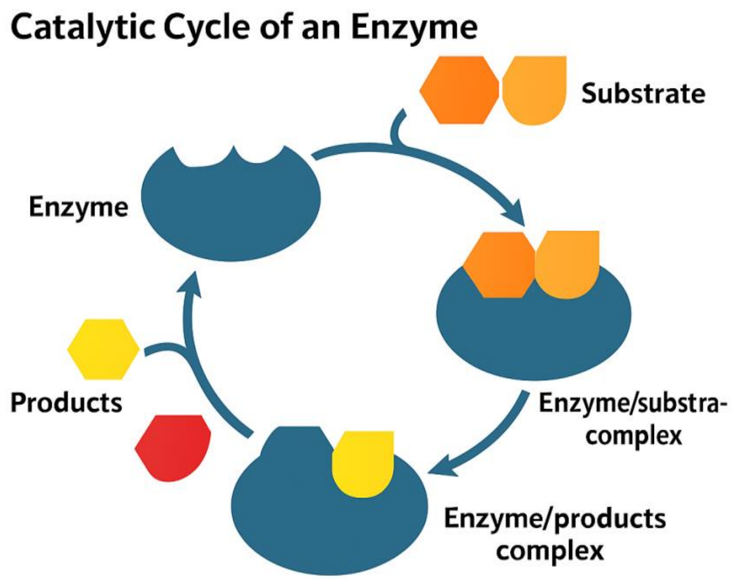


**Fig. 2: Catalytic Cycle of an Enzyme [5]**

## 4. Advantages and Limitations

Enzymes in green chemistry have a number of significant advantages. They are biodegradable and non-toxic, hence environmentally friendly. Enzymes do not require harsh conditions compared to conventional chemical catalysts, consuming less energy input in the process, thus conserving fuel and minimizing emissions. They are also renewable because they can be sourced from nature or through fermentation. All these characteristics make them suitable for sustainable industrial processes.

Despite their advantages, enzymes also possess some disadvantages. They are usually temperature and pH-sensitive, and their activity may be impacted by changes in these conditions. This implies that the stability of conditions in reactions is critical. Another difficulty is the expense of purifying enzymes for utilization, particularly on a large scale. Many enzymes are also only able to act on a specific range of substances. This can be addressed by enzyme engineering, whereby researchers alter enzymes so that they function more efficiently with a larger array of molecules [8].

## 5. Conclusion

In conclusion , enzymes are very crucial in advancing green chemistry. They can function under mild conditions, such as usual temperature and pressure, thus making them energy-saving and environmentally friendly. They minimize the consumption of toxic chemicals and yield fewer waste products. As observed in numerous reactions, transaminases, hydrolases, and oxidases are now extensively applied in the production of medicines, food, and even in pollution cleaning. These biocatalysts are highly selective, so they generate fewer undesired side-products and enhance the efficiency of reactions. Even though there are some drawbacks to enzymes, i.e., they are sensitive to heat or pH and highly expensive in purification, their advantages manifestly outweigh these shortcomings. With increased research and development, researchers are discovering means to enhance enzyme activity and render enzymes more stable and versatile. In general, enzymes facilitate a cleaner, safer, and more sustainable methodology of chemistry.

As such, their utilization is expected to increase in industry and research, which will drive society towards more environmentally friendly technologies and processes.

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## 7.Conflict of Interest

The authors declare that there is no conflict of interest to report in this article.

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