

# THE 12 Principles OF Green Chemistry

## AND HOW BIOCATALYSIS WITH ENZYMES ARE ADDRESSING EACH PRINCIPLE

### Prevent waste

Contrary to harsh chemicals, enzymes are remarkably specific in their synthesis. No by-products are generated, and the enzymes themselves are completely biodegradable.

### Design less hazardous chemical syntheses

Bio-transformations are mainly performed in water, or using Class 3 solvents, which implies a lower toxic potential compared to the use of chemical catalysts.

### Use safer solvents and reaction conditions

As product transformations in water, or Class 3 solvents, can be performed under ambient/moderate temperature conditions, the use of biocatalysts implies little safety risk.

### Use renewable feedstocks

Enzymes work well on a renewable starting material, as both are sourced from nature. Enzymes themselves are manufactured from large-scale fermentation using a microbial source as a starting material.

### Use catalysts, not stoichiometric reagents

Enzymes are effective biocatalysts where a small amount can go a long way. When immobilized in smaller granulates, the recyclability increases even further.

### Analyze in real time to prevent pollution

High selectivity and no formation of by-products, prevent waste treatment and/or pollution.

1

2

3

4

5

6

7

8

9

10

11

12

### Maximize atom economy

As the starting material is selectively converted into the desired product only, enzyme biocatalysis contributes to maximizing the atom economy of the overall process.

### Design safer chemicals and products

Enzymes are per definition non-toxic, and any replacement of metal catalysts or toxic chemicals will imply a safer process with less waste.

### Increase energy efficiency

Biocatalysts reduce both the number of synthetic steps, and the condition requirements for reactions with biocatalysts (no temperature/pressure requirements). Both imply a lower energy consumption.

### Avoid chemical derivatives

The unparalleled selectivity towards the desired end-product without the need for multiple protection/deprotection steps, avoids the use of several chemicals, including any of their derivative steps.

### Design chemicals and products to degrade after use

Enzymes are biodegradable; hence no additional effluent treatment is required.

### Minimize the potential for accidents

With the ease of handling, safe and sustainable processes, biocatalysis also minimize the risk of accidents while handling dangerous chemicals.