

# 12 Principles of Green Chemistry

Developed by Paul Anastas and John Warner\*, the following list outlines an early conception of what would make a greener chemical, process, or product.

*Click on each principle to read more from a green chemistry expert.*

## 1. Prevention

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## 1. **Prevention**

It is better to prevent waste than to treat or clean up waste after it has been created.

## 2. **Atom Economy**

Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.

## 3. **Less Hazardous Chemical Syntheses**

Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.

## 4. **Designing Safer Chemicals**

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Chemical products should be designed to affect their desired function while minimizing their toxicity.

#### 5. **Safer Solvents and Auxiliaries**

The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.

#### 6. **Design for Energy Efficiency**

Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.



## 7. **Use of Renewable Feedstocks**

A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.

## 8. **Reduce Derivatives**

Unnecessary derivatization (use of blocking groups, protection/deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.

## 9. **Catalysis**

Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.

## 10. **Design for Degradation**

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Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.

## 11. **Real-time analysis for Pollution Prevention**

Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.

## 12. **Inherently Safer Chemistry for Accident Prevention**

Substances and the form of a substance used in a chemical process should be chosen to

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Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.