The Green Chemistry

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1 Introduction and Principles

An early conception of “green chemistry was developed in 1990 by P. Anastos and J. Warner[1] trough 12 principles ranging from prevention and atom economy to pollution prevention and an inherently safer chemistry. These principles, described below, offer a protocol to adhere in developing novel chemical processes.

1. ***Waste prevention:*** by prevent waste production, rather than clean up and treat wastes after having produced. Plan to minimize waste at every process’ stage.
2. ***Atom economy:*** reduce waste by recycling the number of atoms from all reagents that are incorporated into the final product. Use atom recycling concept in order to evaluate reaction efficiency.
3. ***Less hazardous chemical synthesis:*** design chemical reactions’ path in order to be as safe as possible. Consider the hazards of all substances handled during each single step of the reaction, including waste.
4. ***Designing safer chemicals:*** minimize toxicity directly by proper design. Predict and analyze factors such as

physical properties, toxicity, and environmental impact of each designed process’ step.

5. ***Safer solvents & auxiliaries:*** look for the safest solvent available for any given step. Optimize the total amount of solvents and auxiliary substances used in order to minimize the waste produced.

6. ***Design for energy efficiency:*** find the least energy-intensive chemical route, thus reducing heating and cooling, as well as pressurized and vacuum conditions (i.e. try to stay as close as possible to ambient temperature & pressure).

7. ***Use of renewable feedstocks:*** use feeds which are made from renewable (i.e. bio-based) sources, rather than other chemicals made from petrochemical products.

8. ***Reduce derivatives:*** minimize the use of temporary derivatives such as protecting groups in order to reduce the waste production.

9. ***Catalysis:*** Look for catalysts that help to increase selectivity, minimize waste, reduce reaction times and increase energy efficiency.

10. ***Design for degradation:*** design products that can degrade themselves easily into the environment. Ensure that both original and degraded products are not toxic, bio-accumulative, or environmentally persistent.

11. ***Real-time pollution prevention:*** real time control of chemical reactions to prevent the formation and the release of any potentially hazardous or polluting products into the environment.

12. ***Safer chemistry for accident prevention:*** developing chemical processes and procedures that are safer to inherently minimize the risk of accidents. Evaluate all the potential risks and assess them beforehand.

Today, more than 98% of all products and materials needed for modern economies is still derived from petroleum and/or natural gas, generating substantial quantities of wastes and emissions.

An exaggerated, but illustrative, view of **twentieth century** chemical manufacturing can be written as a recipe[2]:

- Start with a petroleum-based feedstock.
- Dissolve it in a solvent.
- Add a reagent.
- React to form an intermediate chemical.
- Repeat (2)–(4) several times until the final product is obtained; discard all waste and spent reagent; recycle solvent where economically viable.
- Transport the product worldwide, often for long term storage.
- Release the product into the ecosystem without proper evaluation of its long-term effects.

The recipe for the **twenty-first century** will be very different:

- Design the molecule to have minimal impact on the environment (short residence time, biodegradability).
- Manufacture from a renewable feedstock (e.g. carbohydrate).
- Use a long-life catalyst.
- Use no solvent or a totally recyclable solvent.
- Use the smallest possible number of steps in the synthesis.
- Manufacture the product as required and as close as possible to where it is required.

A typical example of the twentieth century chemical manufacturing production model is represented by plastic materials, which are also a typical example of linear economy: no-renewable resources, oil or ethane in this case, are used to produce plastic materials, which at the end of life become wastes and dispersed into environment. Today, some about 8 million of metric tons escapes into the world’s oceans each year[3], most of it from countries in South East Asia, where plastics use has outplaced waste management infrastructure and the situation is approaching catastrophic proportions.

The green chemistry approach is the correct way to deal with the actual environmental situation, representing a promising strategy of future economic development also for industrialized countries.

Paul Anastas, then of EPA, and John C. Warner developed the Principles of Green Chemistry (Figure 1), which help explain what the definition means in practice. The principles cover such concepts as:

- Designing processes to maximize the amount of raw material that ends up in the product.
- Using safe, environmentally-benign substances, including solvents, whenever possible.
- Designing energy-efficient processes.
- Using the best form of waste disposal: not creating it in the first place.

Figure 1: Principles of Green Chemistry

[1] P. T. Anastas, J. C. Warner, The Twelve Principles of Green Chemistry, Oxford Univ. Press, Oxford – UK (1998).

[2] Based on: Woodhouse, E. J. Social Reconstruction of a Technoscience? : The Greening of Chemistry.

[3] A.H. Tullo, Fighting ocean plastics at the source. Chem. & Eng. News, 96 (16) (2018) 29-34

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