**Green Chemistry promotes Sustainable Development**

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**Abstract**: Sustainable development is one of the most important issues for our society and is a great challenge. Green chemistry, which is the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances, will promote the sustainable development of our society. Herein, the important aspects of green chemistry including atom economic reaction, green catalysis, green solvent, green carbon science and green product are introduced, which may provide solutions to achieve the sustainable development goals.

**Keywords**: green chemistry, atom economic reaction, green solvent, green catalysis, green carbon science, green product, education

**1. Introduction**

Chemistry is a central science that creates new materials and deals with the composition, structure, and properties of substances and with their transformations. Chemistry has greatly contributed to modern civilization, which provides about 97% products in the world and makes our lives better. For example, the invention of ammonia and related fertilizers renders the production of enough foods to meet needs of people all over the world. The medicines protect the health of people, and lengthen their average life span. Man-made materials make the world colorful and wonderful. However, we have to admit that chemistry also has polluted our planet and depleted natural resources greatly, so the sustainable development of our society is confronted with great challenges.

Green chemistry, which is the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances [1], guides the development directions of chemistry using the well-known “Twelve Principles”. The core of green chemistry is to save resources and energy, convert feedstocks into products as far as possible, and reduce or eliminate pollution to environment from the beginning. Green chemistry will promote sustainable development and realize the sustainable development goals (SDGs).

**2. Green chemistry for SDGs**

**2.1 Atom economic reactions**

To achieve sustainable development, we need enough and sustainable resources, but the resources in the earth are fixed and limited. Therefore, the utilization of the natural resources with high efficiency is of great significance for the sustainable development. An important goal of green chemistry is to maximize the efficiency of use of raw materials and to minimize the creation of waste. For a chemical reaction, atom efficiency is defined as the conversion efficiency of a chemical process in terms of all atoms involved and the desired products. Atom economic reaction is considered with high ratio of atom utilization, in which the conversion of raw materials is maximized and the waste emission is minimized. That is, atom economic reaction can generate more product using less feedstocks, thus reducing or eliminating the pollution caused by waste emission from the beginning. The strategies to improve atom economy mainly include designing alternative synthetic methodology, improving selectivity towards target products, and making good use of byproducts. It is crucial to develop robust and environmentally friendly catalysts to achieve a real atom economic reaction. The highly effective economic reaction not only saves resource but also prevents the pollution, which affords a significant way for sustainable development.

**2.2 Green catalysis**

Catalysis represents one of the most important way to achieve the goals established by 12 principles of green chemistry, and is also providing pathways to a sustainable development [2]. Catalysis also plays important role in environmental applications including the destruction of wastes and purification of gases, waters and soil. Noble metal catalysts are widely applied in chemical industry. Due to the limits of the noble metal resources, the low-cost, abundant and environment-friendly metals are expected to replace noble metal catalysts and have been widely investigated with focus on improving their activity comparable to that of noble metal catalysts. Nanocatalysts, particularly, catalysts with single-metal atom, display highly enhanced activity, and have become the frontier of the catalysis in recent years. The metal-free catalysts including organo-catalyst, carbons and ionic liquids without metals have emerged as green alternatives for various kinds of reactions, especially for the production of pharmaceuticals and biologic active molecules.

The bio- and photo-catalysis are considered to be green catalysis, which can be performed in green way under ambient conditions. Electrocatalysis is also a green catalysis, which can adopt green and renewable electricity from wind, tide, etc. However, the efficiency of these kinds of green catalysis is generally very low compared to that of thermo-catalysis. Therefore, exploring catalysts with high efficiency for bio-, photo- and electro-catalysis is of significance for sustainable development. The reduction of CO2 into fuels and chemicals via bio-, photo- and electro- catalysis provides green routes for CO2 fixation and transformation, which have been paid much attention in recent years. In addition, the catalysis associated with the use of green solvents is also a green catalytic process.

**2.3 Green solvents**

As known, over 70% chemical processes require solvents, especially organic solvents that are generally toxic, flammable, and/or corrosive. Therefore, study on green solvents is the most active area of green chemistry research [2], which represents an important challenge because the utilization of green solvents is not a simple replacement to the conventional solvents. The widely investigated green solvents mainly include water, supercritical fluids, ionic liquids and biomass-derived solvents. Besides their green features, the unique properties of green solvents should be investigated to meet the requirements for their applications. Water has been widely applied in inorganic industry, and prevention of water pollution is the main problem in its applications. Recent researches indicate that water is also a good reaction solvent for some organic reactions, showing promising potentials in organic synthesis. Supercritical fluids have temperature- and pressure-controlled properties with liquid- and gas-like performances, which, especially supercritical CO2, have shown promising applications in chemical processes. Ionic liquids that are completely composed of ions can be designed with green features together with unique properties, which are considered as a kind of green solvents and have attracted much attention in green chemistry. In addition, biomass-derived solvents like glycerol also have attracted attention, which may have great potentials.

**2.4 Green carbon sciences**

Carbon, the fourth most abundant element in the universe, is the key element of life on earth, and offers us organic materials. The efficient utilization of carbon resources and carbon recycling are of great importance for the sustainable development of our society. In the foreseeing future, fossil resources (raw oil, coal, natural gas and minerals) will still be the main resources of energy and chemicals, thus exploring green technologies for efficient utilization of fossil carbon resources will still be important task of chemists and engineers. With gradual consumption of fossil carbon resources, biomass as the largest renewable carbon resources has attracted much attention, and related technology to utilize biomass are being developed. The utilization of fossil resources and biomass emits huge amount of CO2, which results in the CO2 concentration in air to reach up to 415 ppm in 2018, thus causing serious environmental and social problems. Chemically, feasible and effective solutions to this problem are the efficient use of the limited fossil resources and the development of processes to convert biomass and CO2 into fuels and value‐added chemicals on a large scale. Therefore, Chinese scientists [3] proposed concept of green carbon science with four principles, which focuses on the transformations of carbon-containing compounds in the entire carbon cycle, with the ultimate aim at using carbon resources efficiently and minimizing the net CO2 emission. This holistic view also has ramifications for related fields including petroleum refining and the production of liquid fuels and chemicals from coal, methane, CO2, and biomass.

 In addition, the recycling and reuse of organic polymers is also an important aspect of green carbon sciences. The spent polymers provide rich renewable carbon resources, and their degradation into chemicals is of significance for sustainable development, which can not only reduce the pollution to the environment but also save the carbon resources.

**2.5 Green products**

Green products are necessary for sustainable development, which should have the following features: nontoxicity, environmental-friendliness, long life span for use, available recycling, production from natural and/or renewable feedstocks, fabrication with low energy cost, high biodegradability. The green chemicals for agriculture including fertilizers, pesticides, and insecticides can guarantee safe production of enough foods for us. Green pharmaceuticals and medicines can protect our health and lengthen the life span of our humans. Other green products including natural additives for foods, biomass-derived functional materials, natural clays, green coating materials, and so on, can make our life better.

In addition, the recycling of solid wastes including plastic waste, metal waste, glass, and so on, is also of great significance for sustainable development. Transformation of such solid waste into chemicals or useful materials needs chemistry, which is an aspect of green chemistry.

**3. Education**

Education is perceived as the master key to achieving a sustainable society. The core role of chemistry and chemical industry for sustainable development in modern societies suggests a central role for chemistry education. Green chemistry education aims at incorporating the concept of green chemistry into chemical education, and a major objective is to foster sustainable scientific literacy and to develop corresponding skills among the present and future generations [4]. More importantly, the intention of green chemistry education is to promote the desired types of awareness in the young generations, keeping in mind the importance of social and environmental sustainability and the role that chemistry can play to promote sustainable development, being to allow them to actively learn how to shape society in a positive, sustainable fashion. Therefore, green chemistry education should be and also has been paid much attention all over the world.

Nowadays, more and more female students are educated at high schools and universities, and they should be have equal rights to be educated with green chemistry. More and more female scientists are working in green chemistry fields, and they should be supported equally. It is believable that women are also able to contribute to sustainable development.

**4. Conclusion**

Green chemistry provides important solutions to sustainable development, which will give us a beautiful and sustainable world. Women working in green chemistry is an important power to contribute to sustainable development of our society. Let’s work together, and make our life better and better.

References

[1] P. T. Anastas and J. C. Warner, in Green Chemistry: Theory and Practice, Oxford University Press, New York, 1998.

[2] P. Anastas, N. Eghbali, Green Chemistry: Principles and Practice, Chem. Soc. Rev., 2010, 39, 301–312.

[3] M. Y. He, Y. H. Sun, B. X. Han, Green Carbon Science: Scientific Basis for Integrating Carbon Resource Processing, Utilization, and Recycling, Angew. Chem. Int. Ed. 2013, 52, 9620-9633.

[4] Worldwide Trends in Green Chemistry Education, Edited by V. G. Zuin and L. Mammino, The Royal Society of Chemistry, 2015.