

• **Special Topic**

# Green Chemistry at the present in Korea

Seung-Kyu Lee, Hyeon-Soo Park

TO21, Co.,Ltd., Seoul, Korea

**Objectives** Despite the great contribution made by chemical substances to the development of modern civilization, their indiscriminate use has caused various kinds of damage to the global environment and human beings. Accordingly, the major developed countries and international society have tried to ensure the safe use of chemicals and a reduction in the use of hazardous chemicals through the establishment of the United Nations Environment Programme and various international agreements. In this reason, we tried to introduce about Green Chemistry progress at the present in worldwide and Korea.

**Methods** We checked and analyzed relative journals, reports using keyword as like Green Chemistry, alternative chemicals, eco-friendly etc. and major country's government homepage search.

**Results** Green Chemistry theory, which argues for the reduction or removal of harmfulness in chemicals throughout their entire life-cycle, has been spreading, and major developed countries, such as the US and Denmark, have developed and operate programs to provide reliable chemical information to help replace hazardous chemicals. Korea has also been conducting studies as like eco-innovation project. Through this project the "Alternative Chemical Search program," has been developed, distributed, and operated since 2011 to provide reliable information to small and medium-sized businesses that have difficulties collecting information to ensure conformity to international regulations. The program provides information that includes the regulations of major countries and Korea, information on 340 alternative chemicals, 70 application cases, and 1:1 consulting.

**Conclusions** The Alternative Chemical Search program is expected to contribute to the establishment of response systems for regulation of Korean small and medium-sized businesses, and it also will be used to provide basic data for Korean hazardous chemical regulation, together with the Act on the Registration and Evaluation, etc. of Chemical Substances and the Chemical Control act, making it possible to establish an infrastructure for Green Chemistry in Korea and to increase national competitiveness..

**Keywords** Alternative chemicals, Chemical regulation, Eco-innovation, Green Chemistry, Green solution, Substitute chemicals

## Introduction

Although chemical substances are a very important factor in the realization of current industrialization, because they were used indiscriminately without a full understanding of the damage they could cause, issues have arisen on a continual basis, such as global environment changes like ozone depletion and

global warming, and chemical damage cases like Minamata disease and Itai-Itai disease, so that the importance of safe chemical use has emerged. Consequently, the major developed countries and international society agreed in 1972, at the United Nations (UN) Conference on the Human Environment held for safe use and control of chemicals, to the need for a specialized agency affiliated to the UN to deal with global environmental problems;

**Correspondence:** Hyeon-Soo Park  
24 Boramae-ro 5ga-gil, Dongjak-gu,  
Seoul 156-710, Korea  
Tel: +82-2-6005-1200  
Fax: +82-2-6005-1299  
E-mail: hspark@to21.co.kr

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**Table 1.** Global value of green markets in \$m for 15 countries in 2011-2012

Rank	Country	Sales US\$m	% of total
1	USA	1028140	19.2
2	China	691366	12.9
3	Japan	331886	6.2
4	India	328027	6.1
5	Germany	226034	4.2
6	United Kingdom	199387	3.7
7	France	162136	3.0
8	Brazil	161175	3.0
9	Spain	143363	2.7
10	Italy	139238	2.6
11	Russian Federation	135880	2.5
12	Mexico	109270	2.0
13	South Korea	95929	1.8
14	Canada	95143	1.8
15	Indonesia	84133	1.6

the the UN Environment Programme was thus established through the 27th UN General Assembly. Further efforts to ensure the safer use of commercial chemicals and for reduction in the use of hazardous chemicals have included the Stockholm Convention on Persistent Organic Pollutants for restriction of volatile organic compounds (VOCs) and the Rotterdam Convention to regulate the international trade in hazardous substances.

Dr. P. T. Anastas of the US Environmental Protection Agency (EPA) proposed “Green Chemistry” theory in 1998, arguing for a systemic reduction in the use of hazardous chemicals and the safer use and control of chemicals. The theory is composed of 12 principles to reduce or remove the harmfulness of chemicals throughout their entire life-cycle, from raw material step to the waste disposal step, via manufacturing and production to safer use of hazardous chemicals. Risk assessment studies of chemicals and research into the development of alternative chemicals have been actively carried out, in recognition of their value as a practical alternative for the establishment of an infrastructure for Green Chemistry; such investigations have been led by the major developed countries. In addition, national support for the establishment of an infrastructure for Green Chemistry has been provided, along with award programs, to encourage the active participation of industry [1].

The Green Chemistry market of South Korea (hereafter Korea) is about US\$ 96.4 billion, placing it at 13th in the world, after major developed countries such as the US, China, and Japan, and accounting for about 1.8% of the entire Green Chemistry market, alongside Canada. The global Green Chemistry market is expected to grow continuously to about US\$3000 billion by 2020, and efforts to monopolize the Green Chemistry market

have swiftly centered on the major developed countries. Since it is necessary for Korean industries, which occupy only 1.8% of the global Green Chemistry market, to enter into overseas markets, various environmental changes, along with growth of the green market, may provide a chance—but also a crisis—for Korean industries, so that a response from the Korean government is very crucial (Table 1) [2].

## Research Conditions for Green Chemistry in Foreign Countries

### US Environmental Protection Agency

Since the proposal of the Green Chemistry concept by Dr. P. T. Anastas, the EPA has maintained various policies to spread Green Chemistry, including environmental assessments of hazardous chemicals by the federal government; relevant research and education; support for environment-related industries, such as prevention programs and energy saving; the Presidential Green Chemistry challenge awards; and support for the reduction in use and generation of hazardous substances. The EPA also developed and distributed a tool to provide information about the results of the policies related to Green Chemistry, including Green Chemistry Expert System (GCES) and Green Chemistry Assistant (GCA).

GCES is composed of five modules that enable industries to identify information for evaluation and prediction, leading to the selection of safer Green Chemistry alternative chemicals. First, the Synthetic Methodology Assessment for Reduction Techniques module receives inputs such as information about chemicals, number of reactions, and yield of reactions; identifies properties of the chemical reaction process; and estimates and assesses the amounts of products and wastes. Second, the Green Synthetic Reaction module makes it possible to identify reaction information to synthesize chemicals in a safer and less hazardous way, with the input of basic information about chemicals. Third, the Designing Safer Chemicals module proposes compound designs and analyzes toxic mechanisms, which supports the prediction of structures that can reduce toxicity. Fourth, the Green Solvent/Reaction Condition module makes it possible to identify information on the physical-chemical properties of about 600 different solvents, as well as the reaction conditions for some alternative chemicals that have been confirmed. Fifth, the Green Chemistry Reference module has been designed to search and identify reports and data related to studies on Green Chemistry [3].

A web-based program developed collaboratively by the EPA and St. Olaf College, GCA has functions to calculate the theoretical yields of reactions, using chemical reaction equations,

and the appropriate amounts of chemicals that are required for reactions; this avoids the need to use chemicals during design. In addition, it provides information on about 60000 chemicals and about 600 solvents through a search function linked with GCES database [4].

### Toxics Use Reduction Institute (US)

State governments and a number of colleges in the US have made various attempts to establish an infrastructure for Green Chemistry, alongside the US federal government. Massachusetts state has established and operates the Toxics Use Reduction Institute, in collaboration with industries and government agencies, in line with the Toxics Use Reduction Act for research and public relations on the reduction in the use of hazardous chemicals. To reduce hazardous chemicals, the institute has been running various environmental protection programs, including continuous education for industry and the general public, reduction technology, funding, a chemical fact sheet provided by the Toxic Use Reduction Science Advisory Board, and evaluation of research on alternatives to hazardous chemicals like hexavalent chrome and diethylhexyl phthalate. It provides related information, too. The institute has also developed Pollution Prevention Options Assessment System, an Excel-based program that has the function of calculating the harmfulness scores of chemicals, based on the collected toxicity information, in order to help users to understand objectively and easily and

to allow them to evaluate comparatively [5].

### Massachusetts Institute of Technology (US)

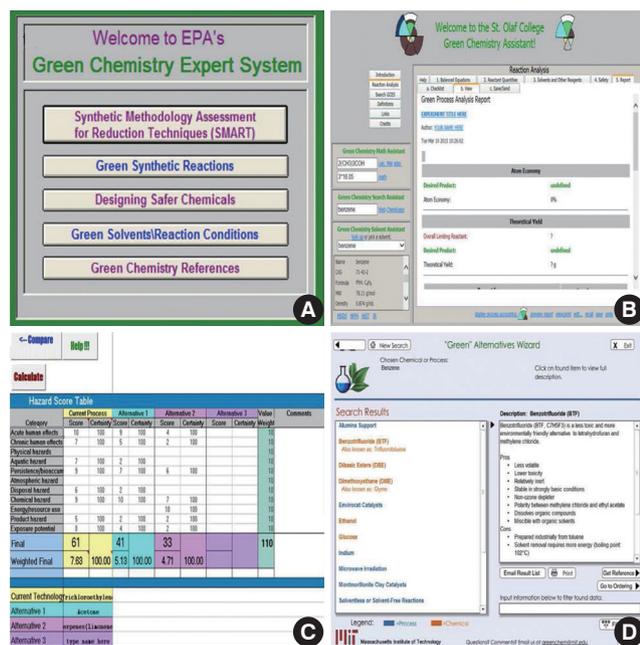
Massachusetts Institute of Technology of the US has formed a network of research organizations, academics, and research institutes related to Green Chemistry. This network has constructed a database focusing on data from major journals and has been running the Green Alternatives Purchasing Wizard, which provides information about hazardous chemicals. This is part of an eco-friendly purchasing policy to minimize waste and prevent pollution, in line with the Resource Conservation and Recovery Act. The wizard is a web-based program that was developed for cost reduction purposes achieved through reduction in hazardous wastes and environmental loads from research institutes. It also provides information about alternative chemicals, their advantages and disadvantages, and sources; it is linked to a purchasing system called Systems Applications and Products to facilitate purchases (Figure 1) [6].

### Clean Production Action (US)

Clean Production Action (CPA) is a project run by the Tides Center, a non-profit profit organization that financially supports innovative and creative groups in the US. In order to provide Green Chemistry solutions to the design and production of sustainable eco-friendly products, for the safety of products and materials, and for rapid and effective methods of toxicity evaluation, CPA has produced Green Screen, composed of four categories—environmental fate, eco-toxicity, human health, and physical-chemical properties—and 17 detailed evaluation items, presented in four types, as benchmark 1 to 4, based on the evaluation results [7].

### Catalogue of Example of Substitution of Hazardous Chemicals (Denmark)

The EPA of Denmark developed a web-based program in 2003 to search for hazardous chemicals and alternatives, based on a case report called a catalogue of example of substitution of hazardous chemicals, which in 1989 provided information on alternatives to 162 hazardous chemicals and actual cases that utilized alternatives. The program provides information, collected from Danish businesses, about alternative chemicals and technologies, the Occupational Health Service, and the Danish Working Environment Authority. The program provides information on 311 actual cases in 83 companies where alternative chemicals were used and encourage more active use of alternative chemicals in industry [8].



**Figure 1.** Green chemical system in the USA. (A) Green Chemistry Expert System (B) Green Chemistry Assistant (C) P2OASys, and (D) Green Alternative Wizard.

### Current Support Situations for Green Chemistry in Korea

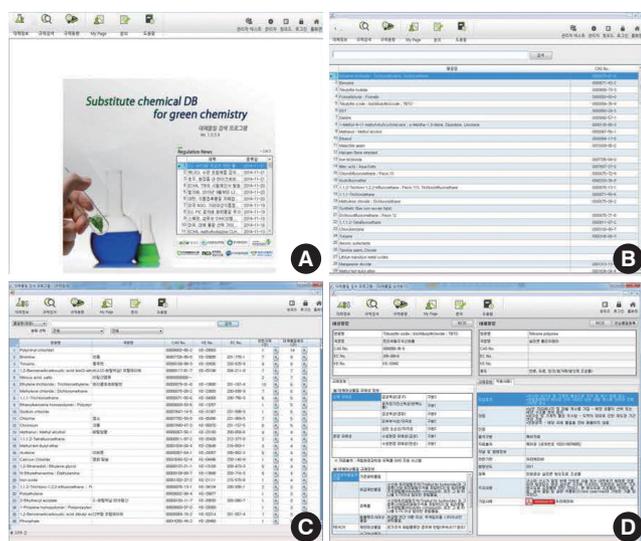
In 2009, the Ministry of Environment of Korea formed a forum composed of representatives from industry, academia, and research institutes in recognition of the strengthening international regulation of hazard and risk controls of chemicals; the ministry proposed a measure for the advance of chemical management to move toward a Green Chemistry system in order to improve the chemical management system in Korea and to support the chemical industry. Accordingly, the “green shift” to move toward Green Chemistry has ultimately been pursued in the direction of advancing management of the risks of hazardous chemicals; of safety management, people’s health, and environmental protection from chemicals and chemical products; of advances in the management of chemical information; of the construction of mutual communication and cooperation systems between interested parties; and of the attainment of two goals: “health and environmental protection” and “improvement of the competitiveness of the chemical industry” [9].

As a part of this project, the Ministry of Environment of Korea has run the Next-generation Eco-innovation (EI) project since 2011, with the goals of constructing the infrastructure for Green Chemistry in industrial facilities in Korea and of improving foreign trade competitiveness. The project also had “the research group on Green Chemistry management techniques” along with four sub-organizations, led by the Korea Environment Corporation, in order to construct the Green Chemistry policy/application support system. In particular, the project has been developing a search program for related alternative chemicals

for small and medium-sized businesses that have difficulty being competitive because of difficulties in accessing information about the regulation of chemicals and the regulation of alternative chemicals in Korea and other countries. The program has enabled them to identify and search for information about reliable alternative chemicals and rapidly changing international chemical regulations. The project has collected information about alternative chemicals based on domestic and international journals, research data, and particularly patent data. It has analyzed this information, verified it with the help of experts in the field to secure the reliability of data, and then presented it. In addition, successful cases of the application of alternative chemicals to actual processes were focused on in the process of collection and presented in order to increase the applicability of alternative chemicals. At present, information on a total of 341 alternative chemicals by use and 75 application cases have been collected and provided. The program can be downloaded from the next-generation EI research group homepage and the homepage of TO21 Co., Ltd.; it is distributed to companies free of charge (Figure 2).

### Conclusion

In recent international trade, the Free Trade Agreement has promoted an increase in trade between countries by removing or reducing the existing trade barriers, such as customs or import restrictions. As such, major developed countries have utilized technology regulations called Technical Barriers to Trade (TBT) as new non-tariff barriers, including energy saving, a reduction of carbon emissions, and environment-related standards, in order to protect the environment but also the trade of their own countries. According to a report from the World Trade Organization, the number of TBT notice letters increased from 638 cases in 2004 to 1491 in 2013 [10]. In addition, there have been various efforts to develop alternative chemicals and alternative process technologies to meet stronger technology regulations. Accordingly, various environment-related projects, including the Next-generation EI project, have been implemented in collaboration with industry, academia, and research institutes in Korea since 2011, in order to improve the international competitiveness of Korean businesses; through the project, various forms of content were developed and provided to companies. In addition, the existing hazardous chemical control act has been completely changed, becoming the Act on the Registration and Evaluation, etc. of Chemical Substances and the Chemical Control act, based on the obtained data, to protect the Korean environment and businesses, and through which Korea has endeavored more complete chemical control.



**Figure 2.** Substitute chemical program in Korea. (A) Main page, (B) list of substitute chemicals, (C) result of substitute chemical, and (D) regulation list.

Previously, the chemical industry was evaluated by its ability to synthesize a higher amount of chemicals and to develop new chemicals. However, conversion to Green Chemistry, which uses chemicals that are safer and less harmful, will be an important force for national growth in the future, and it may provide a good opportunity to secure the competitiveness of Korean industrial facilities in the international markets.

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## Conflict of Interest

The authors have no conflicts of interest with material presented in this paper.

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