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Process Technology and Sustainable Development

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Preface

Green chemistry and technology is a new interdisciplinary subject with significant social needs and clear scientific objectives, which emerged in the 1990s. It is the forefront and important field of international chemical and chemical research. The development of traditional chemistry to green chemistry has become the inevitable trend of chemical industry from "extensive" to "intensive". It is the only way for China's environmental protection to adopt the environmental protection concept of treating both symptoms and root causes.

Under the guidance of one belt, one road to respond to the call of the national "13th Five-Year plan", "Green is the necessary condition for sustainable development", Zhejiang Shuren University and Belarus National University signed a memorandum of cooperation in education and research, and set up the "Belarus research center" and awarded the Ministry of education's national and regional research center. The two sides jointly discussed how to protect the ecological environment and realize the construction of an ecological country while vigorously applying green chemical technology to promote the economic development of the two countries. In order to publicize the concept of green chemistry and sustainable development, and let environmental education actively penetrate into chemical education, scholars from both sides jointly compiled "Green Chemistry—Process Technology and Sustainable Development".

Based on the principle of green chemistry, this paper reviews the progress of green chemistry at home and abroad, and systematically introduces the advanced, practical, and prospective green chemistry technology and its sustainable development in modern chemical industry. It comprehensively discusses the major sources of practice, principle, sustainable development, and the methodology of ecological chemistry. The development of green chemistry in Belarus and China is introduced, which fully embodies the connotation and extension of green chemistry, and shows the brilliant prospects of green chemistry. The book consists of seven chapters. Chapters 1 and 2 is the background of green chemistry, which mainly introduces principles and aims of green chemistry. Chapter 3 mainly introduces the applications of green chemistry, including the concept of green chemical synthesis, green chemistry in catalysis, and green solvents. Chapter 4 is about green activation methods. Chapter 5

introduces sustainable development concept and green management of chemicals. Chapter 6 introduces renewable raw materials and energy, expounds the advantages of biomass as green chemical synthesis raw materials, and introduces the relevant commercial products. Chapter 7 takes the development status of green chemistry in Belarus and China as an example, and advocates the education mode that integrates the truth of green chemistry science with the rationality of human needs.

This book is comprehensive in content, illustrated, and highly targeted. It has been designed as a series of lectures delivered for Belarusian and Chinese students.It is suitable for teachers, students, and researchers engaged in the research of chemistry, chemical engineering, and environment. This book shows readers a continuous development of a complete green chemical system, so that more scholars and the public have a relatively clear understanding of green chemistry and chemical industry, so as to promote the healthy development of green chemistry.

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Chapter 1
Principle of Green Chemistry

Abstract The need of ecological civilization gives a thorough exploration of resources and ecological environment in the world. The author makes an active attempt to seek available ways to keep the sustainable development of green economy, resources, environment, and green chemistry to change the pattern of rising and sustainable development of the economy. To develop the green industry means industrial ecologicalization. To depend on the law and economic means to strengthen national consciousness of environmental protection.

Keywords Sustainable development · Cleaner production · Green chemistry

1.1 Green Economy

Green has always symbolized life, hope, and recently has come to mean welfare and prosperity as well. That's why **ecological civilization** is considered a result of **sustainable development**. The term sustainable development has become firmly entrenched in the professional vocabulary in economic, social, ecological, and other spheres. A conceptual definition of this term, although interpreted by linguists as continuous steady growth, implies the further development, which does not contravene the continued existence of mankind and its development in the same direction.

Economists, such as Daniel Bell, have suggested a new term to describe the current stage of development of society—a so-called post-industrial society or **knowledge society** [1]. Its sustainable development is based on the **knowledge economy**. This relatively new term means that the economy encompasses not only technologies but also the whole process of knowledge production. The **knowledge triangle**, which embodies a key driver of a knowledge-based economy, refers to the interaction between research, education, and innovation. The use of scientific knowledge and technological ideas does not lead to their depletion, but rather facilitates the accumulation of intellectual potential of a nation. Knowledge, unlike gas and oil, may be considered a renewable resource. Knowledge economy has also been proclaimed as a top priority of Belarusian economic development in the coming years. President Alexander Lukashenko noted that "there's only one way namely

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an expedited transition to innovative, knowledge-based, resource-saving, globally competitive economy." [2].

Economic growth and environmental protection complement each other on the path toward sustainable development. In this connection, the term green economy has been coined. President of the People's Republic of China Xi Jinping has pointed out that "green is gold" and that moving toward a new era of Ecocivilization and building a "Beautiful China" are key to realizing the "Chinese Dream" of rejuvenating the nation [3].

The Green Economy Initiative, supported by more than 20 states, was put forward by the United Nations Environment Programme (UNEP) in 2008 [4]. It defined a green economy as low carbon, resource efficient, and socially inclusive. This economy also enhances social welfare, ensures social equality, while mitigating environmental risks and diminishing the prospects of environmental degradation. Three years after Irina Bokova, UNESCO Director-General, looking back on 2011 and setting some priorities for 2012, emphasized that it's necessary to build up not only green economy but also green society [5]. Even though little time has passed, there's no doubt the green strategy affected all spheres of life and our world is well on the way toward the new **ecological civilization**. This way in its turn more and more seldom resembles attempts of NGOs to combat environmental pollution and pollutants. For instance, at the United Nations Conference on Sustainable Development—Rio + 20—held in Rio de Janeiro, Brazil, on June 20–22, 2012, member states spotlighted the exigencies of technological innovation and also laid down some particular criteria for green technologies. On September 25, 2015, the 193 countries of the UN General Assembly adopted the 2030 Development Agenda titled *Transforming our world: the 2030 Agenda for Sustainable Development* which renewed hope for a bold transition toward a low-carbon economy, greater efficiency of natural resources, inclusive green economic growth, and overall sustainable development. To take the next step—moving from commitment to action—countries must have an integrated approach to implementation that harmonizes environmental integrity, social inclusiveness, and economic prosperity. For instance, the National Communication (2012) specified the main trends and principles of Belarus's transition toward a green economy, as an essential tool for ensuring sustainable development and environmental security. According to the Country Report "China's Path to Green Economy" (2015), the current period can be considered as the "great leap-forward" of China's green economy agenda both conceptually and implementation-wise.

1.2 The Sustainable Development Concept

In recent years, green development trends ceased being the subject of popular publications only and shifted toward actual use. For example, green building, as a special system for construction solutions assessment, in many countries is already regulated by the set of national standards. The development of this system is primarily stimulated by those who engage in investment and further facility operation, those who

wish to have a comprehensive assessment of the expediency of the made decision, of the convenience of buildings in the process of operation, of their impact on the environment and the economy. For instance, if the construction takes place in an area, which has some clean water issues, any solution enabling to save water will be rated higher. The European Union even adopted Directive 2010/31/EU of 19 May 2010 on the energy performance of buildings. Under this Directive, Member States must ensure that by December 31, 2020 all new buildings shall be nearly zero-energy consumption buildings. Much attention is paid to the reuse of materials. An example of the use of a green building is Sochi Olympic facilities. The consumption, output expansion, and active advertising of green goods accounted for the fact that an estimated 95% of the European respondents are ready to purchase green goods, 75% of them are aware of this type of goods, and 63% try to find them on store shelves.

Public polls revealed the dependence of green goods consumption level on the level of education. Meanwhile, modern education in different regions around the world is gradually turning toward greenness. Bypassing various types of labor activities, it becomes apparent that content, approaches, and methods of green economy education coincide with that of sustainable development education. Sometimes green economy education is interpreted in a more narrow sense, defining it as a type of education focused on changing the employment structure. It's also targeted at increasing demand for professionals in environmental technology, goods and services, and training of specialists of new professions, so-called green collars, along with the specific specialists, for instance, specialists in biofuel production. In fact, sustainable development education is generally expected to conduct effective training of creative individuals capable of solving uphill tasks through innovative techniques. At the same time, it's necessary to be conscious of its interdisciplinarity and social responsibility to society. The first ones to recognize it from this perspective were chemists, who faced the public outcry, while regarded as being accounted for environmental contamination. Their consequent actions targeted toward changing the negative image resulted in that chemistry became the first natural science to be granted the green status. Perhaps, if biology developed in such a way as chemistry did, it would potentially become green.

The diversity of shades of green in the higher education system is instantiated by **green university** and green campus conceptions, which are implemented in several countries. The United Nations Environment Programme (UNEP) has defined the goals and objectives of green universities in "Green University Toolkit" publication. Green university works toward environmental protection, namely carbon emission reduction, separate waste collection, water and electricity saving, ecological infrastructure development, and outreach campaigns. Green students participate in eco-projects and events, carry out researches and project works on environmental protection. In 2009, Grist, an American online magazine, issued the list of Top Green Colleges and Universities. The green cohort comprised educational institutions of the USA, the UK, Canada, Costa Rica, and Scotland. Such institutions as Harvard University, the London School of Economics, and the University of Copenhagen have been for years committed to the green principles of their economic and sustainable development. The Centre for Bioeconomy and Eco-innovations (CBE) at Moscow

State University named after Lomonosov together with Tetra Pak and World Wildlife Fund has started the "Green universities for Green economy" project in Russia. The main objective of the project is to educate the new generation of professionals, who will take into account environmental factors in their activities.

There is another **green university ranking**—UI Green Metric World University Racking—which aims to draw the attention of the academic community to the problems of ecology. In 2013, 301 universities from 61 countries tried out for this ranking. As in the academic rankings, the leading positions were occupied by universities of the UK and the USA. Among those universities, that made it to the Top-10, were the University of Nottingham (UK), University College Cork (UCC) (Ireland), Northeastern University (USA), the University of Bedford (UK), the University of Connecticut (USA), etc. However, the makeup of the Top-10 green university ranking differs from the established global academic university rankings. In the former, the assessment is carried out on the basis of criteria, such as specific eco-indicators, delineating campus attitude to the environment, the use of energy-efficient appliances, facing the waste recycling university program, etc. There's no doubt that the assessment of greenness of laboratory practical works must be appended to the number of these indicators. The researchers conducted in American and European universities show that an estimated 90% of all emission is accounted for by university labs, with about 88% of it being toxic substances of various types.

At the present moment, by all accounts, chemistry does not correlate with the concept of green science. The survey data submitted by Lomonosov Moscow State University in 2010 attest to the fact that biology is generally recognized by the public as the main green science [6]. No wonder, as in the chemical sector of the economy there is a direct correspondence between the benefit of goods and the damage, caused to the environment and human health by the manufacturing process. Many major industrial areas around the globe are now subject to significant chemical pollution. Considerable funds are spent on the establishment of wastewater treatment plants and hazardous substances disposal. Such a method of solving ecological issues at the end of the production process is called the **end-of-pipe approach**.

Parallel to this method, another one, a so-called precautionary approach, has become increasingly prominent over the past two decades. It focuses on prevention rather than dealing with the consequences of environmental degradation. In practice, the **precautionary approach** encompasses the optimization of production processes, energy-saving technologies implementation, the selection of more environmentally friendly raw materials, new product design, internal and external waste recycling, reducing the use of toxic and hazardous substances.

1.3 Cleaner Production Strategy

A Cleaner Production (CP) strategy, coined in 1989 by UNEP, has firmly established itself as revolutionary, as it enables chemists to produce required substances in a more environmentally friendly way, which is harmless to the environment at any

stage of the manufacturing and is safe for those who engaged in this process. In fact, Cleaner Production represents a systematic approach to environmental protection, dealing with all the phases of manufacturing, as well as disposal process, i.e., the entire lifecycle "from cradle to grave," aimed at prevention or decreasing short and long-run risks, threatening human health and the environment. In addition to "Cradle to Grave" mentality, "Cradle to Cradle" concept has been recently introduced as an innovative way of creating products. William McDonough, co-author of the book "Cradle to Cradle: Remaking the Way We Make Things," said "Cradle to cradle is a strategy of hope; it's about sharing the resources and the planet we have. It's about rethinking our role in our planet and on the environment." [7].

Cleaner Production strategy has led to the emergence of a brand new branch of chemistry, termed green chemistry, which can be regarded as one of the Cleaner Production methods.

1.4 Green Chemistry: Principles, Current State, and Development Trends

Green chemistry in the 21st century is not just a fashionable trend, it is an urgent need. Green chemistry is an essential tool for achieving sustainable development goals. In 2017, within the IUPAC the Interdivisional Committee on Green Chemistry for Sustainable Development was created. In Fig. 1.1 the phrase "Green Chemistry" is written using symbols of chemical elements. It was molded in the USA, then outspread to Europe, seeped into Russia, and has reached Belarus and China. It's also been recently given prominence in the developing countries. For instance, the Green Chemistry Congress held in Addis Ababa (Ethiopia) in November 2010 featuring Prof. Paul T. Anastas, co-founder of green chemistry, resulted in launching the Pan Africa Chemistry Network.

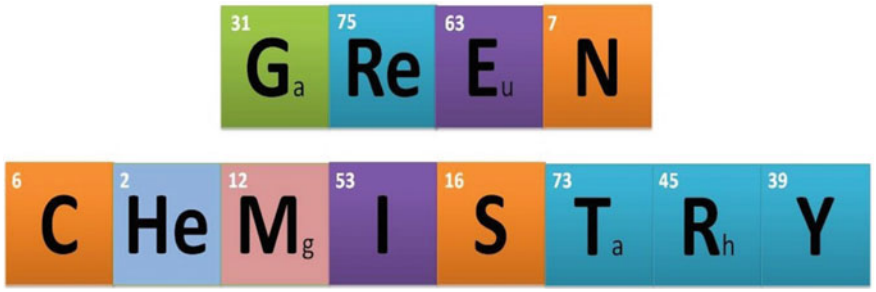

Fig. 1.1 "Green chemistry" written by the symbols of the chemical elements of the Periodic Table

The main historical milestones in green chemistry development are the following:

1962—Rachel Carson, writer, biologist, and environmental conservation icon, published the first of three installments of "Silent Spring". The publication helped spread public awareness of the hazards of environmental pollution and pesticides to the environment.
1969—President Richard Nixon established the Citizen's Advisory Committee on Environmental Quality and a Cabinet-level Environmental Quality Council (http://www.presidency.ucsb.edu/). Later that year, Nixon expanded his environmental efforts by appointing the White House Committee to determine whether an environmental agency should be developed.
1970—The Environmental Protection Agency (EPA) was launched.
1980s/1988—Shift from end-of-pipeline control to pollution prevention was recognized, leading to the Office of Pollution Prevention and Toxics in 1988. In the same years, safe chemistry activities were performed in Great Britain, Japan, France, yet they were not regulated at the state level, as in the United States.
1990—The Pollution Prevention Act under the George H. W. Bush Administration was passed.
1993—The EPA implemented the Green Chemistry Program, which served as a precedent for the design and processing of chemicals that lessen the negative environmental impact.
1995/1996—In 1995, President Bill Clinton established the Presidential Green Chemical Challenge Awards, which served to encourage those involved with the manufacture and processes of chemicals to incorporate environmentally sustainable design and processes in their practices. The following year, the first recipient received the award, the only award issued by the president that honors work in chemistry. Source: http://portal.acs.org/.
1997—The Green Chemistry Institute was launched. It was created to advance the broader chemistry enterprise and its practitioners for the benefit of Earth and its people. Source: http://portal.acs.org/.
1998—"Twelve Principles of Green Chemistry" was published by Paul Anastas and John Warner. Within the same year, Green Chemistry Network was formed by the Royal Society of Chemistry, backed by the Department of Chemistry, University of York.
2000s–Present—Some major green chemistry achievements include the California Green Chemistry Initiative. In 2006, the first International IUPAC Conference on Green Chemistry as a Chemistry for Sustainable Development was held in Dresden, 2 years later the second one takes place in St. Petersburg. In 2008, Governor Arnold Schwarzenegger signed the bills, which served to develop policy options for green chemistry (http://www.dtsc.ca.gov). One year later, President Obama nominated Paul Anastas as head of Research and Development at the EPA.

The concept was first introduced by Paul Anastas and John Warner in 1998 [8]. Today, any type of advancement in chemistry contributing to the improvement of environmental conditions is called green chemistry. Paul Anastas once noted that the best chemists go in for green chemistry, and that green chemistry is just a part of

doing good chemistry. Green chemistry has also prompted the change in the equation: "Risk = Hazard * Dose (Exposure)," by excluding the hazard component for its impact time. In other words, it has reduced the risk by making reactants and processes less dangerous. It all boils down to the formal definition of green chemistry "as a philosophy of chemical synthesis that minimize the use and generation of hazardous substances." The notion, however, is not quite accurate, if it's treated solely as a branch of chemistry that embeds new safe manufacturing processes which help to reduce or eliminate the use of hazardous substances. Green chemistry is a revolutionary concept invented to minimize and prevent environmental contamination. Before people often used the same definitions for green and sustainable chemistry calling green chemistry is sustainable chemistry. But as once Joaquin Barroso, the Italian chemist said we need to differentiate Green Chemistry and Sustainable Chemistry or we take the risk of confusing purpose and procedure. Green Chemistry is oriented toward the way we perform chemistry in order to achieve a sustainable chemical industry. Sustainable Chemistry is the philosophical approach with which the ongoing transformations can still be performed while the damage to the environment, namely our ecosystems, is brought to a minimum in order to maintain our industry and the benefits there from for generations to come and spread to a larger scale. But this is not only a matter of environmentalist nature; it is also an economical matter. Qing-shi Zhu, a physical chemist and manufacturer of methanol automobile fuel from biomass sources, during a press conference said: "The 'green' in green chemistry is also the color of money."

Green chemistry requires in-depth consideration, as the basis for a systematic approach to the chemical products manufacturing. The novelty of this approach lies in the fact that a manufacturer is responsible not only for manufacturing process to be ecologically friendly, but also for the entire "life cycle" of the product, controlled at various stages. In 2010, the International Standard ISO 26000:2010 was released, providing guidelines for social responsibility including environmental issues, which can be thus named green.

Green chemistry concept can be imaged by a mnemonic, **PRODUCTIVELY**, which captures the essence of **the twelve principles of green chemistry**: **P**—Prevent wastes; **R**—Renewable materials; **O**—Omit derivatization steps; **D**—Degradable chemical products; **U**—Use of safe synthetic methods; **C**—Catalytic reagents; **T**—Temperature, pressure ambient; **I**—In-process monitoring; **V**—Very few auxiliary substances; **E**—E-factor, maximize feed in product; **L**—low toxicity of chemical products; **Y**—Yes, it is safe.

These 12 principles display the current situation in the USA and Europe. The influence of national features on the formulation of the green chemistry principles can be observed in the greening principles, stated at the 1st Green Chemistry Congress, held in Africa in 2010.

G—generate wealth not waste;
R—regard for all lives and human health;
E—energy from the sun;
E—ensure degradability and no hazards;