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# Best Available Techniques and Green Chemical Technology: Possibilities for Convergence of Concepts

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**Abstract**—A comparative analysis of the best available techniques (BAT) and green chemistry concepts is given. It was assessed whether their convergence is possible and reasonable. The environmental and technological concept of BAT is briefly described, which has become widespread and legally formalized in many countries of the world. The best available techniques were shown to be a tool for increasing the resource efficiency of production and reducing the negative impact on the environment. The requirements of BAT apply to all subsectors of chemical industry. Determination of BAT for chloralkali and pulp and paper industries was considered as a practical example. It was proposed that green chemistry principles, aimed at preventing or reducing the formation of hazardous substances throughout the life cycle of chemical products, should be taken into account when determining BAT for chemical industry. This will help to improve the efficiency of technological regulation in the field of environmental protection. It was assumed that convergence of BAT and green chemistry concepts would create conditions for the formation of green chemical technology as a field of scientific knowledge and for the development of social and environmental responsibility of enterprises. It was emphasized that imperative compliance with BAT requirements as a key criterion for evaluating the life cycle of products, for expert evaluation of sustainable development projects (including green projects), and for substantiation of environmental marketing status would prevent dissemination of unreasonable information about the products of various industries promoted on the market.

**Keywords:** best available techniques, chemical technology, resource efficiency, green chemistry, information and technical reference books, negative impact on the environment, circular economy, taxonomy of green projects

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## INTRODUCTION

The possibilities of enhancing the resource and environmental efficiency of industry are associated with technological developments. In chemical technology, these developments are the subject of research by leading scientific schools in Russia and abroad [1]. Many researchers cooperate with the Russian Bureau of Best Available Techniques (BAT), which coordinates the creation of information and technical reference books (ITRs) on BAT—new documents of the national standardization system that set requirements to industrial enterprises for technological regulation and stimulating Russian enterprises to increase the resource efficiency and modernization of technological processes [2]. Although the BAT concept has been known for more than 50 years, discussions are still under way about identification (determination in Russian-language articles) of the best available techniques, compulsory use, resource and environmental efficiency, contribution to the formation of circular economy, etc. [2, 3]. Green chemistry (or green chemical technology) is also widely discussed by researchers, industry leaders, and officials [4]; probably, the only indisputable question is that green chemistry is the development of new chemical products and processes aimed at eliminating (or reducing) the formation and use of hazardous substances [5]. The goal of this study was a comparative analysis of BAT and green chemistry concepts and assessment of the convergence of these concepts: whether it is possible and justified.

## THEORY. REFINEMENT OF NOTIONS

*Chemical Engineering and Best Available Techniques.* In accordance with the classical definition,

chemical technology is the science of economically and environmentally reasonable methods and means of chemical processing of natural and secondary resources into consumer goods and intermediate products [6]. Chemical technology studies production processes in chemical, petrochemical, metallurgical, pulp and paper, food, textile, light, and other industries.

In ordinary consciousness, the chemical industry is often perceived as a cause of environmental problems arising in connection with the production and consumption of products in a given sector of economy. However, it is exactly chemical technology that makes it possible to increase the resource and environmental efficiency of many industries. Within the framework of chemical technology, new processes, production cycles that are closed in terms of material and energy flows, and methods for reducing emissions of pollutants into environment are being developed. Chemical technology plays the key role in the formation of circular economy as it is chemical processes that allow the processing and recycling of secondary resources [1, 7, 8]. In addition, without chemical technology it is impossible to eliminate objects of accumulated environmental damage, which, in some cases, are industrial sites of closed chemical, petrochemical, and pulp and paper enterprises.

The best available techniques is a set of cost-effective technological, technical, and management solutions that provide high resource and environmental efficiency of production [9]. That is, we are talking not only about basic technological solutions, but also about environmental protection techniques, as well as environmental and energy management systems [10].

The internationally accepted criteria for classifying technologies as BAT include the use of low-waste production methods; the use of less hazardous chemicals; high resource (including energy) efficiency of processes; minimization of emissions (into the air, discharge of pollutants and waste into water bodies); organization of closed flows; recycling of substances, return of secondary resources to production where possible; and minimizing the risk of accidents. We emphasize that when classifying a technology as BAT, the time period required for the industry to implement the technology (technical solution) is taken into account, including the technical and economic conditions [11].

In Russia, the information about BAT is systematized in standardization documents: information and technical reference books (ITRs, or BAT Reference documents (BREFs)) developed with participation of leading research and educational institutions and regularly updated to ensure the enforcement of BREFs for issuing integrated environmental permits (IEPs) and to clarify the quantitative characteristics of resource consumption and formation of emissions [2]. Twelve of 51 BREFs describe the technological processes implemented at enterprises of various subsectors of chemical industry, and chemical technologies are given considerable attention in many other ITRs (on pulp and paper production, production of rare and rare earth metals, light industry, bleaching and dyeing of textiles, etc.). In Russia, as well as abroad, from the whole variety of technological processes analyzed by experts, the best available and promising techniques are identified, and their quantitative characteristics are determined.

In the Russian Federation, the technological criteria of emissions and pollutant discharges are approved by government decrees or orders of the Ministry of Natural Resources and Ecology; the compliance with these requirements (i.e., with BAT requirements) is compulsory for all large enterprises of the Russian Federation that operate in industries belonging to areas of BAT application and have to obtain IEPs [2].

*Green chemistry and green chemical technology*. The green chemistry and BAT concepts have a common basis: the principle of prevention of pollution at its source or prevention of negative environmental impact (NEI), which was used in the 1990s in various countries and regions to prepare new regulatory legal acts. The novelty of these concepts lay in the fact that the development of technological processes with high resource and environmental efficiency became a priority; at the same time, the environmental protection technique has not lost its significance, but has become a system of "secondary" or "end-of-pipe" solutions necessary in those cases when the main processes cannot ensure minimization of NEI [11]. The pollution prevention principle and the BAT and green chemistry concepts are also present in many international conventions and green project taxonomies of industrial development [12, 13].

Thus, green chemistry is the development of new chemical products and processes, aimed at eliminating (or reducing) the formation and use of hazardous substances. Green chemistry requires consideration of the entire life cycle of a chemical product from development, production, and use to final disposal [5]. The adjective "green" can be considered a synonym of "excluding the use or formation of hazardous substances" and "friendly to the environment and humans."

The 12 green chemistry principles proposed back in the 1990s are often cited in the literature [14, 15]. They are slightly of journalistic style, some of them being repetitive. The key principles are: waste prevention; development of methods for the synthesis of chemical substances that increase the completeness of the use of the starting components ("atoms saving" according to the figurative expression of concept makers) and minimize the use and/or formation of hazardous substances; creation of chemical products with high efficiency and low toxicity and of degradable products (that decompose at the end of their use); energy efficiency enhancement of processes and use of renewable

resources; pollution prevention and accident risk reduction [5].

Experts from the Organization for Economic Cooperation and Development (OECD) proposed that the green chemistry concept be expanded and defined the chemistry for sustainable development as a scientific concept aimed at increasing the efficiency of the use of natural resources to satisfy the need for chemical products and services. The chemistry for sustainable development covers the development, production, and use of efficient, safe, and more environmentally friendly chemical products and processes [16]. Both concepts deal with the development and implementation of technological solutions and methods for treatment of chemicals (products containing them), rather than with chemistry as the science of substances and the laws of substance transformations.

Thus, a comparative analysis of the concepts suggests that the principles of green chemistry and chemistry for sustainable development should be considered as specification of BAT principles as applied to chemical technology, while simultaneously extending the resource and environmental efficiency requirements to the entire life cycle of chemical products. However, green chemistry is focused on the development of new products and processes ("emerging" in accordance with international terminology, or "promising" in the terminology of BREFs), while the best available techniques should now be technically and economically accessible and ready for practical implementation in industry.

## RESULTS AND DISCUSSION

*Determination of best available techniques for related industries*. The best available techniques are determined for BAT applications by technical working groups (TWGs), which include researchers, practitioners, representatives of authorities and civil society organizations. This is an internationally accepted approach. Various TWGs function independently of one another, although many experts are members of more than one TWG [11].

Let us consider the procedure for determining industrial BAT. Experts perform a comparative analysis (benchmarking) of resource and environmental efficiency indicators achieved by industrial enterprises, take into account the criteria described in the previous section, and set BAT technological indicators in such a way as to stimulate gradual modernization of the industry [17]. In Russia, the work of the TWGs is coordinated by the BAT Bureau, which forms the ITR project and submits it (as well as the proposed values of technological parameters) for public discussion [2, 11].

In India, the regulatory system based on the pollution prevention principle includes legally binding emission standards for each industry that has a significant impact on the environment. The requirements of these industry standards should be satisfied using solutions systematized in industry guidelines developed for many subsectors of chemical industry (including the production of chlorine and alkalis), and also for the pulp and paper and textile industries [11].

The determination of BAT based on the green chemistry principles should consider what raw materials are used to produce the desired product and whether any hazardous substances were used in the extraction of raw materials or their beneficiation; and it should also assess the applicability of renewable or secondary resources (Fig. 1).

For example, when analyzing pulp and paper production and determining BAT for the pulp bleaching stage [18], the origin of chlorine used for bleaching should be considered. If bleaching is performed using sodium hypochlorite, the latter is mostly obtained by a chemical method, namely, by the interaction of gaseous chlorine with sodium hydroxide.

Thus, determination of BAT for the pulp and paper industry based on the green chemistry principles should take into account the use of the electrochemical method for the production of chlorine and alkalis with a mercury cathode in the chain of processes preceding pulp bleaching. There are precedents: for example, in international reference books and in the Russian ITR 38-2017, a transition to the use of low-sulfur fuel in energy production to minimize sulfur dioxide emissions into the atmosphere was classified as BAT [19]. However, this is implementation of the pollution prevention principle, while taking into account the origin of chlorine and alkalis used in the pulp and paper or textile industry can create conditions for implementation of the principle of rejecting the use of hazardous substances in production cycles.

In the Russian Federation, more than one third of entire production of sodium hydroxide is produced by the mercury method, although the share of enterprises using the membrane method is gradually increasing [20]. A number of international reference books indicate that the mercury method for the production of chlorine and alkalis cannot be classified as BAT, and, in accordance with the Minamata Convention on Mercury, its use for this production should be stopped in 2025 [12, 21]. However, the Minamata Convention did not establish clear requirements to measures on elimination of mercury pollution in those places where enterprises using the mercury production method have been operating for many years. In Russia, some industrial sites of chemical enterprises closed in the 2000s have become objects of accumulated environmental damage, which are currently being liquidated as part of the Clean Country federal project [22]. The government also decided that a special ITR 53 "Liquidation of objects of accumulated environmental damage" should be developed in 2022–2023. Thus, rejection of the mercury method for the production of chlorine and alkalis and intro-

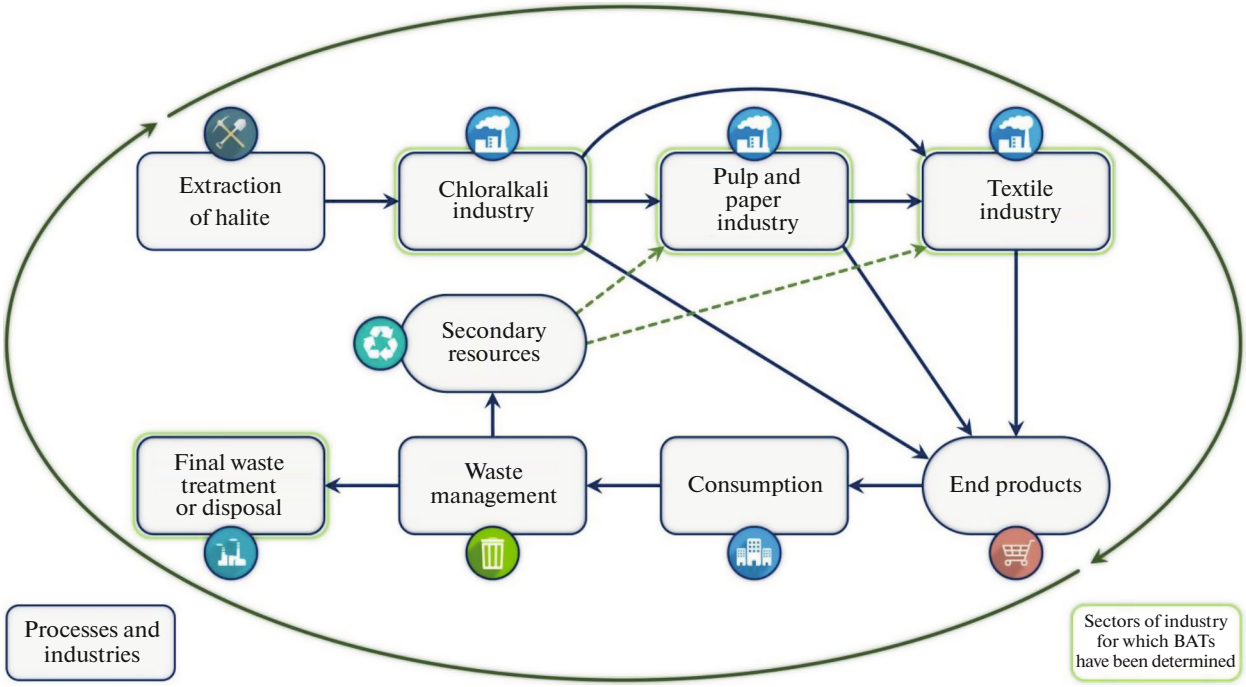


**Fig. 1.** Determination of the best available techniques for related areas of BAT application.

duction of an appropriate provision in BREF will prevent environmental pollution caused by the operation of existing enterprises and will also help to reduce the risk of accumulation of mercury compounds in hydrobionts and conservative environments (bottom sediments, soils) and the formation of objects of accumulated environmental damage.

*Best available techniques, environmental declarations, and green product marketing*. In continuation of the chain of interrelated industries and BREFs (Fig. 1), we can consider the production of viscose fiber. This is a multistage process, at the beginning of which pinewood pulp is treated with a concentrated alkali solution (steeping stage). Therefore, life cycle analysis is required in order to substantiate the basically marketing statement about the environmental friendliness of viscose fiber.

In accordance with the international standard ISO 14044, life cycle assessment covers the environmental aspects and potential environmental impacts at all stages of the product life cycle from the acquisition of raw materials, production and use of products to end-of-life processing, recycling, and final neutralization or disposal ("from cradle to grave" cycle) [23]. That is, in order to prepare a reasonable statement (environmental declaration), manufacturers of viscose fiber and products from it should take into account the specifics of the preparation of sodium hydroxide used at the steeping stage, and also of carbon disulfide, in which a cellulose suspension is dissolved to form cellulose xanthate, which is then kept in a sodium hydroxide solution until a viscose substance is formed. Thus, the preparation of viscose is associated with handling highly toxic substances of the second hazard class.

This does not mean, however, that the "origin" of sodium hydroxide should be discussed in detail in a section of ITR 39-2017 [24], which contains a description of the fiber steeping process; it suffices to consider the principle of reducing the involvement of hazardous substances in production cycles. As is known, modern technologies allow the processing of wood pulp in the production of lyocell by directly dissolving it in the N-methylmorpholine-N-oxide solvent (moderately hazardous substance), which is almost completely regenerated and does not form harmful products of decomposition.

At the same time, for the products of industries classified as BAT applications, it is necessary to take into account compliance with BAT requirements when preparing an environmental declaration or other documents aimed at promoting them products as green products that differ from similar ones in greater resource efficiency of production and lower negative impact on the environment. Figure 2 shows that six of the 12 green chemistry principles are fully implemented in the BAT concept. This conclusion is valid for all areas of BAT application and does not require sectoral binding. Moreover, the "atoms saving" or the development of methods for the synthesis of chemical substances that increase the completeness of the use of the starting components is nothing else but an increase in the resource efficiency of processes. The remaining principles are also becoming increasingly widespread

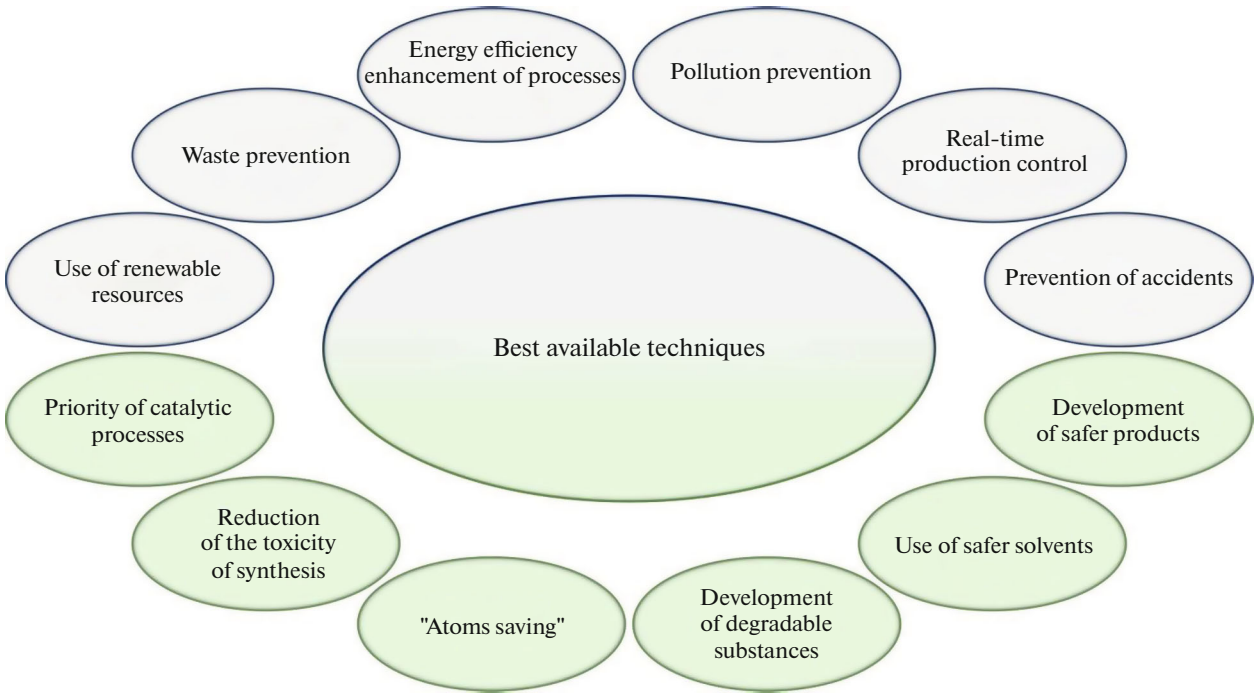


**Fig. 2.** Relationship between the best available techniques and green chemistry concepts.

in the development of new (promising) processes and their application at enterprises in many countries of the world.

We emphasize once again that the best available techniques should be technically and economically accessible and ready to be introduced in industry. When updating BAT reference books, the descriptions of promising technologies are carefully analyzed and given the status of BAT if practical applicability and economic feasibility of these technologies have been proved since the publication of the ITRs.

Since 2019, large enterprises in key industries in the Russian Federation have to obtain integrated environmental permits and achieve the level of environmental efficiency established by BAT technological indices [2]. However, some companies disseminate information about the environmental friendliness of products and environmental social governance (ESG) of business using such terms as "innovative green technologies," "green solutions," "organic products" [25], and at the same time they declare the excessive rigidity of BAT requirements and the impossibility of complying with them. These are cases of greenwashing. Thus, according to the Carbon Disclosure Project (CDP) rating, high positions are occupied by some Russian enterprises in chemical and pulp and paper industries, which are forced to develop environmental efficiency improvement programs (EEIPs) to meet industry BAT requirements within 7 years. EEIP is a tool for environmental and technological upgrading and increasing the resource efficiency of production, and significant investments are made in the implementation of such programs. However, we cannot talk about compliance with BAT requirements and especially about achieving exceptional environmental results and release of green products until the implementation of EEIP has been completed.

The extensive use of the practice of expert evaluation of compliance with BAT and the development of a green funding system give us hope that environmental marketing in Russia will gradually become the science and art of attracting and retaining consumers by creating a new, resource and environmentally efficient value and dissemination of sound information about it (the position was formulated based on the definition of marketing given by Ph. Kotler [26]).

In 2021, Russian researchers proposed a comprehensive criterion for evaluating green projects [13, 27]:

$$K = K_1 \wedge K_2 \wedge K_3,$$

where $K_1$ is the compliance of the project with priority areas (BAT applications) and achievement of environmental efficiency indices (technological indices); $K_2$ is the achievement of resource (including energy) efficiency indices established in the BREF; and $K_3$ is the evidence of the fulfillment of additional requirements (e.g., due to international commitments) and the achievement of a significant positive environmental effect from project implementation.

The complex criterion $K$ is a predicate that takes on a true value only if all the three subcriteria ($K_1$, $K_2$, and $K_3$) are met [13, 27]. Compliance of the project with these criteria is determined by expert evaluation with

participation of the members of the BAT expert community established in Russia in 2015.

This criterion was used in the development of the Russian taxonomy of sustainable (including green) development projects [28]. It seems that taking into account the green chemistry principles, e.g., refusal to use hazardous substances in processes, should be classified as evidence of the fulfillment of additional requirements ($K_3$). Then projects on the introduction of pulp bleaching with hypochlorite to reduce the formation of organochlorine compounds and their accumulation in the bottom sediments of water bodies that receive treated wastewater from pulp and paper mills, can be considered green projects. One of these projects is currently being implemented in the Siberian Federal District. Directions are now being discussed for harmonization of the approaches of BRICS states to the creation of green project taxonomies in order to take into account the peculiarities of the resource potential of these states, national development goals and priorities, and opportunities for strengthening cooperation in the scientific and technical field.

The proposal to take into account the green chemistry principles in BAT determination and to strengthen links between different ITRs is also consistent with the international trend of extending the BAT concept to the whole value chain. These approaches are currently being discussed within the framework of the OECD project, in which experts from many countries of the world take an active part [29].

## CONCLUSIONS

The results of our comparative analysis of best available technologies and green chemistry concepts suggest that they are based on a single principle of environmental pollution prevention. Both concepts are being consistently developed: new criteria for classifying technologies as BAT or promising solutions are being formed, and formulations of green chemistry principles are being refined. The materials of case studies carried out for interrelated chlorine and alkali production, as well as pulp and paper and textile products, indicate that the green chemistry principles should be considered as a specification of BAT principles as applied to chemical technology, while simultaneously extending the requirements for increasing the resource and environmental efficiency to the entire life cycle of chemical products. At the same time, in accordance with Russian and international requirements, the best available technologies should be technically and economically accessible and ready for practical implementation in industry, while green chemistry is mainly focused on new developments and hence on the creation of promising technologies.

Consistent convergence of BAT and green chemistry concepts will create conditions for the formation of green chemical technology as a field of scientific knowledge and for the development of the social and environmental responsibility of enterprises. Compulsory compliance with BAT requirements as a key criterion for assessing the life cycle of products, expert evaluation of green projects, and substantiation of environmental marketing positions will prevent the dissemination of unsound information in market promotion of the products of various industries.

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