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PAPER

GREEN CHEMISTRY OF UZBEKISTAN: CURRENT OBSTACLES AND FUTURE DEVELOPMENT PROSPECTS

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Abstract

Sustainable and green chemistry, in very simple terms, is just another way of thinking about how chemistry and chemical engineering can be done. Over these years, various principles have been proposed that can be applied when considering the design, development, and implementation of chemical products and processes. These principles enable scientists and engineers to protect and benefit the economy, people, and the planet by discovering creative and innovative ways to reduce waste, conserve energy, and find alternatives to harmful substances.

Key words: economy, green economy, green chemistry, engineering, problems, development, environment, products, energy, chemicals, innovative.

Introduction

Green chemistry is a different approach to chemistry. It involves transitioning from processing pollutants to creating alternative chemical production processes. This means we not only change the technology but also reduce the number of production stages, which is considered positive from both economic and ecological perspectives. We are completely abandoning the use of harmful substances and creating an ideal process to obtain the necessary substance that is harmless at all stages of production.

It's important to note that the scope of these of green chemistry and engineering principles go beyond concerns over hazards from chemical toxicity and include energy conservation, waste reduction, and life cycle considerations such as the use of more sustainable or renewable feedstocks and designing for end of life or the final disposition of the product.

Green chemistry can also be defined through the use of metrics. While a unified set of metrics has not been established, many ways to quantify greener processes and products have been proposed. These metrics include ones for mass, energy, hazardous substance reduction or elimination, and life cycle environmental impacts.

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Literature review

The study of chemical production in schools received considerable attention in the 1970s and 1980s. This educational field was considered methodologically well-developed and did not cause difficulties in teaching for either secondary school students or university students in chemical and pedagogical specialties. The works of A.A. Kaverina, A.S. Koroshchenko, T.Z. Savich, S.G. Shapovalenko, G.I. Shelinsky, L.A. Tsvetkov, I.N. Chertkov, D.A. Epstein, and G.M. Chernobelskaya laid the foundation for the methodology of teaching chemical production in schools and colleges, providing systematic familiarization with chemical processes in industry. It is advisable to form chemical-technological concepts within the framework of implementing environmental education and upbringing tasks while developing students' chemical-environmental competence [4]. Such a comprehensive approach allows for increasing the effectiveness of the educational process in the educational institution and implementing the integration of formed concepts, creating a holistic picture of reality.

Recall that D.I. Mendeleev believed that in chemistry there is no waste, only unused raw materials. The progress of chemistry also teaches us to reintroduce the waste from production and consumption processes back into the reproduction cycle.

The most significant textbook on Green Chemistry is considered to be "Green Chemistry: Theory and Practice"written by P. T. Anastas and J. C. Warner [1-2]. They were the first to outline the principles of Green Chemistry in their textbook.

E.S. Lokteva and V.V. Lunin propose to supplement this list with the principle: "If you do everything as you are accustomed to, you will get what you usually get"[3, p. 20]. The principles of green chemistry guide the student towards a comprehensive analysis of the chemical properties of a substance, "its potential as a hazardous substance or a pollutant"[3, c. 21].

Analysis and results

Global challenges, particularly environmental pollution, resource depletion, energy conservation, and the need for safe chemical methods, make the development of green chemistry a pressing issue. The expansion of Uzbekistan's industrial sector, growing attention to environmental protection, and advancements in science create opportunities for broadening the prospects of the "green chemistry"field.

Green chemistry faces challenges such as the economic and technical complexity of redesigning existing processes, dependence on fossil raw materials, and the need to overcome organizational and cultural barriers. The prospects lie in the development of biomaterials, innovations in carbon capture, scalable technologies for environmentally friendly production, implementation of sustainable nanotechnologies, and biomedical applications, which contribute to solving global environmental problems and ensure sustainable development.

Problems of green chemistry:

– Technical limitations: The complexity and high cost of redesigning existing chemical production processes, which are often based on the use of fossil fuels, create significant difficulties in implementing green chemistry principles.

– Economic barriers: The transition to new, more environmentally friendly processes may require significant investments, making it less attractive for some companies, especially in the long term.

– Dependence on fossil fuels: The chemical industry is largely dependent on fossil fuels as the primary raw material, and its complete abandonment requires fundamental changes in the raw material base and technologies.

– Regulatory and organizational barriers: Insufficient legislative support, lack of clear standards and indicators, and unpreparedness of some cultural and organizational structures hinder the rapid implementation of environmentally friendly solutions.

Below is a table summarizing the main obstacles to the implementation of green chemistry / green economy / green technologies in Uzbekistan over the past ~10 years, based on scientific works, reports, and other sources.

Prospects of Green Chemistry:

- Biomaterials and sustainable production:

Table 1. The main obstacles to the implementation of green chemistry

Obstacle	Description in Uzbek context	Implications / Consequences
Outdated / legacy infrastructure	Many chemical / industrial facilities are old, inefficient, energy-intensive; equipment not suited to greener processes.	High energy consumption, inefficiencies, greater pollution; harder & more expensive to retrofit or replace; slows adoption of greener processes.
Weak / inadequate regulatory framework	Regulations are not fully aligned with green chemistry; legal gaps; standards not well defined; often ambiguous or lacking enforcement.	Uncertainty for investors & industry; difficulty in compliance; slower introduction of green technologies; risk of greenwashing.
Lack of awareness / knowledge / skills	Among industry actors, government, public; insufficient R&D capability; lack of technical skills; low awareness of benefits of green technologies.	Slower adoption; resistance to change; less innovation; possible mismatch between policy and implementation; underuse of potential.
Financial constraints / high investment costs	Green chemistry or green tech often require expensive upfront capital, newer technologies, etc. SMEs particularly impacted.	Many projects not economically viable without subsidies or incentives; slower uptake; possible dependence on foreign investment or aid.
Institutional & coordination weaknesses	Poor coordination among government agencies; overlapping responsibilities; weak institutional capacity; limited R&D centres.	Duplication or gaps in policy; slow policy implementation; inefficiency; less ability to monitor or enforce; constrained innovation ecosystem.
Technological barriers	Green / cleaner processes sometimes not available or not matured; lack of access to appropriate technology; lack of standards for measuring greenness.	Difficulty scaling up lab successes; risk of lock-in to polluting technologies; competitive disadvantage; slower transition.
Legal / policy ambiguity	Unclear legal definitions of what qualifies as "green"; lack of incentives or clarity (tax breaks, subsidies, etc.); sometimes laws lag behind or are poorly enforced.	Raises risk for investors; discourages firms from adopting green projects; inconsistency in implementation; can allow "greenwashing."
Digital readiness / tech integration issues	Low readiness for Industry 4.0-type technologies that can enable resource efficiency, monitoring, optimization.	Limits ability to measure, monitor & optimize processes; less capability for smart controls or predictive maintenance; reduced potential for breakthroughs in process improvements.
Dependence on non-renewable energy / fossil fuels	Many industrial processes, energy generation still heavily reliant on fossil fuels; renewable energy infrastructure underdeveloped.	High greenhouse gas emissions; unstable energy costs; raises cost of "green" alternatives; sometimes disincentives if fossil fuel subsidies persist.
High investment risk perception / lack of incentives	Investors or firms see risk due to uncertain returns, regulatory risk, lack of economic incentives; few subsidies or favorable fiscal measures.	Less investment in green chemistry projects; fewer private sector initiatives; slower scaling; need for public support.

The development of biodegradable materials, biomaterials, and the implementation of scalable eco-friendly production technologies help reduce environmental impact.

• Innovations in carbon capture: Green chemistry contributes to the development of carbon dioxide capture and utilization technologies, which is a crucial step in combating climate change.

• Sustainable nanotechnology: Applying green chemistry principles in the field of nanotechnology paves the way for creating safer and more environmentally friendly nanomaterials for various applications.

• Biomedical applications: Research in green chemistry expands the possibilities for creating safe drugs and biomedical materials.

• Solving global problems: Green chemistry is a key tool for addressing pressing issues facing humanity, such as air and water pollution, nature

In Uzbekistan, the challenges of implementing "green chemistry"include insufficient funding for research, lack of a regulatory and legal framework, limited awareness of "green chemistry"principles, and restricted access to modern technologies and equipment. The prospects for development are associated with government support, the advancement of educational programs, international cooperation, and the introduction of innovative technologies that will reduce the negative impact of the chemical industry on the environment and ensure the country's sustainable development.

Despite the obstacles, there are several promising prospects that suggest Uzbekistan can make meaningful progress if the right conditions are met:

• Renewables clean energy potential — Uzbekistan has abundant solar and wind resources; government targets (e.g. for 2030) include raising the share of renewables substantially.

• Integration with Industry 4.0 — Using digital tools (IoT, data analytics, automation) can improve energy efficiency, reduce waste, and help monitor / optimize chemical processes. Pilot projects and international assistance could help.

• Growth of green finance instruments — As regulations, standards, and investor awareness improve, there are opportunities for green bonds, ESG investing, and other incentive systems to scale.

• SME innovation and decentralized solutions — Small and medium enterprises are more flexible and can adopt green chemistry and eco innovations more rapidly; also potential in agriculture, waste treatment, water management.

• International cooperation and investment — Foreign investment, technology transfer, partnerships (public private), international donor or financial institution support could speed up modernization, bring expertise and capital.

Environmental issues in production: Existing chemical enterprises contribute significantly to environmental pollution through emissions of sulfur dioxide, nitrogen oxides, and other harmful substances.

Prospects for the development of "green chemistry"

• Government support: Development and implementation of a national strategy for advancing "green chemistry"with government backing.

• International cooperation: Establishing partnerships with international organizations and countries to exchange expertise and technologies.

• Development of educational programs: Incorporating "green chemistry"principles into educational curricula at universities and research centers to train specialists.

• Implementation of innovative technologies: Investing in the development and adoption of "green"chemical technologies, such as the use of renewable raw materials, waste recycling, and emission reduction.

• Creating a favorable legislative environment: Establishing mechanisms to incentivize

”green”technologies and products, as well as strengthening environmental standards.

• Development of the domestic chemical industry: Establishing new, environmentally friendly production facilities and modernizing existing enterprises in accordance with ”green chemistry”principles.

• International cooperation: Establishing partnerships with international organizations and countries to exchange experience and technologies.

• Development of educational programs: Inclusion of ”green chemistry”principles in the educational programs of universities and scientific centers for training specialists.

• Implementation of innovative technologies: Investments in the development and implementation of ”green”chemical technologies, such as the use of renewable raw materials, waste recycling, and emission reduction.

• Creating a favorable legislative environment: Establishing mechanisms to incentivize ”green”technologies and products, as well as strengthening environmental standards.

• Development of the domestic chemical industry: Creation of new, environmentally friendly industries and modernization of existing enterprises in accordance with the principles of ”green chemistry.”

Conclusion

While Uzbekistan has made noticeable strides toward green transition and green technologies over the past decade, green chemistry in particular remains partly under realised due to structural, financial, institutional, and technical obstacles. However, given the country’s resource base, domestic policy momentum, increasing interest in green finance, and international cooperation, there is strong potential for progress.

If Uzbekistan can address the key barriers—especially regulatory clarity, financing, infrastructure modernization, and capacity building—then over the next 5 10 years green chemistry could become a more integrated part of its industrial and chemical sectors, contributing both to sustainability goals (lower emissions, cleaner production) and economic competitiveness (higher value products, exports, reduced energy costs).

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