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CRITERIA AND INDICATORS FOR COMPREHENSIVE ASSESSMENT OF THE DIGITIZATION OF THE CHEMICAL INDUSTRY

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Abstract:

The chemical industry plays a crucial role in the global economy, supplying essential materials for various sectors, including manufacturing, pharmaceuticals, agriculture, and consumer goods. Given its significance, a comprehensive evaluation of the chemical industry is vital to ensure sustainability, safety, and compliance with regulatory requirements. This article explores the criteria and indicators used for a thorough assessment of the effectiveness and impact of digitization in the chemical industry.

Keywords: Investment, digital transformation, digital technology, automation, scientific research, fundamental research, applied research, experimental research, innovation

I. INTRODUCTION

The comprehensive assessment of the digitization level of the chemical industry encompasses a multifaceted evaluation, covering environmental, economic, safety, technological, social, and supply chain aspects. By establishing clear criteria and relevant indicators, stakeholders can gain valuable insights into industrial activities and their impacts on society and the environment. This integrated approach not only strengthens compliance with regulatory documents and enhances risk management but also supports innovations and sustainable practices, paving the way for a more responsible chemical industry in the future.

II. LITERATURE REVIEW

Issues related to the transformation and efficiency improvement in the chemical industry have been addressed in the scientific works of foreign scholars such as D. Shalmo, A. Williams, L. Viitaoja, J. Schumpeter, A. Blaiser, D. Ties, R. Davidson, T. Berry, S. Lambert, and others. [1]

Among the scholars from the CIS countries, M.P. Galimova, N.V. Gorodnova, Yu.Ya. Yelenova, I.A. Zubritskaya, T.V. Kokuiceva, E.E. Panfilova, I.V. Tarasova, and others have thoroughly studied certain issues related to this research area. [2]

According to foreign scholars, Racchinger et al., the fourth industrial revolution has forced companies to question their existing strategies and explore new business opportunities [3]. Soutto, Mat, Fitzgerald et al. emphasize that "how companies use digital technologies is increasingly important for their innovative potential and growth" [4]. Müller et al. believe that "Industry 4.0 can offer enormous opportunities for the creation of new products and services, better ways of serving customers, improved integration across the value chain, and the adoption of innovative business models" [5].

Some aspects of problems related to enhancing the efficiency of industrial enterprises, digital transformation, enterprise management, and the evaluation of their efficiency have been examined in the scientific works of leading economists in our country, including S. Gulomov, B. Berkinov, A. Ishmukhamedov, D. Suyunov, E. Mahmudov, A. Yusupov, T. Qodirov, N. Mahmudov, M. Tursunkhodjaev, S. Turabjonov, N. Ziyavitdinova [6] and others.

However, the aforementioned scientific research has not specifically studied the methods for evaluating the effectiveness of digital transformation implemented to enhance the efficiency of the republic's chemical industry as a distinct scientific research object. This study examines the degree of digitization of chemical industry enterprises in our country, taking into account the current characteristics of evaluating the effectiveness of implementing digital transformation. This focus on the chosen research topic offers significant opportunities to define its relevance, objectives, and the scope of issues to be addressed.

III. RESEARCH METHODS

The research process utilized logical reasoning, structural and comparative analysis, scientific generalization, economic-mathematical modeling, empirical methods, and econometric analysis.

Purpose of the Research

The purpose of the research is to elucidate the methodological foundations of economic criteria in the comprehensive assessment of the digitization level of the chemical industry and the results of digital

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transformation, as well as to develop proposals and recommendations for its improvement.

Tasks of the Research

The tasks of the research include:

- Highlighting the role and unique characteristics of the chemical industry in the development of the economy;
- Assessing the development of the chemical industry sector and the factors influencing it;
- Investigating issues related to enhancing economic efficiency in industrial enterprises from a scientific and theoretical perspective;
- Developing the methodological foundations for evaluating the degree of digitization of industrial enterprises and the effectiveness of implementing digital transformation.

Subject of the Research

The subject of the research is the effectiveness of economic relations that arise during the transformation of the chemical industry and the enhancement of economic efficiency.

IV. RESULTS AND DISCUSSION

The chemical industry is one of the main sectors of the economy, which plays an important role in the production of various products. In order to effectively manage and develop this industry, it is necessary to comprehensively assess its state and growth.

In assessing the level of digitization of chemical enterprises, open innovation in the field of robotic process automation (RPA) and research and development (R&D) in business strategies is playing an important role.

Robotic process automation (RPA) is a software technology that automates repetitive, rule-based tasks traditionally performed by people.[7][8][9] In essence, software "robots" imitate human movements, interacting with digital systems and software in the same way as humans.[10] These robots can understand what is on the screen, press keys, control systems, extract data, and perform a wide range of specified actions. They work faster and more continuously than humans, without breaks or fatigue[10].

Robotic process automation (RPA) is particularly useful for tasks involving legacy systems that lack APIs or database access. It streamlines workflows and makes organizations more efficient, flexible, and responsive. It increases employee satisfaction by freeing them from tedious tasks, allowing them to focus on more complex and engaging work. Robotic process automation (RPA) is also a critical component of digital transformation, enabling faster efficiency and improved ROI. Open innovation is a business strategy that goes beyond a company's internal resources to develop new products, services, and business models.[7][8] It involves actively seeking and integrating external knowledge, technologies, and resources into the innovation process.[9][10] This approach differs from the traditional "closed innovation" model, where companies rely solely on their internal R&D departments and keep their innovations secret.

Open innovation takes two main forms:

Inbound open innovation: This involves leveraging external knowledge and expertise.[7][8][9] Companies using this approach may scan the external environment for new ideas, collaborate with external partners, or solicit customer feedback.[7] This helps speed up the innovation process and brings diverse perspectives to problem solving.[11]

Outbound innovation: This focuses on commercializing internally developed ideas in the external environment.[7] This may involve licensing technologies, forming joint ventures, or starting new businesses.[10] This allows companies to monetize innovations that they are not using themselves and to gather feedback from the market.

There are several benefits to adopting an open innovation strategy:

- Accelerated innovation: Access to external resources and expertise speeds up the development process.
- Cost reduction: Sharing resources and leveraging external knowledge reduces research and development costs.
- Enhanced competitive advantage: Having diverse perspectives and leveraging advanced technologies helps companies stay ahead of their competitors.
- Improved product development and market entry: Incorporating external feedback and insights leads to better products that meet market demands.
- Open innovation can be implemented in a variety of ways, including:
- Trend management and technology scouting: Identifying emerging trends and technologies that are relevant to the business.
- Collaboration with external partners: Collaborating with startups, universities, research institutes, and other companies.
- Crowdsourcing: Asking a large group of people for ideas and solutions.
- Innovation ecosystems: building networks and communities around a common innovation goal.[8]

While open innovation offers many advantages, it also requires a different governance approach than traditional closed innovation.[11] Companies need to be comfortable sharing knowledge, managing external relationships, and integrating diverse perspectives. They also need to establish clear rules and processes for open innovation initiatives.[11]

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The following criteria and indicators are important for assessing the level of digitalization of chemical companies.

1. Economic Criteria

Production Volume: The total production volume of the chemical industry is one of the main indicators for assessing its economic efficiency. This indicator reveals the industry's market share and competitiveness.

Export and Import: The volume of exports indicates the chemical industry's position in the international market, while imports reflect the level of domestic demand fulfillment.

Production Value and Profitability: These indicators assess the economic viability and cost efficiency of the chemical industry.

Profitability: Analysis of profit margins and return on investment (ROI).

Economic Efficiency

2. Innovations and Technological Development

Innovations and Research: The implementation of modern technologies and the utilization of research results ensure the technological development of the chemical industry.

-Research and Development (R&D): Investments in scientific research are critical for sustainable practices and product innovation.

-Adoption of Green Chemistry: Implementing processes that minimize hazardous substances.

- Automation of Production Processes: The level of automation aids in increasing production efficiency and product quality.

Indicators for Evaluating Innovation and Technological Development:

-Expenses on Research as a Share of Revenue: The ratio of investments in research to generated revenues.

- Number of Patents Filed: Assessed through the number of patents related to innovative processes and products.

3. Environmental Criteria

Emissions to the Atmosphere: Compliance of waste with environmental standards, measuring greenhouse gases, volatile organic compounds (VOCs), and other pollutants is crucial for evaluating the ecological safety of the chemical industry.

Water and Energy Efficiency: The application of low-energy-consuming technologies and the assessment of water and energy use in production processes positively impacts the environment.

Environmental Assessment Indicators:

- Carbon Emissions: Total greenhouse gas emissions per unit of production.

- Water Usage Efficiency: The amount of water used per produced product.

- Waste Production: The quantity of hazardous and non-hazardous waste generated.

4. Social Criteria

Job Creation: The impact of the chemical industry on employment reflects its social significance.

Working Conditions: Labor safety and conditions affect workers' productivity and health.

Indicators for Assessing Social Criteria:

- Community Investments: Financial contributions to local initiatives and charitable organizations.

- Employee Satisfaction Index: Measures of employee morale and retention rates.

5. Supply Chain Sustainability Criteria

Raw Material Supply Sources: Evaluation of the stability of raw material sources and suppliers.

Logistics and Transportation: Assessment of the carbon footprint associated with product distribution.

Supply Chain Sustainability Can Be Evaluated Through:

- Sustainable Source Share: The proportion of raw materials obtained from sustainable practices.

- Transport Emissions: Assessment of CO2 emissions per transported unit.

A comprehensive assessment of the digitization level of chemical industry enterprises necessitates considering the above criteria in full. This article analyzes the impact of digitization on the economic criteria, drawing from data on major chemical industry companies worldwide, particularly focusing on their investments in innovation and research, summarized in Table 1.

Table 1

Key Economic Indicators of the Top 10 Chemical Industry Companies Worldwide, 2022

Company	Revenue (billion USD)	Profit Margin	R&D Expenses (billion USD)	Ratio of revenue spent on R&D (%)
1	2	3	4	5=4/2*100
BASF SE	94	10%	2,2	2.3 %

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Dow Inc.	55	12%	1,7	3.1 %
Sinopec Limited	375	6%	1,3	0.3 %
SABIC	47	15%	1	2.1 %
LyondellBasell Industries	46	10%	0,2	0.4 %
Mitsubishi Chemical Holdings	16	8%	0,7	4.3 %
DuPont de Nemours, Inc.	18	12%	1,6	8.9 %
AkzoNobel	25	11%	0,3	1.2 %
Covestro AG	16	14%	0,310	1.9 %
Huntsman korporatsiyasi	8	10%	0,150	1.9 %

From the table above, we can see that large chemical companies are investing significant amounts in innovation and scientific research. BASF SE allocated the most funding for innovation and research and development (R&D) in 2022, amounting to 2.2 billion USD. Sinopec Limited, which holds the largest market share, invested 1.3 billion USD. By examining the other economic indicators of these companies, it can be observed that BASF SE has been experiencing a decline in sales volume year after year, which has prompted them to innovate and develop new technologies, while Sinopec Limited is striving to maintain its market position by continuously investing.

The share of funds allocated to open innovation and scientific research by the top 10 largest chemical industry enterprises in the world can be more clearly understood in the diagram below.

Diagram 1.

The share of funds allocated to open innovation and scientific research by the 10 largest chemical industry enterprises in the world

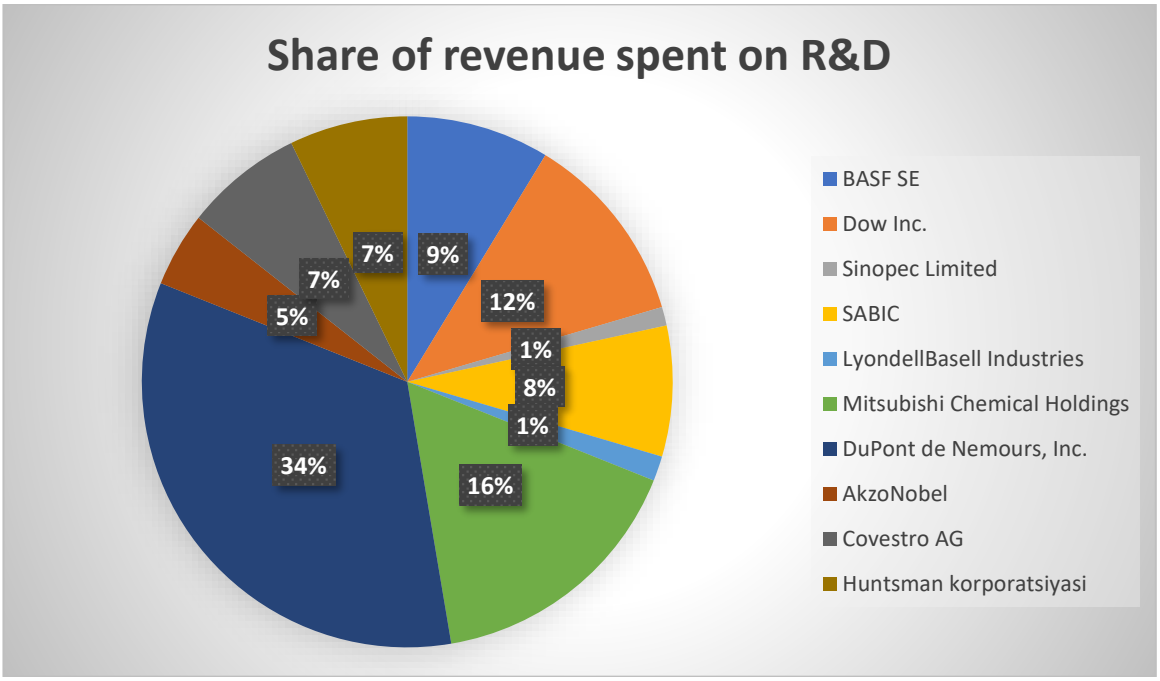

Table 2 analyzes the economic indicators of the largest 10 chemical industry companies among CIS countries in 2022.

Table 2

Key economic indicators of the TOP 10 chemical industry enterprises among CIS countries, 2022.

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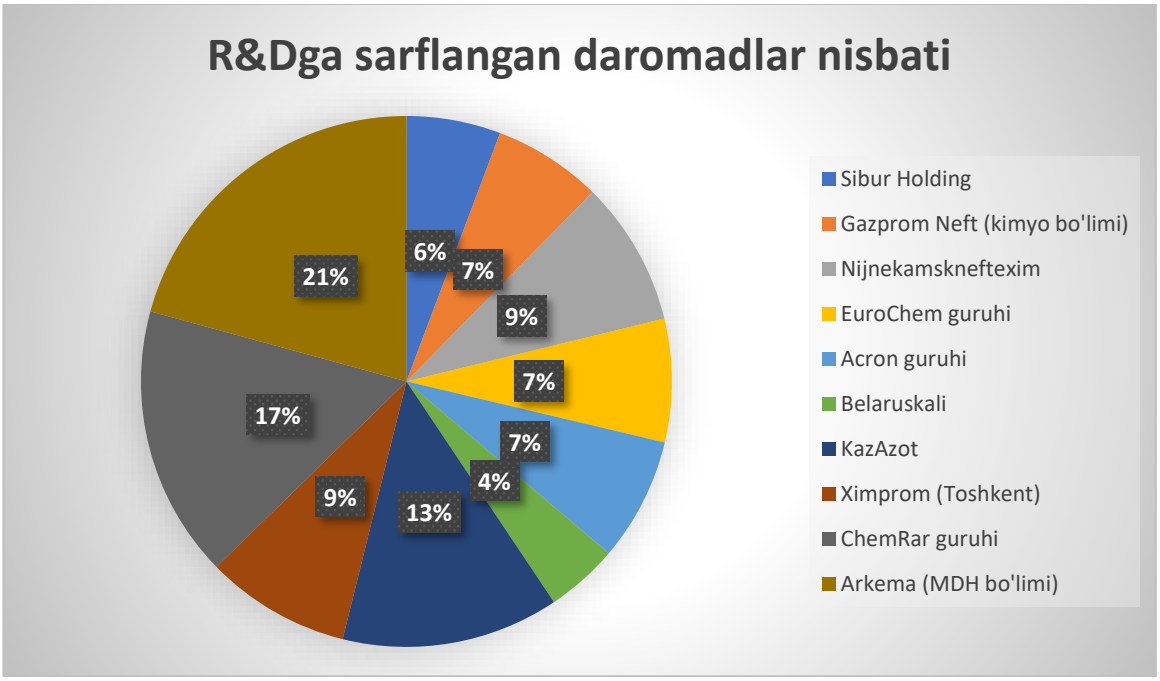
Company	Country	Revenue (billion USD)	Profit Margin	R&D Expenses (billion USD)	Ratio of revenue spent on R&D (%)
1	2	3	4	5	6=5/3*100
Sibur Holding	Rossiya	15	12%	0.2	1.3%
Gazprom Neft (kimyo bo'limi)	Rossiya	10	9%	0.150	1.5%
Nijnekamskneftexim	Rossiya	5	10%	0.100	2%
EuroChem guruhi	Rossiya	7	11%	0.120	1.7%
Acron guruhi	Rossiya	3	8%	0.050	1.7%
Belaruskali	Belarusiya	2	20%	0.020	1%
KazAzot	Qozog'iston	1	15%	0.030	3%
Ximprom (Toshkent)	O'zbekiston	0.5	5%	0.010	2%
ChemRar guruhi	O'zbekiston	0.4	7%	0.015	3.75%
Arkema (MDH bo'limi)	Rossiya	1,5	10%	0.070	4.7%

This table shows that the amounts spent on innovation and scientific research (R&D) by the 10 large chemical enterprises in the CIS countries are significantly lower compared to those spent by companies in developed countries. Sibur Holding, which has a significant position in the world, allocated 200 million USD for these purposes. The list of these companies also includes Uzbekistan's 'Uzkimyosanoat' JSC and 'ChemRar Group' holding company, which respectively allocated 10 and 15 million USD for innovation and scientific research (R&D).

The data in this table can be more clearly understood in the following diagram.

Diagram 2

Comparative ratio of revenues spent on R&D of TOP 10 chemical industry enterprises among CIS countries, 2022



From this chart, we can see that if we look at the ratio of the share of the TOP 10 chemical industry enterprises in the CIS countries that are directed to R&D in relation to their revenues, Arkema has the largest share among the TOP 10 enterprises, with 4.7% of its revenues being directed to R&D, reaching 21%. The Uzbek branch of the ChemRar

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group, although it spent only $ 15 million on R&D, directed 3.75% of its total revenues, which is 17% among the TOP 10 enterprises.

From this we can conclude that even if enterprises with low revenues direct a significant share of their revenues to R&D, this amount will not be large and they will need to make large investments to compete with large companies in the competitive market.

Economic efficiency is determined to solve two main tasks:

I. Assessing the efficiency of the enterprise's activities (using overall (absolute) indicators);

II. Evaluating the efficiency of the proposed options for production development and selecting the most optimal one (using relative indicators).

The digitization of industrial enterprises' efficiency or the level of digital transformation is assessed using overall efficiency indicators, which are divided into two groups: generic and specific indicators.

Generic indicators reflect the overall efficiency of the enterprise or its individual departments. This group of indicators includes:

- Growth rate of product volume
- Growth rate of profit
- Production profitability
- Costs per unit of product.

Based on the reports published by the USA chemical industry at the end of 2023 [12], which hold a leading position in the global chemical industry, we have compiled the following tables according to the aforementioned criteria:

Table 3
Production performance indicators of the US chemical industry,

base year: 2017=100%

Indicators	**2018**	**2019**	**2020**	**2021**	**2022**
Chemical substances	**104,9**	**104,3**	**101,7**	**119,5**	**137,7**
Basic chemicals	106,7	104,6	100,0	122,9	143,0
Inorganic substances	110,3	113,5	109,7	121,4	156,3
Mass petrochemical and intermediate products	106,3	102,5	97,2	121,6	143,5
Special chemicals	102,7	105,2	105,6	112,2	128,8
Agricultural chemicals	107,3	107,5	101,5	126,6	170,7
Consumer products	102,0	102,9	103,1	106,2	116,7
Pharmaceuticals (Drugs)	103,8	106,9	108,6	110,3	114,2
Chemicals and pharmaceuticals	**104,5**	**105,2**	**104,1**	**116,3**	**129,6**
raw materials	129,2	79,3	68,7	169,7	194,8
chemical exort	105,5	104,1	100,8	123,1	130,5
import of chemicals	105,6	102,5	99,0	116,6	134,6

It can be seen from the table above that the production volume of the US chemical industry has been increasing year by year, with a decline observed in 2019-2020 due to the COVID-19 pandemic. In turn, during those years, the

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extraction and supply of raw materials were also significantly reduced. Although the US chemical industry has consistently had a trade balance where exports exceed imports, in 2022, imports surpassed exports.

Table 4
Economic performance indicators of the USA chemical industry

	2018	2019	2020	2021	2022
Current ratio	1.1	1.1	1.2	1.2	1.1
Quick ratio	0.8	0.7	0.9	0.8	0.8
Cash ratio	0.2	0.2	0.3	0.3	0.2
Debet-to-equity ratio	1.4	1.4	1.5	1.4	1.4
Inventory Turnover	1.6	1.5	1.6	1.8	1.6
Operating margin (%)	10.0	9.2	9.0	12.5	11.9
Profit margin (%)	9.0	6.0	7.9	14.5	12.7
Inventories as a % of Revenue	13.6	14.2	13.7	11.9	13.0
Inventory Days of Supply	57.8	60.3	58.1	52.1	56.4
Thousand USA dollar					
Revenues/Employee	884	845	858	1 072	1 228
Net Income/Employee	79.6	51,0	67.9	155.5	155.7

From this table, it can be concluded that the average profit margin of US chemical industry enterprises has been increasing year by year, reaching 12.7% in 2022. However, the operational profit margin was lower in 2021 and 2022 compared to the profit margin, which is directly attributed to higher earnings from financial activities. The average annual income of chemical industry employees has also been increasing year by year, reaching 1,228 thousand USD in 2022.

CONCLUSIONS AND RECOMMENDATIONS

A comprehensive evaluation of the chemical industry requires an extensive analysis of its economic, technological, ecological, and social aspects. The alignment of these criteria and indicators helps ensure the sustainable development of the chemical industry. Through accurate assessments, the strengths and weaknesses of the industry can be identified, allowing for the development of its growth strategy.

The following directions can be proposed as ways to improve the methodological foundations for assessing the efficiency of utilizing the digitization potential in the chemical industry:

1. Modeling and Simulation

Modeling and simulation are important tools for understanding complex processes in the chemical industry. By creating mathematical models representing chemical reactions and operating conditions, companies can simulate various scenarios. This allows for:

- **Predictive Analysis:** Estimating the outcomes of chemical processes under different conditions that could lead to optimized production parameters.
- **Risk Assessment:** Identifying potential malfunctions or risks that may arise in processes before they occur, enabling proactive measures to mitigate risks.
- **Process Optimization:** Iteratively improving processes based on simulation results to increase yields and reduce waste.

2. Data Analysis

The use of big data and advanced analytics is revolutionizing the chemical industry. Data analysis involves:

- **Data Collection:** Gathering large volumes of data from sensors, production lines, and supply chains.

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- Statistical Analysis: Using statistical methods to identify patterns and correlations within the data, leading to actionable insights.

- Machine Learning: Implementing machine learning algorithms to predict equipment failures, optimize supply chains, and improve product quality based on historical data.

3. Automation

Automation technologies, including robotics and artificial intelligence (AI), play a crucial role in enhancing efficiency in the chemical sector:

- Process Automation: Automating repetitive tasks reduces human error and increases efficiency. For example, automated mixing and chemical feeding systems provide more accurate measurements.

- IoT Integration: The Internet of Things (IoT) allows for real-time monitoring of equipment and processes. Sensors can provide immediate feedback, enabling quick adjustments and maintenance, which reduces downtime.

- Smart Manufacturing: Implementing Industry 4.0 principles to create interconnected manufacturing systems that enhance productivity and flexibility.

4. Technological Innovations

The chemical industry can greatly benefit from the application of advanced technologies, such as:

- Nanotechnology: Utilizing materials at the nanoscale can lead to new products with improved properties, such as enhanced catalysts or effective drug delivery systems.

- Biotechnology: Integrating biological processes into chemical production can result in green manufacturing methods, such as using enzymes for chemical reactions or bio-based raw materials.

- Sustainable Chemistry: Innovations aimed at reducing environmental impact, such as processes that minimize energy consumption or utilize renewable resources.

5. Environmental Sustainability

Assessing the environmental impact of chemical processes is becoming increasingly important. Strategies may include:

- Environmental Efficiency Indicators: Developing indicators to assess resource utilization and waste production, enabling companies to measure their environmental footprints.

- Life Cycle Assessment (LCA): Conducting LCAs to evaluate the environmental impacts of products from raw material extraction to disposal, assisting in making more sustainable decisions.

- Circular Economy Practices: Implementing practices that promote recycling and reusing materials in the production process, reducing waste and conserving resources.

6. User Feedback

Collaborating with stakeholders, including customers and employees, is crucial for enhancing efficiency and effectiveness:

- Surveys and Interviews: Gathering feedback on user experiences with products and processes can provide insights for improvements.

- Collaborative Innovation: Encouraging collaboration between different departments (R&D, production, marketing) can lead to innovative solutions that enhance overall efficiency.

- Training and Development: Investing in training employees to effectively utilize new technologies and practices.

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