

<https://doi.org/10.31891/2307-5732-2026-361-37>

УДК 504: 661

**MYKHAILOVA EVGENIYA**

Simon Kuznets Kharkiv National University of Economics

<https://orcid.org/0000-0002-0182-0823>

e-mail: [mykhailova.e@ukr.net](mailto:mykhailova.e@ukr.net)

## METHODS OF UTILIZING CARBON DIOXIDE AS A MAIN GREENHOUSE GAS BY PRODUCING MARKETABLE PRODUCTS

*The problem of anthropogenic greenhouse gas emissions is one of the key environmental challenges of our time. The growth of their concentration in the atmosphere causes global warming, the appearance of anomalous natural phenomena around the world and hurts the development of local and global economies. In this regard, the development of effective methods for neutralizing anthropogenic greenhouse gas emissions becomes relevant. The purpose of the research is to conduct a comprehensive analysis of the problem of anthropogenic carbon dioxide (CO<sub>2</sub>) emissions, as the main greenhouse gas, and to identify promising approaches to its utilization by converting it into marketable products. The article analysed the current state of anthropogenic CO<sub>2</sub> emissions on a global scale and identified the main sources of their formation. It is concluded that in the context of intensification of industrial production and growth in energy consumption, namely carbon dioxide, is a multi-ton greenhouse gas that determines the pace of global warming. The author studied and systematized methods for the utilization of anthropogenic CO<sub>2</sub> emissions. It was established that the introduction of chemical and technological methods is one of the key tools for implementing the policy of decarbonisation of the economy and achieving the climate goals set by the Paris Agreement. It is possible to utilize carbon dioxide by converting it into useful commercial products: methanol, polymers, and urea. Methanol is a universal raw material for the chemical industry and an alternative fuel; the technology is being actively researched and implemented as a way to store "green" hydrogen and, at the same time, utilize CO<sub>2</sub>. Polycarbonates are compounds that can be produced from CO<sub>2</sub> to reduce dependence on oil resources and create materials with a low carbon footprint. Urea is a chemical substance widely used as a fertilizer; this is one example of successful industrial utilization of carbon dioxide on a large scale. It is emphasized that the implementation of CO<sub>2</sub> utilization technologies has not only environmental but also economic significance, as it contributes to the creation of new product markets, reducing dependence on fossil fuels and forming a sustainable low-carbon economy.*

**Keywords:** carbon dioxide, climate change, recycling, methanol, urea, plastic.

**МИХАЙЛОВА ЄВГЕНІЯ**

Харківський національний економічний університет імені Семена Кузнеця

## МЕТОДИ УТИЛІЗАЦІЇ КАРБОН (IV) ОКСИДУ ЯК ОСНОВНОГО ПАРНИКОВОГО ГАЗУ ШЛЯХОМ ВИРОБНИЦТВА ТОВАРНИХ ПРОДУКТІВ

*Проблема антропогенних викидів парникових газів, зокрема карбон (IV) оксиду (CO<sub>2</sub>), є одним із найважливіших екологічних викликів сучасності. Підвищення концентрації CO<sub>2</sub> в атмосфері спричиняє глобальне потепління та негативно впливає на природні й економічні системи. Метою дослідження є аналіз сучасного стану викидів карбон (IV) оксиду і визначення перспективних методів його утилізації шляхом перетворення на корисні товарні продукти. У статті розглянуто основні джерела утворення CO<sub>2</sub> і тенденції зростання його концентрації в атмосфері. Проведено систематизацію сучасних методів утилізації CO<sub>2</sub>. Наведено характеристику хіміко-технологічних методів перероблення карбон (IV) оксиду у метанол, полімери та карбамід. Метанол може використовуватися як сировина та альтернативне паливо, полікарбонати сприяють зменшенню використання нафтових ресурсів, а карбамід є прикладом промислової утилізації CO<sub>2</sub>. Зазначено, що впровадження технологій утилізації карбон (IV) оксиду має важливе екологічне й економічне значення, сприяючи розвитку низьковуглецевої економіки та зниженню залежності від викопної сировини.*

**Ключові слова:** карбон (IV) оксид, зміна клімату, утилізація, метанол, карбамід, пластик.

Стаття надійшла до редакції / Received 12.11.2025

Прийнята до друку / Accepted 11.01.2026

Опубліковано / Published 29.01.2026



This is an Open Access article distributed under the terms of the [Creative Commons CC-BY 4.0](https://creativecommons.org/licenses/by/4.0/)

© Михайлова Євгенія

### General statement of the problem and its connection with important scientific or practical tasks

The most significant problem of the 21st century is global climate change due to the increase in the Earth's global average temperature. This problem affects many aspects of environmental and societal existence. Humanity is already experiencing the consequences of this process, including deterioration of human health, the appearance of anomalous natural phenomena around the world, and a negative impact on the development of local and global economies.

According to the Sixth Assessment Report on Climate Change, published by the Intergovernmental Panel on Climate Change in March 2023, it is anthropogenic greenhouse gas emissions that have undoubtedly caused the increase in global temperatures. In 2011–2020, global temperatures increased by 1.1 °C compared to 1850–1900 as a result of unsustainable energy consumption, fossil fuel use, land use, consumption and production patterns [1].

The main measures designed to reduce anthropogenic greenhouse gas emissions and mitigate the effects of global climate change include the decarbonization processes of economic activity in global society.

### Analysis of research and publications

The climate change problem due to global warming of the Earth has been on the agenda for more than 40 years. During this time, realizing the seriousness of the problem, the world community has taken a course towards decarbonization of the economy. This process is the development and implementation of a set of measures, methods and technologies aimed at limiting the rate of global warming, while meeting the energy and industrial needs of humanity.

Decarbonization is based on two main principles: reducing greenhouse gas emissions into the atmosphere, primarily carbon dioxide (CO<sub>2</sub>), as the largest in tonnage among all greenhouse gases, and limiting the extraction and use of carbon-containing raw materials.

A significant step towards decarbonization at the global level was the adoption of the Paris Agreement in 2015, which replaced the Kyoto Protocol. This took place during the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change. The Paris Agreement entered into force in 2020. The main goal of this document was to limit the increase in global temperature to less than 2 °C and achieve net-zero CO<sub>2</sub> emissions in the second half of the century. In the context of globalization, each individual country cannot plan its economic development, especially the industrial sector, without taking into account the development of the world economy. This provision is agreed upon between different countries at the UN level [2].

One of the requirements of the Paris Agreement for signatory countries is to develop a Low-Carbon Development Strategy by 2050. In this regard, at the COP26 climate summit held in Glasgow in 2021, more than 40 countries around the world agreed to gradually abandon the use of coal for electricity generation. The world's largest economies must abandon coal generation by 2030, smaller ones by 2040.

The governments of the world's leading countries have agreed that achieving the goals of the Paris Agreement is possible by phasing out the use of coal for electricity generation. However, the use of solar power plants and wind turbines does not make it possible to achieve complete decarbonization in many carbon-intensive sectors of the economy, such as transport (aviation), cement production or agriculture. According to the International Energy Agency, the Paris Agreement goals can be achieved by scaling up existing strategies to their maximum practical limits. This means that we do not need to rely on unforeseen technological breakthroughs – we need to leverage existing technologies globally to make progress [3].

Currently, there are several options for solving the problem of global climate change, which are being considered by scientists and leading global companies, namely:

- reducing carbon dioxide emissions in the process of production activities [4];
- increasing the number of carbon dioxide absorbers: projects to plant forests or other vegetation [5];
- storing CO<sub>2</sub> in geological layers [6];
- utilizing CO<sub>2</sub> by producing valuable industrial goods (fuel, urea, methanol, carbonate fibre (carbon plastic), etc.) [7].

From the author's point of view, namely obtaining marketable products from carbon dioxide not only helps reduce greenhouse gas emissions, but also creates opportunities for the formation of a closed carbon cycle in industry.

#### Formulation of the article's objectives

**The purpose of the research work** is to conduct a comprehensive analysis of the problem of anthropogenic carbon dioxide emissions and to determine promising chemical and technological approaches for its utilization to convert into marketable products.

#### Presentation of the main material

Carbon dioxide is a direct-acting greenhouse gas that forms a natural greenhouse effect on our planet. Greenhouse gases do not transmit infrared radiation released by the Earth's surface well, so heat is retained above the planet without leaving the atmosphere. The level of CO<sub>2</sub> in the atmosphere began to grow steadily in the 19th century, at the beginning of the Industrial Revolution. According to scientists, then it did not exceed 280 ppm.

Today, the concentration of carbon dioxide in the atmosphere is the highest and is growing faster than ever in human history due to active anthropogenic emissions. The record level of CO<sub>2</sub> has been updated regularly for the past few years. According to the Mauna Loa Weather Observatory (Hawaii), which has been monitoring various indicators of the Earth's atmosphere since the late 1950s, the concentration of CO<sub>2</sub> in the atmosphere in April 2024 was 4.7 ppm higher than a year earlier. This is the highest jump in the entire time of tracking such indicators. According to the latest readings, the concentration of carbon dioxide in the atmosphere has approached 427 ppm, which is more than 50% higher than the pre-industrial level (Fig. 1) [8].

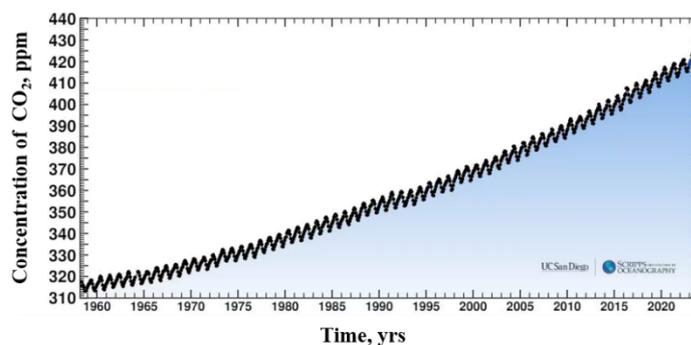


Fig. 1. Concentration of carbon dioxide over the years at the observations of the Mauna Loa Observatory [8]

Scientists believe that the increase in carbon dioxide levels in the atmosphere is mainly due to the use of fossil fuels such as coal, oil, and natural gas. Fossil fuels provide more than 98% of the world's energy needs.

The International Energy Agency (IEA) [9] estimates that the electricity sector has accounted for nearly two-thirds of the record increase in CO<sub>2</sub> emissions since 2013. Global carbon dioxide emissions from the energy sector rose by 1.7% by mass in 2018, reaching a record high of 33.1 Gt CO<sub>2</sub>. The increase in carbon dioxide emissions is driven by high energy consumption as a result of a strong global economy, as well as weather conditions in some parts of the world, which have led to increased demand for energy for heating and cooling.

Also, a significant share of the increase in the concentration of CO<sub>2</sub> in the air is accounted for by the production of steel, aluminium, cement, inorganic synthesis products, etc. Thus, the rapid development of energy and industry will further cause a more rapid growth in anthropogenic carbon dioxide emissions. It is expected that in 2050 the concentration of CO<sub>2</sub> in the atmosphere will reach 550 ppm.

In this regard, the problem of not only reducing CO<sub>2</sub> emissions (gas purification, geological storage) but also its utilization becomes relevant. It is possible to utilize carbon dioxide by converting it into useful, economically valuable substances – marketable products.

The main marketable products that can be obtained by utilizing carbon dioxide include:

- methanol – a universal raw material for the chemical industry and an alternative fuel. The technology is being actively researched and implemented as a way to store “green” hydrogen and at the same time utilize CO<sub>2</sub>;
- polycarbonates, the production of which allows for the reduction of dependence on oil resources and creates materials with a low carbon footprint;
- urea – a chemical that is widely used as a fertilizer. This is an example of the successful industrial utilization of carbon dioxide on a large scale.

#### *Production of methanol from carbon dioxide*

Methanol (CH<sub>3</sub>OH) is the simplest monohydric alcohol. It is widely used as a raw material for the synthesis of formaldehyde, acetic acid, methylamines; in the production of plastics, synthetic fibers; as a fuel or fuel additive (methanol fuel); as an energy carrier in fuel cells.

Modern chemistry is looking for a sustainable alternative to the traditional method of producing methanol from natural gas (CH<sub>4</sub>). Producing methanol from CO<sub>2</sub> is one such way.

The reduction of CO<sub>2</sub> to methanol occurs according to the following reaction:



This is an exothermic reaction ( $\Delta H < 0$ ) that requires the use of catalysts, high temperatures (200–300 °C) and pressures (5–10 MPa). The key component in the synthesis of methanol is hydrogen (H<sub>2</sub>). It can be obtained in several ways:

- by water electrolysis (“green” hydrogen – using renewable energy);
- from biomass or natural gas (“grey” hydrogen);
- by photocatalysis.

For environmental efficiency, it is preferable to use hydrogen derived from renewable sources.

Copper-based catalysts (Cu/ZnO/Al<sub>2</sub>O<sub>3</sub>) are the most effective for the process of methanol synthesis from carbon dioxide. They are similar to those used in methanol synthesis from syngas. New nanostructured and photocatalysts are also being investigated to reduce energy costs and increase reaction selectivity.

There are several possible technologies for the production of methanol from carbon dioxide:

- heterogeneous catalysis, in which the target reaction is carried out in the gas phase on the surface of a solid catalyst under high pressure. This is a traditional industrial technology [10];
- electrochemical reduction of CO<sub>2</sub>, which is carried out using electrodes in an aqueous environment. This technology requires the development of new efficient electrocatalysts [11];
- photocatalytic conversion of CO<sub>2</sub> – a process carried out using UV radiation on the surface of the catalyst. This is a promising technology that is still at the stage of laboratory research [12].

The advantages of methanol synthesis technology through carbon dioxide utilization include:

- reduction of CO<sub>2</sub> emissions – combating global warming;
- reduction of dependence on fossil fuels and use of renewable energy sources – sustainable development;
- accumulation of energy in the form of methanol – integration with the system of including energy obtained from renewable sources into the country's overall energy system.

In addition to the environmental benefits, there are certain challenges to the technology of methanol synthesis from CO<sub>2</sub>. These include the high energy cost of hydrogen production, the need for new highly efficient catalysts, and infrastructure constraints. But in the future, with the improvement of technologies and the reduction in the cost of renewable energy, the production of methanol from carbon dioxide can become an important part of a carbon-neutral economy.

Thus, the production of methanol from carbon dioxide is a scientifically and technically sound approach to converting CO<sub>2</sub> into valuable chemical raw materials. This direction combines the achievements of modern chemistry, eco-technologies and energy. It has the potential for widespread implementation in the context of the transition to a sustainable and carbon-free economy.

#### *Production of plastic from carbon dioxide*

Plastic is a synthetic or semi-synthetic polymeric material that consists of long chains of molecules called polymers. These polymers are formed as a result of the chemical reaction of polymerization of monomers – small molecules that can connect. Different types of plastic have specific structures and properties that can be modified by adding various additives. Production of plastic from carbon dioxide promises not only to reduce greenhouse gases but also to provide an environmentally friendly alternative to traditional methods of polymer production. The process of using carbon dioxide as a raw material for producing plastic typically involves the following key stages: extraction of

CO<sub>2</sub> from industrial emissions or atmospheric air; conversion of CO<sub>2</sub> into monomers through catalytic, electrochemical, and biological technologies; and polymerization of monomers to obtain products with specified properties.

Catalytic conversion of carbon dioxide is based on its interaction, with other chemicals with the participation of catalysts [13]. This process is possible due to the use of metal complex and acid-base catalysts or enzymes. These substances activate CO<sub>2</sub> molecules and promote their incorporation into polymer chains.

Among the main methods of catalytic conversion of carbon dioxide, the following can be distinguished:

- polycarbonatization – obtaining polymers based on polycarbonates by interacting CO<sub>2</sub> with epoxides;
- polymerization of cyclic carbonates – using CO<sub>2</sub> for the synthesis of monomers (butylene carbonate, glycerol carbonate), which are subsequently polymerized;
- copolymerization of CO<sub>2</sub> with olefins – obtaining complex polymer structures with the participation of polyolefins.

One of the promising methods is the electrochemical conversion of carbon dioxide into polymeric materials [13]. This process is carried out in special electrochemical cells, where catalytic reactions of CO<sub>2</sub> reduction to target organic molecules occur under the influence of an electric current. Catalytic reduction of CO<sub>2</sub> occurs when it interacts with an electrode on the surface of which catalysts (metals, metal oxides or organic catalysts) are placed. During this process, various monomers (ethylene, methanol, ethanol, propanol, glycols, oxalates) can be formed. The chemical nature of monomers will depend on the conditions of the redox reactions. The resulting monomers are then used for the synthesis of polymers.

Current research is also aimed at developing biotechnological methods for converting CO<sub>2</sub> into useful materials, in particular, bioplastics [14]. Such methods are based on the use of microorganisms and biocatalysts that are able to absorb carbon dioxide and synthesize polymers. Biotechnological methods for converting carbon dioxide involve the use of microorganisms (bacteria, cyanobacteria, algae) that can fix CO<sub>2</sub> through photosynthetic or chemoautotrophic processes. The resulting polymers, such as polyhydroxyalkanoates (PHA), are the basis for the production of bioplastics. These materials are biodegradable and can completely replace traditional plastics.

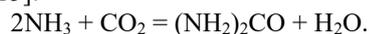
The production of plastic from carbon dioxide has significant advantages, which include reducing greenhouse gas emissions, reducing the use of oil and gas, producing biodegradable materials that do not harm the environment. However, there are also certain problems associated with the technologies listed above. These include the high cost of production processes compared to traditional methods, the need to develop effective catalysts and improve technologies, and the lack of large-scale industrial implementation.

The growing interest of governments and environmental organizations in reducing carbon dioxide emissions creates favorable conditions for investment in this area. In the future, plastic made from carbon dioxide may become not only an ecological alternative to traditional polymers, but also a key element in the fight against climate change. Despite the challenges, these technologies have significant potential and can be an important step towards creating sustainable production of materials that minimize human impact on the environment.

#### *Production of urea from carbon dioxide*

Urea (CO(NH<sub>2</sub>)<sub>2</sub>) – one of the most important chemical products, which is widely used in agriculture as a nitrate fertilizer, as well as in the chemical, pharmaceutical and polymer industries.

Traditionally, urea is produced by reacting ammonia (NH<sub>3</sub>) with carbon dioxide under high pressure (13–21 MPa) and temperature (160–200 °C) [15]:



However, modern challenges of sustainable development and reduction of greenhouse gas emissions stimulate the development of alternative technologies, in particular electrochemical synthesis of urea. This method is based on the simultaneous electroreduction of CO<sub>2</sub> and nitrogen-containing compounds (NO<sub>3</sub><sup>-</sup>, NO<sub>2</sub><sup>-</sup>, N<sub>2</sub>) in the presence of an appropriate catalyst. The process may include stages of reduction of nitrogen compounds to ammonia, as well as parallel conversion of carbon dioxide to activated forms capable of forming urea, for example, carbon oxide (CO).

Electrochemical synthesis of urea can be carried out in an electrolyzer under ambient conditions [16]. This makes it more energy-efficient compared to traditional methods. The efficiency of the process largely depends on the choice of electrocatalyst. Current research indicates that molybdenum, copper or iron-containing compounds, organometallic frameworks, transition metal heterostructures, and monatomic catalysts that demonstrate high selectivity for urea formation are most effective. Catalysts should provide simultaneous binding and activation of CO<sub>2</sub> molecules and nitrogen-containing compounds, promoting the formation of C–N bonds.

The advantages of electrochemical synthesis of urea include: environmental friendliness (using CO<sub>2</sub> as a raw material helps reduce greenhouse gas emissions), energy efficiency (the process can be carried out at room temperature and pressure), the possibility of using renewable energy sources – solar or wind plants, modularity and scalability (the possibility of building local plants for urea synthesis near places of consumption).

Despite its potential, the electrochemical method faces a number of technical and scientific challenges, namely: low yield and product selectivity due to competition with the hydrogen evolution reaction, the need for highly selective and stable catalysts, the difficulty of detecting and quantifying urea in the presence of by-products. However, active research in the field of electrocatalysis, nanotechnology and reactor optimization opens up broad prospects for the commercialization of this process.

#### **Conclusions from this study and prospects for further exploration in this direction**

Carbon dioxide is the main anthropogenic greenhouse gas that significantly affects global climate change. Reducing its concentration in the atmosphere is one of the key tasks of modern environmental policy and industrial ecology.

Utilization of CO<sub>2</sub> with the production of marketable products is a promising direction that combines environmental feasibility with economic benefit. The conversion of CO<sub>2</sub> into chemical compounds with added value contributes to the implementation of the principles of a circular (closed) economy and the rational use of carbon resources.

Among the main methods of CO<sub>2</sub> processing, chemical, electrochemical, and catalytic approaches are distinguished. Each of them has its own advantages and limitations, due to energy costs, the yield of the target product and the scalability of the process. The most practically significant directions are the synthesis of methanol, synthetic gas, polymers, mineral carbonates and fuels, which are already used in industry or are undergoing the stage of experimental implementation.

Further development of CO<sub>2</sub> conversion technologies requires integration with renewable energy sources, improvement of catalysts and an increase in the efficiency of fixation processes. This will create conditions for the large-scale implementation of such technologies in industry and will contribute to reducing the carbon footprint of the global economy. Thus, the utilization of carbon dioxide with the production of marketable products is not only environmentally sound, but also a strategically important direction that combines the tasks of environmental protection and the formation of sustainable production of the future.

## References

1. Climate Change 2023: AR6 Synthesis Report. IPCC. <https://doi.org/10.59327/IPCC/AR6-9789291691647>.
2. Mykhailova E. O. (2023). Analiz problemy vykydiv parnykovykh haziv ta metodiv yikh zneshkodzhennya [Analysis of the greenhouse gas emissions problem and the methods of their disposal]. The scientific paradigm in the context of technological development and social change : scientific monograph. Part 2. Riga, Latvia: "Baltija Publishing", pp. 25–59. <https://doi.org/10.30525/978-9934-26-297-5-21>. [in Ukrainian].
3. Snaebjörnsdóttir S. O., Sigfússon B., Marieni C., Goldberg D., Gíslason S. R., & Oelkers E. H. (2020). Carbon dioxide storage through mineral carbonation. *Nature Reviews Earth & Environment*, 1(2), 90–102. <https://doi.org/10.1038/s43017-019-0011-8>.
4. Mykhailova E. O., Panasenko V. O., & Markova N. B. (2020). Problema vykydiv karbon (IV) oksydu ta mozhlyvi shlyakhy yiyi vyrishennya [Carbon (IV) oxide emissions problem and the possible ways to its solving]. *Visnyk NTU "KHPI". Seriya: Novi rishennya v suchasnykh tekhnolohiyakh*, 1 (3), 80–88. <https://doi.org/10.20998/2413-4295.2020.03.11> [in Ukrainian].
5. Prabakaran Ganeshan, Vigneswaran V S , & Sarath C. Gowd (eds.) (2023). Bioenergy with carbon capture, storage and utilization: Potential technologies to mitigate climate change. *Biomass and Bioenergy*, 177, 106941. <https://doi.org/10.1016/j.biombioe.2023.106941>.
6. Mykhailova E. O. (2023). Problemy ta perspektyvy heolohichnoho zberihannya vuhlekysloho hazu [Problems and prospects of carbon dioxide geological storage]. *Ekolohichna bezpeka: problemy i shlyakhy vyrishennya : zb. nauk. statey XIX Mizhnarodnoyi naukovo-praktychnoyi konferentsiyi, 14–15 veresnya 2023 roku*. Kharkiv: UKRNDIEP, pp. 269–274. [in Ukrainian].
7. Bhavsar A., Hingar D., Ostwal S., Thakkar I., Jadeja S., & Shah M. (2023). The current scope and stand of carbon capture storage and utilization – A comprehensive review. *Case Studies in Chemical and Environmental Engineering*, 8, 100368. <https://doi.org/10.1016/j.cscee.2023.100368>.
8. Dance Scott. (2024, May 10). Hawaii's Mauna Loa Observatory just captured ominous signals about the planet's health. *The Washington Post*. <https://www.washingtonpost.com/weather/2024/05/10/carbon-dioxide-record-mauna-loa/>.
9. Global Energy & CO<sub>2</sub> Status Report 2019. IEA. <https://www.iea.org/reports/global-energy-and-co2-status-report-2019/emissions#abstract>.
10. Azhari N. J., Erika D., St Mardiana, Ilmi T., Gunawan M. L., Makertihartha I. G. B. N., & Kadja G.T. M. (2022). Methanol synthesis from CO<sub>2</sub>: A mechanistic overview. *Results in Engineering*, 16, 100711. <https://doi.org/10.1016/j.rineng.2022.100711>.
11. Leonzio G., Hankin A., & Shah N. (2024). CO<sub>2</sub> electrochemical reduction: A state-of-the-art review with economic and environmental analyses. *Chemical Engineering Research and Design*, 208, 934–955. <https://doi.org/10.1016/j.cherd.2024.07.014>.
12. Jiao J., Ma Y., Han X., Ergu A., Zhang C., Chen P., Liu W., Luo Q., Shi Z., Xu H., Chen C., Li Y., & Lu T. (2025). Sun-simulated-driven production of highpurity methanol from carbon dioxide. *Nature Communications*, 16, 857. <https://doi.org/10.1038/s41467-025-56101-8>.
13. Centi G., & Perathoner S. (2021). Catalytic Technologies for the Conversion and Reuse of CO<sub>2</sub>. In: Lackner M., Sajjadi B., & Chen W. Y. (eds.) *Handbook of Climate Change Mitigation and Adaptation*. New York: Springer, pp. 1–50. [https://doi.org/10.1007/978-1-4614-6431-0\\_119-1](https://doi.org/10.1007/978-1-4614-6431-0_119-1).
14. Almomani F., Abdelbar A., & Ghanimeh S. (2023). A Review of the Recent Advancement of Bioconversion of Carbon Dioxide to Added Value Products: A State of the Art. *Sustainability*, 15(13), 10438. <https://doi.org/10.3390/su151310438>.
15. Ding J., Ye R., Fu Y., He Y., Wu Y., Zhang Y., Zhong Q., Kung H. H., & Fan M. (2023). Direct synthesis of urea from carbon dioxide and ammonia. *Nature Communications*, 14, 4586. <https://doi.org/10.1038/s41467-023-40351-5>.
16. Kohlhaas Y., Tschauer Y. S., Plischka W., Simon U., Eichel R. A., Wessling M., & Keller R. (2024). Electrochemical urea synthesis. *Joule*, 8(6), 1579–1600. <https://doi.org/10.1016/j.joule.2024.04.004>.