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Carbon Dioxide as a Fundamental Component in Sustainable Organic Synthesis

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Abstract

A lot of people are interested in carbon dioxide (CO_2) as a cheap, plentiful, and safe source of carbon for making chemical processes more sustainable. Using it as a C1 building block in organic synthesis is a promising way to make products with added value while having less of an impact on the environment. This article examines current advancements in CO_2 fixation into organic compounds, emphasising the creation of effective catalytic systems for synthesising carboxylic acids, ureas, carbonates, and cyclic carbonates. The focus is on transformations mediated by transition metals and organocatalysts, as well as new methods that use photochemical and electrochemical activation of CO_2 at low temperatures. Innovative catalyst design and reaction engineering help solve problems like CO_2's low reactivity and 17thermodynamic stability. This work emphasises the potential of carbon dioxide as a renewable carbon source in green chemistry and stresses the necessity of including CO_2 utilisation into future synthetic techniques to facilitate circular economy models.

Keywords: Carbon dioxide utilisation, sustainable synthesis, CO_2 fixation, green chemistry, catalytic transformation

INTRODUCTION

Carbon dioxide is the most important greenhouse gas that people make, and it also hurts the ozone layer the most. It can be made, moved, and stored safely because it doesn't react with anything. People also employ naturally fixed CO2 as a raw material to make fuels, chemicals, and materials. Carbon dioxide is a real chance to use less fossil fuels, close the carbon cycle, and keep CO2 levels in the air steady. A significant challenge for civilisation is to devise and advance innovative chemical and biological techniques for the incorporation of CO2 into valuable products. In this setting, chemists and physicists still need to find better ways to exploit CO2 The direct utilisation of carbon dioxide as a sustainable feedstock in organic synthesis is examined.

WHAT CARBON DIOXIDE DOES IN ORGANIC CHEMISTRY

Since the beginning of organic chemistry, carbon dioxide (CO2) has been an important one- carbon building block in organic synthesis. Because it is present in almost every field of science and technology and is known to be a major greenhouse gas caused by humans, there is a lot of interest in technologies that can control its release and turn it into useful compounds. The scientific community has been working on finding renewable sources and sustainable techniques to replace fossil-derived feedstocks because they are worried about climate change and the loss of resources. CO2 is the easiest renewable source of one carbon, and it is used more and more in organic synthesis. A full range of techniques for fixing CO2 in organic compounds has changed the way we think about classic reactions. CO2 is plentiful, easy to get, cheap,

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renewable, safe, and cheap. These factors provide problems while simultaneously providing opportunity to create novel changes through alternate activation pathways. It is possible to imagine both catalytic and non-catalytic ways to use CO2 [1, 2].

Context in History

In the eighteenth century, the discovery of catalytic mineralisation of CO2 by hydrogen facilitated its utilisation as a renewable and non-toxic C1 building block in organic synthesis. The development of sustainable technologies, especially electro-mediated methods, has made it more useful in organic transformations. The usage of CO2 is a significant part of the circular carbon economy because it is meant to replace fossil-based carbon compounds. Because of its particular qualities—stability, non-toxicity, abundance, and availability—it has only been used as a solvent in supercritical CO2 or in the field of tricarbonylchromium chemistry. Carbon dioxide emerged as a viable candidate early on due to its relative availability and non-toxicity. Carbon dioxide can theoretically substitute carbon-based feedstocks in carboxylation processes and facilitate the development of a circular carbon economy, regardless of its origin from fossil fuels or biogas. However, it is crucial to think about a few things, like how much carbon trioxide is available in North America and Europe. Carbon dioxide comes from fossil fuels all across the world, but in Europe it comes from living things. When looking at the reaction pathways of carbon dioxide [3, 4], it's vital to make a clear difference between catalytic and non-catalytic processes.

What is Being Used Right Now

Today, making chemical compounds with added value from carbon dioxide is very interesting. Using carbon dioxide as a raw material instead of more common ones, including those from fossil fuels, could provide a number of benefits. In this case, turning carbon dioxide into usable molecules is more of a chemical equilibrium problem than a thermochemical one. This means that the right design of reaction processes is very important if we want to get the most of this chemical system. In the last few decades, worries about too much carbon dioxide being released into the air have made people work together to control and lower the levels. Even if there is a need for development and numerous research have been done in the last few decades, the main way to stop the rise in atmospheric CO2 is still carbon capture and storage (CCS).

WAYS TO USE CARBON DIOXIDE

There is a lot of stress on using carbon dioxide in ways that are good for the environment. A mechanistic analysis of the current trends in the utilisation of carbon dioxide in organic chemistry is presented. We talk about both catalytic and non-catalytic ways to use carbon dioxide. We look at and group the most modern thermochemical, electrochemical, and photo/electrochemical processes that use carbon dioxide. Carbon dioxide is one of the most important molecules when it comes to sustainability and the environment. There has been a lot of attention lately in how to turn it into carbon monoxide or formic acid by mixing photo and electrochemical processes with solar and wind energy. Additionally, the utilisation of carbon dioxide as a foundational element for the production of value-added products has garnered significant interest.

The use of carbon dioxide is definitely something that more and more people are interested in and studying. You can get carbon dioxide from the air, but most of it comes from burning things in factories and making chemicals. Because of these things, carbon dioxide is often seen as a waste when it is used for synthesis, and there are concerns about how it is made and how it affects the environment. But carbon dioxide can be used to make other organic chemicals that are more useful, which means that fewer fossil-based precursors need to be used. From a practical standpoint, the potential for carbon dioxide utilisation can be highlighted in relation to waste reduction, land use, and energy consumption. More and more people are worried about greenhouse gas emissions and how they affect the environment. This is a good thing for carbon dioxide use.

Processes That Use Catalysts

Organocatalysis is still a very important part of CO_2-utilization processes. It is often seen as the best way to make cyclic carbonates, polycarbonates, and other similar products. Heterogeneous organocatalysis is a specialised field that uses supported catalysts, which are a type of material-supported catalyst, to add CO_2 under mild conditions. Electrochemical CO_2 conversion uses metal catalysts on the surfaces of electrodes, while enzymatic conversions use enzyme catalysts, which are occasionally fixed to supports to make them last longer and work better. So, heterogeneous catalysis is a unifying idea, and all catalytic processes depend on a catalyst, which shows how many ways there are to incorporate CO_2 [5, 6].

Processes That Don't Use Catalysts

Non-catalytic CO_2 chemistry is very important for the selective incorporation of CO_2 into organic molecules in sustainable chemical synthesis. It works well with catalytic techniques. CO_2 is stable and kinetically inert at room temperature, thus stoichiometric reagents can be used to make it more reactive so that nucleophiles can be made on demand. For instance, bases create thermodynamic equilibrium that favours the creation of carbamate or alkylcarbonate anions when there are no catalysts present. After that, the anion hits a nucleophile to make the desired product. Non-catalytic CO_2 chemistry provides various pathways for the application of CO_2 in organic synthesis.

WAYS TO CHANGE CO2 THAT ARE GOOD FOR THE ENVIRONMENT

At room temperature and pressure, electrochemical, thermochemical, and biological techniques may turn CO_2 into usable chemicals with 100% atom economy. The approaches are examined in the sections under "Electrochemical Methods of CO2 Utilisation," "Thermochemical Methods of CO2 Utilisation," and "Biological Methods of CO2 Utilisation." [1, 5].

Electrochemical Reduction

Electrochemical reduction appears to be a promising approach for synthesising organic compounds directly from carbon dioxide (CO_2) under ambient settings. If the chemical industry can find good ways to turn CO_2 into small organic C1- and C2-building blocks, it may move towards a model that relies on sustainable feedstocks. Carbon monoxide (CO), a key building element that has traditionally come from fossil fuels, is a key part of making both hydrocarbons and oxygenates. A lot of work has gone into designing and characterising molecular electrocatalysts that selectively turn CO_2 into CO while lowering the amount of overpotential needed. The electrochemical apparatus has been shown to be strong and able to be recycled. The procedure can also start with CO_2 from the atmosphere, which shows that it might be used to directly add the greenhouse gas as an alternative C1 source [7]. Gas Chromatography-Mass Spectrometry and Ion Chromatography are used to find and measure liquid products during electrochemical reduction. Gas chromatography is used to find gaseous species. Complementary computational studies utilise quantum mechanical calculations via the Vienna Ab Initio Simulation Package (VASP), employing the Perdew–Burke–Ernzerhof (PBE) variant of the generalised gradient approximation (GGA) for exchange-correlation potentials, supplemented by the GGA+U method to address hybridisation effects in iron 3d and oxygen 2p orbitals. The projector augmented wave (PAW) formalism is used to deal with the valence electrons, and a plane-wave cutoff energy of 520 eV is used [8].

Thermochemical Techniques

Even though people are interested in electrochemical methods, a lot of thermochemical methods have been made to turn CO_2 into basic compounds. In the last few decades, a lot of metal complex-based catalysts have been used successfully to efficiently reduce CO_2 in homogeneous conditions. In these reactions, the metal centre acts as a "electron transfer mediator" between the electrode and substrate, and changing the coordination sphere of the complex has a big effect on how well the catalyst works. Putting these complexes on the electrodes is a good way to combine the catalyst's effectiveness with a simple way to recycle and recover it. The findings indicate that the nanostructured electrocatalysts have both high activity and optimal selectivity [3]. Thermal catalysis is one of the most important ways that industries turn CO_2 into something else. It can be done in several ways, such as heterogeneous, homogeneous, photo-, and bio-catalysis. Photocatalytic conversion strategies depend on analogous chemical reactions as electrochemical methods, differing solely in the use of a catalyst capable of transferring excited-state electrons to CO_2. Supported semiconductors are the most studied photocatalysts. Recently, molecular-based photocatalysts have become a new type of very selective and powerful catalysts [9, 10]. Biological thermal catalysis can be categorised into two principal processes for CO_2 utilisation: the microbially driven process and the enzymatic catalytic process at ambient temperature and pressure.

Biological Pathways

The goal of the Sustainable Aviation Fuel Grand Challenge is to make transformation technology work on a larger scale such that it can make high-quality sustainable aviation fuel from nonpetroleum hydrocarbons like biomass and carbon dioxide (CO_2). Biological systems use enzymes and catalysts to turn CO_2 and electrons into things. For decades, people have been looking into CO_2 recycling as a way to make fuel alternatives that are long-lasting, cheap, and produce a lot of energy. There are many investments in research to find better fuel alternatives for long-distance highways. However, other engineers are focused on the future of air travel and hydrogen jets, looking for ways to make fuel that is 100% sustainable utilising existing turbofan engines [10].

CO_2 IN ORGANIC SYNTHESIS CASE STUDIES

One of the most promising ways to fix CO_2 in organic synthesis is to make dioxolanones by adding epoxides to carbon dioxide 5 (Fig. 9). This technique works better with well-defined 1,3-dioxolan-2-one molecules that can be used in many ways. The beginning components are easy to find because there are many different types of epoxides. Furthermore, the important oxazolidinone motif can be easily obtained from dioxolanones by a simple two-step process.

Ureas and Carbonates

Carbon dioxide is a cheap and plentiful chemical that can be used to make organic molecules. Over the past few decades, there has been a lot of interest in finding ways to turn carbon dioxide into useful chemicals. Using carbon dioxide in chemical reactions is another way to make organic compounds from carbon dioxide.

Making ureas from amines and carbon dioxide is one of the easiest and most cost-effective techniques to turn carbon dioxide into useful compounds [11]. Ureas have garnered interest as intermediates for synthesising nitrogen- and carbonyl-containing chemicals and are significant substances utilised in insecticides, herbicides, and resins.

Current methodologies frequently necessitate costly and complex systems, such iridium catalysts with phosphine ligands, selenium-based reagents, or stoichiometric dehydrating agents such as reactive azides and acyl chlorides. Recently, catalytic systems that make it possible to use carbon dioxide to make ureas from amines have been made.

Using disilylamines as substrates is a frequent way to get around this problem because the reaction between disilylamines and carbon dioxide doesn't make water [12]. This allows for the omission of a base and the prevention of catalyst deactivation in catalytic processes. While the combination of disilylamines and carbon dioxide is often used as a good substitute for amines, no one has yet documented making ureas from disilylamines and carbon dioxide at room temperature.

In this context, an oxovanadium(V)-catalyzed amination of carbon dioxide at ambient pressure is introduced for the manufacture of ureas. Using an oxovanadium(V) compound that is available on the market as a catalyst, carbon dioxide and different disilylamines can be turned into the right ureas with good to great yields.

Acids That Have Carboxylic Groups

Electrochemical reduction of CO_2 is an interesting option that can be done at room temperature without the need for transition-metal catalysts [2]. For carbonates, a further benefit is that C– O bonds are easy to make [13]. You can also get the carboxylic acid by adding CO_2 to an organo-metallic reagent. However, this method needs to first make reactive organometallics from the right starting ingredients. Electrochemical fixation of CO_2 is useful because it only takes one or two electrons per molecule of the substrate. On the other hand, electrocatalytic reduction of CO_2 to fuels or bulk chemicals needs to convert multiple electrons to make formic acid, formaldehyde, methanol, or methane.

Making Polymers

When CO_2 and epoxides are copolymerised together, they make polycarbonates. When CO_2 and butadiene-derived disubstituted lactones are copolymerised in an alternating pattern, they make polyesters that can be made from scratch [14]. Both procedures show promise as ways to add CO_2 to polymers that can break down in the environment, which would make CO_2 use more than just chemical intermediates like carbonates and carboxylic acids. Recycling plastic waste has many benefits, such as lowering its dependence on petroleum feedstocks and limiting its contamination downstream.

Adding CO_2 to polymers has good effects on their characteristics. For example, ester exchange copolymerisation makes polymers that are stable, have high start thermal-decomposition temperatures close to 300 °C, good mechanical strength ($\sigma y = 30.1$ MPa), and elongation at break that is close to 800%. By switching from catalysis to copolymerisation of epoxide and CO_2 with ring-opening polymerisation of ε-decalactone, it is possible to make ABA-block polymers with better processability and material qualities, as well as 6–23 wt% CO_2 contents. In this instance, block-polymerization enhances heat stability (~280 °C), augments toughness (112 MJ m^{-3}), and elevates elongation at break (>900 %) compared to similar polycarbonate homopolymers.

PROBLEMS WITH USING CO2

Carbon dioxide (CO_2) is a well-known molecule for capturing and storing carbon and a possible renewable source of carbon for making fuels and organic compounds. It is a naturally sustainable substitute for fossil-derived "C1" building components like carbon monoxide (CO), phosgene ($COCl_2$), and syngas.

Because CO_2 doesn't react very easily, most conversion processes need highly reactive reagents, stoichiometric additions, or energy-intensive conditions. This means that atom economy goes down, waste goes up, or energy needs go up [10]. Many of the processes that have been found so far still use catalysts that are expensive, hard to get back, and/or poisonous. Also, many of the chemicals used to change CO_2 come from fossil fuels instead of renewable sources. Dominant routes only provide a few number of bond types, which makes it hard to employ CO_2 as a universal building block [9]. Lastly, problems related to the high amount of CO_2 needed to make CO_2-based processes widely used have only just begun to be solved.

Economic Viability

The economic viability of techniques that transform CO_2 into value-added products is a significant determinant affecting their development and large-scale adoption. Using CO_2 in chemical production could help cut down on both greenhouse gas emissions and the need for hydrocarbon feedstocks at the same time. But for now, it costs three to five times more to capture CO_2 from flue gases than it does to get ethylene and other common hydrocarbon feedstocks, which makes many present technologies not worth the money [9].

For example, in the cement business, a procedure that uses sodium salicylate suspended in toluene combines with pressurised CO_2 to make salicylic acid through a Kolbe–Schmitt reaction. The global market for salicylic acid is more than 50 kt per year. If only 10% of this demand were met, it would remove around 100 kt of CO_2 from the atmosphere each year. This shows that CO_2 may be used in a substantial way.

One approach employs a functionalising reagent and a reductant, which may be individually adjusted to transform CO_2 into formamides, N-heterocycles, methylamines, and methanol, using hydroboranes, hydrosilanes, or formic acid as reductants. Applying this procedure to other oxidised substances, such as SO_2, also makes it possible to turn them into value-added compounds like sulfones without using metals, which makes these methods even more attractive from an economic point of view [3]. In this setting, innovation is still very important in the fields of sustainability, catalysis, and engineering, and there are clear chances for these fields to work together and come together.

Technical Limitations

The atmosphere still has a CO_2 concentration of a few hundred ppmv because of geothermal activity on other planets during Earth's history. If all CO_2 intake stopped, the current rate of volcano degassing would bring these levels back to where they were in a few thousand years. This shows how the ocean may be a long-term carbon sink. Underground point sources, including the flue gases from fossil fuel power plants and the off-gases from natural gas processing, have a lot of CO_2 that is available at higher pressures and concentrations, which makes it easier to convert. Different chemical fixation procedures use CO_2. For example, mineral carbonation is used for inorganic materials like limestone and aggregates. CO_2 is also used to make organic chemicals including methanol, cyclic carbonates, hydroxy-aryl ketones (HACAs), and polycarbonates. Even if the world doesn't need these CO_2-based organic compounds enough right now to make a big difference in emissions, they are a crucial part of a bigger plan. Researchers have looked at heterogeneous catalytic systems that use noble or 3d-metals to speed up RWGS. However, getting both high CO_2 conversion and selectivity towards CO is quite hard, therefore they need to look into multicomponent catalysts [4].

Things To Think About for the Environment

Burning fossil fuels is the main cause of anthropogenic CO_2 emissions, which raise the level of CO_2 in the atmosphere across the world. People's actions have caused the amount of CO_2 in the air to rise, which is thought to be the cause of the recent changes in the climate [9]. In 1950, human-made CO_2 emissions were 0.7 Gt y^{-1}. By 2019, they were expected to exceed nine Gt y^{-1}. The rise in emissions stopped for a short time at the start of the COVID-19 epidemic, but it still reached 36.4 Gt CO_2 (11 GtC). The globe is using more fossil fuels to make electricity, fuels, and chemicals like steel, cement, and other chemicals. This is what causes these emissions.

Carbon Capture and Storage (CCS) systems are used to store CO_2 that comes from burning fossil fuels in empty reservoirs. There is a lot of CO_2 in the world, and it is easy to gather from power plants and some chemical factories. It is a cheap and easy-to-find raw resource that is mostly used to make steel (about 14%), cement (about 10%), and ammonia (about 7%). New basic research is focused on finding new ways to use this by-product and new ways to make things that use CO_2 as a raw material. Carbon Capture and Utilisation (CCU) is the utilisation of CO_2 to make chemicals or fuels, which is a direct revalorization of CO_2.

FUTURE OUTLOOKS

Strategies for the use of CO_2 are moving forward at the same time as new technologies are being developed. At a global scale, the use of changing regulatory tools like carbon farming incentives, carbon credit trading schemes, or gradually pricing CO_2 emitters and companies that recover a lot of fossil carbon is a sign of what future regulatory systems will be like.

There are already some good models for CO_2 recycling and restoration that don't utilise new resources for production. In this scenario, technological progress is likely to play a bigger role. Likewise, emulating natural photosynthetic carbon fixation at both methodological and mechanistic levels may influence future strategies [13]. Current leading methodologies consider the influence of energy supply and demand, indicating a strategic benefit for high- heat/fuel applications situated near geothermal, solar, and wind park facilities [1].

New Technologies

Carbon dioxide is a cheap and easy-to-get source of carbon that may be used over and over again. Because it is always stable thermodynamically and doesn't react with other chemicals, CO_2 only makes up a minor part of the carbon used in organic chemical synthesis. Even though a lot of work has gone into making methods for capturing, storing, and using CO_2, it is hard to use them on a big scale because of problems with availability, transport, storage, and environmental issues, such as its high thermodynamic stability.

The reverse water-gas shift process, which turns CO_2 and H_2 into carbon monoxide, is quite interesting. CO is a key component in organic chemistry and the chemical industry, and heterogeneous catalytic devices that speed up this reaction are very useful. Researchers have looked into catalysts made of precious and 3D metals supported on oxides, but it is still hard to get high CO_2 conversion and selectivity at the same time. Pd/TiO_2, Pd/ZnO, Pt/SiO_2, and other bimetallic catalysts are examples of systems that have good CO selectivity but low conversion levels. Copper-based catalysts usually make CO with low to moderate selectivity and a lot of methanol or methane. To get high CO selectivity, you need multicomponent catalysts [10].

Rules and Policies

Using carbon dioxide (CO_2) as a long-term source of carbon is in line with the concepts of Green Chemistry. It also helps to minimise our reliance on fossil fuels and lower the amount of this greenhouse gas in the air [9]. In addition to creating new ways and methods for adding CO_2 to organic compounds, changing the rules and policies around CO_2 use in synthesis is also very important. Carbonates made from CO_2 show how CO_2 may be used to make controlled polymers and turn CO_2 into useful molecules 10. As technologies for capturing the gas get better, there are still some problems that need to be solved before CO_2 may be used as a feedstock in business.

A COMPARISON OF CO2 SOURCES

Plants release carbon dioxide back into the air through photosynthesis and respiration, while microorganisms do the same. About 41% of the 43 billion tonnes of carbon emissions from people throughout the world come from industrial operations like making steel and cement [1]. These vast amounts are only released for partial capture, which will make it much harder to use CO_2-based chemical synthesis in the future. The optimal utilisation of these fugitive sources across various locations continues to be a significant concern, exacerbated by geographical variations in infrastructure development for industrial recovery and storage, which consequently restricts the options for prospective supply [10].

Natural CO2 versus Industrial CO2

Carbon dioxide exemplifies the De Saussure–Forster–Berthollet link between organic and inorganic chemistry [3]. To make carbon-carbon bonds, you usually need reactive, reduced carbon reagents. These are often hard to get, poisonous, or need their own multistep synthesis. Carbon dioxide, on the other hand, is a safe, highly oxidised, and plentiful feedstock that transition metal complexes can use directly and that speeds up catalytic reactions.

The seas are the biggest store of inorganic carbon, and they take in a lot of CO_2 from the air. Most natural systems that fix carbon start with bicarbonate instead of molecular CO_2. This shows how important it is to find out the exact oceanic and geological conditions that allow molecular carbon dioxide to be directly assimilated. This kind of examination of the natural world suggests that deep-sea hydrothermal vents could be a good place to look. Biogenic carbonates are another big place where carbon is stored. Organisms that are strongly mineralised make them by putting a lot of CO_2 into the air. On the other hand, diffuse volcanic emissions set the highest level of natural carbon dioxide that can be reached. Consequently, on contemporary Earth, the natural carbon dioxide source is confined to a designated geographic area of around 5×10^5 km2 on the Earth's surface, equating to ~0.1%, with total CO_2 emissions restricted to about 2×10^{10} t year−1. Anthropogenic emissions from fossil-based infrastructure and power plants are estimated at 3.6 × 10^10 t year−1, which is almost twice the natural supply. These emissions are spread out all over the world, but they are often concentrated at geological places that trap carbon.

Differences in Geography

Carbon dioxide (CO_2) is everywhere. It smells like tobacco, especially near vents from incinerators, which is a sign that it is there. Researching how to use CO_2 shows how important it is to choose the right source: compressed, undiluted industrial emissions or naturally obtained dry ice are the best choices. The best sources rely on the specifications of the application, as well as the composition of the emissions and the chains of by-products [1].

Industrial versions sometimes come with flue gases that have pollutants like SOx, NOx, CO, and hydrocarbons that haven't reacted yet. To get high purity, you need to pre-treat the material. There are already a lot of ways to separate things, such as multistage flash, pressure swing adsorption, vacuum or membrane-assisted absorption, cryogenic distillation combined with liquefaction or chemical absorption, and different types of absorption processes. More research is being done.

Geographical differences affect the availability and prevalence of CO_2 sources. In places like New Zealand and Alaska, extractive industries produce a lot of high-purity CO_2. In places like North West England, on the other hand, CO_2 is made as a by-product of the Ethylene Oxide manufacturing chain.

HOW IT AFFECTS THE PRINCIPLES OF GREEN CHEMISTRY

Using CO_2 as a building block in chemical synthesis addresses several green chemistry principles, such as waste reduction and energy efficiency, which are important for sustainability. Using CO_2 efficiently reduces the amount of chemical waste produced and makes it possible to use it in processes that use renewable energy, which cuts down on the use of fossil fuels. The idea of turning CO_2, which is easy to find, into useful molecules is appealing, especially when there is a lot of renewable energy available. This alignment makes chemical manufacturing more sustainable, even though there are operational problems and limits to how big it can get.

Less Waste

The utilisation of CO_2 as a basis for the sustainable synthesis of organic compounds is receiving significant attention, as the creation and reduction of waste are crucial for sustainable development and resource management. Waste reduction is the first step in the Twelve Principles of Green Chemistry, and energy efficiency is the fifth step [1]. This shows how important CO_2-based syntheses are to modern society.

Using Energy Wisely

A lot of the ways people are trying to use CO_2 require a lot of energy, but to different degrees. When making fuels from CO_2-based feedstocks, these extra energy needs can be seen as storing solar energy, which is a form of energy efficiency. To make operations more energy- efficient and economically viable, some CO_2 activation methods can only be used with renewable energy sources. These methods include electrochemical, photoelectrochemical, thermochemical, and biological activation. Combining solar-powered ways with CO_2 conversion makes storage easier, solves problems with scaling up and safety, and gives you another way to get rid of the problem of solar energy being available only sometimes. Using CO_2 to make chemicals can help make chemistry more sustainable by cutting down on waste and making reactions more energy-efficient [9].

TECHNOLOGIES FOR CAPTURING AND STORING CARBON

Carbon capture and storage (CCS) technologies capture CO_2 emissions from stationary sources like power plants and big industrial processes. They then compress the gas and send it by pipeline to underground storage sites in depleted oil and gas reservoirs or deep saline formations 10. We take CO_2 from the source and turn it into a liquid for storage. Capture can be combined with renewable energy sources to make fuels and feedstocks that don't add to the amount of carbon in the air. Many customised capture methods have been created, and their integration has been improved.

One of the most important phases in capturing CO_2 is separating gases. Over the years, other ways to capture have been made, like low-temperature capture using aqueous ammonia and a variety of organic solvents. Distributed flow analysis at a big capture plant has shown how this method may be utilised to improve the whole site. After then, carbon dioxide is deposited underground in geological formations including saline aquifers and depleted fields. However, only a small number of sites have been shown to be safe for this.

Technologies of the Present

Carbon dioxide utilisation (CCU) technologies are potential ways to cut down on greenhouse gas emissions by turning waste CO_2 streams into chemicals and fuels via thermochemical, electrochemical, and photochemical methods. These technologies allow for energy storage for making power and making carbon-based products. There are a few different ways to collect carbon right now. One is post-combustion methods that use chemical absorption with aqueous alkanolamine solutions. Another is oxy-fuel combustion. And another is pre-combustion methods like reforming and gasification. Iron-based looping cycles have efficiency problems right now, but using synergistic capture techniques together could make single-step CO_2 capture more successful, which would make the whole process more cost-effective. Electrochemical CO_2 reduction provides an alternate method for transforming collected CO_2 into chemical and energy products. So, using CO_2 as a different raw material is a good way to start building a sustainable, circular carbon economy. [1]

Future Changes

CO_2 is a great starting material for making chemicals since it is cheap, safe, plentiful, and can be used again and again. But carbon dioxide can only be used as a building block in a few activities so far. One reason is that CO_2 is a relatively stable molecule that needs reactants or catalysts with a lot of energy. These kinds of reagents often lead to bad atom economy or a lot of waste. Difficult conditions also make any chemical process less sustainable as a whole. Burning fossil fuels can provide some of the energy needed for some industrial operations, which is definitely not helpful when it comes to lowering CO_2 emissions.

To make greater progress, we need to take more measures, such as making the setup easier, using dilute CO_2 directly, speeding up the reaction rates, recycling the catalyst, using more proton-sensitive functions, and using renewable energy sources. A lot of projects are working on these problems right now. There are also new ways to do electrochemical, photoelectrochemical, and photochemical reductions that could modify the picture. Knowing more about how these processes work will make them more selective and efficient. Using CO_2 as a feedstock will be sustainable, however it will depend on the energy and requirements of the final material. The supply should be carefully looked at and changed to meet the demand [1].

COMBINING WITH RENEWABLE ENERGY SOURCES

Biogenic carbon sources may continue to accumulate in the atmosphere, while fossilised carbon would persist for millennia; thus, utilising CO_2 from renewable sources epitomises the gold standard for sustainable development. In this context, CO_2 is primarily a carbon source and is renewable since it originates from photosynthesis, whereas fossil carbon is non- renewable due to its long-term storage in geological reservoirs for millions of years.

Solar and wind power technologies, such as photovoltaics, piezoelectricity, wind turbines, and electrostatics, can turn CO_2 into chemicals, fuels, or reagents with a small carbon footprint. Using solar power and the right catalysts to directly reduce CO_2 has gotten a lot of attention, and it takes twelve photons to make one molecule of ethylene. These methods are economically beneficial solely when the electricity is sourced from waste or renewable energy sources [3 4]. Wind power is also becoming more competitive when it comes to making electricity and storing energy with electrochemical technologies

[1]. A lot of electrochemical depolymerisation research is done on synthetic polymers, however if the right technology were made, biogenic polymers (including cellulose, chitin, and lignin) could be depolymerised efficiently to make useful compounds A few systems use these ideas to lower the price of CO2.

Uses of Solar Energy

The rapid rise in energy use due to population growth and heavy industrialisation has put a lot of stress on nature and natural resources, leading to an energy crisis around the world. It is now very important to employ renewable energy sources efficiently in order to meet the growing need for energy in many places. In this scenario, sunlight served as a renewable heat source to synthesise various tetrahydrobenzo[b]pyran scaffolds via a cyclisation reaction involving arylaldehydes, malononitrile, and dimedone, adhering to a straightforward protocol without the necessity of a catalyst or solvent, conducted in the open atmosphere, yielding excellent results [15-17].

Transforming carbon dioxide (CO2) into useful fuels or organic molecules is essential for creating carbon-neutral cycles that last. Using solar energy to turn CO2 into something useful is a great idea for a sustainable and carbon-neutral economy. The photochemical reduction of CO2 to carbon monoxide (CO) has become a prominent research focus; yet, the complete conversion of CO2 to CO remains a frequently neglected factor that hinders the efficient and direct utilisation of CO in the synthesis of high-value compounds. Achieving full and fast CO2- to-CO photocatalytic conversion unlocks the straightforward conversion of CO into fields related to radiochemistry with carbon isotopes and opens new opportunities for accessing C- and C-labelled pharmaceuticals from the primary isotopic sources.CO2 reduction is crucial for transforming greenhouse gases into high-value molecules, but gaps remain between the photoreduction of CO2 into CO and its subsequent use. A high CO2-to-CO conversion rate and a CO purity of more than 90% would mean that less energy would be needed to purify the CO. People typically forget about full CO2-to-CO conversion, yet it is necessary for applications that are both efficient and long-lasting [18].

Uses of Wind Energy

Wind energy helps make power sources that don't add to carbon emissions by turning the wind's linear motion into electrical energy [10]. Some of the best things about this technology are that it is renewable, clean, and green; that it is well developed; that the conversion efficiency is rising quickly; that there is a lot of technical potential; and that progress is being made quickly in various important industrial sectors. Burning fossil fuels has created an extremely high amount of greenhouse gases in the last few years. These gases have caused global warming and acid rain, which are both very dangerous to human existence. Solar and wind energy sources are clean and long-lasting, so they have gotten a lot of attention. However, their output is not always steady, which has made it hard for them to grow. Thermochemical conversion by redox cycles is seen as one of the most promising ways to use solar and wind energy. This is because it has a high energy storage density and can change heat into chemical energy directly.

HOW PEOPLE SEE AND ACCEPT

The use of carbon dioxide as a building component in the production of chemicals that are useful for business has drawn a lot of interest from people all over the world, including governments, scientists, manufacturers, and investors [9 3]. In Europe, almost 70% of people over 14 knew something about CO2 emissions and climate change, but only 39% were well- informed. In Europe, Germans are the most aware of CO2 emissions and climate change, with over 83% of respondents saying they are. In the US, 74% of respondents say they are aware.

Campaigns To Raise Awareness

People don't think highly of organic chemistry, even though it has a big impact on everyday life. People are slowly learning about the many safety steps that go into making food and drugs, as well as how innovative and sustainable the profession is. It's interesting to see how worried young people are, and there will be many solutions offered to help schools and businesses grasp the problems and help people make decisions. The university is still a great place to learn about this subject, thanks to classes, internships, and the best way: being exposed to science 9. A good attitude may really make a difference, and using a friendly and practical way of talking will help. A bachelor's degree in chemistry is the first step. After that, you should take courses and obtain training that are relevant to the fields you want to work in. To come up with a good plan for sustainable development, we looked at the positions of all the stakeholders and tried to find a way to meet their requirements and expectations. The most important thing to do is to try to listen to young people, because they will have an impact on others one day [3].

Involving Stakeholders

For carbon-neutral fuels, chemicals, and other materials to be successful, the public must accept them [9] A growing number of stakeholders contend that public engagement improves the policymaking process related to sustainable technologies. On the other hand, it is still hard to figure out how much the public knows, how much the people engaged know, what their roles are, and how much power they have over the formation of society. Research on CCS shows that most people don't know about the hazards and costs of CO2 capture. Because of this, those who are involved in the policymaking process often feel like they aren't ready to help.

Demographic considerations, media exposure and information campaigns, education level, risk perception, and familiarity with associated technology are all important for assessing public awareness.

ECONOMIC EFFECTS OF USING CO2

Using CO2 instead of fossil carbon helps the circular economy by expanding the global industrial feedstock base. As more CCU projects are announced, the world's ability to absorb and use CO2 keeps growing. The need for non-fossil C1-feedstock arises from the chemical industry's overall move towards decarbonisation and a net-zero emission agenda that focusses on fossil feedstock's production, use, and disposal. As a result, the price of non-CO2 feedstock goes up and becomes less competitive in the future. This makes enterprises even more interested in finding competitive, non-fossil-carbon sources like CCU [19].

Right now, about 230 million tonnes of CO2 are used as raw materials in a number of industries, such as making inorganic materials like limestone and aggregates, and organic compounds like methanol, cyclic carbonates, hydroxy aromatic carboxylic acids (HACAs), and polycarbonates. Even though there isn't enough demand for CO2-based organic compounds right now to make a big difference in global CO2 emissions, these kinds of procedures are still very important for making a complete plan. Future demand for methanol and other CO2-based compounds is anticipated to increase, hence improving the prospects of this method. Using methanol made from CO2 as fuel only stores CO2 for a short time. This is an important part of carbon capture, utilisation, and storage (CCUS) strategies [1].

As CO2 use increases, so do efforts to find ways to convert CO2 that use less energy. CCS's main goal is to cut down on CO2 emissions from big sources or the air around us. Still, there aren't many economic reasons to deploy. On the other hand, CCU benefits from existing incentives, even though it only stores carbon temporarily before releasing it back into the environment. Capture and compression of CO2, which make up around 80% of the total expenditures, show how important it is to lower costs in CCS. To reduce the risk of corrosion, contaminants must be removed from transit. Technologies that make things like urea, salicylic acid, methane, and polycarbonates have reached a technology readiness level (TRL) of 9. Currently, around 220 million tonnes of CO2 are employed annually for chemical production, not accounting for other applications such as methane generation and calcium carbonate formation [10].

Trends in the Market

Carbon dioxide (CO2) makes for roughly 4% of all greenhouse gas emissions around the world, which is why there is a lot of work being done to replace fossil fuels with carbon-based renewable feedstocks [1]. Carbon dioxide can be easily separated in high purity and is readily available from point sources and directly from the air. Because of the huge amounts of flue gases released around the world and the high demands for sustainability and environmental compatibility, a lot of research is needed to meet the objectives of a closed carbon cycle. Over time, many procedures that use CO2 as a cheap, non-toxic, non-flammable, renewable, and available C1 source have been documented. At the moment, different industries consume over 230 million tonnes of CO2 as raw materials every year.

Ways to Invest

The Kolbe–Schmitt process uses carbon dioxide (CO2) to make salicylic acid. This is a good goal for Carbon Dioxide Utilisation (CDU) because there is a lot of demand for this hydroxy aromatic carboxylic acid, which is about two million tonnes per year [1]. About 230 million tonnes of CO2 are used as raw materials every year in a number of industries. New ways to fix carbon include making inorganic materials like limestone and aggregates, as well as organic chemicals like methanol, cyclic carbonates, hydroxy aromatic carboxylic acid (HACAs), and polycarbonates. Even though there isn't enough demand for CO2-based organic compounds right now to make a big difference in reducing emissions, this method is nevertheless an important part of a whole, multi-faceted plan to decarbonise. Hydroxy aromatic carboxylic acids offer a lot of potential for the long term.

Fossil fuels still provide about 80% of the world's energy supply, even as greenhouse gas emissions are rising to very dangerous levels. 95% of chemical goods are made from non- renewable hydrocarbon feedstocks. Synthetic pathways utilising CO2 are particularly noteworthy as alternative sources of C1 units. The availability of CO2 from biomass and industrial sources presents an additional incentive: unlike other CCS approaches that simply trap CO2, chemical modification creates opportunities for value-added use of this molecule, which may otherwise be regarded as waste [9]. Feeding CO2 is another way to "close the carbon cycle" by reusing materials in a renewable-carbon economy, which is in line with the ideas of Green Chemistry.

CONCLUSION

Carbon dioxide is a widely available, renewable C1 source, and its use in industry is growing quickly. There is more pressure to cut down on greenhouse gas emissions, which gives companies more reasons to add it to their products. The fact that it is widely available and that there are incentives to use it are two major reasons to come up with novel, sustainable, catalytic techniques to turn carbon dioxide into useful chemicals [3]. not utilised, likely to escape into the air. Every year, over 10 gigatons of carbon dioxide are trapped. over 230 million tonnes of that is used as raw materials and chemicals [1]. Current use shows that there are chances to use it even more. Still, measures for cutting emissions can't depend only on better use. In the short run, replacing fossil fuels with carbon dioxide without cutting back on total use only makes us more dependent on fossil fuels.

To use the CCU approach in a "chemicals" setting, you need conversion technologies that can turn carbon dioxide into long-lasting chemicals. Reports suggest the manufacture of inorganic materials like limestone and aggregates that interact with cement, as well as organic compounds such as methanol, cyclic carbonates, hydroxy aromatic carboxylic acids (HACAs), and polycarbonates. Salicylic acid is an important part of making hydroxy aromatic carboxylic acids. Salicylic acid drugs make billions of dollars in sales each year. The Kolbe–Schmitt reaction is used in current commercial methods. It involves heating nitrates or sodium phenolates at high temperatures and pressures. It seems that industrial methods that use carbon dioxide are more promising. Salicylic acid is one of the most important hydroxy aromatic carboxylic acids. About two million tonnes are made each year, and most of it is used to make aspirin, which is its most important derivative. The standard Kolbe–Schmitt process, which includes heating phenol and sodium in the presence of carbon dioxide, is still used in commercial manufacturing. An analysis of use suggests an integrated strategy that includes CCU, CCS, and direct emission reduction to get big and long-lasting drops.

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