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Biochar in Carbon Capture and Soil Remediation

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Abstract. Global greenhouse gas emissions are growing year after year. Although there is a temporary drop in 2021, the general trend is upward. Reduced greenhouse gas emissions are a critical goal. By evaluating the relevant literature, this research investigates the function of carbon capture systems, as well as their benefits and drawbacks. Carbon capture is a method of capturing carbon dioxide emissions at the source or straight from the air. Carbon dioxide emissions are either removed or converted into usable goods. Carbon capture technology is one of the most essential techniques of achieving zero carbon emissions. Biochar is one of the most commonly utilized because of its porous nature and capacity to absorb more substances. Biochar is primarily utilized for carbon sequestration and soil remediation. When biochar is changed using a mix of physical, chemical, and physical-chemical processes, its adsorption capability is considerably increased. The ease with which biochar may be made makes it simpler to encourage its usage. It is critical for lowering carbon dioxide levels in the natural environment.

1 Introduction

Human carbon dioxide and other greenhouse gas emissions are a key driver of climate change and one of the largest issues in the world [1]. Extreme weather occurrences (such as floods, droughts, storms, and heat waves); increasing sea levels; changed agricultural growth; and disruption to water delivery systems are among potential consequences of climate change. At a time when global emissions should be declining, they are actually increasing, and the globe has not yet reached its peak [1]. Biochar is a solid material produced by thermochemical conversion of biomass into a low oxygen environment [2]. Biochar is highly carbon and porous [2]. Biochar is usually made up of carbon and ash, and its elemental composition and properties vary according to the base material and pyrolysis conditions [3]. Biochar is currently a byproduct of the thermochemical conversion of biomass to bio-energy [2].

Biochar is extremely stable, having around 65% carbon [4]. The chemical composition is highly influenced by the feeding load and pyrolysis conditions [4]. Biochar with a high fixed carbon content and stability is produced from pyrolyzed biomass. Many soil-borne toxins (pesticide and antibiotic residues, antibiotic resistance genes and heavy metals) can be absorbed by plants and enter the food chain. This is a global issue, and remediation of polluted soils is critical to ensuring sustainable food supply. Biochar's soil stability is critical for its long-term environmental advantages. Pesticides, antibiotic residues, antibiotic resistance genes, and heavy metals can all be stopped or reduced by biochar. Biochar can be used to trap carbon and counteract climate change by locking it into the soil due to its long-term stability. Biochar's stability guarantees that the anticipated benefits to soil, agriculture, water resources, and climate change mitigation persist. Biochar also controls and improves the availability of cationic plant nutrients including P, K, Na, and Mg [4]. Aside from the direct agronomic benefits (improved fertilizer use efficiency, higher yields, and improved soil fertility), biochar has three major environmental benefits: carbon sequestration in the soil, reduction of GHG emissions, and reduction of pollution and pesticides from fertilizer run-off into watercourses and groundwater [4].

The biochar industry's carbon sequestration potential is predicted to be as high as 2 billion tonnes per year, which is twice as much as Germany's yearly CO_2 emissions [4]. Biochar is simple to make and transport. Biochar has made great strides in reducing greenhouse gas emissions and global warming. Biochar is a commercially viable biological product with use in agriculture, industry, and energy. Biochar production can so improve soil qualities while also providing prospects for additional revenue [4]. The elemental content and qualities of biochar vary depending on the feedstock material and pyrolysis circumstances. As the world's population grows, so does global energy consumption, because energy is required in all sectors of any country. Currently, fossil fuels are the most important source of energy. Biomass is a form of renewable energy. It can be prepared mechanically, biologically, physically and thermochemically.The high-quality and effective thermochemical conversion process breaks down the original chemical bonds of

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biomass, resulting in the formation of biochar, bio-oil and synthetic gas. Economic benefits, sustainable benefits and increasing demand from the environment and energy sectors, a large amount of biomass is converted to biochar [4].

2 Carbon capture technology

Carbon capture and storage (CCS) technology is a form of carbon sequestration which will play a key role in achieving net-zero emissions by 2050 5.
Existing climate change mitigation strategies primarily focus on reducing carbon emissions from processes such as electricity generation or transportation. However, The CSC is studying how carbon dioxide can be captured directly from the atmosphere or at the emission point and safely stored in the natural environment [5]. There are two types of CCS: Organic carbon sequestration and storage. Carbon dioxide is absorbed by natural habitats such as forests and seas. The second is artificial/geological carbon capture and storage, which involves extracting CO_2 from anthropogenic activities and storing it in massive subterranean facilities.

2.1 Types of carbon capture technology

The following are four distinct carbon capture systems [5]. First and foremost, carbon sinks: CCS in its natural form includes huge areas where natural ecosystems such as forests, seas, grasslands, and wetlands collect carbon dioxide from the atmosphere. Then there are deep saline aquifers, which are subterranean geological formations consisting of huge porous sedimentary rocks loaded with salty water. Carbon dioxide may be injected and kept in them indefinitely. Furthermore, the massive air tower purifies the air by pulling it into a glass chamber heated by solar radiation to generate a greenhouse effect. This warmed air is sent into the tower and filtered before being released into the environment in the form of clean air. Finally, the molecular structure of the two-dimensional "ionic" liquid allows for higher CO_2 absorption rates.

2.2 Advantages and disadvantages

Using carbon capture technology has various advantages [6]. To begin with, carbon capture boosts the electricity provided by a CO_2-based steam cycle. Carbon dioxide is pressurized by a supercritical fluid in this process, allowing more efficient heat transfer and using less energy to compress the vapour.The geologically stored carbon dioxide can then be used to recover geothermal heat from the injected sites, leading to geothermal energy in the long run [6]. Furthermore, the captured CO_2 may be used for the production of polymers and chemicals, including polyurethane. Finally, the fixed carbon dioxide can be blended with concrete for reinforcing, increasing the infrastructure's life. The carbon capture business as an emerging career offers more employment opportunities, especially for qualified engineers and technicians [6].

There are two sides to every coin. There are several drawbacks that must be overlooked. To begin with, the cost of power facilities that generate energy from fossil fuels is quite expensive [6]. The safety of storing large volumes of carbon dioxide in a single location presents a number of problems due to the possibility of leakage, which can lead to pollution if not controlled properly. Second, it is insufficient to address climate change successfully. The use of fossil fuels to generate heat and power accounts for roughly 25% of total GHG emissions, with the remaining 60% accounted for by transportation, agriculture, and other related industrial activities. At the moment, these emissions are not being captured and trapped in carbon [6]. Currently, these emissions are not being caught and trapped in carbon [6].

CCS technology is classified into three categories: solvent-based processes (absorption), sorbent-based processes (adsorption), and membrane-based processes. The regeneration energy of solid sorbents is quite low [7]. Adsorption on carbonaceous materials is advantageous because it uses adsorbents with a highly porous structure and a large surface area. Then, Adsorbents are affordable since they are manufactured from naturally occurring materials. (e.g., biomass) [7]. As a consequence of its high adsorption capacity, quick CO_2 adsorption rates, and simplicity of adsorbent regeneration, adsorption technology is widely employed in CO_2 capture applications [7].

3 Modification of biochar

Biochar is a potential CO_2 capture material. It is made from a wider variety of basic materials and has a lower environmental impact than other absorbent materials. While virgin biochar can be used directly for the removal of CO_2, its adsorption characteristics are often low. As a result, for practical uses, biochar must be changed to increase specific surface area, pore structure, surface functional groups, and other physicochemical properties [8]. Changing the pyrolysis temperature, for example, can change the characteristics and adsorption capability of the biochar [7]. Chemical alterations involve the use of acids, bases, oxidants, and metal ions. The effect of acid alteration on biochar surface area varies according to the kind and concentration of acid used. Base changes often increase the biochar's surface area. In general, the alterations attempt to increase surface area, change functional groups, and improve magnetic characteristics and catalytic capacity [7].

3.1 Chemical modification

Because biochar adsorption cannot match the present standards, numerous innovative modification techniques have been developed.Magnetic and mineral alterations are the traditional ways of modification. Magnetic biochar has been widely researched as a wastewater treatment adsorbent [9]. Biochar may be easily retrieved by external magnetic fields after being modified with ferromagnetic elements such as Fe, Co, and Ni and their oxides, making cleaning and regeneration easier [9]. Natural minerals have long been employed in environmental applications due to their low cost and environmental friendliness 8. Clay minerals (such as albite, montmorillonite, and vermiculite) have a well-developed pore structure and a high ion exchange capacity, which can improve the performance of biochar. Studies on the impact of alkali and alkaline earth metal additions on biochar formation have revealed that the addition of tiny quantities of these metals may greatly boost the carbon yield and hence the carbon sequestration potential of biochar [9]. Of course, biochar has undergone several revisions. Oxidant alterations can boost the amount of oxygen-containing functional groups and enhance heavy metal complexation. The kind of pollutant and the removal technique are used to target heavy metal stabilisation in soils [8]. Biochar can accomplish photocatalytic degradation of organic pollutants after being modified with metal oxide-based semiconductors such as TiO_2, Cu_2O, CuO, and ZnO. Biochar acts as an electron trap in the conduction band of the semiconductor, speeding up electron transfer and separation of electron-hole pairs, which helps explain organic pollutants[9]. Electrochemical change introduces certain functional groups to the surface of the biochar and chemical impregnation. This approach has been demonstrated to be successful in soil metal stabilisation processes [8].

3.2 Physical modification

The temperature at which biochar is pyrolyzed effects its structure and physicochemical properties, such as surface area, pore structure, surface functional groups, and elemental concentration. Numerous studies have found that high pyrolysis temperatures enhance the surface area of biochar [9]. Depending on the settings, pyrolysis may be classified into three types: long and slow pyrolysis at 300 °C, intermediate pyrolysis (300~500 °C), and short and quick pyrolysis at >500 °C [10]. According to Chatterjee, R. et al., At around 400-500°C, the process begins with initial cleavage, subsequent breakdown, and the production of oxygen functional groups [10]. As a result, A temperature of 500 °C is considered sufficient for commencing pyrolysis and creating coke. In general, the ideal range of pyrolysis temperatures for biochar generation is estimated to be 500-800 °C [10].

4 Utilization in soil

Biochar application in soils can have a considerable influence on a number of soil properties [11]. This impact is more obvious in non-irrigated locations, where agricultural water availability improves and the likelihood of water shortages during rains decreases. Biochar use lowers soil capacity [11]. Another factor that contributes to soil aggregation and stability is biochar's greater organic carbon content and surface charge [11]. Stable soil aggregates alter soil structure, boosting water retention and infiltration while decreasing runoff and erosion. Biochar has the ability to trap carbon while also improving soil performance.After a short period of incorporation into the soil, the interaction between the biochar and the soil, microbes and roots of the plants takes place [11].

5 Discussion

Biochar absorbs atmospheric carbon and acts as a carbon sink for farmers. Biochar can be used to absorb net carbon from the atmosphere by trapping fixed carbon in soil for hundreds or even thousands of years. Aside from long-term carbon sequestration, biochar increases soil performance through improving water and nutrient retention and diffusion. Biochar also minimizes the requirement for fertilizer. Without a question, biochar has emerged as a key potential tool for environmental applications [9]. Several aspects must be studied in order to encourage more biochar applications. Modification techniques and environmental uses of engineered biochar should be increased in order to simplify the procedures, decrease costs, maximize the applicability of particular forms of engineered biochar, and assure sustainability [9]. The mechanisms involved in the environmental application of modified biochar should be the focus of future study. While various studies have shown that acid- or base-activated biochar may fix CO_2, the mechanisms involved and those that govern these activities are still unknown [9]. It should be noted that if the feedstock contains pollutants (e.g., some types of sewage sludge, demolition wood, phytoremediation biomass), the dangers of contaminant release should not be overlooked [9].

6 Conclusion

It is critical to address the greenhouse gas problem as soon as possible. This research introduces carbon capture technology, which reduces carbon emissions nearly entirely. There are several issues with carbon capture technology, including high application costs and the fact that carbon capture is not completely efficient. Some of these issues may be addressed by biochar. Biochar is a solid produced by the thermochemical conversion of biomass into a medium with low oxygen content. This study investigates the origins and applications of biochar. The use of qualitative analysis is being employed to investigate the usage of biochar in soil remediation and carbon capture. This material is easy to prepare and work with. The price is also quite reasonable. It has several uses in everyday life. This paper's study offers a synopsis of future biochar research. Although biochar offers numerous advantages, it also has certain disadvantages. Heavy metal ions are better employed, particularly in the field of chemical heavy metal ion modification, but the long-term consequences are not yet obvious and must be monitored continually.

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