



Adsorption and Biomass: Current Interconnections and Future Challenges

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Abstract

Purpose of Review The present study focuses on investigating the interconnections between adsorption technology and biomass energy production processes. A critical review on the different roles and perspectives of adsorption in these processes and on the potential of biochar as a solid bio-sorbent is investigated.

Recent Findings Adsorption plays a role in CO₂ capture as a purification final step and can be viable for capture at low to medium scale. Promising materials and processes are proposed in the literature. Biochar produced from biomass pyrolysis shows properties comparable with commercialized adsorbents.

Summary Adsorption in biomass associated with carbon capture and storage (Bio-CCS) is expected to grow if new adsorbents and processes are performant at larger scale. New biomass-based processes involving adsorption can be developed; methanation coupled with methanization is one of them. Biochar is technologically ready for water depollution and soil amendment but further work is needed for CO₂ capture applications. These challenges will necessitate adapted policies and R&D to decrease the production costs. Industrial exploitation of biomass necessitates interdisciplinary work.

Keywords Biomass · Adsorption · Carbon capture and storage · Biochar

Introduction

In 2014, the 5th assessment report of the Intergovernmental Panel on Climate Change (IPCC) [1•] confirmed the need to deliver to 2050 all key greenhouse gas (GHG) emission mitigation methods such as fuel switch, energy efficiency, renewables, and nuclear energy. It showed that bioenergy associated with carbon capture and storage (Bio-CCS) could be a promising solution to remove historical CO₂ emissions from the atmosphere. A large majority of IPCC scenarios of CO₂ equivalent emissions pathways to 2100 compatible with the

2 °C objective requires intensive use of negative emissions technologies such as Bio-CCS (or BECCS), afforestation, direct air capture, enhanced weathering, and ocean fertilization/alkalinization [2•]. As explained by Kemper [3••], the definition of Bio-CSS is not consistent throughout the literature. In this work, the definition from the Zero Emission Platform (ZEP) and the European Biofuels Technology Platform (EBTP) is adopted [4]. This definition encompasses all “processes in which CO₂ originating from biomass is captured and stored.” In 2015, the Paris agreement [5] aimed at stabilizing the rise in global average temperature below 2 °C above pre-industrial conditions and proposed to go further with a limitation of this increase to 1.5 °C. Therefore, biomass is expected to play a major role in energy transition [6, 7]. Biomass contributes to carbon abatement, first as a neutral energy source and second as a transformed material (i.e., biochar and other materials fixing carbon) derived from the initial feedstock.

Considering the global energetic dependency on fossil fuels [8••], it is urgent to search new solutions to mitigate the GHG impact. Biomass with CCS processes combining with other mitigation methods will be necessary to limit the global warming effect. Moreover, during the CCS sequence, adsorption can be used for capture and purification. One aim

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of this work is to emphasize the latter point and deal with large-scale Bio-CSS projects related to energy production (post-combustion CCS and ethanol plants) [9] along with smaller and emerging applications.

CO₂ needs to be captured before conversion and/or direct transportation and further storage in geological formations. The capture can be operated in post-combustion or in the exhaust gases of an industrial plant (cement, steel, ethanol, biogas plants), in oxy-combustion, and in pre-combustion. In oxy-combustion, oxygen replaces the air in the combustion process leading essentially to CO₂ and water in flue gases without nitrogen. In pre-combustion, the resources (biomass or fossil fuel) are transformed into syngas and then treated in a water-gas-shift reactor to form a mixture of H₂ and CO₂. The latter gas is then captured while H₂ is burnt to produce energy without CO₂ emissions. The first part of this article investigates the classical technologies applied for CCS and defines adsorption. The second part of this article deals with adsorption in post-combustion applications. In the third part, projects on pre-combustion and other applications are overviewed. The last part is dedicated to the residue of processes involving a partial combustion of biomass. Pyrolysis and gasification produce a solid material called biochar (or charcoal if used as a combustible) which can have a specific interest as adsorbent. Biochar is also a sequestration media exhibiting a higher carbon density than raw biomass and permitting soil amendment [10].

Traditional Methods Employed for CO₂ Capture and Adsorption Definition

For economic reasons, CCS technology was essentially applied to industrial sites emitting large amounts of CO₂ and already equipped (over 0.1 MtCO₂/year according to special IPCC report [11]). Out of a total of 13.5 GtCO₂/year worldwide in 2000, electricity generation from fossil fuels represented 78% of CO₂ fixed source of emissions, against 7% for cement plants, 6% for refineries, 5% for steel plants, 1% for oil and gas industry, and 1% for bioenergy plants [12]. Addressing Bio-CSS represents today a minor case of study. However, the role of biomass in energy, chemicals, and materials production is expected to grow.

Traditional methods for carbon capture from large point sources provide a panel of technologies readily available for Bio-CSS that only needs adjustments regarding the nature of the exhaust gases. The different classical ways to remove CO₂ from the air and industrial flue gas streams are the following: (a) physico-chemical processes such as absorption, adsorption, membranes, hydrates formation, and cryogenic processes, (b) biological processes (microorganisms, coalbed methanogenesis, algae's systems for biomass production),

and (c) geological processes (in the oceans or with soil mixed biochar).

The absorption process dates back to 1933 [13]. It generally consists of two columns, one for acid gases absorption with an alkanolamine solution (MEA, DEA, MDEA, mixtures...) and the second to desorb CO₂ and regenerate the solvent. The process is already in use in many plants for gas purification and intensive research has been pursued in the last decade to improve its performance [14–16]. Therefore, it is difficult for other technologies to compete economically with this process of reference.

The adsorption process based on physical porous activated carbons is already widely used for gas separation/purification in the petro-chemical industry. To tackle the CO₂ capture issue, gas adsorption can be complementary with processes based on amines or membranes, because of its high selectivity. The process relies on interfacial mass flow transfers in a medium exhibiting at least two phases where physico-chemical reactions can occur at the interface. The phenomenon of adsorption occurs when a gas is in contact with a porous solid (activated carbon, biochar). It describes a variation of the molecules gas density between the bulk or compressed phase and the adsorbed phase. Adsorption is an exothermic and reversible process occurring at equilibrium. The amount of adsorbed gas depends on several parameters such as gas/solid nature, gas critical temperature, nature of the interactions, and solid porous surface. When the solid is highly porous typically several thousands of square millimeters per gram, a large amount of gas is adsorbed and adsorption can be preferred to other techniques. The adsorption equilibrium between the amount of adsorbed gas per unit mass of solid and the pressure of the bulk gas can be represented by the adsorption isotherm [17]. There are several types of isotherms as defined by the IUPAC classification. Generally, the excess amount expressed in mass of adsorbed gas per solid mass increases then reaches a plateau. After the adsorption phenomenon, the material is regenerated at high temperature to release the adsorption sites. Thus, in addition to adsorbent intrinsic properties (specific surface area, porosity, particle size distribution, solid shape), the material cyclic resistance properties, i.e., both mechanical and thermal, are also evaluated for applications.

Adsorption in Post-combustion Bio-CCS Capture Processes

Post-combustion Bio-CCS exhibits large flue gas volumes with low CO₂ partial pressure (15%vol or less, i.e., around 0.15 bar), because of nitrogen dilution. Using sorption technology is a great challenge conditioned by the properties of the solid. Indeed the sorbent should (1) be able to permit high loading with high selectivity for CO₂ due to an adapted particle size distribution (PSD), (2) be easily regenerated at high

temperature, and (3) exhibit appropriate mechanical properties, particle size, and good stability with moisture associated to low costs of the material synthesis.

The performance of solid materials for CO₂ adsorption depends on several criteria:

- High adsorption capacity or gas loading [18–20] and specific selectivity for CO₂ while using small amounts of sorbent. High gas selectivity can be obtained with porous materials; moreover additional surface modifications can also increase the material adsorption capacities (pore network functionalization, amine impregnation, etc. [8••]).

Also other parameters enter into account such as:

- Facility of solid regeneration under non-binding conditions that ensure the process viability
- Ability to process large volumes of gas per solid unit mass
- High availability of the adsorbent
- High mass transfer and fast reaction kinetics impact the equipment size
- Low heat of adsorption
- Yield (amount of pure gas output/amount of gas mixture input)
- Both chemical and thermal stabilities for adsorption/solid regeneration steps
- Process energy efficiency per unit volume of the pure gas produced that can make CO₂ capture economically viable

The most advanced capture technology for post-combustion capture is absorption with chemical solvents and amines specifically. Physical solvents are limited by the low concentration of CO₂ in post-combustion. Using adsorption to remove low CO₂ content in gas streams necessitates to combine high selectivity and capacity with easy regeneration. The two classical groups of solid adsorbents are the ultra porous carbonaceous materials and the zeolites. Activated carbons exhibit high CO₂ adsorption capacities but low adsorption selectivity of CO₂ relatively to the other gases of the mixture conversely for zeolites. To improve the material selectivity, the surface of the adsorbents can be modified by functionalization, cation substitution, coating, chemical treatment, and impregnation with amines. It is also possible to change the process conditions of TSA and pressure swing adsorption (PSA) cyclic processes or its complexity (by adsorption and absorption combination, PTSA process, etc.) [21•, 22–25]. The capacity of adsorption increases at low temperature and high pressure. Therefore, post-combustion conditions (low pressure, high temperature) penalize adsorption thermodynamically. The TSA process would require heating and cooling large quantities of adsorbent while PSA could work despite the volume of gas to be compressed. The

economic viability largely depends on the performance of the adsorbent. To this end, many studies are devoted to a better understanding of CO₂ adsorption mechanisms [19, 26–28] and to an improvement of adsorbents selectivity for CO₂ with respect to H₂O and N₂. Moreover, the preparation of low-cost and environmentally friendly carbon adsorbents by single-step activation enables energy savings [29]. Along with classical carbonaceous and zeolites adsorbents, research on MOFs (metal organic frameworks) is also very active [8••, 30•, 31, 32]. It shows promising results for CO₂ capture and conversion. Research projects on PSA capabilities [33•] and novel processes such as PTSA [34], electric swing adsorption [35, 36], thermal swing sorption-enhanced reaction [37], and mixed matrix MOFs membranes [30•] are also conducted in parallel.

Adsorption in Other Bio-CCS Capture Processes

Oxy-combustion and pre-combustion Processes

In oxy-combustion processes, pure oxygen replaces air in the combustion process. For this purpose, adsorption of N₂ by zeolites with desorption controlled by temperature or pressure is still less efficient than cryogenic distillation. However, promising membrane technologies such as ITM oxygen process (air products) or BOC ceramic autothermal recovery (CAR) process could be able to compete with cryogenic distillation [8••]. Oxy-combustion flue gases contain up to 90% of CO₂ so the purification step is operated by cooling and compressing. The only issues relate to diluents and contaminants [38]. Similarly, bioethanol plants produced off gases close to 100% CO₂ on a dry basis meaning that the separation is only required to meet specifications (O₂, H₂O).

Pre-combustion processes are on the contrary promising for adsorption. Indeed, CO₂ partial pressure is high; therefore, the challenge is to compete with absorption by physical or chemical solvents. After the gasification of the feedstock into syngas, the water-gas-shift reaction allows adjusting the ratio H₂/CO depending on the objective (H₂ production in this case). CO and H₂O are transformed into CO₂ and H₂. At this point, CO₂ is captured traditionally by physical adsorbents [8••] and then H₂ is combusted with residual CH₄, CO and N₂.

Pre-combustion capture resulted to the concept of Integrated Gasification Combined Cycle (IGCC), which takes advantage of the heat of combustion to produce electricity with steam and gas turbines. As an example, Nuon Magnum (the Netherlands, [39]) launched in 2012 its first IGCC power plant project with mixed sources including biomass and CCS technology (physical solvent absorption). IGCC can be combined with CCS technology and use biomass as a feedstock (BIGCC). Fantozzi and Bartocci wrote recently a book

chapter [40] on the topic and conclude like Siemens [41] that, for this application, biomass should be co-gasified with coal to be attractive. That was also the choice of Nuon Magnum.

The previous paragraph on post-combustion demonstrated intense research in the development of new adsorbent materials and processes for CO₂ separation. However, the challenge of minimizing the energy requirement is still topical. In the case of pre-combustion, recent publications [33•, 42, 43••, 44] proved that adsorption could be an interesting alternative for small to medium cases and even larger scale if promising materials (enhanced adsorbents, MOFs, K-HTC) and processes are validated at pilot scale.

In the meantime, the HyGenSys process [45] from IFPEN (France) already uses PSA adsorption process on molecular sieves to purify H₂ after amine scrubbing. Finally, the pre-combustion case illustrate globally the separation issue for H₂ production from biomass in other cases of biomass valorization since the water-gas-shift reaction can be applied to anaerobic digestion on CH₄ to produce H₂ and CO₂, to bioethanol obtained by fermentation, directly to pyrolysis gases, or to gasified pyrolysis oil leading to similar separation issues. Pyrolysis processes need more developments to introduce CO₂ capture.

Methanization and Industrial Plants Coupled with Methanation

A complementary solution to CO₂-CCS is to reuse the CO₂ captured to produce CH₄ using the methanation process. The CH₄ distribution network is already well developed [46], and CH₄ is generally produced from fossil resources. Therefore, CH₄ production from biomass-based industries emitting CO₂ is currently under investigation. The first application targeted is methanization (20–50% vol CO₂) and power plants (power-to-gas). Contrarily to biological methanation that can only proceed at low temperatures, catalytic methanation uses H₂ produced from electrolysis to react at high temperature. With H₂ produced from renewables, it provides a flexible and sustainable energy system. As an illustration of a power-to-gas installation experimentation, the Jupiter 1000 project [47•] will permit to produce a CH₄-rich gas mixture from CO₂ captured from industrial exhaust gases and H₂ generated from a green electrolysis process using methanation. The gas mixture obtained can further be separated into its main components using a selective adsorption process modulated in pressure and/or temperature. Similarly, in the framework of the European project STORE&GO, a new methanation plant in Falkenhagen (Germany) was completed in May 2018 as an expansion to the existing power-to-gas plant producing so-called windgas. Research on methanation is still active in coordination with adsorption research teams.

Biochar as an Adsorbent

Biochar Production

Biochar is produced from biomass thermochemical degradation processes which are differentiated by O₂ input level such as combustion, gasification, or pyrolysis. Biochar is obtained with various physico-chemical properties depending on process parameters [48•, 49]. When stoichiometric conditions are reached, biochar is not produced in large quantities and is not proper for adsorption (many ashes, broken structure). In the case of pyrolysis, the process is operated under inert atmosphere. The heat provokes the breakdown of the feedstock into a solid, a gas mixture, and also liquids, if a condenser is used. Roughly, two types of pyrolysis can be differentiated: fast pyrolysis with residence time below 1 s and slow pyrolysis for residence times of minutes and more. In the case of gasification, the process is operated on sub-stoichiometric conditions. The feedstock is converted into a gas mixture at higher temperature than pyrolysis, and less biochar is produced [50].

The factors influencing biochar yield and properties are:

- The biomass chemical composition and structure which have an influence on pH, chemical composition, porosity, and yield of biochar [51]
- The type of process which influences biochar yield: surrounding 12% for fast pyrolysis, 35% for slow pyrolysis, and 10% for gasification [52]
- The heating rate and the residence time which have a direct influence on char yield, on char absolute composition (CHONS analysis), and on the material porosity [53]
- The operating temperature (pyrolysis starts at around 300 °C). It affects the pH and carbon concentration of the biochar (both increasing with temperature). The nitrogen, hydrogen, and oxygen concentrations are expected to decrease with rising temperature. Moreover, the crystalline biochar structure changes with the temperature [54]. Finally, the porosity increases with the temperature to an optimal value around 600–700 °C [53, 55, 56]. Nowadays, biochar is commonly used for water and soil depollution. It can also participate to decrease emissions of GHG in the atmosphere and for many other applications.

Biochar as a Sequestration Media

In 2017, 3 billion tons of biochar were produced [57]. Even if it is commonly used for soil and water treatment [58, 59], for a medical use [60] or to improve soils fertility, the long biochar residence time (1300–1400 years) [61] and its interesting cycle carbon assessment [62] make it a potential solution for the GHG emissions.

The porous structure and special chemistry composition favor biochar for organic pollutants adsorption when mixed to soil. Pollutants are trapped on the surface by chemical reactions. CO₂ is captured, thanks to biochar's minerals such as Mg, Ca, Fe, and K which form mineral complexes by chemisorption [63].

Biochar's porosity is classified in three general categories: micropores ($d < 2$ nm), mesopores ($d = 20$ – 50 nm), and macropores ($d > 50$ nm). The adsorptive capacity is based on the amount of micropores and narrow micropores ($d < 0.7$ nm) while macropores play a role in gas diffusion in the solid. Thanks to all these capacity, biochar can be used as a universal bio-adsorbent, as shown in Table 1 [64–89]. This table shows panel of different biochar potentialities for the capture of a large variety of compounds. It includes soil amendment in which various properties are considered such as material stability in soils and material porosity. The latter property is known to have a positive impact on soils [90].

In the study [91], an economical adsorption method to minimize the environmental GHG in highly polluted regions was tested using a biochar fluidized bed column to reduce the CO₂ concentration in the air. The adsorbed CO₂-biochar system can further be tested as soil fertilizer to increase crop production [92–94]. Experiments showed that biochar sorption can be effective without any transformation for water and soil treatment, but, for CO₂ sorption, biochar needs to be transformed to be competitive against commercial activated carbon.

Biochar Modification

Biochar activation (physical or chemical) aims at increasing specific area and pore fraction. Physical activation uses gases such as steam, CO₂, and ozone at temperatures above 700 °C. In the chemical activation, the char is doped by a chemical

Table 1 Panel of the extent of biochar applications

References	Adsorbate	Adsorbate origin	Adsorbent
[65]	H ₂ S and SO ₂ (acid gases)	Oil and gas production processing	Activated biochar (with steam, CO ₂ , or H ₃ PO ₄)
[66]	CH ₄	GHG and energy storage	Waste wood biochar
[67, 68]	VOC (volatile organic compound) such as acetone cyclohexane and toluene	Industry, chemical pollution	Vapor sorption process on biochar
[69]	Hydrogen	Green energy storage	Slow pyrolysis biochar
[70]	Ozone	Ozone reactor	Slow pyrolysis biochar
[71]	NO _x , SO ₂	GHG	Biochar from a fixed bed pyrolysis reactor
[72]	Formaldehyde	Indoor air pollutant (ex from tobacco)	Activated biochar (with ammonia or KOH)
[73]	Pyrene	Atmospheric pollution	Slow pyrolysis biochar
[74]	Lithium selenium	Energy storage, battery	Activated biochar
[81]	Element mercury Hg(0)	Coal-fired power plant	Chemisorption by pyrolysis biochar
[75]	Water	For dehydration	Hydrochar and pyrochar
[76]	Pesticide	Agriculture	Wood biochar treated with heat and iron
[77]	Carbaryl	Agriculture (pesticide)	Hydrolysis of pesticide with biochar
[77]	Atrazine	Agriculture (pesticide)	Hydrolysis of pesticide with biochar
[78]	Diclofenac	Pharmaceutical pollutant	Activated carbon from biochar
[79]	Heavy metals	Industry	Slow pyrolysis biochar
[80]	Ammonium nitrogen	Agricultural waste	Biochar heated at 550 °C
[82]	Inorganic compounds (Cd ²⁺ , Cu ²⁺ , Hg ²⁺ , Pb ²⁺ , Zn ²⁺ , NH ₄ ⁺ , NO ₃ ⁻ , PO ₄ ³⁻ , CrO ₄ ²⁻ , and AsO ₄ ³⁻)	Water pollution	Activated biochar and sorption improved by metal cation
[83, 84]	Cadmium	Inorganic pollutant	Phyllostachys pubescens biochar
[83]	Lead	Inorganic pollutant	Phyllostachys pubescens biochar
[85]	Sulfonamides and chloramphenicol	Antibiotic	Functionalized biochar for water and wastewater treatment
[64]	Aromatic compounds	Water pollution	Biochar from biomass pyrolyzed at 700 °C
[86]	Carbamazepine	Anti-epileptic drug	Biochar with hydrophobic π - π sites
[87]	Methylene blue	Dye pollutants	Sludge-derived biochar
[88]	Dyes	Clothe industry	Biochar from agricultural waste
[89]	Phosphorous	Water pollution	Biochar from magnesium-pretreated biomass

agent, which produces micropores by dehydration and oxidation [95, 96]. A biochar specific area surrounding 300 m²/g can be enhanced to 900 m²/g after activation [97]. Another possibility is to increase the pressure. It raises the adsorption capacity until the isotherm curve reaches a plateau [29]. Conversely, temperature has little impact on biochar adsorption capacity; room temperature is satisfying [97]. Furthermore, the influence of water steam on CO₂ adsorption capacity is negligible because of the slow kinetics of adsorption of H₂O [29]. Thus, the ideal experimental conditions for CO₂ adsorption are obtained and adapted to various environmental conditions.

Nowadays, other techniques for adsorption improvement are developed, such as nitrogen enriched biochar. In this technique, biochar is heated at high temperature in a 99.99% N₂ atmosphere, and then N₂ is replaced by other chemical components such as CO₂ or ammonia in order to improve biochar sorption performance [98, 99]. Sometimes, acid pre-dishing treatments are performed to enhance both physical and chemical adsorption capacities of derived nitrogen-enriched biochar, by destroying C-O-Si bounding in the biomass structure [100]. Another example of biochar treatment is the formation of a metal composite [101]. Creamer et al. [102] proved that a Fe₂O₃ biochar composite has a higher surface area than a simple biochar; moreover, this material demonstrates low regeneration cost and temperature desorption (120 °C).

Thanks to its highly porous structure, its specific mineral composition, and its ability to be modified, biochar is not only a CO₂ adsorbent but could be considered also as a universal sorbent. It is an adsorbent of dangerous pollutants as shown in Table 1, which can be used for gas, water and soil depollution. Moreover, thanks to its methane [103], and hydrogen [104] sorption capacity, biochar is a promising alternative for renewable energy storage and transportation problematic.

Conclusions

This review highlighted the numerous interconnections between biomass and adsorption. It showed that the competition for CO₂ capture between technologies is severe and restrained by economic imperatives. Other conversion technologies such as solar-to-fuel [105] or biological processes using microorganisms, not developed in this article, will also emerge. Companies like LanzaTech (New Zealand, commercial plants in 2014) are already developing plants with their technologies. CCS and Bio-CSS in particular as negative emission technology have been clearly identified as key technologies for GHG emission mitigation at the levels recommended by IPCC [1, 11]. Bio-CSS and biochar production will confront general issues related to biomass industrial use such as the sustainability of the source of biomass (pressure on water, lands, forests, competition with food/feed, use of pesticides), logistics, size

of the plant, legal framework, and public perception. Few studies on social acceptance of Bio-CSS such as [106] can be found in the literature. However, public acceptance can have a sufficient impact to lead to the abortion of a project [107] and then Bio-CCS could learn from the experience of other bioenergy projects.

The focus of IPCC on Bio-CSS technology led to many publications questioning its limits of application [2, 3, 108, 109]. Kemper defends righteously the need of a nexus approach because of the complex links between food, water, energy, and climate. How to reconcile large-scale projects with sustainability and biodiversity preservation is one of major pending issue.

Bio-CSS projects should be currently operating, and some are underway but more demonstrations are needed to prove the reliability of the technology and decrease the costs. Financial incentives, regulations, and policies could be a way to move forward.

Finally, Bio-CSS will have to take part in next generation processes for biofuels, biochemicals, and material production from lignocellulosic feedstock (agricultural and forestry residues, short rotation crops, algae) in biorefinery approaches.

From a technical perspective, biomass density and heat capacity are fundamentally lower than fossil fuels. This implies a technical challenge to obtain high-performance processes able to convert efficiently the biomass into fuels and also the need to valorize byproducts to increase the profitability.

The review showed that adsorption already has a place in Bio-CSS as a final purification step and can be competitive in pre-combustion gasifiers and methanization. Other opportunities might appear with the development of new technologies. The direct catalytic conversion of CO₂ into CH₄ through methanation process is also an interesting option which allows the local production of methane next to the biogas or biomass powered plant. The separation of the exhaust gases could rely on adsorption, and the transportation on the local gas network. Adsorption technology (physical and chemical) is mature and widely applied in the industry but since it requires the use of chemical solvents, the process can be corrosive, energy-consuming, and expensive. The adsorption technology has interesting characteristics due to its high flexibility, minimum energy requirements, and simplified procedure that contributes to the reduction of operating costs. In order to be competitive with other technologies, adsorption needs to be less adsorbent consuming and tried at larger scale. At the moment, biochar is not able to compete with classic commercial activated carbon because of the lack of mass production system; besides, biochar activation needs additional investments. In the future, it might be interesting for adsorption in Bio-CSS and biochar production to target niche markets such as high purity H₂ production, soil depollution, and heavy metals while developing pilots and materials for large-scale application.

Compliance with Ethical Standards

Conflict of Interest M. Dicko, M. Guilmont, F. Lamari declare no conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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