

Hemp-Derived Carbon Nanosheet Structures

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Abstract

Hemp-derived carbon nanosheet structures, similar to graphene, have emerged as a new wonder material with a multitude of applications in various industries. This essay/report explores the potential uses of hemp-derived carbon nanosheets in healthcare, military, industrial, armor, space applications, boats, aircraft, space elevators, space stations, and carbon sequestration.

1. Introduction

1.1. Background on hemp-derived carbon nanosheet structures

Hemp is a game-changer for carbon sequestration due to its rapid growth cycle, high biomass yield, and minimal water and pesticide requirements. It can be used to create carbon nanosheets for supercapacitors and batteries, offering a renewable alternative to traditional lithium batteries. Hemp has been shown to absorb substantial amounts of CO₂ from the atmosphere, with the potential for two crops per year doubling the absorption. Its carbon uptake can be accurately validated annually, providing a level of certainty not available through any other natural carbon absorption process. In addition to carbon sequestration, hemp can be used to produce various materials, effectively locking in CO₂ and saving additional emissions by substituting unsustainable raw materials. Overall, hemp offers considerable environmental benefits and valuable materials for various industries, playing a crucial role in mitigating climate change and promoting sustainable development. See references: (Guan et al., 2019)^[4], (Rodriguez-Mirasol et al., 2008)^[6], (Hemp-based Building Materials for Storage of Carbon in Built Environment, 2024)^[19].

1.2. Significance and potential applications of the material

The potential applications of hemp-derived carbon nanosheet structures are vast, making them an intriguing material in the realm of advanced technology and industry. The unique properties and composition of hemp-derived carbon nanosheets present a valuable alternative to other carbon nanomaterials like graphene. With their lightweight, high strength, and superb conductivity, hemp-derived carbon nanosheets can find utility in numerous industries. In the healthcare sector, hemp-derived carbon nanosheets hold promise for medical imaging, diagnostics, drug delivery systems, tissue engineering, and regenerative medicine. Their

biocompatibility and interaction with biological systems make them particularly well-suited for these applications.

In military and defense contexts, hemp-derived carbon nanosheets can contribute to the development of lightweight armor and protective gear, as well as ballistic-resistant materials. Their durability and strength give them an advantage in reinforcing defense equipment.

A wide range of industrial uses for hemp-derived carbon nanosheets includes energy storage devices such as batteries and supercapacitors. They also show promise in water filtration systems due to their exceptional absorbent properties.

The aerospace industry stands to benefit from incorporating hemp-derived carbon nanosheets into aircraft structural components and spacecraft materials to reduce weight and enhance performance. These structures offer a promising solution for achieving high performance with reduced weight requirements.

Furthermore, space exploration applications such as the development of space elevators and utilization in space stations for various purposes can reap the benefits of the unique properties of hemp-derived carbon nanosheets.

The potential for using hemp-derived carbon nanosheet structures in carbon sequestration is also significant. They can be utilized for carbon capture technologies while harnessing hemp as a sustainable source for carbon sequestration.

In summary, the significance and potential applications of hemp-derived carbon nanosheet structures are extensive. From healthcare to space exploration, these materials present exciting possibilities across diverse industries. See references: (Noller et al., 2023)^[3], (Guan et al., 2019)^[4], (Can Hemp be a Viable Alternative to Lithium Battery Technology?, 2024)^[5], (Biomass-derived carbon materials with structural diversities and their applications in energy storage, 2017)^[9], (Hamid et al., 2021)^[13].

2. Properties and Structure of Hemp-Derived Carbon Nanosheets

2.1. Comparison to graphene and other carbon nanomaterials

Hemp-derived carbon nanosheets have been found to rival or even surpass graphene in terms of strength, tear resistance, and conductivity. While graphene is the industry standard, its expensive production process makes it costly. On the other hand, hemp-derived carbon nanosheets offer a more cost-effective alternative without sacrificing quality. These nanosheets are mechanically robust, possess excellent thermal and electrical conductivity, high tensile strength, and superior barrier properties, making them suitable for various applications.

Compared to other carbon nanomaterials, hemp-derived carbon nanosheets provide a sustainable and cost-effective alternative while offering similar properties. They can enhance polymer nanocomposites and have potential uses in healthcare, military defense, energy storage devices, and aerospace applications. In healthcare, they can be used in medical imaging, drug delivery systems, tissue engineering, and regenerative medicine. In military and defense, they can be utilized in lightweight armor and protective gear. In energy storage devices, their porous structure allows for efficient ion diffusion and high specific surface areas. In aerospace, they can be used in aircraft structural components and spacecraft materials for

reduced weight and enhanced performance. Overall, hemp-derived carbon nanosheets show promise for versatile applications across various industries. See references: (Hemp Batteries Revolutionize Energy Storage, 2024)^[11], (Hamid et al., 2021)^[13], (Ahmad et al., 2023)^[16], (Terranova et al., 2023)^[25].

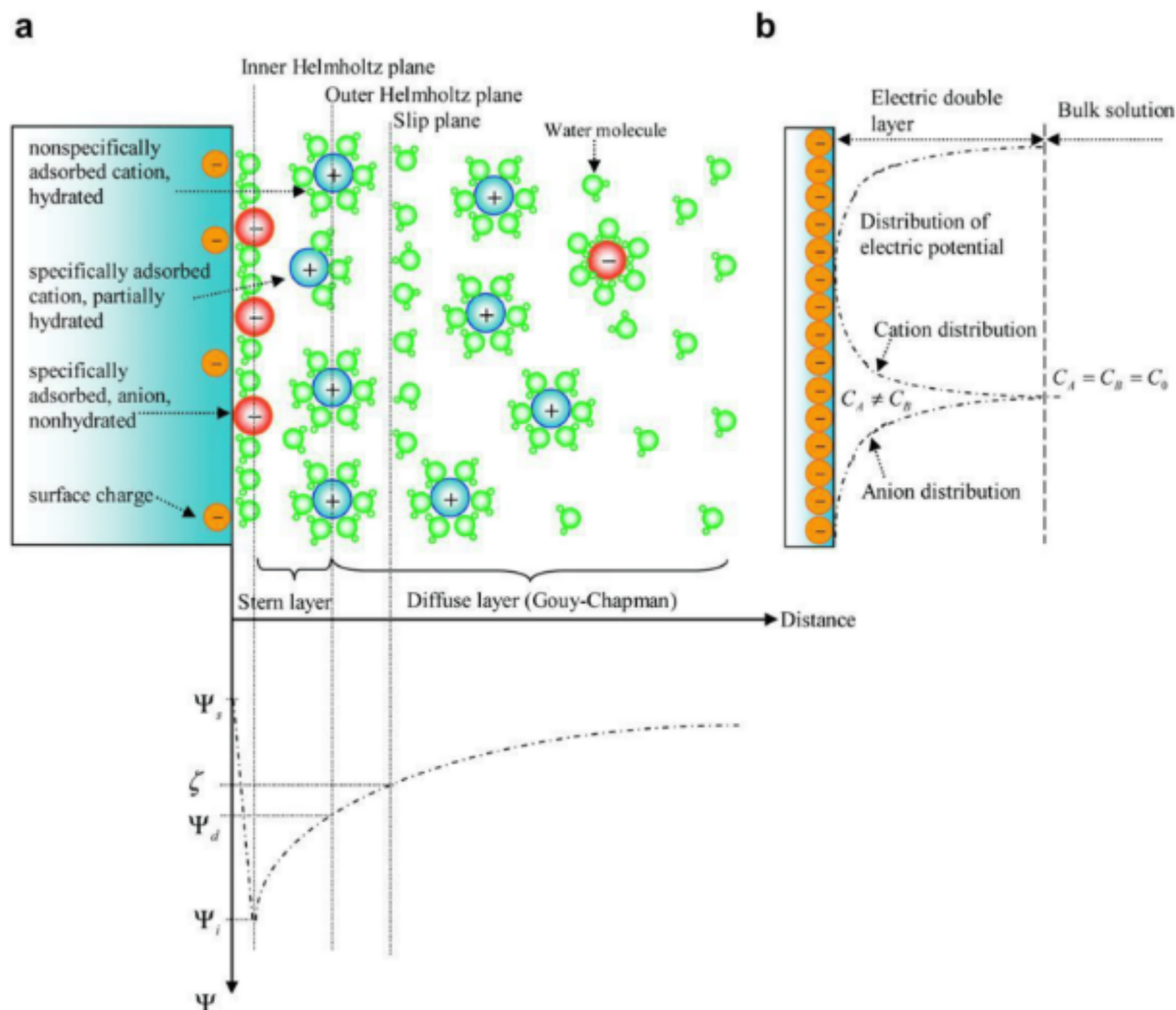


Figure 1: Schematic illustration of the (a) structure and (b) property of the electrical-double-layer in solution. Reproduced from, with permission from Elsevier, 2010. (source: reference (Liu et al., 2018)^[12])

Carbon Nanoparticle	Dimension	Hybridization	Thermal Conductivity ($\text{Wm}^{-1} \text{K}^{-1}$)	Electrical Conductivity (Sm^{-1})	Hardness
Graphene	2	sp^2	4840–5300	Around 2×10^5	Highest (for a single layer material)
Carbon nanotube (CNT)	1	Generally sp^2	Around 3500	Depends on the CNT structure used	High
Graphene oxide	2	sp^3	Around 72	0.1	High

Fullerene	0	Generally sp ²	0.4	10	High
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Table 1: Comparison between various properties of different carbon nanoparticles. Data adapted from. (source: reference (Hamid et al., 2021)^[13])

Method	Carbon (wt%)	Oxygen (wt%)	Water (wt%)	Ash (wt%)	Carbon to Oxygen Atomic Ratio
Hummers'	47.06	27.97	22.99	1.98	2.25
Staudenmaier	52.11	23.99	22.20	1.90	2.89

Table 2: Comparison of graphite oxide produced by Staudenmaier and Hummers' method in terms of compositions. Data adapted from. (source: reference (Hamid et al., 2021)^[13])

2.2. Manufacturing process and characteristics of hemp-derived carbon nanosheets

Hemp-derived carbon nanosheets are produced as an environmentally friendly and cost-effective material with exceptional electrocatalytic performance. The manufacturing process involves low-temperature carbonization and high-temperature activation, resulting in porous carbon with a high specific surface area and active sites. Chemical activation methods using activators like potassium hydroxide (KOH) and sodium bicarbonate (NaHCO₃) are crucial for creating the porous structure and increasing the specific surface area. These materials possess primarily microporous structures, with additional mesopores and macropores contributing to their high specific surface area. Introducing nitrogen or heteroatoms during the synthesis process enhances catalytic performance, particularly for applications such as oxygen reduction reaction (ORR).

The resulting hemp-derived carbon nanosheets demonstrate outstanding catalytic activity for ORR, stability, and resistance to methanol, making them suitable for various applications in healthcare, military and defense, industrial, aerospace, and space exploration. Additionally, they have the potential to contribute to carbon capture technologies due to their capacity to sequester more CO₂ per hectare than most agricultural commodity crops.

In conclusion, the production process of hemp-derived carbon nanosheets leverages biomass materials like hemp stems to produce porous activated carbons suitable for a diverse range of applications, including medical imaging, lightweight armor, energy storage devices, water filtration systems, aircraft structural components, and space exploration. This aligns with the environmental benefits of hemp as a sustainable crop that can absorb toxic elements from polluted soils through phytoremediation. See references: (Guan et al., 2019)^[4], (Biomass-derived carbon materials with structural diversities and their applications in energy storage, 2017)^[9], (Liu et al., 2018)^[12], (Hemp derived N-doped highly porous carbon containing Co nanoparticles as electrocatalyst for oxygen reduction reaction, 2020)^[21].

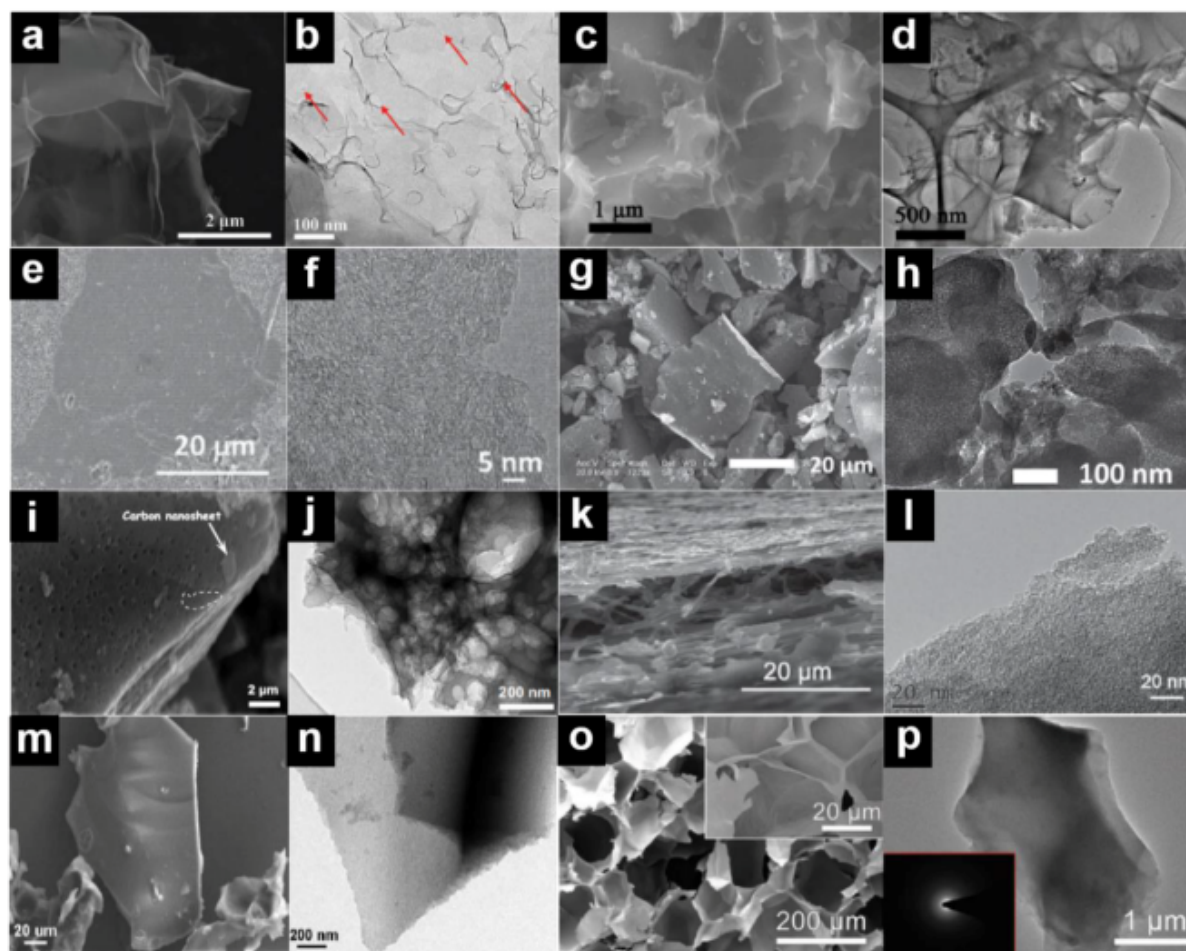


Figure 2: SEM and TEM images biomass-derived carbons produced from various precursors, including (a, b) highly graphitic carbon nanosheets from wheat stalk. Reproduced from, with permission from Royal Society of Chemistry, 2016; (c, d) N,S-doped porous carbon nanosheets from willow catkin. Reproduced from, with permission from Elsevier, 2016; (e, f) B/N co -doped carbon nanosheets from gelatin. Reproduced from, with permission from John Wiley and Sons, 2015; (g, h) heteroatom-doped carbon from microorganism (*Bacillus subtilis*). Reproduced from, with permission from John Wiley and Sons, 2012; (i, j) porous graphene-like carbon from fungus (*Auricularia*). Reproduced from, with permission from Elsevier, 2015; (k, l) carbonized eggshell membrane from chicken eggshell. Reproduced from, with permission from John Wiley and Sons, 2012; (m, n) hair-derived micro/mesoporous carbon from human hair. Reproduced from, with permission from Royal Society of Chemistry, 2014; (o, p) puffed rice derived carbon from rice. Reproduced from, with permission from John Wiley and Sons, 2017. Insets show the corresponding magnified SEM image and SAED pattern, respectively. (source: reference (Liu et al., 2018)^[12])

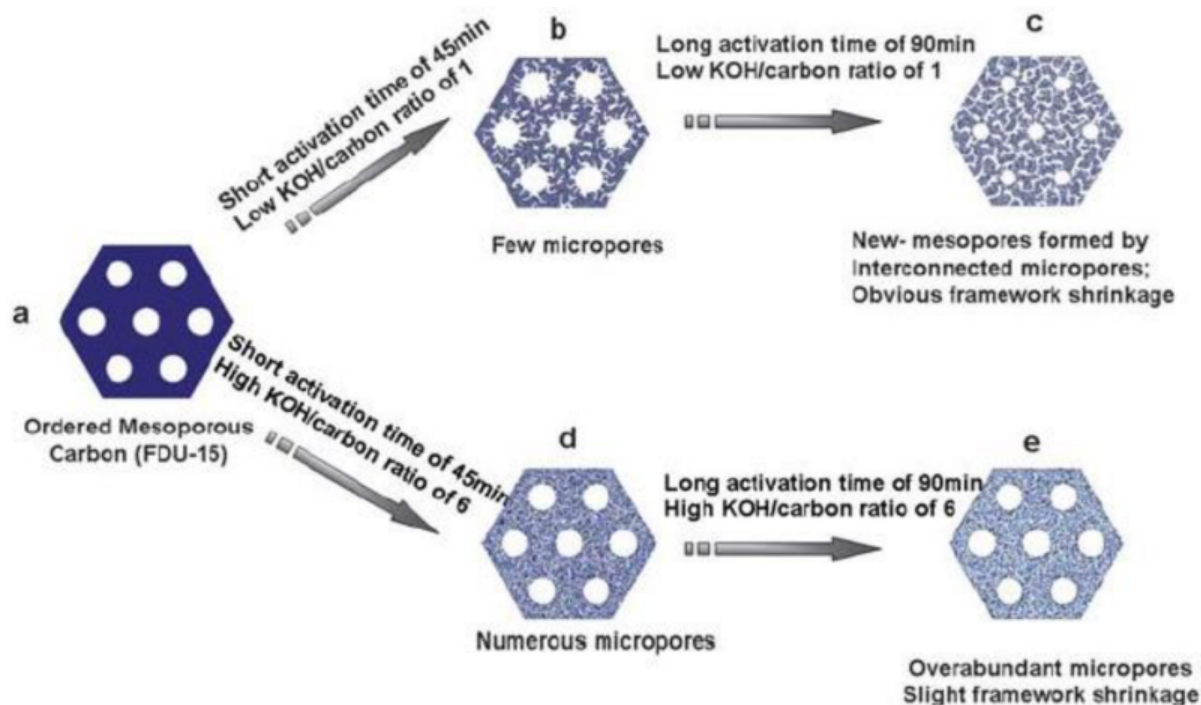


Figure 3: a - e) Schematic illustration of the effects of KOH activation on the porosity development. Reproduced from, with permission from Royal Society of Chemistry, 2012. (source: reference (Liu et al., 2018)^[12])

3. Healthcare Applications

3.1. Medical imaging and diagnostics

The utilization of hemp-derived carbon nanosheets in the realm of medical imaging and diagnostics has shown tremendous promise. These nanomaterials possess distinct qualities that render them appropriate for a wide range of healthcare uses. One of the primary benefits of hemp-derived carbon nanosheets is their exceptional biocompatibility, making them well-suited for medical imaging purposes. They can serve as contrast agents in imaging modalities such as MRI and CT scans, leading to improved visualization of tissues and organs. Additionally, hemp-derived carbon nanosheets have been investigated for their potential application in drug delivery systems. Their expansive surface area and unique structure make them effective carriers for delivering therapeutic drugs to specific areas within the body. This targeted drug delivery approach can help minimize side effects and enhance treatment efficacy. Furthermore, hemp-derived carbon nanosheets exhibit promise for applications in tissue engineering and regenerative medicine. Their capacity to support cell growth and tissue regeneration positions them as valuable materials for developing scaffolds and implants to repair damaged tissues or organs.

The research on hemp-derived carbon nanosheets has also showcased their potential across military and defense, industrial, aerospace, space exploration, and carbon sequestration domains. The distinctive properties and versatile nature of these nanomaterials make them a

valuable asset in a variety of fields. See references: (Noller et al., 2023)^[3], (Rodriguez-Mirasol et al., 2008)^[6].

3.2. Drug delivery systems

Hemp-derived carbon nanosheets have attracted significant interest for their potential in drug delivery systems and various other applications. Similar to graphene, these nanosheets offer a large surface area and high porosity, making them well-suited for transporting drugs to targeted areas within the body. They are biocompatible and can easily penetrate cell membranes, making them valuable for medical imaging, diagnostics, tissue engineering, and regenerative medicine.

In military and defense contexts, hemp-derived carbon nanosheets can be used in protective gear and ballistic-resistant materials due to their lightweight yet sturdy nature. They also show promise in energy storage devices and water filtration systems, thanks to their high surface area and porosity. The aerospace industry could benefit from incorporating these nanosheets into aircraft structural components to reduce weight without sacrificing integrity.

Additionally, hemp-derived carbon nanosheets may have potential in space exploration and carbon sequestration efforts, aligning with the sustainable nature of hemp as a source material. Overall, the unique properties and versatile applications of these nanosheets make them an exciting area of research with potential benefits across various fields. See reference (AbouAitah et al., 2023)^[2].

	Natural Drugs	Synthetic Drugs
Advantages	- Ease of access - Relative safety - Synergistic effects - Cultural acceptance - Long history of use - Traditional knowledge - Environmentally friendly - Complex chemical composition - Health benefits beyond treatment - Potential for novel drug discovery	- Cost-effectiveness - Potency and efficacy - Targeted drug design - Rapid drug development - Precision and consistency - Controlled side effect profile - Intellectual property protection - Improved stability and shelf life - Reduced contamination and allergenicity
Disadvantages	- Limited supply - Variable potency - Limited shelf life - Ethical considerations - Lack of standardization - Potential contamination - Risk of allergic reactions - Lack of rigorous clinical trials - Interaction with other medications - Standardization and regulatory challenges	- Drug resistance - Ethical concerns - Drug interactions - Environmental impact - Side effects and toxicity - Lack of natural synergy - Limited natural diversity - Patent exclusivity and cost - Development time and costs - Unforeseen long-term effects

Table 3: Advantages and disadvantages of natural and synthetic drugs. (source: reference (AbouAitah et al., 2023)^[2])

Biochar	Pyrolysis conditions	Feedstocks	Biochar dosage	Inhibitor	Fermentation pattern	References
Wheat straw	550 °C	Food waste and sludge	10 g L ⁻¹	Volatile fatty acids (> 4000 mg L ⁻¹)	Propionate reduced to 1460 mg L ⁻¹ ; specific	Kaur et al. ()

					methane yields improved to 24%	
Sewage sludge	350 °C	Fruit waste and activated sludge	0.5, 1, 1.5, and 2 g L ⁻¹	Volatile fatty acids (2587 mg L ⁻¹)	Total volatile fatty acids volume were reduced to 387, 1196, 1465, and 1594 mg L ⁻¹ for biochar additions, respectively	Ambaye et al. ()
Sewage sludge				Volatile fatty acids (2943 mg L ⁻¹)	Total volatile fatty acids volume reduced to 1196, 1821, 646, and 1142 mg L ⁻¹ for biochar additions, respectively	Ambaye et al. ()
Sawdust waste	500 °C for 1.5 h	Food waste and sludge	20 g L ⁻¹	Volatile fatty acids (57,900 mg COD L ⁻¹)	– Butyrate decreased up to 70% – Methane content boosted over 70%	Wang et al. ()
Vermicompost	500 °C for 2.0 h	Chicken manure and kitchen waste	24 g L ⁻¹	Volatile fatty acids (> 12,000 mg L ⁻¹)	Total volatile fatty acids reduced from 10,798 to 3957 mg L ⁻¹	Wang et al. ()
Wood chips	800 °C	Food waste	5 g L ⁻¹	Volatile fatty acids (> 3000 mg L ⁻¹)	Methane outcome boosted by 18%	Lim et al. ()
Rice husk	550 °C for 2 h	Corn stover and chicken manure	10 g L ⁻¹	Total ammonia nitrogen (> 6300 mg L ⁻¹)	Methane generation aspect enhanced by 28–96%	Yu et al. ()
Macadamia nutshells	350 °C for 2 h	Food waste	33.3 g L ⁻¹	Ammonia nitrogen (1500 mg L ⁻¹)	Chemical oxygen demand removed up to 90%, compared with 8% without biochar	Su et al. ()
Fruitwood	800–900 °C	Glucose solution	10 g L ⁻¹	Ammonia (7 g-N L ⁻¹)	Peak methane generation rate prompted by 47.1%	Lü et al. ()
Pine pellets	Gasification 600–710 °C	Primary sludge	2.49 and 4.97 g per gTS sludge	Ammonia nitrogen (400–450)	– Increased methane yield by 3.9–9.5% – Increased ammonia nitrogen quantity by 67% for anaerobic system without biochar compared with by –7.2 to 4.7% with biochar	Shen et al. ()
Corn stover	Gasification 850 °C	Primary sludge + waste activated sludge	0.25, 0.375, 0.5, and 1 g per d	–	Enhanced methane content by 13.7–25.3%	Shen et al. ()

Wheat bran pellets	Pyrolysis 800 °C	Wheat bran pellets	25 g L	Ammonia nitrogen (200–250)	– Increased total volatile fatty acids removal and reduced lag phase – No adsorption of ammonia by biochar	Viggi et al. ()
Wheat straw	Pyrolysis 350, 450, and 550 °C	Chicken manure	5% w/w	Total ammonia nitrogen (4.48 g L ⁻¹)	Total ammonia nitrogen reduced by 25% than the control	Pan et al. ()

Table 4: Utilisation of biochar to alleviate stressors in anaerobic digestion systems From: Biochar for agronomy, animal farming, anaerobic digestion, composting, water treatment, soil remediation, construction, energy storage, and carbon sequestration: a review (source: reference (Farghali et al., 2022)^[1])

3.3. Tissue engineering and regenerative medicine

Hemp-derived carbon nanosheets have sparked significant interest in tissue engineering and regenerative medicine. These nanosheets possess distinct properties that render them suitable for a wide range of healthcare applications. One of the main advantages of hemp-derived carbon nanosheets is their biocompatibility, allowing them to interact with biological systems without causing any adverse effects. This quality makes them ideal for use in medical implants and tissue scaffolds, where they can support cell growth and tissue regeneration.

In addition to their biocompatibility, hemp-derived carbon nanosheets also boast high surface area and porosity, making them effective for drug delivery systems. Their large surface area enables the attachment of drug molecules, while their porous structure allows controlled release of these drugs over time. This feature can be particularly beneficial in the treatment of cancer and other diseases where targeted drug delivery is crucial.

Furthermore, the conductive nature of hemp-derived carbon nanosheets makes them suitable for applications in medical imaging and diagnostics. They can serve as contrast agents in various imaging techniques, providing clearer visualization of tissues and organs. Additionally, their ability to interact with light and electromagnetic radiation makes them valuable tools for developing advanced diagnostic technologies.

In conclusion, hemp-derived carbon nanosheets hold promise for revolutionizing the field of tissue engineering and regenerative medicine. Their unique properties make them versatile materials that can be tailored to specific healthcare applications, offering new possibilities for improving patient outcomes and advancing medical treatments. See references: (Hemp: A Game Changer for the Building Industry, 2023)^[10], (Hemp-based Building Materials for Storage of Carbon in Built Environment, 2024)^[19].

4. Military and Defense Applications

4.1. Lightweight armor and protective gear

The application of hemp-derived carbon nanosheets for lightweight armor and protective

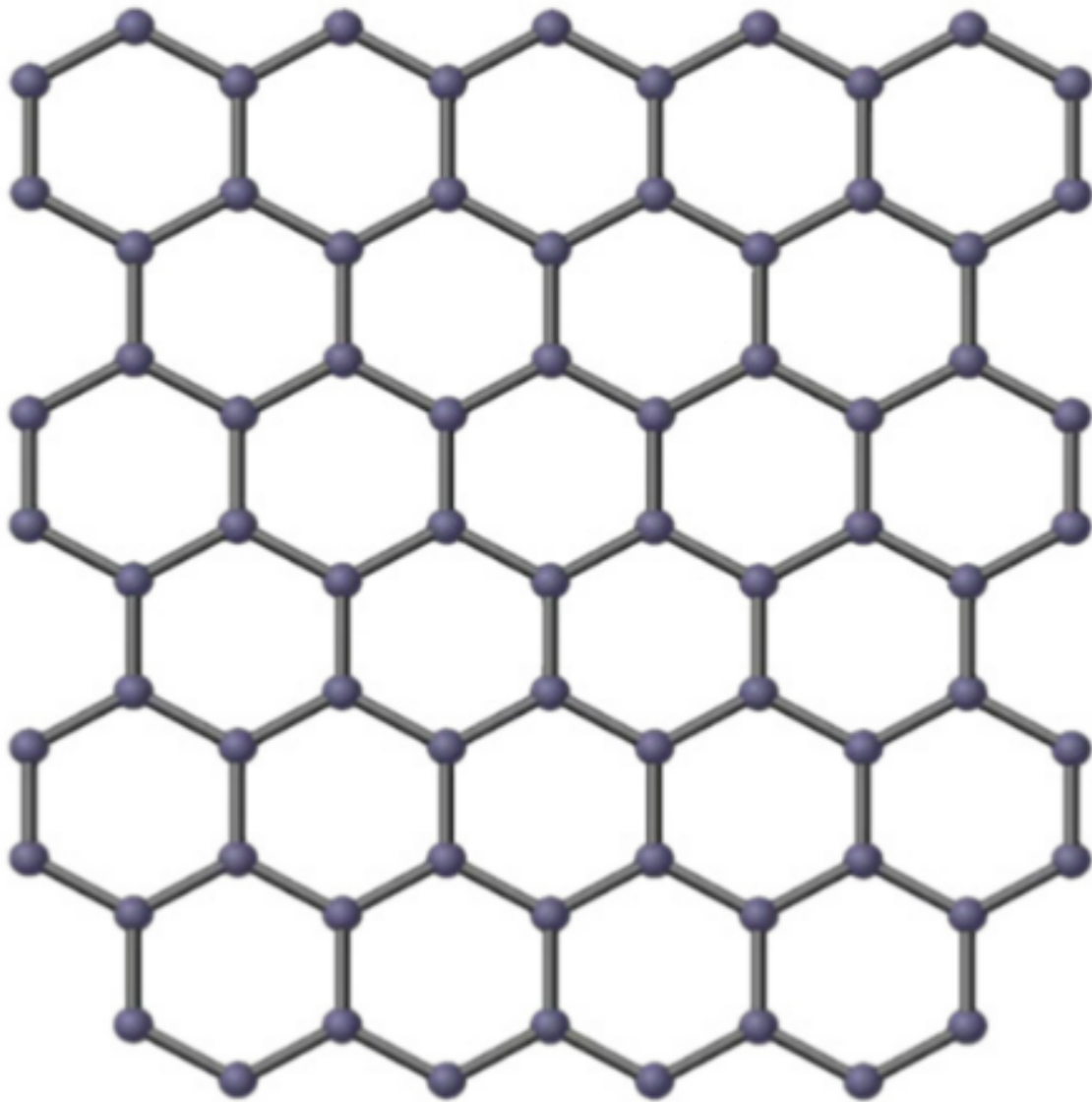
equipment presents significant potential in military and defense settings. With their high strength-to-weight ratio, these nanosheets offer effective protection while minimizing added bulk and weight for the wearer. The properties of hemp-derived carbon nanosheets make them comparable to graphene and other carbon nanomaterials, positioning them as excellent candidates for use in protective gear.

Extensive research has been conducted on the manufacturing process and characteristics of hemp-derived carbon nanosheets. They have been found to exhibit exceptional tensile strength, flexibility, and durability, all of which are critical factors in the development of lightweight armor and protective gear. Additionally, their high thermal stability makes them suitable for use in extreme conditions encountered in military and defense environments.

In terms of military applications, hemp-derived carbon nanosheets can be utilized in the creation of lightweight armor for personnel and vehicles. Their ballistic-resistant properties make them well-suited for body armor, helmets, and vehicle armor plating. The incorporation of these nanosheets can enhance the protection provided to military personnel while reducing the overall weight burden they must bear.

Furthermore, the potential industrial applications of hemp-derived carbon nanosheets include energy storage devices like batteries and supercapacitors. This could have implications for military operations by offering lightweight power sources for electronic equipment used in the field.

In conclusion, the advancement of hemp-derived carbon nanosheet structures holds immense promise for military and defense purposes. Their lightweight yet durable nature makes them suitable for a variety of protective gear including armor plating, body armor, helmets, and vehicle protection. This innovative utilization of hemp-based materials showcases their versatility and potential impact across different industries. See references: (Stratmann, 2023, pages 1-5)^[5], (Rodriguez-Mirasol et al., 2008)^[6], (Terranova et al., 2023)^[25], (Synthesis of highly porous hybrid nanocomposite of hemp derived carbon nanosheet/carbon nanotube/manganese cobalt oxide for asymmetric supercapacitor, 2024)^[26].



Graphene

[Figure 4](#): Graphene and graphene oxide. (source: reference (Ahmad et al., 2023)^[16])

4.2. Ballistic-resistant materials

Graphene has long been hailed as a groundbreaking material with extraordinary properties for space-related purposes. Its strength, flexibility, and ability to withstand harsh conditions make it a valuable asset in the construction of spacecraft and satellites. However, hemp-derived carbon nanosheets also hold tremendous promise for use in ballistic-resistant materials for military and defense uses. These nanomaterials have exhibited remarkable electrical, thermal, and

mechanical properties, making them suitable for enhancing the protective capabilities of armor and gear utilized in military space systems. Furthermore, their lightweight nature offers the potential for fuel savings and reduced weight in aerospace engineering.

The combination of hemp-derived carbon nanosheets with traditional materials such as polymers or fibers can result in composites with improved ballistic protection and durability. Specifically, the addition of graphene nanoplatelets to carbon, jute, or glass fibers has shown promising results in increasing EMI-shielding efficiency, making them valuable for military vehicles and personal protective equipment. These advancements highlight the versatility of hemp-derived carbon nanosheets in enhancing the performance of materials used in military space applications.

Moreover, the high strength and Young's modulus of fiber/graphene-derived nanocomposites make them ideal for aerospace structures, contributing to improved longevity and fuel efficiency in aircraft. The unique properties of hemp-derived carbon nanosheets offer a wide range of applications across military and defense sectors related to space exploration, making them an exciting area for further research and development. See references: (Ahmad et al., 2023)^[16], (Space Exploration and Carbon Fibre: Building the Next Generation of Spacecraft, 2024)^[18].

5. Industrial Applications

5.1. Energy storage devices (batteries, supercapacitors)

Hemp-derived carbon nanosheets offer great potential in advancing energy storage technology, particularly in the realm of batteries and supercapacitors. These nanosheets, extracted from hemp stems, boast a natural porous structure with a well-balanced distribution of pore sizes, predominantly microporous with additional mesopores and macropores. This unique architecture enables an outstanding reversible capacity of 495 mAh/g after 100 cycles at 0.2 C when utilized as the anode of lithium-ion batteries. Moreover, the interconnected carbon nanosheets derived from hemp can be utilized to construct supercapacitors that match or exceed the performance of graphene, surpassing commercial supercapacitors in both energy density and temperature range.

In terms of energy storage applications, hemp-based supercapacitors have demonstrated remarkable energy densities reaching up to 12 Watt-hours per kilogram, which is two to three times higher than commercial counterparts. Additionally, they are capable of operating across an impressive temperature range, from freezing temperatures to over 200 degrees Fahrenheit. With these exceptional performance characteristics and lower production costs compared to lithium-based batteries and graphene, hemp-derived carbon nanosheets have the potential to bring about a revolution in the field of energy storage devices.

The versatility and sustainability of hemp as a raw material make it an appealing choice for producing carbon nanosheets for energy storage applications. The abundance and affordability of hemp stems position them as a promising source for developing high-capacity lithium-ion battery anodes while also contributing to waste reduction in landfills. As researchers continue to delve into the full potential of hemp, we can anticipate further innovations that will contribute to a greener and more sustainable world. See references: (Guan et al., 2019)^[4], (Rodriguez-Mirasol et al., 2008)^[6], (Guan, 2019, pages 1-5)^[8], (Hemp Batteries Revolutionize Energy Storage, 2024)^[11].

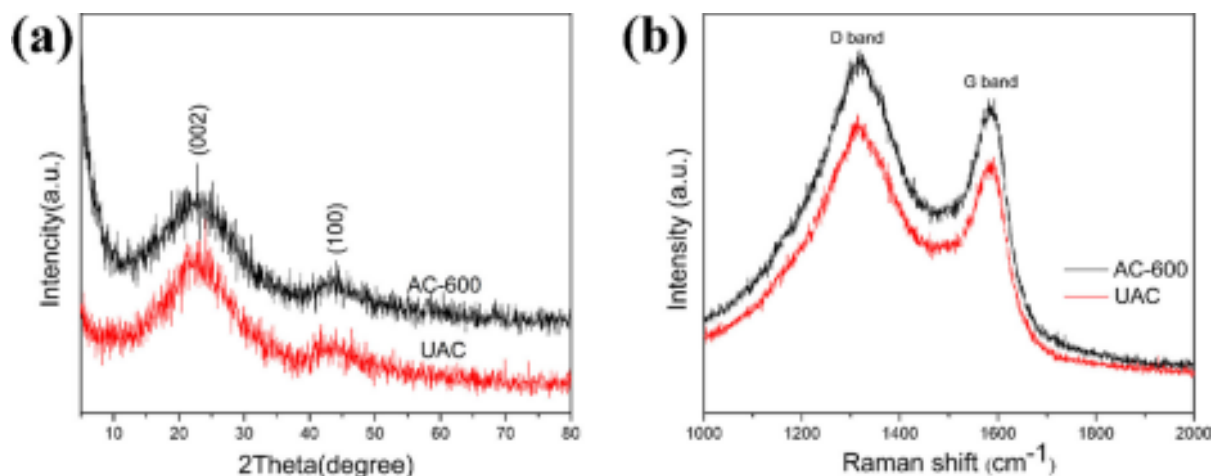


Figure 5: a TEM pattern of UAC. b TEM pattern of AC. c HRTEM pattern of UAC. d HRTEM pattern of AC. The results of the surface area and pore size distribution of AC are shown in Fig. 4. The isotherm can be expressed as type I, indicating that the carbon material has plenty of micropores. The closed hysteresis loop of the adsorption-desorption isotherm can be classified as H4 type, indicating the presence of slit-like pores, which are formed by the accumulation of material debris particles. It delivers an excellent specific surface area that BET value is 589.54 m²/g. The pore size of AC is mainly distributed in the range of micropores that refers to pores of smaller than 2 nm, which is consistent with the results of the N₂ adsorption-desorption isotherm. The pore volume and average pore diameter of AC were 0.332 cm³/g and 2.250 nm, respectively. There are not only many micropores, but also mesopores in the material, providing more active sites, and facilitating the cycling insertion and extraction of lithium ions. The transfer speed of ions is improved, and the impedance of batteries reduces. In order to investigate the electrochemical behavior of the porous material, the material was analyzed by cycle stability performance, rate performance, impedance, and (source: reference (Guan, 2019)^[8])

5.2. Water filtration systems

Hemp-derived carbon nanosheets exhibit tremendous potential for a wide range of applications, including air purification technologies. The distinctive properties of these nanosheets, such as their expansive surface area and porous structure, make them highly effective at removing impurities and toxins from the air. Additionally, their renewable and sustainable nature makes them a more environmentally conscious option compared to traditional filtration materials.

The use of hemp-derived carbon nanosheets in air purification systems has the potential to significantly improve air quality in various environments. These nanosheets can efficiently capture pollutants, allergens, and harmful particles from the air, thereby creating a cleaner and healthier atmosphere for occupants. This application is particularly crucial in urban areas and industrial settings where air pollution poses significant health risks.

Moreover, the unique structure of hemp-derived carbon nanosheets allows for efficient filtration without obstructing the airflow. This means that these nanosheets can be integrated into a wide range of air purification systems, including HVAC units, industrial smokestack filters, and portable air purifiers.

In summary, the utilization of hemp-derived carbon nanosheets in air purification systems presents a promising solution to global challenges related to air quality and public health. By harnessing the exceptional properties of these nanosheets, researchers and engineers can

develop innovative solutions that benefit both human well-being and the environment. See references: (Biomass-derived carbon materials with structural diversities and their applications in energy storage, 2017)^[9], (Liu et al., 2018)^[12], (3D mesoporous hemp-activated carbon/Ni₃S₂ in preparation of a binder-free Ni foam for a high performance all-solid-state asymmetric supercapacitor, 2019)^[17].

6. Aerospace Applications

6.1. Aircraft structural components

The potential of graphene and graphene-derived nanomaterials in the aerospace industry has been a focus of exploration. Graphene, renowned for its exceptional strength, lightness, and flexibility, has shown promise in the development of impact-resistant aircraft and helicopters. Its high electrical conductivity has also made it valuable for deicing systems on aircraft wings. Additionally, graphene nanomaterials have been utilized in wind farms to prevent interference with radars. The European Space Agency (ESA) and Novespace have collaborated on the creation of graphene-based coatings for heat exchangers and cooling systems in satellites, showcasing the diverse applications of graphene in space technology. Furthermore, the use of graphene in microgravity has led to the innovation of cooling systems for satellites. These examples underscore the versatility and potential of graphene nanomaterials in the aerospace industry.

Moreover, polymer/graphene nanocomposites have been specifically engineered for aerospace structures such as the Composite Exploration Upper Stage (CEUS) NASA project. These nanocomposites, composed of graphene/carbon fiber/polymer, have been employed to enhance resistance to open-hole compression failure in launch vehicle structures. In fact, these panels demonstrated a 22% reduction in weight compared to conventional composite panels due to the incorporation of graphene.

The integration of graphene into aerospace structures has also extended to commercial applications, as evidenced by the Orbex Prime rocket unveiled by Orbex, a UK-based orbital launch services company. The main structures and fuel tanks of the rocket are constructed using polymer/carbon fiber/graphene composites, highlighting the practical application of graphene in space exploration technology.

In summary, graphene and its derivatives have proven their potential to enhance aerospace structures and technologies. From improving mechanical properties to reducing weight in launch vehicle components, these materials are paving the way for advancements in space exploration. See references: (Ahmad et al., 2023)^[16], (Terranova et al., 2023)^[25].



Figure 6: The design of the Orbex Prime body (credits: Orbital Express Launch Ltd., London, UK). (source: reference (Terranova et al., 2023)^[25])

6.2. Spacecraft materials for reduced weight and enhanced performance

The utilization of carbon fiber composites in spacecraft components has played a pivotal role in enhancing performance, resilience, and effectiveness in space missions. The remarkable strength-to-weight ratio of carbon fiber makes it an optimal choice for constructing structural elements like the frame, body, and support structures of spacecraft. Its lightweight nature and durability also make it well-suited for supporting solar panels in solar arrays, maximizing power generation while minimizing overall spacecraft mass. Furthermore, carbon fiber is utilized in building antennas and communication dishes on spacecraft due to its electromagnetic transparency, ensuring dependable communication between the spacecraft and mission control. In addition, carbon fiber components are frequently incorporated into deployable booms and other appendages that need to extend or retract during a mission. The material's strength and flexibility are advantageous in these dynamic applications. Components designed for re-entry into Earth's atmosphere, such as heat shields and thermal protection systems, benefit from carbon fiber's low thermal expansion and excellent thermal conductivity.

Carbon fiber composites are also employed in constructing propellant tanks and containment structures due to their resistance to corrosion and high strength. Moreover, carbon fiber is used for mounting structures for scientific instruments and payloads on spacecraft, leveraging the material's stiffness and rigidity to ensure precise positioning and stability for sensitive

instruments.

Furthermore, carbon fiber finds diverse applications in spacecraft designed for planetary exploration, such as landers and rovers, often being incorporated into their landing gear and structural components due to its durability.

In summary, the distinctive properties of carbon fiber make it an invaluable material for spacecraft components across various applications. See reference (Space Exploration and Carbon Fibre: Building the Next Generation of Spacecraft, 2024)^[18].

7. Space Exploration Applications

7.1. Development of space elevators

The notion of a space elevator represents a groundbreaking and efficient method for reaching space from Earth's surface. The key to this concept lies in the creation of ultra-strong materials capable of supporting such a structure. Carbon nanotubes were initially identified as potential candidates for this purpose, given their necessary strength and lightness for constructing a space elevator. However, the challenge has been to produce macroscopic-sized carbon nanotubes that remain flawless on a microscopic scale.

Recent advancements in material science have resulted in the production of extended strands of carbon nanotube material, making it feasible to contemplate the construction of a space elevator. These carbon nanotubes are lightweight, flexible, and strong, meeting the specific strength requirements for such a monumental structure. NASA has shown interest in utilizing carbon nanotubes for building a space elevator as an alternate mode of space transportation. The potential advantages of a space elevator include cost-effective and relatively environmentally friendly transportation to space, opportunities for expanding space tourism, research expeditions for astronauts, and even possibilities for space colonization. Furthermore, emerging technologies and collaborative efforts are underway to tackle challenges such as avoiding space debris and minimizing environmental impact.

In conclusion, the progress made in developing extended strands of carbon nanotube material has brought us closer to realizing the concept of a space elevator. This innovative transportation idea has the potential to revolutionize access to space by providing safer, quicker, and more economical means of venturing beyond Earth's atmosphere. See references: (Long, Stretchy Carbon Nanotubes Could Make Space Elevators Possible, 2024)^[20], (Space elevator - Wikipedia, 2024)^[22], (1, 2005, pages 1-5)^[23], (A colossal elevator to space could be going up sooner than you ever imagined, 2024)^[24].

7.2. Use in space stations for various purposes (structural, radiation shielding)

The use of hemp-derived carbon nanosheets in space stations has significant potential for various applications, including structural uses and radiation protection. As interest in space exploration and space elevators grows, the need for durable lightweight materials becomes more crucial. Ultra-high strength carbon nanotube reinforced composites are essential for space elevator ribbon construction, providing the necessary tensile strength to anchor the elevator to the ground and potentially for future space station construction. Graphene, 200 times stronger than steel, is being considered for tether construction in space elevators, with efforts underway

to produce lengthy continuous graphene sheets. Despite challenges such as debris avoidance and recycling, scientists are optimistic about the feasibility of using these materials in future space station construction.

The International Space Elevator Consortium (ISEC) is actively supporting research and development related to space elevators, focusing on sustainable and efficient space access methods. Ongoing research is also exploring environmentally friendly alternatives to traditional spacecraft materials and manufacturing processes, aiming to reduce the ecological impact of space exploration.

Overall, hemp-derived carbon nanosheets show great promise for use in future space stations for structural components and radiation shielding. With ongoing research into stronger and lighter materials, the potential applications of hemp-derived carbon nanosheets in space exploration are increasingly feasible. See references: (Space Exploration and Carbon Fibre: Building the Next Generation of Spacecraft, 2024)^[18], (Long, Stretchy Carbon Nanotubes Could Make Space Elevators Possible, 2024)^[20], (1, 2005, pages 1-5)^[23], (A colossal elevator to space could be going up sooner than you ever imagined, 2024)^[24].

8. Carbon Sequestration with Hemp-Derived Carbon Nanosheets

8.1. Carbon capture technologies

Carbon sequestration plays a vital role in mitigating the impact of greenhouse gas emissions on the environment. Hemp-derived carbon nanosheets offer significant promise in this area, particularly within the construction industry. For instance, hemp concrete has been recognized as a carbon sequester because it can store more carbon than is released during its production. This makes it a crucial material for achieving carbon-neutrality in buildings, a key objective outlined in the European Green Deal.

Beyond construction materials, hemp-derived carbon nanosheets also hold potential applications in anaerobic digestion systems and biogas upgrading. Research has indicated that specific biochar materials can enhance methane production and improve the degradation of organic matter, resulting in reduced greenhouse gas emissions. Additionally, utilizing hemp and wood raw materials for long-lasting products and materials has been shown to have a substantial carbon removal potential when used in construction. This includes quantifying the amount of carbon stored in these raw materials per year and per hectare, as well as calculating the associated greenhouse gas emissions.

In conclusion, structures made from hemp-derived carbon nanosheets exhibit significant potential for carbon sequestration across various industries, such as construction, anaerobic digestion, and biogas upgrading. By harnessing the unique properties of these nanosheets, we can continue to explore innovative methods for addressing climate change and minimizing our impact on the environment. See references: (Farghali et al., 2022)^[1], (Stratmann, 2023, pages 1-5)^[6], (Hemp, 2024)^[14].



Figure 7: Lime hemp concrete, hemp wool and fibre-board insulation are used in the construction sector due to their energy efficient properties. (source: reference (Hemp, 2024)^[14])

Criteria	Biochar co-feed criteria values
Polycyclic aromatic hydrocarbons	Less than 4 mg kg ⁻¹
Carbon content	More than 80%
Heavy metals	Arsenic: Less than 2 mg kg ⁻¹
	Lead: Less than 10 mg kg ⁻¹
	Cadmium: Less than 1 mg kg ⁻¹
	Mercury: Less than 0.1 mg kg ⁻¹
Benzo-a-pyrene	Less than 25 µg kg ⁻¹
The dioxin-like polychlorinated biphenyls	A start value of 0.35 ng TE kg ⁻¹
Polychlorinated dibenzo-p-dioxins and dibenzofurans along with dioxin-like polychlorinated biphenyls	Less than 1.25 ng TE kg ⁻¹
Polychlorinated dibenzo-para-dioxin/ Polychlorinated dibenzofurans	A limit of 0.75 ng TE kg ⁻¹
Fluor	Less than 150 mg kg ⁻¹
Dry matter, insoluble-, and crude- ashes	Same as standard values imposed by EU regulations for feed
Crude protein, crude fat, and crude fibre	0 g kg ⁻¹ due to pyrolysis effect
Paint and solvents	Free
Contaminants such as plastics, rubber, and electronic scrap	Free

Table 5: Biochar standards for obtaining the European certificate of feed-grade biochar From: Biochar for agronomy, animal farming, anaerobic digestion, composting, water treatment, soil remediation, construction, energy storage, and carbon sequestration: a review (source: reference (Farghali et al., 2022)^[4])

Biochar biomass	Pyrolysis condition	Specific surface area (m ² g ⁻¹)	Porous size (cm ³ g ⁻¹)	Impurity removed	Removal rate (mg g ⁻¹)	References
Rice straw	312.5 °C for 20 min	122.2	0.083	Carbon dioxide	57.5	Huang et al. ()
Rice husk	550 °C for 30 min	263.4	0.209	Carbon dioxide	138.2	Chiappero et al. ()
Sawdust	700 °C for 60 min	773	0.32	Hydrogen	54.8	Ma et al. ()

				sulphide		
Maple wood	500 °C for 10 min	161	0.095	Hydrogen sulphide	219	Choudhury and Lansing ()
Pig manure	500 °C for 4 h	47.4	–	Hydrogen sulphide	59.6	Xu et al. ()
Food Waste and sludge	700 °C for 30 min	220.5	0.099	Hydrogen sulphide	66.6	Hervy et al. ()
Corn stover	500 °C for 10 min	23.5	0.011	Hydrogen sulphide	238	Choudhury and Lansing ()

Table 6: Potential role of biochar in biogas upgrading From: Biochar for agronomy, animal farming, anaerobic digestion, composting, water treatment, soil remediation, construction, energy storage, and carbon sequestration: a review (source: reference (Farghali et al., 2022)[\[4\]](#))

Biochar materials	Pyrolysis temperature	Feedstock	Biochar concentration	Anaerobic digestion performance	References
Wheat straw, fruitwood, and chicken manure	350, 450, 550 °C	Chicken manure	5%	Enhanced methane production by 69% at 550 °C	Pan et al. ()
Manure	350 °C	Air-dried manure	10 g L ⁻¹	Diminished lag phase and enhanced methane yield by 35.71%	Jang et al. ()
Fruitwoods	800 °C	Food waste	0.25–2.5 g per g total solids	Lowered lag phase by 36.3–54.0%; inoculum to substrate ratio at 0.8–2 improved the maximum methane generation aspect by 100–275%; Enhanced organic matter degradation	Cai et al. ()
Pine sawdust	650 °C	Food waste	8.3–33.3 g L ⁻¹	Declined lag phase by 36–41%; Increased hydrogen and methane yield by 31% and 10%, respectively; Increased volatile fatty acid consumption	Sunyoto et al. ()
Forest waste	450 °C	Sludge	0.5–12.0 g per g total solids	0.8 and 3.7 g per g VS improved methane generation by 192–61% during the first 16 d of digestion	Cimon et al. ()
Wood-pellets mixed with timber waste	800 °C	Poultry litter	100% poultry litter total solids	Decreased lag phase by 41%; Improved maximum daily methane generation by 136%	Indren et al. ()
Rice straw	260 °C	Dead pig carcass	2–10 g L ⁻¹	Improved biogas yields up to 61–91%	Xu et al. ()

Table 7: Performance of anaerobic digestion systems with varying types of biochar From:

Biochar for agronomy, animal farming, anaerobic digestion, composting, water treatment, soil remediation, construction, energy storage, and carbon sequestration: a review (source: reference (Farghali et al., 2022)[\[4\]](#))

8.2. Hemp as a sustainable source for carbon sequestration

Hemp is an excellent option for carbon sequestration due to its rapid growth, high biomass yield, and minimal water and pesticide requirements. It can also aid in soil remediation through phytoremediation. The cellulose in hemp fibers can be turned into carbon nanosheets, which are ideal for creating supercapacitors and batteries with enhanced energy storage capabilities. Hemp has been shown to absorb substantial amounts of CO₂ from the atmosphere, and one hectare of industrial hemp can absorb 22 tonnes of CO₂ per year. Additionally, hemp can be used to produce various materials, such as building materials, plastics, cosmetics, and insulation, effectively locking in CO₂ and substituting unsustainable raw materials. Overall, hemp offers significant environmental benefits while providing valuable materials for various industries, and has the potential to play a crucial role in mitigating climate change and promoting sustainable development. See references: (Can Hemp be a Viable Alternative to Lithium Battery Technology?, 2024)[\[5\]](#), (Microsoft Word - CarbonFarmsub0804, 2024, pages 1-5)[\[5\]](#).

9. Conclusion

9.1. Summary of the potential uses and benefits of hemp-derived carbon nanosheet structures.

Hemp is a game-changer in the realm of carbon sequestration, providing a sustainable solution for capturing atmospheric carbon. One of its key advantages is its rapid growth cycle, reaching maturity in just a few months. This allows for frequent harvesting and biomass production, making it an attractive source for carbon sequestration materials. In addition to its rapid growth, hemp boasts high biomass yield and requires minimal water and pesticides, reducing strain on local ecosystems and contributing to soil remediation through phytoremediation.

The cellulose in hemp fibers can be converted into carbon nanosheets, which have excellent electrical conductivity and high surface area - ideal properties for creating supercapacitors and batteries with enhanced energy storage capabilities. These nanosheets offer a renewable and environmentally friendly alternative to traditional lithium batteries that rely on potentially scarce metals.

Furthermore, hemp has been demonstrated to absorb substantial amounts of CO₂ from the atmosphere. One hectare of industrial hemp can absorb 22 tonnes of CO₂ per hectare, with the potential for two crops per year doubling the absorption. The carbon uptake of hemp can be accurately validated annually by calculations derived from dry weight yield, providing a level of certainty not available through any other natural carbon absorption process.

In addition to its role in carbon sequestration, hemp can also be used to produce building materials, plastics, cosmetics, composite boards, insulation materials, and more - effectively locking in CO₂ and saving additional emissions by substituting unsustainable raw materials with

products derived from harvested hemp.

Overall, the use of hemp as a sustainable source for carbon sequestration offers considerable environmental benefits while providing valuable materials for various industries. From energy storage devices to construction materials and environmental remediation efforts, hemp-derived carbon nanosheets have the potential to play a crucial role in mitigating climate change and promoting sustainable development. See references: (AbouAitah et al., 2023)^[2], (Rodriguez-Mirasol et al., 2008)^[6], (Guan, 2019, pages 1-5)^[8], (Biomass-derived carbon materials with structural diversities and their applications in energy storage, 2017)^[9], (Hemp Batteries Revolutionize Energy Storage, 2024)^[11], (3D mesoporous hemp-activated carbon/Ni₃S₂ in preparation of a binder-free Ni foam for a high performance all-solid-state asymmetric supercapacitor, 2019)^[17].

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