

BIOMASS DERIVED MATERIAL FOR SYNTHESIS OF CNTs

Priyanka Vikram Dudheinamdar¹, Sonali Vaibhav Dhamal^{2,*} and Jayant Chandrakant Thorat³

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Abstract

This paper offers a comprehensive exploration of the structure, morphology, synthesis methods, purification techniques, characteristics, advantages, and diverse applications of carbon nanotubes (CNTs) derived from sustainable and renewable biomass sources, encompassing leaves, tubers, fruits, seeds, bark, etc. The high carbon content inherent in biomass plays a pivotal role as the principal component in CNT synthesis. The paper highlights cost-effective and easily accessible sustainable sources, such as straw, rubber wood sawdust, palm fiber, wheat husk, groundnut shell, coconut shell, date pits, bamboo dust, sugarcane, banana peel, and papaya oil cake, for CNT synthesis. They exhibit potential in combining or absorbing therapeutic and diagnostic materials for drug delivery and serving as biological sensor platforms for various illnesses with noninvasive blood level monitoring. The paper underscores the significant attributes of CNTs, such as high surface-to-volume ratios, enhanced conductivity and strength, biocompatibility, ease of functionalization, and optical qualities. Additionally, it summarizes recent developments and research activities in CNT synthesis, emphasizing biomass's role as a renewable hydrocarbon resource for creating carbon materials, green chemicals, and bioenergy. The versatile adsorption properties of biomass position it as a valuable resource for the global pharmaceutical industry and various sectors.

Keywords: Biomass; Carbonation; Carbon material; Carbon nanotubes; Sustainable source

Introduction

Compact carbon tubes having a diameter in the nanometre range are known as carbon nanotubes, CNTs. They are one of the many forms of carbon. The diameter of a single-walled carbon nanotube is between 0.5 to 2.0 nm, or around 100,000 times

smaller than the breadth of a human hair (Zhu *et al.*, 2012).

Two naturally occurring crystalline forms of pure carbon are known as diamond and graphite. In diamond, carbon atoms show hybridization, a three-

¹ Department of Chemistry, BVDU Yashwantrao Mohite College of Arts, Science & Commerce, Kothrud, Pune– 411038, (MH), India. E-mail: priyanka.dudheinamdar@gmail.com

² Department of Basic Humanity and Science, BVDU College of Engineering, Pune-411043, (MH), India. E-mail: svdhamal@bvucop.edu.in

³ Bharati Vidyapeeth's College of Engineering, Kolhapur- 416013, (MH), India. E-mail: jaythorat28@gmail.com

* Corresponding author

dimensional network that is incredibly rigid because four bonds are directed toward the corners of a regular tetrahedron. CNTs also known as bucky tubes, are hollow tubes composed of carbon with a diameter of nanoscale. They are created by folding or rolling two-dimensional graphite into a cylindrical shape. The diameter of a carbon nanotube is typically 1-3 nm, and the length of a CNT is typically much longer than its diameter, reaching a few micrometers (Melati and Hidayati, 2016; Li *et al.*, 2017).

Since its discovery in 1991 by Iijima, CNTs have been of interest from a fundamental standpoint as well as for potential uses in the future. Its structure's intriguing properties include its electrical, mechanical, optical, and chemical properties, which can be measured on individual nanotubes and pave the way for potential uses in the future. Large quantities of purified nanotubes are required for commercial applications (Mopoung, 2011).

From an elastic modulus and tensile strength perspective, carbon nanotubes are the stiffest and strongest materials found to date. (Yu *et al.*, 2000). Carbon nanotubes can be metallic or semiconducting, with a varying bandgap, based on their structural makeup (Yamamoto *et al.*, 2012).

Carbon nanotubes' excellent electrical conductivity is one of their best features. The heat conductivity of CNTs is high. When temperature varies, CNT's electrical resistivity alters (UnderstandingNano, 2025). The layered pattern of arrangement created by the sp² characteristic of carbon hybridization has strong forces at the inner plane limits and weaker plane bonding of Vander Waals forces at the outer bounds (Jagadeesan *et al.*, 2020). In the presence of a magnetic field, CNTs alter their electrical resistance. The remarkable properties of carbon nanotubes include their light weight, rapid transfer of electron kinetics, high biocompatibility, ability to immobilize proteins, huge surface area, chemical inertness, numerous antibacterial and antifungal properties, ability to function as protein carriers and exposed functional groups (Anzar *et al.*, 2020). Because of their superior field-emitting properties, CNTs are utilized in lightning, flat-panel displays, and electron microscope sources. For all kinds of plastics, CNTs are an extremely tiny, high aspect ratio conductive addition. Compared to other conductive additions, a lower loading (concentration) of CNTs is required to produce the same electrical conductivity because of their high aspect ratio (Dresselhaus *et al.*, 1998).

The paper covers the most recent developments and research activities in the synthesis of CNTs and carbon nanofibers (CNFs)

through pyrolysis assisted by microwaves, addressing several facets of the creation process and use. A renewable hydrocarbon resource, biomass is utilized to produce carbon materials, green chemicals, and bioenergy. Furthermore, biomass is a potential source of enhanced carbon compounds (Qadri *et al.*, 2018).

The production of CNTs from waste materials has gained significant attention in recent times because of the expanding cost and duration of traditional synthesis techniques. The microwave-assisted synthesis technique is advantageous over conventional methods such as arc discharge, chemical vapor deposition (CVD), laser ablation, and others because of its quick reaction time and volumetric heating, economy, and environmental benefits. There are three leading methods of CNT synthesis, specifically laser ablation, chemical deposition, and electric arc discharge (Hakim *et al.*, 2018). This paper presents an overview of the structure and synthesis of CNTs from different plant materials.

Nowadays, there are several and varied ways used to synthesize carbon nanotubes. Produce type can often specify CNT attributes (Mirabootalebi and Akbari, 2017). Because it is easy to use, reasonably priced, and capable of producing huge quantities of high-quality CNTs, the arc discharge method is an important approach for creating CNTs. Arc discharge is a highly effective technique for creating high-quality MWNTs and SWNTs (Moeller and Matyjaszewski, 2012). Nowadays, organic chemistry and the pharmaceutical sector both have sophisticated sonochemistry research areas. Because of its many benefits, including shorter reaction times, greater yields, lower costs, and more comfortable circumstances, ultrasound irradiation is a valuable technique in organic synthesis (Brahmachari, 2021). Since it allows for fine control over evaporation and yields huge amounts of nanocrystalline material, the laser ablation method is an important means to synthesize CNTs (Shahid *et al.*, 2022). Laser ablation offers improved control over evaporation because of its rapid evaporation process (Chrzanowska *et al.*, 2015). CNTs can be easily and affordably synthesized at low temperatures using the traditional pyrolysis method (Hamid *et al.*, 2017).

Catalytic pyrolysis is a cost-effective, versatile, and easily controlled method for generating CNTs (Wu *et al.*, 2022). CVD offers distinct benefits in thin-film deposition, such as cost-effectiveness, scalability, homogeneity, and high purity (Wang *et al.*, 2019). Advantages of the electrolytic approach include minimal energy consumption during electrolysis, low apparatus complexity, and the ability to manage the synthesis

process through the various electrolysis modes. Using inexpensive raw materials, having one-step carbon phase doping, and being able to manage product morphologies and architectures (Novoselova *et al.*, 2008).

CNTs are made from sugarcane bagasse (SCB), which is cheap, plentiful, and has a large surface area (Surendran *et al.*, 2024). Because of its large surface area and relatively flexible structure, the highly conductive carbon material SCB was chosen as a carbon source. Because of its relatively low lignin content, SCB is suitable for biotransformation and can be used as an environmentally friendly green catalyst for the synthesis of MWCNTs (Ji *et al.*, 2021).

CNTs are synthesized using green catalysts, which are obtained from various plant parts and are an inexpensive and abundant natural source. The idea is novel, and it is effectively implemented by straightforward CVD growth that avoids any possible risks to the environment or life that could result from metal catalysts (Tripathi *et al.*, 2017). Lignocellulosic materials, such as peanut shells, are a rich and affordable kind of agricultural waste and lack any marketable value. Rich cellulose, hemicellulose, and trace levels of N and P components can be found in the many microfibers that make up peanut shells (Liang *et al.*, 2023).

Coconut shell is said to be one of the most promising feedstocks for various minerals among biomass fuels. Even though reports regarding these minerals' impact on the pyrolysis process. Because it is inexpensive and easily scaled, plant material—a plentiful and natural resource—is often utilized to make activated carbons and charcoals. Different plant materials serve as an alternative to different inorganic elements. Examples include bamboo, wheat straw, peanut shells, rice husks, banana peels, date palms, and coconut shells. These inorganic elements were used as catalysts to synthesize CNTs from plant biomass recently (Araga *et al.*, 2017).

Although bamboo plants are native to East Asia, they are currently grown throughout the world's subtropical zones. Bamboo plants are an appealing biomass resource for activated carbons due to their widespread availability. According to reports, a metal catalyst in an H₂ environment can help upload CNTs onto bamboo charcoal (Zhu *et al.*, 2012). Because it is an inexpensive, plentiful, renewable, and carbon-rich resource, rice husk makes an excellent starting material for the synthesis of CNTs (Asnawi *et al.*, 2018).

As the most common and vital grain for human consumption, wheat comes in second place in terms of overall cereal crop production. The outer shell of the wheat grain is called the wheat husk, and it is removed during the wheat milling process.

Wheat husk, on the other hand, could contain more than 70% carbon. A necessary ingredient in the creation of activated carbon is wheat husk (Baig and Gul, 2021).

Date palm fiber is an affordable, sustainable raw material that can be used to make activated carbon, which can then be used to make CNTs, another material with promising potential applications because of its unique physical and chemical characteristics, including high surface area, high mechanical strength, and chemical stability (Basheer *et al.*, 2023). Among the world's most popular dry fruits is the walnut. Because of the environmental safety involved, the synthesis of carbon nanotubes from walnut shells has acquired relevance. This review concentrated on using wall nut shells as a raw material for the synthesis of CNT to optimize the resource utilization of their waste (Roquia *et al.*, 2021).

There are numerous applications for CNTs' thermal conductivity that require heat transmission. In electronics, more especially sophisticated computing, where uncooled chips are now routinely beyond 100 °C, such a use can be discovered. The process that produces CNT ribbons and aligned structures (Walters *et al.*, 2001).

Vascular stents and neuron development and regeneration are two examples of biomedical applications made possible by the ability to functionalize (chemically alter) the sidewalls of CNTs. (AZoNano, 2025). CNTs have several additional possible applications, such as solar collecting, catalytic supports, nanoporous filters, and various coatings (Dresselhaus *et al.*, 1996). The intrinsic properties of CNTs make them ideal materials for use as electrodes in batteries and capacitors, two fast-developing technologies. In addition to having a very large surface area, CNTs also exhibit good electrical conductivity. Most significantly, though, their surface is highly accessible to the electrolyte due to their linear structure. According to research, among all the carbon materials that can be used in lithium-ion batteries, CNTs have the largest reversible capacity (Gao *et al.*, 2000). Due to its high electrical conductivity, CNT can also be utilized in current collectors and gas diffusion layers (Ma *et al.*, 2000). CNTs have applications in biosensors that track chemical characteristics and blood levels, as well as drug delivery devices. Additionally, they are employed in cancer therapies (Shariatnia *et al.*, 2001). CNTs are utilized in water management, marine, aerospace, and automotive applications to reinforce materials. To add conductivity to polymers, CNTs are utilized (Ouyang, 2019).

It discusses the various ways to functionalize CNTs using conventional methods as well as a range of plant parts functional materials, like the shells of peanuts, sugar cane cubes, banana peel, coconut shells, rice husk, and bamboo steam, to use CNTs to cover a specific application. Finally, it presents recent approaches related to industrial applications for adsorbent, effluent, domestic applications for hydrogen storage, and biomedical applications for drug delivery systems, bioimaging, and antimicrobial activity with the functionalization of CNTs including real-world applications (Asnawi *et al.*, 2018).

Notably, these CNTs find applications in energy storage, model devices, and diverse industries due to their vast surface area, suitable for automobile parts, boat hulls, sporting goods, water filters, thin-film electronics, coatings, actuators, and electromagnetic shields. The unique chemical, dimensional, optical, electrical, mechanical, thermal, magnetic, and structural properties of CNTs make them promising candidates in pharmacy and medicine.

This review included an overview of the several plant materials that are utilized as a feedstock for the synthesis of carbon nanotubes (CNTs), as well as CNT synthesis methods, applications, and a comparative study of the characteristics of CNTs made from different biomass sources.

Distinct plant materials utilized as feedstock to create CNTs

The various biomass conversions are useful for the synthesis of CNTs, and it has enormous applications in different fields including biomedical, electrochemical, tissue engineering, and energy storage. The present review is focused on the synthesis of CNTs from organic materials with high carbon content that are abundant and cheaply available sources which include rice husk, bamboo dust, coconut shell, peanut shell, sugarcane, banana peel, walnut shell, Sunflower seeds, etc. have been as the feedstock for CNTs. Selected plant materials are shown in Figure 1 to Figure 10

Saccharum officinarum - Sugar cane

This is a large, strong-growing species of grass and rich in sucrose, it simply accumulates in the stalk internodes. It is cultivated in tropical and subtropical countries worldwide to produce sugar, ethanol, and other byproducts. Using the pyrolysis process, sugar cane could be transformed into CNTs. Making MW-CNTs from bagasse from

sugarcane was reported recently by Aboul-Enein. The researchers used the usage of zeolites as a catalyst in the pyrolysis process for sugarcane bagasse (SCB) (Raghavendra *et al.*, 2021). From the literature study, the synthesis of carbon nanomaterials (CNMs) by using SCB pyrolysis with specific two-stage processes. Bio-silica extracted from rice husk was considered a catalyst to produce CNMs from pyrolysis products. The SCB could be regarded as an affordable and easily available source for the production of valuable CNMs (Romanovicz *et al.*, 2014). The CNTs with a catalyst for proton exchange membranes using sugar cane and anodic aluminum oxide (AlO) were synthesized (Thambiraj *et al.*, 2016). In the presence of a novel precursor, controlled temperature and inert gas flow rate were established. (Omoriyekomwan *et al.*, 2019) Catalytically cleaved sugarcane cubes with a natural precursor in a closed copper tube, preventing oxidation and converting tubular nanostructures to amorphous carbon. Carbodiimide chemistry was applied to covalently attach ACV on purified CNTs. MWCNTs were manufactured by Sneha Surendran *et al.* utilizing sugarcane bagasse and a biogenic catalyst at 700°C in an inert atmosphere with LPG acting as a carbon source. While the diameter was ascertained by TEM, they used SEM characterization to verify the production of MWCNTs. RAMAN spectroscopy was used for structural characterization, and XRD revealed that the generated MWCNTs are graphitized (Surendran *et al.*, 2024).



Figure 1. Saccharum officinarum - Sugar cane.
(Family: Poaceae, Subfamily: Panicoideaea)

Arachis hypogaea - Peanut/Groundnut

Groundnut, or peanut (*Arachis hypogaea*), is a legume crop cultivated primarily for its edible seeds. Legumes have nitrogen-fixing bacteria that live in symbiotic relationships in root nodules improving soil fertility and enhancing crop

rotations. It is significant to both small and large commercial growers, and it is widely grown in the tropics and subtropics. It falls within the category of an oil crop due to the high oil content in grain legumes (Thambiraj and Shankaran, 2016). Peanut shells were thermally treated in atmospheres of nitrogen and argon, respectively, to produce Silicon carbide and silicon trinuclear nanoparticles. The processed samples with argon atmosphere were associated with SiC nanoparticles and nanotubes of the 2H and 3C polytypes Raman spectroscopy, transmission electron microscopy analysis, and X-ray diffraction were applied in this process. Peanut shells were calcinated in an N₂ gas atmosphere, and α -Si₃N₄ nanoparticles and nanorods were formed (Omoriyekomwan *et al.*, 2019).

Nuilek *et al.* synthesized a high percentage carbon content nanostructured particle. Natural resources such as peanut shells and nettle stems were pyrolyzed to provide raw materials for the production of carbon. The natural structures of Nettle and peanut shells, which are composed of cellulose, made significant contributions. Precursors in the development of highly ordered carbon nanosheets. Aqueous solutions of KOH and NaOH were considered for activation purposes and sulphuric acid (H₂SO₄) was used for exfoliation (Nuilek *et al.*, 2020).

In 2017, Yallappa *et al.* reported synthesizing Nano Carbons from natural biowaste, such as groundnut shells, using a catalyst-free pyrolysis process at distinct temperatures. Various physicochemical techniques were used to characterize the materials as they were produced (Yallappa *et al.*, 2017).

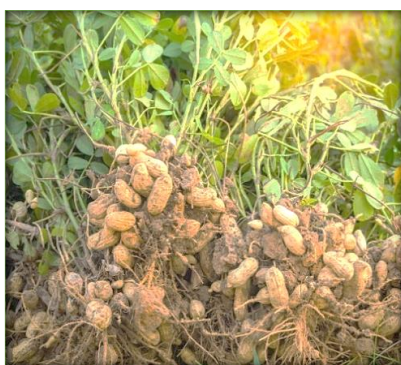


Figure 2. *Arachis hypogaea* - Peanut / Groundnut (Family: Fabaceae / Leguminosae)

***Musa acuminata* - Banana**

The freshly Silver nanoparticles made from extracted banana leaves (BL-AgNPs) were validated using the procedures for FT-IR, UV-

visible, and scanning electron microscopy (SEM). The nanoparticles were produced by extracting particles from banana leaves, a bio-waste, using a microwave (Raghavendra *et al.*, 2021).

CNTs and nanocarbon synthesis were carried out by pyrolysis with precursors in a closed stainless-steel tube with a diameter of 12.7 mm, a thickness of 1.0 mm, and a length of 200 mm, at 1000 to 1200°C (Mopoung, 2011). A mixture of 2% mineral oil and activated carbon from banana peels were precursors for synthesis.

The extraction and derivation of carbon nanotube, which was utilized as a precursor for CNT and nanocarbon, from a mixture of 2% mineral oil and activated carbon from banana peels has been described by Noor *et al.* Precursors are pyrolyzed at high temperatures in a closed stainless steel tube as part of the synthesis process. SEM and EDX were used to analyze the finished goods (Noor and Talal, 2013).



Figure 3. *Musa acuminata*, - Banana (Family: Musaceae)

***Cocos nucifera* - Coconut**

The coconut tree yields food, fuel, cosmetics, building materials, traditional medicine, and more. Mature coconuts have been used as edible seeds. Coconut flesh has been processed for oil and plant milk while coir is made from the fiber husk and charcoal from the hard shell. Sweet coconut sap has been enhancing the taste in drinks as well as has been fermented to produce coconut vinegar or palm wine. The lengthy pinnate leaves, fibrous husks, and hard shells have been applied for furnishing and decoration (Iqbal *et al.*, 2020).

CNTs have been synthesized using a convenient and eco-friendly method called the one-step water-aided (quenching) technique with graphite flakes which were prepared from coconut shell wastes (Hakim *et al.*, 2018). Various techniques have been developed for the synthesis of CNTs, including chemical vapor deposition (CVD),

arc discharge, pyrolysis, laser vaporization, and one-step water-assisted (quenching) method.

Melati and Hidayati investigated the pyrolysis approach mixed with the CVD or wet chemical processes at 6000°C and obtained attainably aligned MWCNT with high purity (Melati and Hidayati, 2016). Coconut shell is involved as an active carbon source at elevated temperatures of 500-6000°C in order to produce activated carbon and convert it in the preparation of CNTs. These CNTs were utilized for identifying the expression of biological components that are suggestive of cancer at an early stage. Hence CNT Biosensor treated as clinical biomarkers for cancer detection.

MWCNTs were synthesized from charcoal which was derived by pyrolysis of coconut shells at 900°C (Araga *et al.*, 2017). The 450°C temperature was utilized to perform the PECVD process, which is boosted by plasma. In the growth of CNTs, acetylene (C₂H₂) and hydrogen (H₂) are involved as an etchant gas with controlled plasma pretreatment time, flow rates of H₂ and C₂H₂, and temperature. Inter-electrode distance, anode and gas shower distance Radio frequency power, and the gas mixture ratio (C₂H₂/H₂) were adjusted during the process. In 2024, Ibrahim and Sulaiman. conducted a study on the adsorption of crude oil utilizing synthesized CNTs made from coconut shells. The CNTs were created using batch adsorption tests under various conditions, after the confirmation of their creation by analytical techniques including UV-vis, FTIR, and SEM (Ibrahim and Sulaiman, 2024).



Figure 4. *Cocos nucifera* - Coconut (Family: *Arecaceae*).

***Bambusa vulgaris* - bamboo**

The majority of bamboos are evergreen perennial flowers belonging to the Poaceae grass family's subfamily Bambusoideae. Bamboo is included in some of the fastest-growing plants in the world (Kelchner and Group., 2013). An *et al.*,

(2010) studied morphologies and process of bamboo mode structure formation. CNTs were methodically created with the use of chemical vapor deposition and microwave plasma. Two types of bamboo mode structures are reported as follows: cylindrical and cone-shaped. Hence the base growth mode was detected as more common during CNT growth with the formation of compartments which were assigned due to the variation in carbon species' surface and bulk diffusion across the catalyst.

Zhu *et al.* (2012) studied the heating of fresh bamboo material at 1000-1500°C for the synthesis of charcoals. MWCNTs were prepared by chemical vapor deposition of charcoals in the presence of ethanol vapor. The mineral phases' structure and elemental content in the bamboo charcoal were analyzed at different temperatures. The results demonstrated that the nucleation and growth of MWCNTs was carried out at 1200-1400°C with Mg₂SiO₄ and calcium silicate. The formation of MWCNTs was described by a vapor-liquid-solid model that includes the first dissolving of carbon in molten silicate to break down ethanol vapor into carbon.



Figure 5. *Bambusa vulgaris*-bamboo (Family: *Poaceae*)

***Oryza sativa* - Rice Husk**

In counties that produce rice, rice husk is a plentiful agricultural by-product that makes up, on average, 20% of the total weight of paddy produced (An *et al.*, 2010). Hongo *et al.* (2013) studied rice husk ash (RHA). In their study, they obtained a silica component The aluminosilicate nanotube (ASNT) material was successfully synthesized using this (RHAS) as a raw material from a rice husk power plant in Myanmar. Over 90 weight percent of silica was present in the RHA. Large volumes of RHA are released from rice husk power plants, thus it would be ideal to create a productive system for recycling this waste. The fibrous bundles

that make up the web-like structure of the synthesized ASNT contain numerous individual ASNT (Fathy, 2017). The successfully prepared CNTs by carbonizing hydrothermally treated rice straw in the presence of a gaseous carbon source released from heating camphor under flowing N₂ gas, either a mono-catalyst of ferrocene (RS-H/Fe) or a combined catalyst of ferrocene and nickel nitrate (RS-H/Fe-Ni). Rice straw and camphor are two inexpensive, renewable, and environmentally beneficial carbon sources for CNT preparation.

Using rice husk powder, M. Asnawi *et al.* (2018) developed CNTs, using a microwave oven. To continue this synthesis, they have been demonstrated that a carbon supply, catalyst, and commercial microwave oven are required for the induction of plasma. In the presence of ferrocene, the plasma accelerates and improves the catalytic breakdown of rice husk. To verify the existence and caliber of generated carbon nanomaterials, SEM, TGA, and Raman spectroscopy were used (Asnawi *et al.*, 2018).



Figure 6. *Oryza sativa*: Rice Husk (Family: Poaceae)

Triticum aestivum - Wheat

Gao *et al.* (2018) reported an eco-friendly and sustainable activation process to produce high-density carbon nanotubes made from scaffolds of fermented wheat dough without additional catalysts or carbon sources. Self-catalysis' growth mechanism investigated the production of CNTs generated from yeast. When the carbon nanotube / activated wheat dough (AWD/CNT) scaffold is processed with the sulfur host for the production of the lithium-sulfur (Li-S) battery cathode. With a well-retained capacity of around 450 mA h g⁻¹, the constructed Li-S cell demonstrated exceptional cycling performance, even after 1500 cycles at a high charge/discharge rate of 1°C.

CNTs were synthesized in 2019 by P. Hidalgo *et al.* utilizing a ferrocene and charcoal combination along with microwave-assisted heating. For the synthesis of carbon nanotubes (CNTs), and biochar samples they have been generated from pyrolyzed hazelnut hulls, oat hulls, wheat straw, and rapeseed cake. Transmission electron microscopy, Raman spectroscopy, UV-VIS spectroscopy, and dynamic light scattering were used to analyze the synthesized CNTs. The degree of wall graphitization in CNTs synthesized from wheat straw and hazelnut husk biochar is higher, indicating better CNT quality (Hidalgo *et al.*, 2019).



Figure 7. *Triticum aestivum*: Wheat (Family: Poaceae, Subfamily: Pooideae)

Phoenix dactylifera - Date palm

Few wall carbon nanotubes (FWNTs) were reported by using date palm seeds from Iraq as natural materials (Kahdum *et al.*, 2016). Chemical vapor deposition reactors are applied in the synthesis process to precipitate carbon. The process is carried out using non-volatile material in the solid state with a specially modified reactor to evaluate the carbon content in the gas phase for precipitation. The N₂ gas was considered as the carrier gas for reaction at temperature 750°C with a tri-metallic catalyst (Fe: Mg: Mo) at the silicon surface which supported precipitation. The waste Iraqi date palm seeds were used as an excellent precursor for the synthesis of CNTs. This product is mostly a mixture of FWNTs with a purity of 70%. The inner diameter of the synthesized product was determined about 6.63-11.40 nm and the outer diameter ranged from 2-5 nm with a length of 0.5-2.6 µm. In this study, Iraqi kantar date palm seeds were treated as an ambient agricultural raw material for the effective synthesis of CNTs, which were characterized by using various analytical and spectrophotometric techniques.

In 2023, Basheer *et al.* will examine the structural features and attributes of low-cost CNTs derived from date palm fiber and nanostructured powder-activated carbon. Eco-friendly methods were used to prepare the CNTs, which were then described and examined using TEM, XRD, and FESEM. They studied the structural features and attributes of nanostructured powder-activated carbon (DP-NPAC) and low-cost carbon nanotubes (CNTs) based on date palm fiber (Basheer *et al.*, 2023).



Figure 8. Phoenix dactylifera: Date palm (Family: Palmae or Arecaceae)

Juglans regia - walnut

Amateur Roquia *et al.* (2021) conducted a study on the synthesis of carbon nanotubes from walnut shells. They describe the pyrolysis method used to create the nanotubes, which were then characterized using X-ray diffraction, Fourier-transform infrared spectroscopy, and scanning electron microscopy. This study demonstrates that the synthesized nanotubes are highly pure and multi-walled, making them suitable for a variety of downstream applications.



Figure 9. Juglans regia: walnut (family: Juglandaceae)

Pyrolysis was used to synthesize CNTs. Benzene and ferrocene were combined with activated carbon made from walnut shells in a container. The mixture was subjected to pyrolysis for four hours at 700°C in a horizontal furnace with argon gas present. The carbon nanotubes that were obtained underwent additional characterization (Basu *et al.*, 2018; Zheng *et al.*, 2019; Roquia *et al.*, 2021).

Helianthus annuus: Sunflower

Zhang *et al.* (2015) used the Brunauer-Emmett-Teller method and methylene blue method to estimate the surface areas of CNTs in their findings. Additionally, the natural sunflower seed hulls (designated as CNTs-1) and sago (designated as CNTs-2) were pyrolyzed to create the CNTs, which have capacitances of 26.7 F/g and 86.9 F/g, respectively (Zhang *et al.*, 2015).

By pyrolyzing combinations of sunflower oil and ferrocene ($\text{Fe}(\text{C}_5\text{H}_5)_2$), scientists Rajesh Kumar *et al.* created bamboo-shaped carbon-nitrogen (C-N) nanotubes, with NH_3 serving as the nitrogen source. Ferrocene's ideal temperature and concentration were 825°C and 10 mg/ml, respectively. In their analysis, transmission electron microscopy and scanning electron microscopy highlighted the hollow and vertically aligned structural morphology of the nanotubes, while FTIR demonstrated the inclusion of N atoms into the carbon framework (Kumar *et al.*, 2011).



Figure 10. Helianthus annuus: Sunflower (Family: Asteraceae or Compositae)

CNT Synthesis methods

Various methods have been documented for the carbon materials synthesis by using biomass. The following are chemical vapor deposition, cyclic oxidation, Pretreatment for hydrothermal

carbonization and combustion technique, and conventional pyrolysis. However, greener methods to produce CNTs with appropriate properties have been investigated to prevent the use of harmful or poisonous chemical substances and complex tools. Researchers have selected inexpensive, environmentally friendly raw materials for agriculture as well as biowastes for reactions. Methods required costly apparatus, chemical catalysts, and excessive energy usage (Mostafavi *et al.*, 2022). CNTs produced utilizing three primary methods: arc discharge, laser ablation, and chemical vapor deposition (CVD) (Salah *et al.*, 2021). This review focused on a green-synthesis attribute that permits inclusion. Green-synthesis approach depended on biomasses such as wood, leaves, plant husks, peanut shells, coconut shells, and fruit peels with specific precursors for developing carbon materials (Qasim *et al.*, 2023). The following three main types are CNT Green synthesis, Chemical synthesis, and Physical synthesis. Greener synthesis would be applied to materials with low cost, cheap, and non-hazardous to the environment (Journet *et al.*, 1997).

ARC Discharge Method

The arc-discharge method is the conventional method used to create carbon nanotubes. It involves creating an arc between two graphitic rods that are kept a specific distance apart, usually a few millimeters. When it comes to carbon nanotube production, the arc-discharge method is the most economical and time-efficient way relative to other approaches (Sharma *et al.*, 2015). This method includes an inert gas-immersed pair of graphite electrodes with a direct-current arc voltage between them helium. One common technique for producing SWNTs is arc discharge. After completion of the process, high-quality SWNTs are collected at the cathode for simple harvesting. The arc discharge method could produce large quantities of single- and multi-walled CNTs (Park *et al.*, 2002).

Sono chemical Hydrothermal

The process by which liquid bubbles expand and then implasively collapse is known as acoustic cavitation, from which Sonochemistry is derived passed through temperatures and pressures that were extreme, and then cooled down quickly. Shape and size-selective nanoparticle production is frequently caused by these characteristics (Patil and Bhanage 2016).

Laser ablation

One kind of physical vapor deposition technology is laser ablation. Here, the graphite target is evaporated by a laser source. The target is

placed in the middle of a quartz chamber that is heated to 1200°C and filled with argon gas. A laser source that pulses or runs continuously vaporizes the target. The vaporized target atoms (carbon) are drawn toward a cooled copper collector by the flow of argon gas, where they settle and grow into CNTs (Iqbal *et al.*, 2020).

Conventional pyrolysis:

Catalytic pyrolysis is a common process for producing CNTs with a controlled reaction process. It is highly adaptable due to low cost because its feedstock is selected from a wide range of sources, including organics low-rank coal with high volatiles, and C1 chemicals. The most frequently considered transition metal catalysts like Fe, Co, and Ni or their alloys in the preparation of CNTs (Jagadeesan *et al.*, 2020).

Chemical Vapour Deposition

One procedure that is quite flexible is chemical vapor deposition (CVD), which produces film or particle growth by breaking down gas phase molecules into reactive species. This process is carried out with methane as a carbon source at temperatures between 850 to 1000°C. CVD has been a specialized method for producing high-quality nanotubes on a large scale (Bagotia *et al.*, 2018). In CVD, a carbon atom-containing gas continuously flows through the catalyst to produce a nanoparticle. The synthesis involves the decomposition of a catalyst to produce a carbon source, which is typically hydrocarbon gas, working at a high enough temperature in a tubular reactor (Wu *et al.*, 2022).

Electrolysis

The primary goal of electrolysis is to electro wine alkali (Li, Na, K) or alkaline-earth (Mg, Ca) metals from their chloride salts on a graphite cathode, and then the metal being deposited interacts with the cathode to produce CNTs (Ahmed *et al.*, 2019). During the electrolysis process, the carbon cathode erodes, and the electrolytic products are a mixture of CNTs and a sizable number of graphite cathode-derived carbon nanoparticles with varying morphologies (Wang *et al.*, 2019). A mixture of CNTs and a sizable amount of carbon nanoparticles with different shapes that come from the graphite cathode are the electrolytic products, which are produced when the carbon cathode erodes during the electrolysis process. The electrolytic method shows the following advantages: easy apparatus to use; low energy consumption for electrolysis; controllable synthesis process through electrolysis modes; use of inexpensive raw materials; and the ability to control product

structures with morphologies. It also includes carbon phase doping in a single step (during synthesis) through optimization of electrolysis conditions and composition of the electrolytic bath (Novoselova *et al.*, 2008).

Applications of CNTs

Drug delivery

The ability to deliver anticancer drugs to cancer cells or cancer tissues with high selectivity is known as "target treatment". It would lead to a revolutionary improvement in therapeutic effects, selected in the given Figure 11. Establishing efficient target drug delivery systems might be the first step toward realizing target treatment. This system consists of drugs and carriers acting as the means of target delivery. Three requirements decide the potential of a carrier that contributes to an ideal target drug delivery system: (1) they should be target effective (2) they should have strong adsorptive effects at target sites, and (3) they should be able to release a specific dose of the drugs for necessary effect at target sites. This review highlights the development of CNTs as target carriers in cancer treatment medication delivery systems. The delivery capabilities of CNTs with unique physicochemical properties would be responsible for the three prerequisites (Zhang *et al.*, 2011). CNTs treated easily with various types of cells by several mechanisms. The special properties of CNTs are elevated surface-to-volume ratios, improved strength and conductivity, biocompatibility, simplicity in functionalization, and optical qualities, etc. Hence CNTs are considered novel drug delivery carriers. They have been applied for special phototherapy due to their unique optical properties and contributed to the delivery of different genes like plasmid DNA (PDNA), micro-RNA (miRNA), and small interfering RNA (siRNA) as gene delivery vectors for various diseases (Zare *et al.*, 2021). The significant characteristics of CNTs are surface area, stiffness, strength, and resilience which have been supportive in the field of drug delivery systems. Because the high surface area was producing ease of conjugation with a wide range of organic and drug groups, including antibiotics, and anticancer agents (Zare *et al.*, 2021).

Diagnostic tool

CNTs have been introduced in biomedical and pharmaceutical applications. For example- Disease diagnosis due to the presence of various functional groups on CNTs surface, such as carboxyl and hydroxyl groups. Hence oxidized MWCNTs have

a higher chemical activity than oxidized SWCNTs, which may contribute to the wide scope of applications. The high density of oxygen-containing functional groups on the sidewalls of MWCNTs makes it possible for finely dispersed nanoparticles (NPs) to adhere to their surface, which may increase the electroactive surface area. CNTs have been applied in components of electrochemical biosensors to enhance sensitivity and to proceed with the specific identification of biomarkers associated with disease. This process improves the sensitivity of electrochemical sensors (He *et al.*, 2022). After a brief overview of Lung cancer concerned with a high death rate, the earliest diagnosis, and essential treatment should be followed with CNTs. The targeted CNT sensors are concerned with drawbacks which could be connected to a modified vapor during screening and non-invasive diagnosis.

The biomarkers of genetic and protein modifications have been known for lung cancer detection. These biomarkers could be suggested for various biosensors for non-intrusive identification. The most recent technique is the use of breath analysis to detect VOCs and tumor markers through CNT application. The laboratory and animal research could be an interesting therapeutic option for diagnosis and treatment (Sheikhpour *et al.*, 2020).

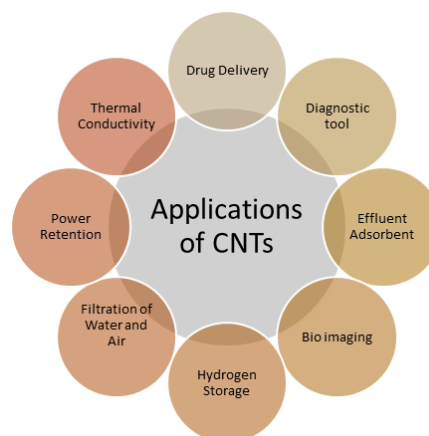


Figure 11. *Helianthus annuus*: Sunflower (Family: Asteraceae or Compositae)

Provision of CNT sensors that are suitable for health monitoring should be with the obligation to ensure safety and efficacy. CNTs could be the most promising materials in the biomedical industry due to their elevated electrical conductivity, flexibility, and ability to be modulated with various stimulations (Rdest and Janas, 2021).

Effluent Adsorbent

Wastewater is contaminated with hazardous and poisonous materials which involve heavy metals and organic contaminants from various industrial sources. Contaminated potable water might be impacted by many chronic or acute diseases; hence elimination of harmful components is essential from the wastewater prior to its release into the drainage network.

Carbon materials are widely used as engineering adsorbents due to their remarkable structural, mechanical, electrical, and thermal qualities. Carbon nanotubes are an appealing adsorbent for wastewater treatment due to have excellent thermal and chemical stabilities and sizable specific surface areas. Studies have demonstrated the great effectiveness of carbon nanotubes in eliminating harmful substances from water, including lead, cadmium, and 1,2-dichlorobenzene (Li *et al.*, 2007). To investigate the ability of nanoparticles to treat water, consider the following: heavy metals and other dangerous water contaminants can be adsorbed, and harmful molecules can be changed into less dangerous chemicals. In the area of water treatment and remediation, nanotechnology appears to offer a potential application whereby different nanomaterials can be utilized to clean water through diverse methods (Ghasemzadeh *et al.*, 2014). Nanotechnology offers a potential use in the cleanup and water treatment industries. Nanoparticles can be used to adsorb various hazardous water contaminants, including heavy metals, and transform them into less hazardous compounds. Nanostructured catalytic membranes have also been shown to be extremely important in water treatment applications (Arora and Attri, 2020). CNTs with a one-dimensional structure have a layered and hollow architecture and are flexible. Surface chemistry, making them similar to miniaturized ACFs. All adsorption loci are located on the surface of the inside and outside layers of CNTs. The CNTs may take a step ahead forming a convincing third generation of carbonaceous adsorbents (Liu *et al.*, 2013).

Power Retention

The intrinsic properties of carbon nanotubes (CNTs) make them ideal materials for use as electrodes in batteries and capacitors-two fast-developing technologies. Crucially, the linear form of CNTs makes their surface extremely accessible to the electrolyte. They also have a very high surface area and good electrical conductivity (Gao *et al.*, 2000).

Moreover, CNTs are used in a range of fuel cell parts. They are beneficial as electrode catalyst supports in fuel cells due to a variety of characteristics, such as their high surface area and thermal conductivity. Due to their high electrical conductivity, they can also be utilized in current collectors and gas diffusion layers (Ma *et al.*, 2000).

Filtration of Water and Air

Fluids can pass through the membrane during the physical and mechanical separation process known as filtration, which also keeps surplus solutes in check. Filtration has been the most widely used water purification technique for many years (Arora and Attri, 2020).

It has been suggested that functionalizing CNTs might improve both their mechanical and chemical properties, particularly their hydrophilicity. Water purification using CNT-based smart membranes has a lot of potential. In water treatment applications, however, the range of composite membranes can be expanded by combining other techniques. In addition to having remarkable mechanical, electrical, and thermal qualities, CNT also possesses some antibacterial activity. They modify the physico-chemical characteristics of membranes, promoting their potential in a variety of applications. As the interior pores of CNTs often function as selective nanopores, the CNT-filled membranes exhibit increased permeability along with improvements in mechanical and thermal properties, all without sacrificing selectivity (Ursino *et al.*, 2018).

Because of their huge surface area, low density, and porosity, CNTs are now thought to be among the best materials for air purification because they act as extremely effective adsorbents. Furthermore, CNTs are the preferred option for usage as adsorbents in gaseous and liquid media due to the comparatively simple procedures for their production and handling, which makes them perfect adsorbents for the remediation of both air and water pollution (Gulati *et al.*, 2022).

Thermal Conductivity

Thermal conductivity, which represents a material's capacity for heat transfer, is another name for heat conduction. Due to their superior thermal conductivity, CNTs are useful in applications involving thermal control. To dissipate heat, avoid overheating, and improve the overall dependability and performance of electronics, they are employed as heat sinks in electronic devices. CNTs are useful in thermal management applications because of their high thermal

conductivity. They increase the overall dependability and performance of electronics by dissipating heat in electrical equipment and preventing overheating (Guo *et al.*, 2021).

CNTs have remarkable mechanical, thermal, and electrical conductivity qualities. And hence the best conceivable electron field emitter. They can be altered and reacted by utilizing the well-known and incredibly complex chemistry of carbon since they are pure carbon polymers. This offers the chance to alter their composition and maximize their solubility and dispersion. More importantly, CNTs are often free of defects in the nanotube structure that would degrade their properties since they are molecularly flawless. As so, their material qualities can come very close to the very high values that are intrinsic to them. These remarkable properties provide CNTs potential in a wide range of applications (Smalley, 2003).

Comparative study of CNT properties Synthesized using different Biomass Resources

Conclusion

This paper explores the production of CNTs from different parts of plants, highlighting various synthesis techniques and the multiple uses of CNTs in various fields. CNTs have attracted significant attention from the scientific community due to their unique properties and wide-ranging applications across technology and research fields. However, there is still a lot we don't know about these nanotubes, such as their potential impact on the environment and human health during large-scale production. As such, there is a need for more affordable mass-production methods using biomass. To this end, numerous studies have been conducted to discover cost-effective and eco-friendly ways to produce CNTs. One such solution is to consider plant extracts and agricultural wastes as natural, renewable, biodegradable, and sustainable sources for producing CNTs from plant biomass. The most recent techniques for producing CNTs from a variety of renewable resources, such as different plant materials used as feedstock, were

Table 1. Comparison of CNTs Properties Synthesized using different Biomass Resources

Sr.No	Distinct Plant Materials used for Synthesis of CNT	Method of Synthesis	Properties	Reference
1	Sugarcane Bagasse	Chemical Vapour Deposition method	Mechanical, electrical, and thermal properties.	(Surendran <i>et al.</i> , 2024)
2	Groundnut shell	Pyrolysis	Strong fluorescence emission properties	(Yallappa <i>et al.</i> , 2017)
3	Banana Peel	Chemical Activation Process	Shows high specific capacitance.	(Tripathy <i>et al.</i> , 2021)
4	Bamboo Charcoal	Chemical Vapour Deposition	Excellent adsorption properties	(Zhu <i>et al.</i> , 2012)
5	Rice Husk	Microwave Plasma Irradiation	High surface area and specific capacitance.	(Asnawi <i>et al.</i> , 2018)
6	Walnut Shells	Pyrolysis	Shows electrical conductors and adsorption of gases	(Roquia <i>et al.</i> , 2021)
7	Coconut Shell	Plasma Enhanced Chemical Vapour Deposition	Excellent combination of its electronic and mechanical properties	(Araga <i>et al.</i> , 2017)
8	Date Palm Seeds	Chemical Vapour Deposition Method	Metallic semiconducting properties	(Kahdum <i>et al.</i> , 2016)
9	Wheat Flour	Chemical Vapour Deposition	High-strength composites	(Gao <i>et al.</i> , 2018)
10	Sunflower Seed Hulls	Pyrolysis	Large surface area and capacitances	(Zhang <i>et al.</i> , 2015)

outlined in the summary. As CNT feedstock, materials such as rice husk, bamboo dust, coconut shell, peanut shell, sugarcane, banana peel, walnut shell, sunflower seeds, etc. are ideal carbon reservoirs that, with the right processing, can yield sustainable single- and multi-walled CNTs. Nanocarbon material was created by processing solid resources, such as plant feedstock, similarly. By utilizing bio-feedstocks as previously mentioned, we can address these issues and bring civilization closer to the circular economy's tenets, which will ultimately lead to a more sustainable global community. Although the disclosed results are highly encouraging, more research is necessary before the technology is ready for widespread commercial use.

References

- Ahmed, I.A., Al-Radadi, N.S., Hussein, H.S., and Ragab, A.H. (2019). Environmentally friendly mesoporous nanocomposite prepared from al-dross waste with remarkable adsorption ability for toxic anionic dye. *Journal of Chemistry*, 2019:1-14. <https://doi.org/10.1155/2019/7685204>
- An, D., Guo, Y., Zhu, Y., and Wang, Z. (2010). A green route to the preparation of silica powders with rice husk ash and waste gas. *Chemical Engineering Journal*, 162(2):509-514. <https://doi.org/10.1016/j.cej.2010.06.012>
- Anzar, N., Hasan, R., Tyagi, M., Yadav, N., and Narang, J. (2020). Carbon nanotube-a review on synthesis, properties and plethora of applications in the field of biomedical science. *Sensors International*, 1:100003. <https://doi.org/10.1016/j.sintl.2020.100003>
- Araga, R. and Sharma, C.S. (2017). One-step direct synthesis of multiwalled carbon nanotubes from coconut shell-derived charcoal. *Materials Letters*, 188:205-207. <https://doi.org/10.1016/j.matlet.2016.11.083>
- Arora, B. and Attri, P. (2020). Carbon nanotubes (CNTs): A potential nanomaterial for water purification. *Journal of Composites Science*, 4(3):135. <https://doi.org/10.3390/jcs4030135>
- Asnawi, M., Azhari, S., Hamidon, M.N., Ismail, I., and Helina, I. (2018). Synthesis of carbon nanomaterials from rice husk via microwave oven. *Journal of Nanomaterials*, 2018(1):2898326. <https://doi.org/10.1155/2018/2898326>
- AZoNano. (n.d.). Carbon nanotube applications. Retrieved January 15, 2025, from <https://www.azonano.com/details.asp?ArticleID=980>
- Bagotia, N., Choudhary, V., and Sharma, D.K. (2018). A review of the mechanical, electrical, and EMI shielding properties of carbon nanotubes and graphene-reinforced polycarbonate nanocomposites. *Polymers for Advanced Technologies*, 29(6):1,547-1,567. <https://doi.org/10.1002/pat.4275>
- Baig, M.M. and Gul, I.H. (2021). Conversion of wheat husk to high surface area activated carbon for energy storage in high-performance supercapacitors. *Biomass and Bioenergy*, 144:105909. <https://doi.org/10.1016/j.biombioe.2020.105909>
- Basheer, A.O., Odeh, A.A., and Al-Douri, Y. (2023). Structural analysis and characterization of date palm fiber-based low-cost carbon nanotubes and nanostructured powder activated carbon. *Heliyon*, 9(8). <https://doi.org/10.1016/j.heliyon.2023.e18205>
- Basu, P. (2018). Biomass gasification, pyrolysis, and torrefaction: Practical design and theory. Academic Press. <https://doi.org/10.1016/B978-0-12-812992-0.00007-8>
- Brahmachari, G. (2021). Green synthetic approaches for biologically relevant heterocycles: Green catalytic systems and solvents-An overview. *Green Synthetic Approaches for Biologically Relevant Heterocycles*, 1-9. <https://doi.org/10.1016/B978-0-12-820792-5.00001-9>
- Chrzanoska, J., Hoffman, J., Małolepszy, A., Mazurkiewicz, M., Kowalewski, T. A., Szymanski, Z., and Stobinski, L. (2015). Synthesis of carbon nanotubes by the laser ablation method: Effect of laser wavelength. *Physica Status Solidi (b)*, 252(8):1,860-1,867. <https://doi.org/10.1002/pssb.201451614>
- Dresselhaus, G., Dresselhaus, M.S., and Saito, R. (1998). Physical properties of carbon nanotubes. World Scientific. <https://doi.org/10.1142/3564>
- Dresselhaus, M.S., Dresselhaus, G., and Eklund, P.C. (1996). Science of fullerenes and carbon nanotubes: Their properties and applications. Elsevier. <https://doi.org/10.1016/B978-012221820-0/50013-7>
- Fathy, N.A. (2017). Carbon nanotube synthesis using carbonization of pretreated rice straw through chemical vapor deposition of camphor. *RSC Advances*, 7(45):28,535-28,541. <https://doi.org/10.1039/C7RA04882C>
- Gao, B., Bower, C., Lorentzen, J.D., Fleming, L., Kleinhammes, A., Tang, X.P. and Zhou, O. (2000). Enhanced saturation lithium composition in ball-milled single-walled carbon nanotubes. *Chemical Physics Letters*, 327(1-2):69-75. [https://doi.org/10.1016/S0009-2614\(00\)00851-4](https://doi.org/10.1016/S0009-2614(00)00851-4)
- Gao, Z., Song, N., Zhang, Y., Schwab, Y., He, J., and Li, X. (2018). Carbon nanotubes derived from yeast-fermented wheat flour and their energy storage application. *ACS Sustainable Chemistry & Engineering*, 6(9):11,386-11,396. <https://doi.org/10.1021/acssuschemeng.8b01292>
- Ghasemzadeh, G., Momenpour, M., Omid, F., Hosseini, M.R., Ahani, M., and Barzegari, A. (2014). Applications of nanomaterials in water treatment and environmental remediation. *Frontiers of Environmental Science & Engineering*, 8:471-482. <https://doi.org/10.1007/s11783-014-0654-0>
- Gulati, S., Kumar, S., Goyal, K., Arora, A., and Varma, R.S. (2022). Improving the air quality with functionalized carbon nanotubes: Sensing and remediation applications in the real world. *Chemosphere*, 299:134468. <https://doi.org/10.1016/j.chemosphere.2022.134468>
- Guo, X., Cheng, S., Cai, W., Zhang, Y., and Zhang, X.A. (2021). A review of carbon-based thermal interface materials: Mechanism, thermal measurements, and thermal properties. *Materials & Design*, 209:109936. <https://doi.org/10.1016/j.matdes.2021.109936>
- Hakim, Y.Z., Yulizar, Y., Nurcahyo, A., and Surya, M. (2018). Green synthesis of carbon nanotubes from coconut shell waste for the adsorption of Pb (II) ions. *Acta Chimica Asiana*, 1(1):6-10. <https://doi.org/10.1016/j.aca.2018.01.002>
- Hamid, Z.A., Azim, A.A., Mouez, F.A., and Rehim, S.A. (2017). Challenges on the synthesis of carbon nanotubes from environmentally friendly green oil using pyrolysis technique. *Journal of Analytical and Applied Pyrolysis*, 126:218-229. <https://doi.org/10.1016/j.jaap.2017.01.006>
- He, Y., Hu, C., Li, Z., Wu, C., Zeng, Y., and Peng, C. (2022). Multifunctional carbon nanomaterials for diagnostic applications in infectious diseases and tumors. *Materials Today Bio*, 14:100231. <https://doi.org/10.1016/j.mtbio.2022.100231>
- Hidalgo, P., Navia, R., Hunter, R., Coronado, G., and Gonzalez, M. (2019). Synthesis of carbon nanotubes using biochar as precursor material under microwave irradiation.

- Journal of Environmental Management, 244:83-91. <https://doi.org/10.1016/j.jenvman.2019.04.046>
- Hongo, T., Sugiyama, J., Yamazaki, A., and Yamasaki, A. (2013). Synthesis of imogolite from rice husk ash and evaluation of its acetaldehyde adsorption ability. *Industrial & Engineering Chemistry Research*, 52(5):2,111-2,115. <https://doi.org/10.1021/ie302379f>
- Ibrahim, M.Y. and Sulaiman, H. (2024). Coconut shell-derived green synthesized carbon nanotubes for clean-up of crude oil spills. *Pure and Applied Chemistry*. <https://doi.org/10.1515/pac-2024-0207>
- Iqbal, M.Z., Khan, J., Awan, H.T.A., Alzaid, M., Afzal, A.M., and Aftab, S. (2020). Cobalt-manganese-zinc ternary phosphate for high-performance supercapattery devices. *Dalton Transactions*, 49(46):16,715-16,727. <https://doi.org/10.1039/D0DT03313H>
- Jagadeesan, A.K., Thangavelu, K., and Dhananjeyan, V. (2020). Carbon nanotubes: Synthesis, properties, and applications, 27.
- Ji, Q., Yu, X., Chen, L., Yardley, O.P.N., and Zhou, C. (2021). Facile preparation of sugarcane bagasse-derived carbon supported MoS₂ nanosheets for hydrogen evolution reaction. *Industrial Crops and Products*, 172:114064. <https://doi.org/10.1016/j.indcrop.2021.114064>
- Journet, C., Maser, W.K., Bernier, P., Loiseau, A., de La Chapelle, M.L., Lefrant, D.S., and Fischer, J.E. (1997). Large-scale production of single-walled carbon nanotubes by the electric-arc technique. *Nature*, 388(6644):756-758. <https://doi.org/10.1038/41972>
- Kahdum, B.J., Lafta, A.J., and Johdh, A.M. (2016). Synthesis and characterization of carbon nanotubes from Iraqi date palm seeds using chemical vapor deposition method. *International Journal of ChemTech Research*, 9(12):2,455-9,555. <https://doi.org/10.1016/j.jenvman.2019.04.046>
- Kelchner, S.A. and Group, B.P. (2013). Higher level phylogenetic relationships within the bamboos (Poaceae: Bambusoideae) based on five plastid markers. *Molecular Phylogenetics and Evolution*, 67(2):404-413. <https://doi.org/10.1016/j.ympev.2013.02.012>
- Kumar, R., Yadav, R.M., Awasthi, K., Tiwari, R.S., and Srivastava, O.N. (2011). Effect of nitrogen variation on the synthesis of vertically aligned bamboo-shaped c-n nanotubes using sunflower oil. *International Journal of Nanoscience*, 10(04n05):809-813. <https://doi.org/10.1142/S0219581X11008502>
- Li, J., Cao, Y., Wang, L., and Jia, D. (2017). Cost-effective synthesis of bamboo-structure carbon nanotubes from coal for reversible lithium storage. *RSC Advances*, 7(55):34,770-34,775. <https://doi.org/10.1039/C7RA04047D>
- Li, Y.H., Zhao, Y.M., Hu, W.B., Ahmad, I., Zhu, Y.Q., Peng, X.J., and Luan, Z.K. (2007). Carbon nanotubes-the promising adsorbent in wastewater treatment. In *Journal of Physics: Conference Series*, 61(1):698. <https://doi.org/10.1088/1742-6596/61/1/140>
- Liang, K., Chen, Y., Wang, S., Wang, D., Wang, W., Jia, S., and Chen, Z. (2023). Peanut shell waste derived porous carbon for high-performance supercapacitors. *Journal of Energy Storage*, 70:107947. <https://doi.org/10.1016/j.est.2023.107947>
- Liu, X., Wang, M., Zhang, S., and Pan, B. (2013). Application potential of carbon nanotubes in water treatment: A review. *Journal of Environmental Sciences*, 25(7):1,263-1,280. [https://doi.org/10.1016/S1001-0742\(12\)60161-2](https://doi.org/10.1016/S1001-0742(12)60161-2)
- Ma, R., Wei, B., Xu, C., Liang, J., and Wu, D. (2000). Development of supercapacitors based on carbon nanotubes. *Science in China Series E: Technological Sciences*, 43:178-182. <https://doi.org/10.1007/BF02872744>
- Melati, A. and Hidayati, E. (2016). Synthesis and characterization of carbon nanotube from coconut shells activated carbon. In *Journal of Physics: Conference Series*, 694(1):012073. <https://doi.org/10.1088/1742-6596/694/1/012073>
- Mirabootelebi, S.O. and Akbari, G.H. (2017). Methods for synthesis of carbon nanotubes-review. *International Journal of Bio-Inorganic Hybrid Nanomaterials*, 6(2):49-57.
- Moeller, M. and Matyjaszewski, K. (2012). *Polymer science: A comprehensive reference*. Newnes. <https://doi.org/10.1016/B978-0-08-088504-9.00001-1>
- Mopoung, S. (2011). Occurrence of carbon nanotube from banana peel activated carbon mixed with mineral oil. *International Journal of Physical Sciences*, 6:1,789-1,793.
- Mostafavi, E., Iravani, S., Varma, R.S., Khatami, M., and Rahbarizadeh, F. (2022). Eco-friendly synthesis of carbon nanotubes and their cancer theranostic applications. *Materials Advances*, 3(12):4,765-4,782. <https://doi.org/10.1039/D2MA00341D>
- Noor, M.D. and Talal, Q. (2013). Carbon nanotube from a natural source: Banana peel (Doctoral dissertation, Department of Mechanical and Production Engineering, Islamic University of Technology, Gazipur, Bangladesh). Retrieved from <http://www.iut-dspace.edu.bd/handle/123456789/1142>
- Novoselova, I.A., Oliinyk, N.F., Volkov, S.V., Konchits, A.A., Yanchuk, I.B., Yefanov, V.S. and Karpets, M.V. (2008). Electrolytic synthesis of carbon nanotubes from carbon dioxide in molten salts and their characterization. *Physica E: Low-Dimensional Systems and Nanostructures*, 40(7):2,231-2,237. <https://doi.org/10.1016/j.physe.2008.02.016>
- Nuilek, K., Simon, A., Kurovics, E., Ibrahim, J.F.M., Varanasi, D., and Baumli, P. (2020). Effect of activation and exfoliation on the formation of carbon nanosheets derived from natural materials. *Journal of Physics: Conference Series*, 1,527(1):012036. <https://doi.org/10.1088/1742-6596/1527/1/012036>
- Omoriyekomwan, J.E., Tahmasebi, A., Zhang, J., and Yu, J. (2019). Mechanistic study on direct synthesis of carbon nanotubes from cellulose using microwave pyrolysis. *Energy Conversion and Management*, 192:88-99. <https://doi.org/10.1016/j.enconman.2019.04.039>
- Ouyang, J. (2019). Applications of carbon nanotubes and graphene for third-generation solar cells and fuel cells. *Nano Materials Science*, 1(2):77-90. <https://doi.org/10.1016/j.nanoms.2019.05.003>
- Park, Y.S., Kim, K.S., Jeong, H.J., Kim, W.S., Moon, J.M., An, K.H., and Lee, Y.H. (2002). Low-pressure synthesis of single-walled carbon nanotubes by arc discharge. *Synthetic Metals*, 126(2-3):245-251. [https://doi.org/10.1016/S0379-6779\(01\)00563-X](https://doi.org/10.1016/S0379-6779(01)00563-X)
- Patil, A.B. and Bhanage, B.M. (2016). Sonochemistry: A greener protocol for nanoparticle synthesis. In *Handbook of nanoparticles*, 143-166. https://doi.org/10.1007/978-3-319-15338-4_4
- Qadri, S.B., Gorzkowski, E.P., Bussmann, K., Rath, B.B., and Feng, J. (2018). Structural and magnetic properties of Fe and carbon nanotubes derived from coconut shells. *AIP Advances*, 8(5). <https://doi.org/10.1063/1.5047359>
- Qasim, M., Clarkson, A.N., and Hinkley, S.F. (2023). Green synthesis of carbon nanoparticles (CNPs) from biomass for biomedical applications. *International Journal of Molecular Sciences*, 24(2):1,023. <https://doi.org/10.3390/ijms24021023>
- Raghavendra, N., Hublikar, L.V., Patil, S.M., and Bhat, P. (2021). Microwave-assisted biosynthesis of silver nanoparticles using banana leaves extracts: Phytochemical, spectral characterization, and anticancer activity studies. *Journal of Water and Environmental*

- Nanotechnology, 6(1):49-61. <https://doi.org/10.22090/jwent.2021.01.003>
- Rdest, M. and Janas, D. (2021). Carbon nanotube wearable sensors for health diagnostics. *Sensors*, 21(17):5847. <https://doi.org/10.3390/s21175847>
- Romanovicz, V., Berns, B.A., Carpenter, S.D., and Carpenter, D. (2014). Carbon nanotubes synthesized using sugar cane as a precursor. *International Journal of Energy and Power Engineering*, 7(12):1027-1030.
- Roquia, A., Alhashmi, K.H., and Alhasmi, H.A. (2021). Synthesis and characterization of carbon nanotubes from the waste of *Juglans regia* (walnut) shells. *Fullerenes, Nanotubes and Carbon Nanostructures*, 29(11):860-867. <https://doi.org/10.1080/1536383X.2021.1900123>
- Salah, L.S., Ouslimani, N., Bousba, D., Huynen, I., Danlée, Y., and Aksas, H. (2021). Carbon nanotubes (CNTs) from synthesis to functionalized (CNTs) using conventional and new chemical approaches. *Journal of Nanomaterials*, 1-31. <https://doi.org/10.1155/2021/4972770>
- Shahid, M., Sagadevan, S., Ahmed, W., Zhan, Y., and Opaprakasit, P. (2022). Metal oxides for optoelectronic and photonic applications: A general introduction. In *Metal Oxides for Optoelectronics and Optics-Based Medical Applications*, pp. 3-31. Elsevier. <https://doi.org/10.1016/B978-0-323-85824-3.00006-3>
- Shariatnia, Z. (2021). Applications of carbon nanotubes. In *Handbook of Carbon-Based Nanomaterials*, pp. 321-364. Elsevier. <https://doi.org/10.1016/B978-0-12-821996-6.00016-6>
- Sharma, R., Sharma, A.K., and Sharma, V. (2015). Synthesis of carbon nanotubes by arc-discharge and chemical vapor deposition method with analysis of its morphology, dispersion, and functionalization characteristics. *Cogent Engineering*, 2(1):1094017. <https://doi.org/10.1080/23311916.2015.1094017>
- Sheikhpour, M., Naghinejad, M., Kasaeian, A., Lohrasbi, A., Shahraeini, S.S., and Zomorodbakhsh, S. (2020). The applications of carbon nanotubes in the diagnosis and treatment of lung cancer: A critical review. *International Journal of Nanomedicine*, 15:7,063-7,078. <https://doi.org/10.2147/IJN.S263238>
- Smalley, R.E. (2003). Carbon nanotubes: Synthesis, structure, properties, and applications.
- Surendran, S., Pathan, M., Walke, P., Syam, K.R., Babu, P.G., Poojary, N., and Sharma, R. (2024). Green synthesis and characterization of multiwall carbon nanotubes from sugarcane bagasse as a biogenic catalyst via chemical vapor deposition method using LPG as hydrocarbon source. *Materials Letters*, 359:135904. <https://doi.org/10.1016/j.matlet.2024.135904>
- Thambiraj, S. and Shankaran, R. (2016). Green synthesis of highly fluorescent carbon quantum dots from sugarcane bagasse pulp. *Applied Surface Science*, 390:435-443. <https://doi.org/10.1016/j.apsusc.2016.08.061>
- Tripathi, N., Pavelyev, V., and Islam, S.S. (2017). Synthesis of carbon nanotubes using green plant extract as catalyst: Unconventional concept and its realization. *Applied Nanoscience*, 7:557-566. <https://doi.org/10.1007/s13204-017-0598-3>
- Tripathy, A., Mohanty, S., Nayak, S.K., and Ramadoss, A. (2021). Renewable banana-peel-derived activated carbon as an inexpensive and efficient electrode material showing fascinating supercapacitive performance. *Journal of Environmental Chemical Engineering*, 9(6):106398.
- UnderstandingNano. (n.d.). Electrical properties of nanotubes. Retrieved January 15, 2025, from <https://www.understandingnano.com/electrical-properties-carbon-nanotubes.html>
- Ursino, C., Castro-Muñoz, R., Drioli, E., Gzara, L., Albeiruty, M. H., and Figoli, A. (2018). Progress of nanocomposite membranes for water treatment. *Membranes*, 8(2):18. <https://doi.org/10.3390/membranes8020018>
- Walters, D.A., Casavant, M.J., Qin, X.C., Huffman, C.B., Boul, P.J., Ericson, L.M., and Smalley, R.E. (2001). In-plane-aligned membranes of carbon nanotubes. *Chemical Physics Letters*, 338(1):14-20. [https://doi.org/10.1016/S0009-2614\(01\)00072-0](https://doi.org/10.1016/S0009-2614(01)00072-0)
- Wang, X.D., Vinodgopal, K., and Dai, G.P. (2019). Synthesis of carbon nanotubes by catalytic chemical vapor deposition. In *Perspective of carbon nanotubes*, 1-19. <https://doi.org/10.5772/intechopen.86995>
- Wu, L., Liu, J., Reddy, B.R., and Zhou, J. (2022). Preparation of coal-based carbon nanotubes using catalytic pyrolysis: A brief review. *Fuel Processing Technology*, 229:107171. <https://doi.org/10.1016/j.fuproc.2022.107171>
- Yallappa, S., Deepthi, D.R., Yashaswini, S., Hamsanandini, R., Chandraprasad, M., Kumar, S.A., and Hegde, G. (2017). Natural biowaste of groundnut shell derived nano carbons: Synthesis, characterization and its in vitro antibacterial activity. *Nano-Structures & Nano-Objects*, 12:84-90. <https://doi.org/10.1016/j.nanoso.2017.09.003>
- Yamamoto, G. and Hashida, T. (2012). Carbon nanotube reinforced alumina composite materials. In *Composites and Their Properties*. IntechOpen.
- Yu, M.F., Lourie, O., Dyer, M.J., Moloni, K., Kelly, T.F., and Ruoff, R.S. (2000). Strength and breaking mechanism of multiwalled carbon nanotubes under tensile load. *Science*, 287(5453):637-640. <https://doi.org/10.1126/science.287.5453.637>
- Zare, H., Ahmadi, S., Ghasemi, A., Ghanbari, M., Rabiee, N., Bagherzadeh, M., and Mostafavi, E. (2021). Carbon nanotubes: Smart drug/gene delivery carriers. *International Journal of Nanomedicine*, 16:1,681-1,706. <https://doi.org/10.2147/IJN.S299448>
- Zhang, H.Y., Niu, H.J., Wang, Y.M., Wang, C., Bai, X.D., Wang, S., and Wang, W. (2015). A simple method to prepare carbon nanotubes from sunflower seed hulls and sago and their application in supercapacitors. *Pigment & Resin Technology*, 44(1):7-12. <https://doi.org/10.1108/PRT-10-2013-0090>
- Zhang, W., Zhang, Z., and Zhang, Y. (2011). The application of carbon nanotubes in target drug delivery systems for cancer therapies. *Nanoscale Research Letters*, 6:1-22. <https://doi.org/10.1186/1556-276X-6-555>
- Zheng, D., Zhang, Y., Guo, Y., and Yue, J. (2019). Isolation and characterization of nanocellulose with a novel shape from walnut (*Juglans regia* L.) shell agricultural waste. *Polymers*, 11(7):1,130. <https://doi.org/10.3390/polym11071130>
- Zhu, J., Jia, J., Kwong, F.L., Ng, D.H.L., and Tjong, S.C. (2012). Synthesis of multi-walled carbon nanotubes from bamboo charcoal and the roles of minerals on their growth. *Biomass and Bioenergy*, 36:12-19. <https://doi.org/10.1016/j.biombioe.2011.10.011>