

“The significant problems we have cannot be solved at the same level of thinking with which we created them.”

- Albert Einstein

1.1. Preamble:

Energy plays a vital role in our modern economy and daily lives, providing the necessary heat and electricity for our needs. It powers industries, transportation, and communication, forming the backbone of our way of living and working. Consequently, uninterrupted access to energy resources is crucial for any nation, regardless of whether its focus is agriculture or industries (Ding 1999).

1.2. Strategic Impact of surging energy demand:

The global demand for energy is rapidly increasing, doubling every fourteen years. The continuous consumption of fossil fuels will inevitably deplete these resources, posing a significant challenge as human life heavily relies on them. This combination of growing demand and diminishing supply gives rise to an energy crisis. By 2030, it is projected that worldwide energy demand will at least double the current levels, potentially leading to dependence on imported energy at inflated prices. Therefore, there is an urgent need for pollution-free and sustainable green energy systems as an alternative to petroleum-based fuels. (Ahmadi 2022 & Viswanath *et al.*, 2023)

In our current society, we are on the point of an energy paradigm shift, necessitating the development of technologies that align with the resources provided by nature and promote sustainability. Various energy storage technologies have emerged, including supercapacitors, batteries, fuel cells, and conventional capacitors. These technologies offer potential solutions to our energy needs (Breyer *et al.*, 2022 & Hosseini 2022).

1.3. The need for energy storage

There is a rise in the rate of depletion of the existing fuel energy sources and an increase in the demand for such sources. In addition, due to the characteristics of fossil

fuel consumption, the consumption of fossil fuels will also have adverse effects on the environment. To overcome the challenges, scientists have shifted their focus towards new, clean energy technologies as potential candidates for replacing fossil fuels. Various energy storage devices like batteries, conventional capacitors and fuel cells are being developed which are necessary for effective energy storage for sustained processes. Among these technologies, supercapacitors have garnered significant attention in recent times due to their exceptional energy and power density properties **(Karaca and Dincer 2021, Makridis 2017, Poizot & Dolhem 2011, Balat 2005)**.

The consequences of depleting reserves of fossil fuels and their combustion have propelled the global community towards the pursuit of clean and sustainable energy sources. Utilizing natural energy forms like wind, tides, and solar power has the potential to generate significant amounts of clean and sustainable energy. However, to effectively harness these renewable energy sources, the development of advanced energy storage devices becomes paramount. Energy storage devices serve as crucial components for establishing a successful and sustainable energy system **(Kang *et al.*, 2022, Kalair *et al.*, 2021, Jain and Mahajan 2023, Hanak and Manović 2020)**.

1.4. Energy Storage Technologies Overview

Batteries, split into primary and secondary types, store and release energy chemically. Primary ones like carbon-zinc and alkaline are disposable, while secondary batteries like nickel-cadmium and lithium-ion are rechargeable but have limitations in lifespan and efficiency. Lead-acid batteries, a secondary type, work by chemical reactions **(Salkind *et al.*, 2000)**. Fuel cells convert fuel and oxidants into electricity. They vary in size and temperature requirements, with proton-exchange membrane cells operating at lower temperatures. However, they can become inefficient under high-power demands, often necessitating hybrids with batteries or supercapacitors. Noble metals in fuel cells add to their cost **(Peter N. Pintauro & Ryszard Wycisk 2008)**. Capacitors store energy through charge separation on electrodes and can handle high currents for short periods due to their low capacitance **(Whittingham *et al.*, 2004)**.

1.5. Supercapacitors

Supercapacitors employ the process of electrostatic charging within the electrochemical double layer to store electrical charges. Similar to fuel cells, they do not require the consumption of fuel for operation. One notable characteristic of supercapacitors is their ability to rapidly deliver a substantial number of charges within a short time frame, often measured in seconds, resulting in a high-power density (**Izadi-Najafabadi *et al.*, 2010**). While supercapacitors bear a resemblance to regular capacitors, they possess an exceptional capacitance value within a compact form factor. The lifespan of supercapacitors is virtually limitless, and their energy efficiency typically remains above 90% when operated within their design specifications. In comparison to batteries, supercapacitors exhibit higher power density, enabling them to deliver energy more rapidly, but they generally have lower energy density, representing the amount of energy stored per unit of volume or mass.

1.6. Energy storage mechanism

1.6.1. EDLC

An electrical double layer capacitor (EDLC) consists of two electrodes submerged in an electrolyte solution, with a separator positioned between the electrodes as illustrated in Figure 1.1. The accumulation of electric charge occurs electrostatically on both sides of the electrode/electrolyte interface, resulting in the formation of an electrical double layer. Unlike conventional capacitors, the thickness of the double layer is typically measured in angstroms, significantly smaller than the separation distance between the plates in conventional capacitors, which typically falls in the micrometer range. By utilizing high surface area materials as electrodes, the capacitance of EDLCs can be enhanced by several orders of magnitude when compared to traditional capacitors. Importantly, since there is no charge transfer across the interface during the charge storage process (non-faradaic), no chemical or compositional changes occur within the system. This characteristic enables EDLCs to exhibit a remarkably high degree of reversibility in repetitive charge/discharge processes and ensures an extended cycle life (**Nigam and Kar 2022 , Janes *et al.*, 2011 , Bedrov and Vatamanu 2013, Andres *et al.*, 2016**).

1.6.2. Pseudo-capacitors

Pseudo-capacitors rely on rapid and reversible reactions occurring on the surface of the electrode as the primary mechanism for energy storage. These reactions encompass several crucial processes, namely: (i) the surface adsorption of ions from the electrolyte, (ii) redox reactions involving ions from the electrolyte, and (iii) the doping and un-doping of active conducting polymers within the electrode. The surface area of the electrode plays a critical role in facilitating the first two processes, whereas the third process, which involves conducting polymers, is less reliant on surface area as it is a bulk process. Nonetheless, a higher surface area with micro-pores facilitates improved ion accessibility to the electrode material. In a supercapacitor system, both the energy storage mechanisms of EDLC and pseudo-capacitors coexist simultaneously, albeit with one mechanism often dominating over the other. Notably, the capacitance of pseudo-capacitors can be 10-100 times higher than that of a carbon double-layer capacitor (Le Comte *et al.*, 2013, Kushwaha *et al.*, 2021, Xing *et al.*, 2012).

1.6.3. Hybrid capacitors

Hybrid capacitors represent a synthesis of both Faradaic and non-Faradaic processes to achieve charge storage. By incorporating the strengths and mitigating the weaknesses of EDLCs and pseudo-capacitors, hybrid capacitors offer enhanced characteristics. They enable the attainment of higher energy and power densities compared to EDLCs while maintaining superior cyclic stability and affordability compared to pseudo-capacitors.

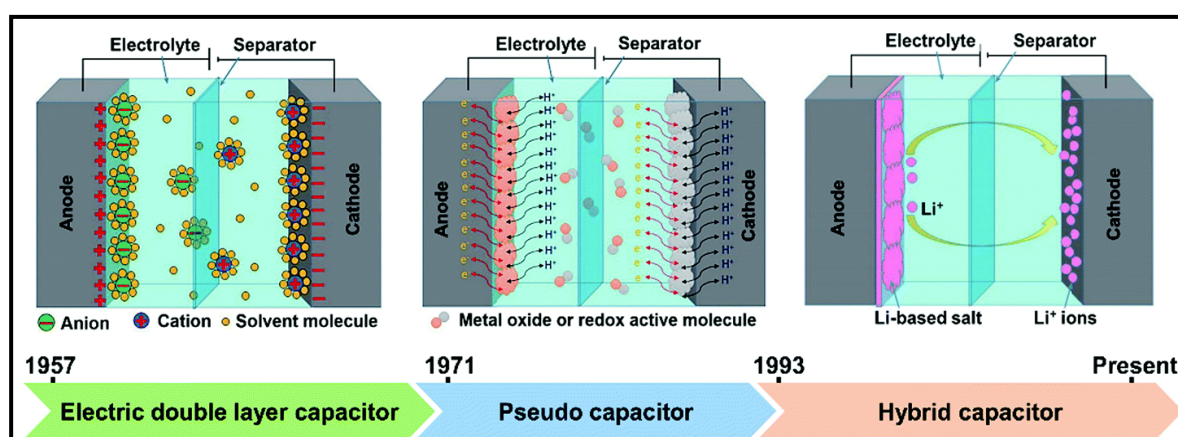


Figure 1.1: Different storage mechanism of supercapacitors (Lee *et al.*, 2022)

The fundamental principle behind hybrid systems lies in the combined utilization of a double-layer electrode, which operates based on electrostatic charge storage, and a pseudo-capacitance electrode, which undergoes reversible redox reactions. This two-mode charging approach contributes to the superior performance of hybrid capacitors. Additionally, hybrid capacitors offer advantages such as higher maximum operating voltage and lower equivalent series resistance, further enhancing their overall performance as supercapacitors (**Panja *et al.*, 2019**).

1.7. Economy of Supercapacitors

India has enormous potential for harnessing its renewable energy. India's geographical and climatic conditions promote several renewable energy technologies such as solar, wind, small hydro, and biomass. India has taken several initiatives to utilize its renewable energy potential in recent years. The prime objective of the study is to understand the present market and forecast India supercapacitors market. In order to forecast India supercapacitor market, a pronged approach of pyrolysis has been used. Multiple industry experts from various manufacturing companies, distributors and user companies were interviewed for validating our baselines assumptions and for getting localized insight of the Indian market dynamics for supercapacitors(**Devender 2023 & Daisy *et al.*, 2017**)

1.8. Applications of supercapacitors

The applications of supercapacitors can be broadly classified into three categories: energy backup, main power sources, and alternating power sources. In the context of energy backup applications, supercapacitors are typically connected in parallel with a primary power source, such as a battery. Even in scenarios involving power outages caused by factors like main power source turn-off, voltage drop, contact issues, or shocks, supercapacitors can continue to provide energy to the system. This functionality positions supercapacitors as crucial components in the commercial market, serving as backup power sources for various devices, including memories, microcomputers, system boards, and clocks (**Oukkacha *et al.*, 2021 & Shahani and Singh 2023**).

Due to significant advancements in energy and power densities resulting from recent research efforts, supercapacitors have emerged as viable main power sources in a wide range of applications, including small portable electronics, transportation systems, and

industrial equipment. In the context of electric vehicles, supercapacitors exhibit remarkable potential as an ideal power source due to their ability to deliver high energy efficiency, high power density, and the capability to recover energy during braking events. While batteries and fuel cells traditionally serve as energy storage devices for electric vehicles, they often struggle to provide rapid power delivery for acceleration and uphill climbs. To overcome this drawback, ultra capacitors are utilized with batteries or fuel cells so that the fuel energy is conserved owing to high voltage rapid charge and discharge characteristics, utilization of regenerative braking mechanisms can reign in fuel use by up to 15% (**Cheng *et al.*, 2022 & Kaustubh Vinayak Kulkarni *et al.*, 2023**).

1.9. Components of supercapacitors

The configuration of a typical supercapacitor encompasses a pair of polarizable electrodes accompanied by current collectors, a separator, and an electrolyte. Electrochemical capacitors can be differentiated based on various criteria, including the electrode material employed, the type of electrolyte utilized, and the design of the cell. Presently, there exists a vast assortment of materials and processes for constructing supercapacitor cells, leading to a wide array of choices and possibilities. In the subsequent discussion, we shall delve into the intricate details and characteristics of the individual components that constitute supercapacitors, shedding light on their diverse functionalities and capabilities (**Chen 2017, Zhang *et al.*, 2012 & Wu *et al.*, 2017**).

1.9.1. Electrode material

The electrochemical behavior and parameters of a supercapacitor are intricately tied to the choice of electrode material which is used. The process of double layer charge storage is largely executed on the electrode surface, making the surface properties are very critical in estimating the total capacitance of the cell. Among the electrode materials, three key categories develop: carbon- based material, metal oxides, and conducting polymers. All the electrode materials are relatively different in terms of their structures and properties which contributes to the performance of the supercapacitor. The choice of any electrode material requires comprehensive evaluation and tailoring to achieve desired capacitance and performance criteria are met for an intended use (**Jiang *et al.*, 2017, Ramachandran *et al.*, 2019, Chen *et al.*, 2016, Forouzandeh *et al.*, 2020 & Ghosh *et al.*, 2023**).

1.9.2. Carbon based materials

Their cost-effectiveness makes them widely used in EDLCs compared to other carbon materials (**Du & Wang 2022**). Carbon aerogels, synthesized from organic aerogels or through poly-condensation and subsequent pyrolysis, offer high conductivity, substantial surface area, and pore size distribution. Varying activation techniques further augment their surface area for enhanced capacitance (**Yang *et al.*, 2019**). Carbon nanotubes (CNTs),

produced through catalytic decomposition, possess unique tubular structures, high strength, and excellent electrical conductivity. The structure of their pores facilitate electrolyte ion penetration and charge storage process which makes them potential for supercapacitor electrode materials (Cai *et al.*, 2024, Zhu *et al.*, 2020).

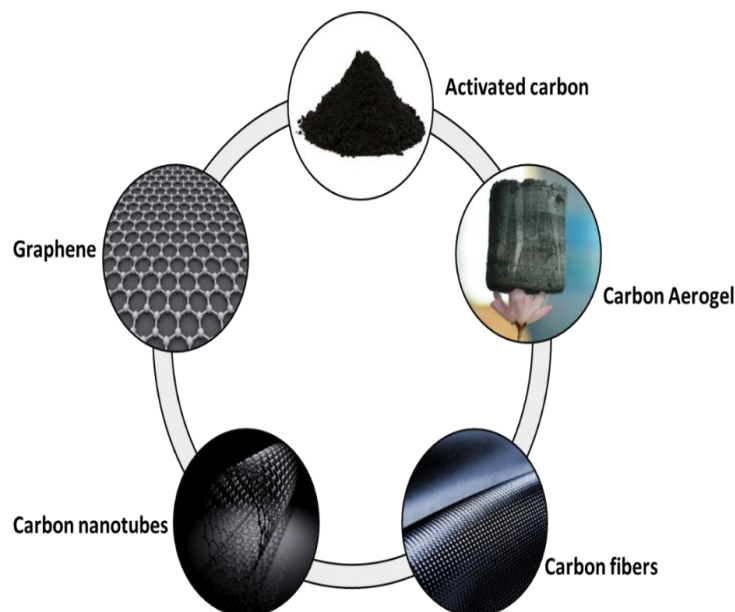


Figure 1.2: Various forms of carbon

1.9.3. Pseudocapacitive materials

Transition metal oxides, conducting polymers, and other pseudocapacitive materials show high versatility and efficiency as supercapacitor electrode materials owing to the rapid and reversible surface redox reactions (Wang *et al.*, 2012). They possess unique electrochemical characteristics which enable storage and transfer of electric charges during redox reactions that make these materials have more specific capacitance than the carbon materials (Forouzandeh *et al.*, 2020). The Csp of pseudocapacitive materials is primarily based on high charge storage capacity owing to effective consumption of both faradaic and non-faradaic charge storage mechanisms.

Transition metal oxides, such as manganese oxide or ruthenium oxide, exhibit a high capacity for redox reactions, while conducting polymers, such as polyaniline or polypyrrole, possess high charge transport properties. These characteristics, combined with their ability to accommodate ions from the electrolyte, contribute to the exceptional electrochemical performance and enhanced energy storage capabilities of pseudocapacitive materials in supercapacitors. Thus, the utilization of these materials as electrode components holds significant potential for advancing the field of supercapacitor technology (Kim *et al.*, 2013 & Chen *et al.*, 2011).

1.9.4. Metal oxides

Metal oxides such as RuO₂, NiO, Co₃O₄, and MnO₂ have received attention for supercapacitor applications because of their high capacitance and low resistivity. Fast

charge transfer kinetics, notable cyclic stability, and good electrochemical properties keep them as essential materials for enhancing supercapacitor performance. The extensive investigation relating to redox activity, morphology, crystal structure and surface area shows mechanisms responsible for the enhanced capacitance, which will lead to its optimal designs and synthesis aimed at superior performance in supercapacitors (De *et al.*, 2020). Ruthenium oxide (RuO₂) possesses a high capacitance of over 750 Fg⁻¹ in sulfuric acid due to efficient adsorption of protons and electrons. However, its use is limited due to high cost. Cobalt oxide has very good capacitive behavior in a range of supercapacitor negative potentials and provides an advantage in the case for asymmetric electrode configuration which improves the entire system performance. Nickel oxide films prepared via Sol-gel and precipitation processes have a specific capacitance value of about 256 Fg⁻¹, however, due to the limitations in capacitance and voltage range, require further optimization (Wei *et al.*, 2010).

Manganese oxides, which are cheaper and ecological friendly, can be prepared using low-cost techniques such as electrochemical deposition and sol-gel methods. The charge storage mechanism of this material involves a combination of cations and protons that makes them appeal for supercapacitor technologies (Liu *et al.*, 2023). Polymers show charge conductivity such as PPY, PANI, PEDOT, PTH, and PPV, which possess π -conjugated chains. These have better capacitance, lower resistance and outstanding conductivity than carbon-based electrode materials. While they are environment and cost friendly, they have cyclic stability complications because of over-oxidation reducing the capacity over time (Dhilip *et al.*, 2022).

1.9.5 Metal Chalcogenides

Transition metal chalcogenides (TMCs), including sulfides, selenides, and tellurides, have garnered considerable attention due to their high electrical conductivity and diverse oxidation states that enhance redox-based charge storage. Examples such as MoS₂, NiCo₂S₄, and CuS show excellent ion intercalation and surface charge storage performance, with layered morphologies supporting fast ion transport and diffusion kinetics (Mishra *et al.*, 2024). These materials are especially promising when used in composite configurations with carbon or polymeric substrates to mitigate cycling degradation (George *et al.*, 2025).

1.9.6 Metal Phosphides

Metal phosphides such as Ni₂P, FeP, and CoP offer metallic conductivity, chemical robustness, and high theoretical capacitance, making them highly efficient pseudocapacitive candidates. Their redox-rich nature enhances energy storage density, and recent studies have demonstrated enhanced performance in hybrid architectures (Mishra *et al.*, 2024; Dai *et al.*, 2022).

1.9.7 Emerging and Hybrid Materials

Emerging electrode materials like MXenes, metal-organic frameworks (MOFs), and covalent organic frameworks (COFs) are shaping the next generation of supercapacitors. MXenes (e.g., Ti_3C_2Tx) provide exceptional electrical conductivity, surface tunability, and interlayer spacing favorable for ion storage (Rostami *et al.*, 2024).

MOFs and COFs contribute with their porous crystalline architectures and tunable surface functionalities, enhancing electrochemical activity and charge transport. These frameworks also serve as templates for deriving metal oxides or carbon-based hybrids, thereby improving electrode surface area and reactivity (Lee *et al.*, 2022). Their combination with traditional materials enables high-performing, stable hybrid systems suitable for asymmetric or solid-state devices.

1.10. The impact of going green

Climate change is one of the utmost intimidations in the modern world. The effects of global warming are being felt globally, thus there is an ever-increasing demand for compact and environmentally friendly clean energy systems. The energy sector is the largest emitter of the greenhouse gas and it is crucial to seek out technology that can effectively reduce the carbon emissions from energy production. Governments, businesses and consumers try to find new ways to decrease their effect on nature. The advent of solar, wind and hydropower energy increases the consumption of alternative energy resources. However, these sources of energy have their challenges, such as intermittency, which makes energy storage a vital need. Ultra-capacitors are a potential and alternative rapidly developing technology that is able to store and discharge energies efficiently, thus essential for the change into a more viable future (Miller and Simon 2008).

1.11. Biomass-based electrode technology: a sustainable source of porous carbon

Conventional supercapacitors use carbon-based materials for their electrodes, such as activated carbon, graphene, or carbon nanotubes. However, the production of such materials often pays high costs and requires significant energy consumption. The biomass-based electrode technology is eco- friendly as it integrates alternative sources such as agricultural by-products, wood residues, or seaweed. Implementing biomass-based electrodes significantly reduces the carbon footprints generated by supercapacitors, thus fostering towards a more sustainable future.

1.12. Benefits of biomass-based electrode technology

- ✚ Biomass based electrode technology offers several advantages and appears to be quite promising and useful in the case of supercapacitors. Biomass is one of the most used and available resources because it is non-depleting and therefore can be replaced constantly in abundance.

- ✚ Biomass based electrodes are more efficient when used to fabricate supercapacitors as less energy is consumed in making the electrodes.
- ✚ Lightweight along with biomass-based supercapacitor electrodes is ideal for usage in energy storage in portable electronics and for automotive electric transportation.
- ✚ Biomass materials possess a larger specific surface area which enhance capacitance and their energy storage capabilities.

1.13. Biomass-Derived Activated Carbon

Biomass derived activated carbon (AC), which is a kind of carbonaceous material constructed by carbonization of renewable biomass in a controlled condition. Biomass is subjected to high temperature heating in a low oxygen environment, with the sole aim at removing volatile substances that will lead to the construction of an ultra-porous and amorphous carbon structure with high surface area (**Minea Kapidzic *et al.*, 2023**). The resultant activated carbon material has excellent adsorption capacity and reactivity because of the high surface area to volume ratio and unique pore structure. These valuable insights developed a wide range of applications of biomass based activated carbon from energy storage systems to environmental remediation, gas separation and water treatment due to its sufficient adsorption capabilities, high stability and low cost making it an eco-friendly alternative for conventional carbon materials (**Zhou *et al.*, 2023, Deng *et al.*, 2016**).

Although there have been previous studies that utilized different raw materials for the preparation of AC, scientists are still exploring new materials for capacitor manufacture depending on their availability and compatibility. In recent years, there has also been a considerable rise in the use of biomass residues for the preparation of activated carbons. These residues are inexpensive, readily available and rich sources for the production of AC. In addition, they are biodegradable and capable of contributing to the reduction of pollution (**Taer *et al.*, 2021**).

1.14. Biomass Carbon as Supercapacitor Electrode Material

Due to its relatively high surface area, porous carbon obtained from biomass as a source of carbon in supercapacitors is also very cost effective and non-detrimental to the environment. Biomass can be processed via pyrolysis into a high surface area carbon, which

would work as a very good supercapacitor electrode. This not only makes use of many types of biomass precursors but also helps to alleviate the adverse effects of energy storage systems on the environment.

Researchers are actively exploring alternative sources, particularly waste biomass, in order to fabricate activated carbon for supercapacitor electrodes and striving to achieve a balance between optimum performance and economic as well as environmental considerations. It also conforms to the '3Rs' ideology of reduction, reuse and recycle with the utilization of biomass derived porous carbon in development of supercapacitor further broadening the horizons of energy storage in the future (Xie *et al.*, 2023, Chernysheva *et al.*, 2018 & Liu *et al.*, 2018).

Biomass to energy storage conversion serves a number of goals such as those in the Agenda for Sustainable Development Goals (SDGs) and in particular, Goal 7- Affordable and Clean Energy and Goal 13- Climate Action. Biomass energy has a low-carbon emitting source and therefore supports the production of clean energy.

SDG 7: Affordable and Clean Energy: There is a need to ensure universal access to modern and affordable energy services by 2030. Production of energy from biomass provides the earlier development of affordable clean energies which deals with SDG 7. Biomass energies enable countries to reduce the usage of fossil fuels, increase better energy forms and enhance the energy pattern of the world to be greener and cleaner.

SDG 13: Climate Action: This goal aims to make initiatives in order to cope with any climate change present and its negative effects. Thus, the development of biomass-based energy storage systems can help in minimizing the amount of emissions. When biomass is used for energy production, it can be considered carbon-neutral, as the carbon dioxide released during combustion is roughly equivalent to the amount absorbed by the plants during their growth. This contrasts with the net addition of carbon dioxide when burning fossil fuels.

By integrating waste biomass into energy storage systems, we can potentially create a more sustainable and climate-friendly energy infrastructure, contributing to the global effort to address climate change and achieve the targets outlined in SDG 13.

Aligning with 7 and 13 SDG's we have focussed on "Extraction of Carbon from waste biomass sources".

1.15. Research Gap

Literature survey (1970-2020) reflects that there has been no investigation utilizing *Spathodea campanulata* and *Tecoma capensis* as precursors for the synthesis of carbon materials specially for supercapacitors applications.

This finding highlights an important research gap in the production of carbon materials suitable for supercapacitor electrodes. Given the abundance of these plant species, exploration of their potential as precursors for carbon materials could lead to the development of novel and sustainable approaches for energy storage, contributing to the advancement of supercapacitor technology and addressing the growing demand for efficient and eco-friendly energy storage solutions.

From the literature survey, the highest capacitance obtained from biomass-derived carbon supercapacitors has been reported to be around 400-500 F/g (farads per gram). However, its essential to note that it may vary depending on the specific biomass material used, the fabrication method, and the testing conditions (**Liu *et al.*,2018**).

The application of *Spathodea campanulata* and *Tecoma capensis* based carbon electrode for energy storage applications is lacking highlighting the existence of the research gap. A significant carbon content suggests that the biomass primarily consists of carbon rich compounds, which can serve as precursors for carbon synthesis and elemental analysis of plant materials indicated nearly 51 % carbon present (**Lugo *et al.*, 2011**) in the raw plant materials which suggests a significant reservoir of carbon within the biomass.

1.16. Plant Description

1.16.1. *Spathodea campanulata*

Spathodea campanulata P.Beauv, commonly known as the African tulip tree, is a majestic and rapidly growing arboreal invasive species indigenous to the lush tropical forests of Africa, where it can attain remarkable heights of up to 80 feet. Renowned for its resplendent floral display, this tree produces an abundance of striking reddish-orange

blossoms, reminiscent of tulips, which captivate the beholder's gaze. Due to its remarkable aesthetic appeal, *Spathodea campanulata* has gained widespread popularity as an ornamental species and has been extensively cultivated in tropical regions across the globe, including the vibrant nation of India (Kumar & Thampi, 2015).

Scientific Classification:

Kingdom: Plantae

Order: Lamiales

Family: Bignoniaceae

Genus: *Spathodea*

Species: *S.campanulata*

Common Name: Flame of forest

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Figure 1.3: *Spathodea campanulata* biomass precursor, Courtesy: Google

1.16.2. *Tecoma capensis*

Tecoma capensis (Thunb.) Spach speculated Cape-honeysuckle flowering plant belonging to the family Bignonaceae is a climbing plant, which extends from India, Australia to Africa tropic region. Famed for its beauty, this particular plant is cultivated widely as an ornamental plant in gardens, especially when in bloom. Nevertheless, *Tecoma capensis* has been classified as an invasive species by several nations including Anguilla, Australia, New Zealand and Tanzania. There is a need for provision of invasive species management and regulatory controls when it comes to *Tecoma capensis* because it poses a threat to the environment. Its uncontrolled spread could cause severe alterations in the balance within natural ecosystems, thus endangering the existence of native plants and animals. The expanding responsiveness of this invasiveness of *Tecoma capensis* helps to develop measures to manage its spread in areas where it is not yet implemented. By heeding the insights provided by scientific research, we can strike a harmonious balance between appreciating the ornamental beauty of *Tecoma capensis* and preserving the integrity of our nature conservation (Simon & Gogotsi 2020).

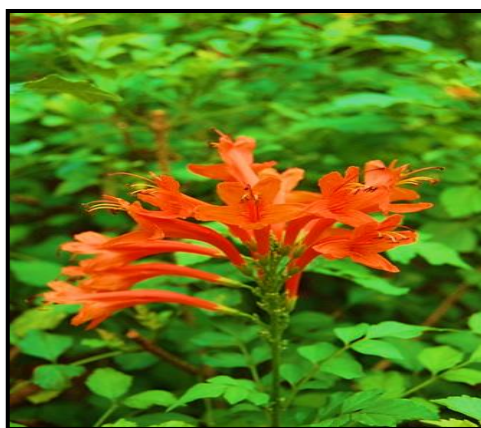
Scientific Classification:**Kingdom:** Plantae**Order:** Lamiales**Family:** Bignoniaceae**Genus:** *Tecoma***Species:** *T. capensis***Common Name:** Cape honeysuckle**BSI/SRC/5/23/2022/Tech/497**

Figure 1.4: *Tecoma capensis* biomass precursor *Courtesy: Google*

1.17. Objectives:

The research aims to develop a direct synthetic approach for producing carbon materials from environmentally friendly biomass precursors at low cost. The key objectives of the study are outlined as follows:

1. To synthesize Biocarbon Materials from leaves of *Spathodea campanulata* and *Tecoma capensis* using direct pyrolysis technique
2. To synthesize Nitrogen Doped Material from prepared Biocarbon material
3. To characterize the synthesized Biocarbon and doped biocarbon material by Structural characterization (FT-IR, XRD, and Raman spectroscopy), Morphological characterization (FESEM, HRTEM, and BET analysis)
4. To derive Carbon Electrodes from the prepared carbon and to assess the electrochemical performance of the bio-carbon electrodes in supercapacitor using Electrochemical characterization through cyclic voltammetry (CV), galvanostatic charge-discharge (GCD), and electrochemical impedance spectroscopy (EIS) for energy storage applications.

By pursuing these objectives, the research aims to advance the understanding and application of biomass-derived carbon materials for supercapacitor technology, offering a sustainable and cost-effective solution for energy storage needs