sustainability

MDPI

Review

Supercapacitor Energy Storage Device Using Biowastes: A Sustainable Approach to Green Energy

Kwadwo Mensah-Darkwa [1], Camila Zequine [2], Pawan K. Kahol [3] and Ram K. Gupta [2,*]

[1] Department of Materials Engineering, College of Engineering, Kwame Nkrumah University of Science and Technology, Kumasi AK-448-6434, Ghana; kmdarkwa.coe@knust.edu.gh
[2] Department of Chemistry, Pittsburg State University, Pittsburg, KS 66762, USA; cmuliternozequine@gus.pittstate.edu
[3] Department of Physics, Pittsburg State University, Pittsburg, KS 66762, USA; pkahol@pittstate.edu
* Correspondence: rgupta@pittstate.edu; Tel.: +1-620-2354763; Fax: +1-620-2354003

Received: 5 December 2018; Accepted: 10 January 2019; Published: 15 January 2019

Abstract: The demand for renewable energy sources worldwide has gained tremendous research attention over the past decades. Technologies such as wind and solar have been widely researched and reported in the literature. However, economical use of these technologies has not been widespread due partly to cost and the inability for service during of-source periods. To make these technologies more competitive, research into energy storage systems has intensified over the last few decades. The idea is to devise an energy storage system that allows for storage of electricity during lean hours at a relatively cheaper value and delivery later. Energy storage and delivery technologies such as supercapacitors can store and deliver energy at a very fast rate, offering high current in a short duration. The past decade has witnessed a rapid growth in research and development in supercapacitor technology. Several electrochemical properties of the electrode material and electrolyte have been reported in the literature. Supercapacitor electrode materials such as carbon and carbon-based materials have received increasing attention because of their high specific surface area, good electrical conductivity and excellent stability in harsh environments etc. In recent years, there has been an increasing interest in biomass-derived activated carbons as an electrode material for supercapacitor applications. The development of an alternative supercapacitor electrode material from biowaste serves two main purposes: (1) It helps with waste disposal; converting waste to a useful product, and (2) it provides an economic argument for the substantiality of supercapacitor technology. This article reviews recent developments in carbon and carbon-based materials derived from biowaste for supercapacitor technology. A comparison between the various storage mechanisms and electrochemical performance of electrodes derived from biowaste is presented.

Keywords: bio-waste; electrochemical double layer; supercapacitor; energy density; power density; electrochemical stability

1. Introduction

The demand for energy worldwide is expected to double in about two decades [1,2]. Energy plays an important role in the quality of our lives, impacting our social and economic development [3]. Modern economies are driven by the availability of reliable energy sources. Conventional energy sources such as fossil fuels (coal, gas, and oil) are being depleted at a fast rate, accompanied by the destruction of ecosystems and habitats, the extinction of wildlife, and pollution of the environment [4–8]. A primary concern of harvesting energy from fossil fuels is that it is unsustainable in the long term, so this has driven researchers and the industry to adopt sustainable and renewable energy technologies. Over the past several decades, there has been a dramatic increase in research on

renewable energy sources such as solar energy, geothermal energy, wind energy, biofuels, etc., while electrochemical energy storage devices such as supercapacitors, rechargeable batteries, etc. have also attracted significant research [9–11]. It is not an overstatement to say that successful development of any renewable energy source (e.g., windmills and solar cells), hybrid and electric vehicles and smart grids depend significantly upon the availability of a suitable energy storage system. A considerable amount of literature has been published on the use of supercapacitors as a viable storage device for renewable energy. Over 20,000 articles, books etc. were published in 2017, a higher number of research work is projected for 2018 (data from google scholar). There has been a geometric increase in the research published since the year 2000. Since supercapacitors were first experimented in 1957 by engineers at General Electric, they have found commercial applications in portable electronics, transportation and aerospace industry [12,13]. These applications of supercapacitors have come about due to advances in materials and manufacturing technologies. The various components such as the anodes, cathodes, separators, binder, and electrolyte have received in-depth research activity leading to improved performance and reduction in the cost of manufacture [14–16].

Energy storage and delivery technologies such as supercapacitors can store and deliver energy at a very fast rate, offering high current in a short duration. Supercapacitors are categorized as an electrochemical storage device, sometimes called an ultracapacitor. They can store and deliver energy at a very fast rate offering high current in a burst. Hence, they have found applications in electric vehicles, uninterruptible power supplies (UPS), and memory backups in IT systems. They also have virtually unlimited cycle life, accompanied by high specific power. They also work better than batteries in extreme temperatures, offering excellent low-temperature charge and discharge performance. The Ragone plot [17–19] shows a comparison between various energy storage devices in terms of power and energy density (Figure 1). Clearly, the plot gives a good overview of energy storage performance; however, the plot is silent on critical factors such as cycle life, cost, and safety. These factors have to be investigated on their own merits to develop a better understanding of a particular energy storage technology.

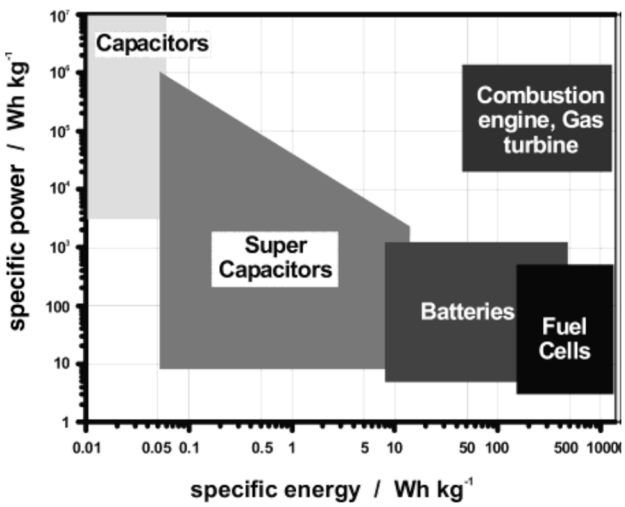

Figure 1. Ragone plot showing a comparison between various energy storage devices ("Reprinted (adapted) with permission from [20], Copyright (2004) American Chemical Society").

Because of the charge storage mechanism, supercapacitors are capable of an extremely long cycling life. It is reported to have a cycle life of over 500,000 [21–23], which is considerably higher than other storage technologies. This is because supercapacitors store reversible electrostatic charges on the surface of electrodes, while other technologies such as batteries really on chemical reactions.

Supercapacitors can be classified as three main types according to the energy storage mechanism. Figure 2 shows the main categorization of supercapacitors and a further classification based on

electrode materials [24,25]. The first type, which is the most common, is called the electrochemical double layer capacitor (EDLC). These commonly use KOH, H_2SO_4 etc. as a liquid electrolyte between the electrodes. The formation of Helmholtz double layers on the interface between the conductive electrodes/electrolyte causes fast adsorption and desorption of the electrolyte ions at the interface, providing high power density through the non-faradaic process. The size of the electrode surface and Helmholtz layer thickness has an effect on the performance of the electrochemical double layer capacitor. Hence, highly porous carbon materials such as activated carbon (AC), carbon nanotube, and graphene are widely used as electrode material in the industry. Activated carbon has a large specific surface area of 500–3000 m^2/g [26–30]. Figure 3 shows a schematic illustrating the basic architecture of an EDLC supercapacitor.

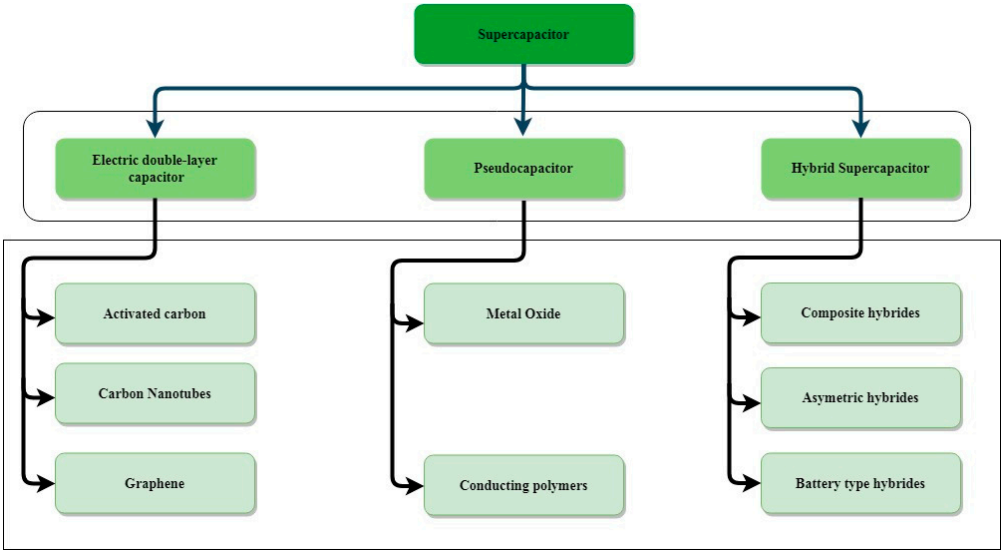

Figure 2. Classification of different supercapacitors.

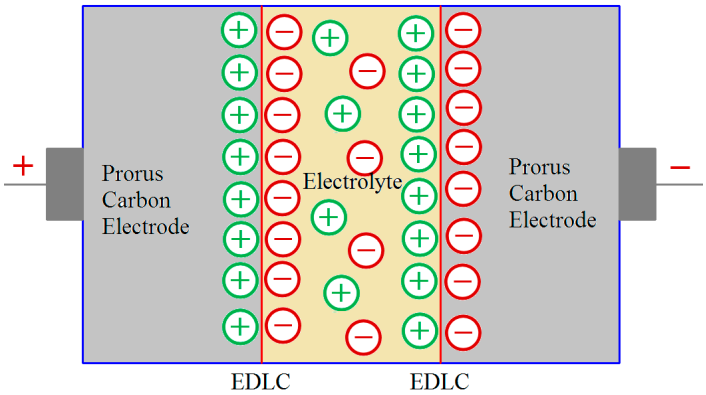

Figure 3. Schematic illustrating a basic EDLC supercapacitor.

The second type is called pseudocapacitors; these operate based on fast reversible Faradaic redox reaction that occurs at the electrode. Similar to EDLCs, reactions occur at the surface of the electrode producing a high energy density at a short cycle life and low rate capability [31]. They, however, operate at a lower voltage compared to EDLCs, thereby limiting their practical energy densities. Pseudocapacitors are typically made using metallic oxides/hydroxides/sulfides or conductive polymers or compounds with O and N functional groups. The third type is essentially a combination of an EDLC electrode and a pseudocapacitive electrode; thus, utilizing the high-power density of EDLC with the high energy of pseudocapacitors combined with good cyclic stability.

Li-ion hybrid capacitors (LIHCs) have emerged as a leader in this field [32], offering a bridge between supercapacitors and Li-ion batteries. This review focuses on providing a summary of the latest advances in electrode materials derived from biowaste for supercapacitors. Furthermore, we briefly discuss and compare the electrochemical performance (charge storage capacity, energy/power densities, cyclic stability) of supercapacitors.

2. Type of Charge-Storage Mechanism

The performance of supercapacitors can be evaluated using similar criteria employed for energy storage systems. Generally, three main techniques, namely, cyclic voltammetry (CV), galvanostatic charge/discharge (GCD) and electrochemical impedance spectroscopy (EIS) are used to evaluate parameters such as specific capacitance, energy density, power density, series resistance, cycling life, rate capability etc. [33–40]. These electrochemical properties are evaluated to characterize a supercapacitor (electrode material) based on specific parameters to be studied [41–43]. Collectively, these techniques complement each other, giving a broad understanding of the energy storage mechanism and the surface phenomena between the electrode and the electrolyte.

Together, these techniques provide important insights into the performance of the electrode; for example, the CV test provides information on the degradation process [44,45], specific capacitance [46,47] and can be used to distinguish between EDLC and pseudocapacitors [46]. Electrochemical properties are evaluated using applied voltage and current response. CV scans fall short of providing valuable thermodynamic properties; however, kinetic aspects are well covered [48]. Just like CV scans, a GCD scan is useful in predicting specific capacitance and differentiating between EDLC and pseudocapacitors. The stability of the supercapacitor can also be evaluated using GCD [49–51]. EIS is a non-destructive technique that is used to evaluate the capacitive performance of the electrode material, while differentiating between resistive and inductive behavior of the energy storage system [52,53].

The specific capacitance of a supercapacitor can be estimated using CV and GCD experiments. The specific capacitance, C_g (F/g) of the electrodes can be evaluated using:

$$C_g = \frac{I}{m\frac{dV}{dt}} \text{ (three electrode system)} \tag{1}$$

$$C_g = \frac{2I}{m\frac{dV}{dt}} \text{ (two electrode system)} \tag{2}$$

where m is the loading, I is the applied current, and $\frac{dV}{dt}$ is the slope of the charge/discharge curve. The energy density, E (Wh/kg) and power density, P (kW/kg) can be calculated using Equations (3) and (4), respectively [36,54,55].

$$E = \frac{1}{2 \times 3.6} CV^2 \tag{3}$$

$$P = \frac{3.6E}{\Delta t} \tag{4}$$

$$P_{max} = \frac{1}{4R_s} V^2 \tag{5}$$

where V (V) is operational voltage window of the cell, Δt (s) is the discharge time, P_{max} (kW/kg) is the maximum power density, and R_s (Ω) is the equivalent inner resistance of the supercapacitor device.

As discussed in previous sections, the electrochemical double layer capacitor exhibits higher energy density compared to the conventional parallel plate capacitors because of the exposed surface area and comparatively small charge separation distance. The mechanism of the charge storage as proposed by Helmholtz in the 19th century involves the alignment of charges at the electrode/electrolyte interface and separated by an atomic distance [23]. Further modification of the Helmholtz model has been reported by Gouy and Chapman [56]. The charge storage characteristics

depend heavily on the choice of electrode material and electrolyte used. Carbon and carbon-based materials that are derived from coconut shells, petroleum pitch and phenol resin together with porous carbon, carbon nanotubes and carbon nanofibers exhibit large specific area (due to the porous structure), good electronic conductivity and high chemical stability have found widespread application in electrochemical double layer capacitor. Also, electrolytes such as KOH, H_2SO_4, Na_2CO_3 etc. have been reported, due to their wettability of the electrode material. EDLCs do have some major drawbacks, as listed below:

- Limited lifespan due to the usage of an electrolyte.
- Incorrect usage of the capacitor may result in electrolyte leakage.
- These capacitors cannot be used in AC circuits because they have a relatively high internal resistance.
- The temperature ranges at which they can be used is limited because of the organic solvents that may be volatile, toxic and inflammable.
- Enhancing surface area of electrodes.
- Relatively low energy density.

Pseudocapacitor is a hybrid between a battery and an electric double layer capacitor. They also consist of an electrode and electrolyte and charge storage mechanisms is through chemical and electrostatic means. Most reported electrode material includes transition metal oxides (such as ruthenium oxide, nickel cobaltite, vanadium oxide aerogels) and conducting polymers. However, pseudocapacitors' performance is reported to be lower than EDLC mainly because of the inherently slow faradaic charge/storage mechanism; this leads to poor cycle life, energy density, and mechanical stability [57]. Conducting polymers used for pseudocapacitors can also be unstable at the nanoscale and ruthenium oxide is extremely costly. Hybrid capacitors occupy the middle ground between batteries and capacitors. These exhibit high energy/power densities compared to EDLCs and pseudocapacitors. They also have a high operational temperature range of −55 °C to 125 °C. Materials mostly used include carbon-coated conducting polymers, metal oxides (such as nickel and manganese-based oxides) and graphene oxides.

3. Carbon from Bio-Wastes as an Excellent Material for EDLC

During the past decade, researchers have shown an increased interest in the use of porous carbon materials as electrodes in high capacity supercapacitors [23]. Several carbon-based materials have been investigated for use as electrodes in supercapacitors because of their outstanding electrical conductivity and high specific surface area. The most investigated carbon-based materials widely reported include activated carbons [58–60], carbon aerogels [61–63], graphene [64–68], carbon nanotubes [69–74], carbon nanofibers [75–80], and nano-sized carbons [81–83]. These materials are popular because of the ease of accessibility, processability, non-toxicity, high chemical stability, and wide temperature range. Activated carbon has received considerable critical attention because of its high porosity and surface area [84]. Table 1 shows a summary of different bio-waste and corresponding Brunauer-Emmett-Teller (BET) surface values for activated carbons. These properties effectively promote charge accumulation at the interface of the electrode and electrolyte, aiding with the formation of electrostatic adsorption of positive and negative charges.

In recent years, there has been an increasing interest in the production of activated carbon from bio-waste for sustainable development [85–93]. Several sources of bio-waste such as animal, mineral, plant, and vegetables etc. have been reported in the literature as base materials for activated carbon production for application as an electrode material for electrochemical energy systems [86,94–109]. Several types of electrodes have been tried and the most common systems today are built on the electrochemical double-layer capacitor that is carbon-based, has an organic electrolyte, and is easy to manufacture.

Table 1. BET specific surface areas for different biowaste.

Bio-Waste	Activation Method	S_{BET} (m^2/g)	Ref.
Almond shell	Physical, steam, 850 °C/30 min	601	[110]
Almond tree pruning	Physical, steam, 850 °C/30 min	1080	[110]
Apricot stone	Chemical, $ZnCl_2$	814	[111]
Bagasse	Chemical, $ZnCl_2$	923	[112]
Bamboo	Chemical, KOH	1533	[113]
Bamboo	Chemical, KOH	1120	[114]
Cocoa pod husk	Chemical, KOH	490	[115]
Cocoa pod husk	Chemical, K_2CO_3	615	[115]
Cocoa pod husk	Chemical, $ZnCl_2$	780	[115]
Coconut shell	Physical, CO_2, 600 °C/2 h	1700	[116]
Coconut shell	Physical, steam, 1000 °C/120 min	1926	[117]
Cotton stalk	Chemical, H_3PO_4	1720	[118]
Coir pith	Chemical, $ZnCl_2$	910	[119]
Durian shell	Chemical, H_3PO_4	1024	[120]
Hazelnut bagasse	Chemical, KOH	1642	[121]
Hazelnut bagasse	Chemical, $ZnCl_2$	1489	[121]
Hazelnut shell	Chemical, $ZnCl_2$	647	[111]
Jute	Chemical, KOH	1769	[122]
Olive stone	Physical, steam, 850 °C/30 min	813	[110]
Palm kernel shell	Chemical, KOH	217	[123]
Peanut hull	Physical, steam, 600 °C/2 h	253	[124]
Pistacio-nut shell	Physical, CO_2, 900 °C/30 min	778	[125]
Rice husk	Chemical, $ZnCl_2$	927	[112]
Sugarcane bagasse	Physical, steam, 900 °C/2 h	320	[126]
Tea	Chemical, KOH	2532	[127]
Walnut shell	Physical, steam, 850 °C/30 min	792	[110]
Wood apple outer shell	Chemical, $ZnCl_2$	794	[128]

Juan Mi et al. [129] focused on the preparations of coconut-shell-based porous carbons with a tunable micro/mesopore ratio for high-performance supercapacitors applications. They used a one-step thermal treatment combined with pyrolysis and steam activation to produce porous carbon. The ratio of mesopore to total pore volume (V_{meso}/V_{total}) was reported to be greater than 75%. Using a three-electrode setup, the cyclic voltammetry (Figure 4a) shows a quasi-rectangular shape, which is perfect for the double layer energy storage mechanism. The specific capacitance values ranged from 209–228 F/g at 5 mV/s depending on the activation, water flow rate, and activation time. Galvanostatic charge/discharge cycling plots (Figure 4b) show negligible voltage drops, indicating that these carbons exhibit good electric conductivity.

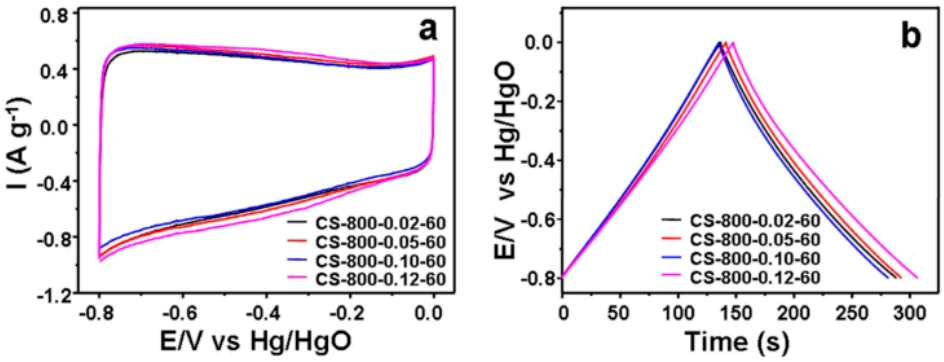

Figure 4. The CV (**a**) and GCD (**b**) curves of the carbon materials of CS-800-0.02-60, CS-800-0.05-60, CS-800-0.10-60, and CS-800-0.12-60 tested with a three-electrode setup in 6 mol/L KOH. at 5 mV/s and 0.5 A/g. (Reprinted (adapted) with permission from [129]. Copyright (2012) American Chemical Society.)

In a similar work [130], coconut shell activated charcoal was synthesized using chemical activation method using KOH as an activating agent. The specific surface area (mesopores size of 3 nm) was reported to be 1640 m^2/g. EDLCs fabricated using the samples as electrode material with polymer electrolyte exhibited energy and power density of 88.8 Wh/kg and 1.63 Kw/kg, respectively. Yin et al. [131] prepared activated carbon from coconut fibers with a multi-tubular hollow structure using KOH for activation. The sample with 4:1 mass ratio of KOH to carbonized coconut fibers exhibited a specific surface of 2898 m^2/g with a pore volume of 1.59 cm^3/g (30% mesopores). The prepared supercapacitor electrode (with 6 M KOH electrolyte) exhibited a specific capacitance of 266 F/g at a current of 0.1 A/g, maintaining 76% of its capacitance at 100 A/g. They found that the 3-dimensional hierarchical porous activated carbon electrode exhibited a high capacitance of 155 F/g at 0.1 A/g and 142 F/g at 10 A/g and achieved a high-energy density of 53 Wh/kg and a high-power density of 8224 W/kg.

A number of researchers have reported on agricultural crops and residues as a major source of carbon-based material. Malik Wahid et al. [132] employed hydrothermal pretreatment on sugarcane bagasse to prepare a three-dimensional (3D) interconnected, conducting, and high surface area carbon nanochannel. The hydrothermal preprocessing is depicted in Figure 5. Samples were prepared with different synthesis protocols (pyrolyzed temperature and atmosphere). Figure 6 shows FESEM images of different carbon forms synthesized from different synthesis protocols with the same basic sugarcane bagasse precursor at 800 °C pyrolysis.

Figure 5. Synthesis of high-capacitive carbon material by hydrothermal preprocessing followed by inert atmosphere KOH activation pyrolysis. (Reprinted (adapted) with permission from [132]. Copyright (2014) American Chemical Society.)

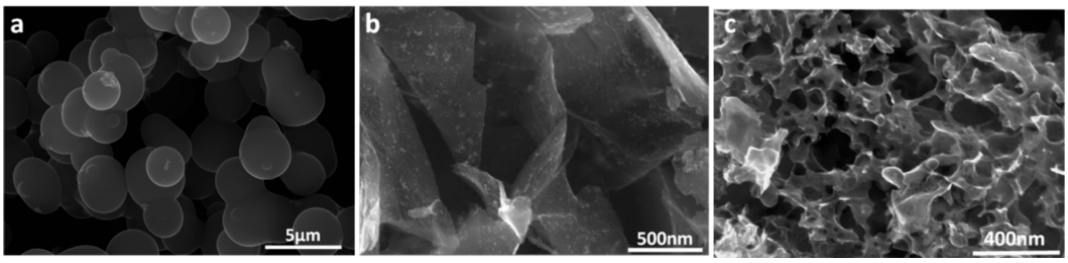

Figure 6. FESEM images of different carbon forms synthesized from different synthesis protocols with the same basic sugarcane bagasse precursor at 800 °C pyrolysis: (**a**) BHC (sample prepared by initial hydrolysis step followed by direct pyrolysis), (**b**) BAC (samples prepared by simple activation), and (**c**) BHAC (hydro-thermally treated and activated sample) (Reprinted (adapted) with permission from [132]. Copyright (2014) American Chemical Society.)

Using a three-electrode cyclic voltammetry method (1 M H_2SO_4, platinum strip as the counter electrode and AgCl as the reference electrode), the researchers reported results of cycling the current density from 1 to 20 A/g a 72% capacitance retention. At a current density of 1 A/g and a scan rate of 5 mV/s, they recorded a capacitance of 280 F/g and 275 F/g, respectively. The material exhibited an energy density of 7 Wh/kg at a power density of 571 W/kg. Izan Izwan Misnon et al. synthesized carbon from oil palm kernel shell for high-performance supercapacitors [99]. The samples that were

chemically activated showed a specific capacitance of 210 F/g in 1 M KOH electrolyte at 0.5 A/g, whereas the physically activated samples exhibited 50% lower specific capacitance. In addition, both samples showed similar quasi-rectangular shape at this scan rate region, indicating EDLC behavior in the charge storage mechanism. The electrodes maintained approximately 95–97% of capacitance after 1000 cycles. Table 2 shows the performance data for electrode materials from biowaste.

Table 2. Performance data for electrode materials from biowaste.

Biowaste	Process	Material Form	Electrolyte	Electrode Configuration	BET Surface Area (m^2/g)	Measurement Protocol	Specific Capacitance (F/g)	Ref.
Bamboo	carbonization and KOH activation	Activated biomass carbon	3 M KOH	3 electrodes	2221	0.5 A/g	293	[134]
Bamboo	KOH activation	activated carbon	6 M KOH	3 electrodes	3000	5 A/g	300	[135]
Corncob residue	steam activation without pre-carbonization	porous carbon	6 M KOH	3 electrodes	1210	1 A/g	314	[133]
Coconut kernel pulp (Milk free)	KOH activation	activated carbon	1 M Na_2SO_4	2 electrodes	1200	10 mV/s	173	[136]
Corn stalk core	KOH activation	activated carbon	-	3 electrodes	2350	1 A/g	140	[137]
Corn syrup (High fructose)	Self-Physical	activated carbon	KOH	2 electrodes	1473	0.2 A/g	168	[138]
Endothelium corneum Gigeriae galli	carbonized	nitrogen-doped porous carbon	6 M KOH	3 electrodes	2150	1 A/g	198	[139]
Fish gill	carbonization and thermal activation	activated carbon	6 M KOH	3 electrodes	2082	2 A/g	334	[108]
Gelatin	hydrothermal	Porous carbon nanosheets	6 M KOH	3 electrodes	1620	50 A/g	183	[140]
Leaves (Fallen)	activations of (KOH and K_2CO_3)	porous active carbon	6 M KOH	2 electrodes	1078	0.3 A/g	242	[141]
Starch (Porous)	carbonisation and KOH activation	porous carbon microspheres	6 M KOH	2 electrodes	3251	0.05 A/g	304	[142]
Sugar cane bagasse	chemical activation with $ZnCl_2$	Activated carbon	1 M Na_2SO_4	2 electrodes	1452	50 A/g	300	[143]
Sugar cane bagasse	calcium chloride ($CaCl_2$) activation	Nitrogen-Rich Porous Carbons	6 M KOH	2 electrodes	806	30 A/g	213	[144]
Waste tea-leaves	carbonisation and KOH activation	activated carbons	2 M KOH	3 electrodes	2841	1 A/g	330	[145]

Qu et al. [133] used corncob residue to prepare a porous carbon for supercapacitor electrodes, using a green and low-cost steam activation method. The carbon obtained at 850 °C, which was further treated with ash removal and acid soaking exhibited S_{BET} of 1210 m^2/g with a yield of 23.2 wt.%. They reported a capacitance of 314 F/g at a scan rate of 5 mV/s and a capacitance retention of 82%. The performance of the samples was attributed to the well-developed porosity and good conductivity. The same authors made use of an organic and 6 M KOH aqueous electrolyte to determine the electrochemical performance of corncob residue-derived carbon. They found an energy density of 5.3 Wh/kg at a power density of 8276 W/kg in 6 M KOH, while the organic electrolyte exhibited energy and power density of 15 Wh/kg and 2827 W/kg, respectively.

Fu et al. [146] obtained multi-hierarchical porous carbon from a typical food waste, crab shell. The multi-hierarchical porous carbon exhibited a specific capacitance of 322.5 F/g and 223.4 F/g at current densities of 1 A/g and 10 A/g, respectively. The same authors reported that the crab shell-derived carbon/$SrFe_{12}O_{19}$ composites showed 94.5% capacitance retention over 10,000 cycles, exhibiting a specific capacitance of 690.4 F/g at 1 A/g, and 401.3 F/g even at 10 A/g. The authors

conclude that such a cheap, green and high-performance electrode composites based on crab shell waste provide good prospects in energy storage applications. In another novel work, activated carbon tubes were prepared from biomass waste cotonier strobili fibers [102]. They reported that the optimized material demonstrated a specific capacitance of 214.5 F/g at 50 A/g in the three-electrode setup. A fabricated supercapacitor exhibited 84.21% capacitance retention at a remarkable specific energy of 33.04 Wh/kg at 160 W/kg.

Ismanto et al. [147] used cassava peel waste as a precursor in the preparation of activated carbon-based electrodes. Proximate analysis results show that the cassava peel had high carbon of 28.7% and low as content of 0.4%, making it a promising precursor for preparation of activated carbon. Various carbon content from biowastes is given in Table 3. The activation of carbon was prepared through a combination of chemical and physical methods and the surface was modified with oxidizing chemical agents (H_2SO_4, HNO_3 and H_2O_2). They reported a BET surface area of 1352 m^2/g. Galvanostatic charge-discharge electrochemical testing was used to investigate the gravimetric specific capacitance. The specific capacitance of unmodified sample was 153 F/g, whereas the modified sample exhibited over 60% increase.

Table 3. Various carbon content from biowastes.

Biowaste	Carbon Content (%)	Ref.
Apricot shell	23.2	[148]
Bamboo	16.60	[149]
Coconut shell	25–40	[58,59,150–153]
Durian shell	23.36	[154]
Palm shell	18.70	[59]
Pitch	33.6	[155–157]
Seaweed	16	[158,159]
Sugarcane bagasse	34.2	[143]
Wheat straw	37	[160]

Guo et al. obtained porous carbon material from soybean roots [161]. The roots were carbonized for 2 h at 500 °C (SRC) under nitrogen atmosphere and further functionalized for 2 h at 900 °C under a nitrogen atmosphere (SRPC-4K-900). Figure 7 depicts the sample preparation and SEM images. Samples were denoted by SRC (Soybean Root-Derived Carbons), and the activated Porous Carbons were named SRPC-*n*K, where *n* represents the KOH/char weight ratio. Using a symmetric two-electrode supercapacitor in 6 M KOH, they reported the existence of quasi-rectangular shapes for CV plots (Figure 8). They found that the sample SRPC-4K exhibited a specific capacitance of 276 F/g at 0.5 A/g and a capacitance retention of 98% after 10,000 cycles (Figure 8). They assembled a supercapacitor using an ionic liquid electrolyte (EMIM BF_4) and reported an energy and power density of 100.5 Wh/kg and 4353 W/kg, respectively.

Ahmed et al. [162] in their studies reported successful preparation of nitrogen-doped activated carbon from orange peels. The investigated the properties of the fabricated capacitor cells using electrochemical impedance spectroscopy, cyclic voltammetry and galvanostatic charge-discharge. The electrochemical performance of the samples was tested in a two-electrode assembly using 6 M KOH as the electrolyte. They observed a surface area of 1577 m^2/g for the activated carbon and established a specific capacitance of 167 F/g at 0.7 A/g. The samples exhibited specific energy and power densities of 23.3 Wh/kg and 2334.3 W/kg, respectively. Li Yin-Tao et al. [141] obtained porous active carbon from fallen leaves (activation process is shown in Figure 9). They employed KOH, K_2CO_3 and mixed KOH, K_2CO_3 for activation and observed that the mixed activation produced enlarged pore sizes for the activated carbon (S_{BET} of 1078 g/cm), noting that the surface area and hierarchical pore structures were related to the mass ratio of two activators. They reported a high specific capacitance of up to 242 F/g (0.3 A/g, 6 M KOH) in a two-electrode system, maintaining a high retention rate.

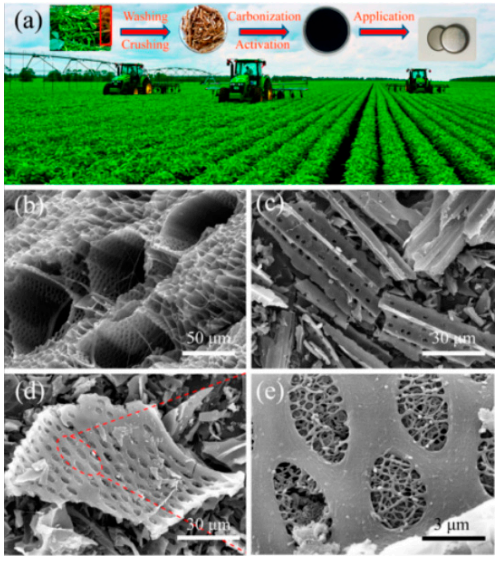

Figure 7. (**a**) Schematic representation of the scalable preparation of SRPCs; (**b**) SEM image of the SRC carbonized at 500 °C; (**c**–**e**) SEM images of SRPC-4K, functionalized for 2 h at 900 °C under nitrogen atmosphere. (Reprinted (adapted) with permission from [161]. Copyright (2016) American Chemical Society.)

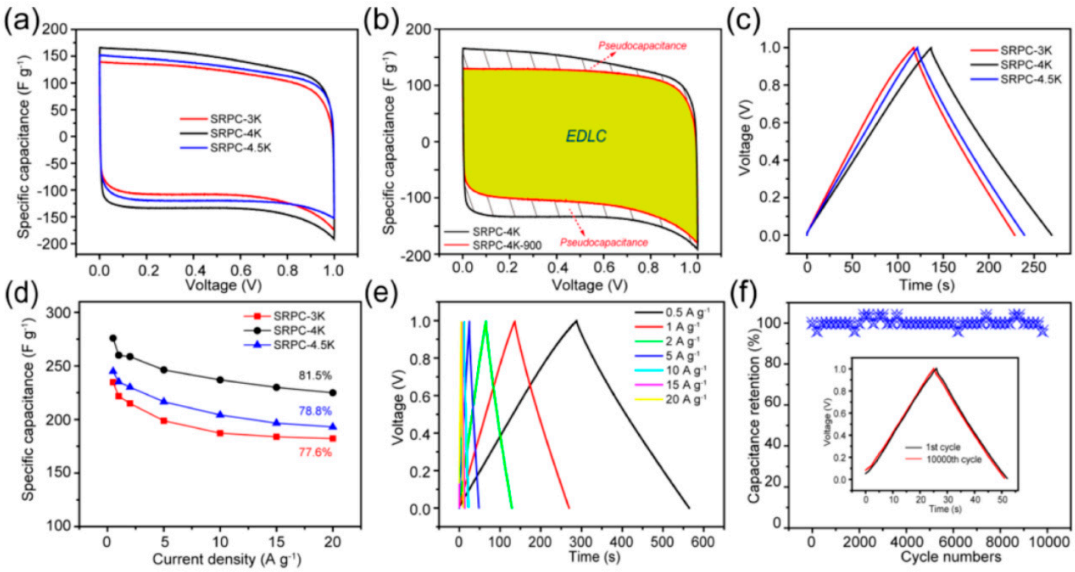

Figure 8. (**a**) CV curves at 5 mV/s of SRPC-3K, SRPC-4K, and SRPC-4.5K in a symmetric two-electrode supercapacitor in 6 M KOH aqueous solution; (**b**) CV curves of SRPC-4K and SRPC-4K-900 at 5 mV/s; (**c**) GCD curves at 1 A/g; (**d**) GCD rate performance SRPC-3K, SRPC-4K, and SRPC-4.5K; (**e**) GCD curves at various current densities; (**f**) cyclic stability at 5 A/g for 10,000 cycles of SRPC-4K (inset: GCD curves of the 1st and 10,000th cycles). (Reprinted (adapted) with permission from [161]. Copyright (2016) American Chemical Society.)

In another work, porous starch was used as a precursor to produce porous carbon microspheres [142]. Samples were stabilized, carbonized and activated in KOH. They reported a high BET surface area of 3251 m^2/g, observing specific capacitances of 304 F/g at a current density of 0.05 A/g and 197 F/g at a current density of 180 A/g in 6 M KOH. Samples exhibited a capacitance retention of 98% over 1000 cycles.

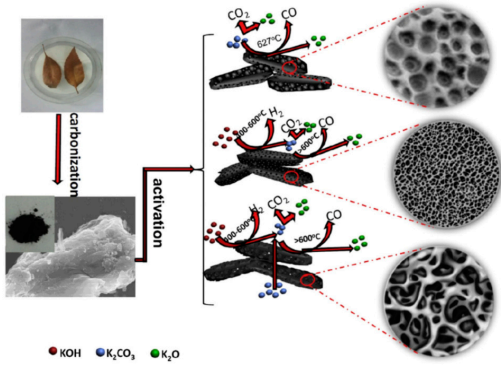

Figure 9. The activation process on ACs from fallen leaves by KOH and/or K_2CO_3. on ACs from fallen leaves by KOH and/or K_2CO_3 [141]. (Reprinted from Journal of Power Sources, 299, Yin-Tao Li, Yu-Tong Pi, Li-Ming Lu, Shun-Hua Xu, Tie-Zhen Ren, Hierarchical porous active carbon from fallen leaves by synergy of K_2CO_3 and their supercapacitor performance, 519–528, Copyright (2015), with permission from Elsevier.)

Kishore et al. [136] recently developed carbonized milk-free coconut kernel pulp at low temperatures. They found that the surface area decreases with increasing temperature; at 600 °C, they observed a surface area of 1200 m^2/g. The measured specific capacitance in 1 M H_2SO_4 electrolyte was reported as 173 F/g for carbon sample prepared at 600 °C. Na et al. [95] used a novel broken eggshell and rice husks to fabricate a novel egg white gel polymer electrolyte and green solid-state supercapacitor (Figure 10). On employing Green-S-SC based on this EW-GPE and RH-AC electrodes, they found that the specific capacitances decrease with increasing scan rate as expected. The sample exhibited good specific capacitance (214.3 F/g at 0.2 A/g), high flexibility and stable cycle performance. Various biowaste used for deriving activated carbon that finds application as an electrode material in supercapacitors are listed in Table 4.

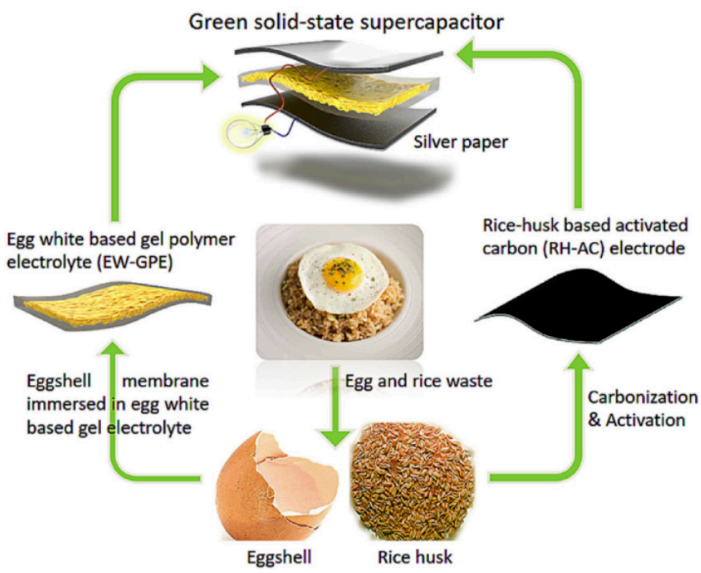

Figure 10. Schematic of the fabrication of the green solid-state supercapacitor using the egg and rice waste (broken eggshell and rice husk) [95]. (Reprinted from Electrochimica Acta, 274, Ruiqi Na, Xinyu Wang, Nan Lu, Guanze Huo, Haibo Lin, Guibin Wang, Novel egg white gel polymer electrolyte and a green solid-state supercapacitor derived from the egg and rice waste, 316–325, Copyright (2018), with permission from Elsevier.)

Table 4. Summary of key performance metrics for activated carbon derived from biowaste for supercapacitors.

Biowaste	Energy Density (Wh/kg)	Power Density (W/kg)	Cycles	Percentage Retention (%)	Ref.
Bamboo	3.3	2250	3000	91	[135]
BambooBiochar	-	-	150	95	[163]
Banana-peel	40.7	8400	1000	88.7	[96]
Banana peel	-	-	5000	~100	[164]
Banana peel waste	0.75	31	-	-	[165]
Bradyrhizobium japonicum with a Soybean Leaf as a Separator	-	-	8000	91	[166]
Celtuce leaves			2000	92.6	[167]
Coconut shells	38.5	-	>3000	93	[129]
Coconut shells	69	-	2000	85	[168]
Coconut shell			3000	97.2	[169]
Coffee beans	10–20	6000	>10,000	-	[170]
Coffee Bean	15	75	10,000	82	[171]
Coffee ground	34	215,000	-	-	[172]
Corncob residue	5.3–15	8276–2827	100,000	82	[133]
Cotton (natural)	-	-	20,000	97	[173]
Dead Neem leaves (Azadirachta indica)	55	569	-	-	[174]
Eucalyptus tree leaves	-	-	15,000	97.7	[175]
Fibres from oil palm empty fruit bunches	4.297	173	-	-	[176]
Garlic peel			100	95–98	[177]
Garlic Skin	14.65	310.67	5000	94	[178]
Gelatin	7.43	263.5	5000	92	[140]
Human hair	29	2243	>20,000	~100	[179]
Indian Cake Rusk	47.1	22,644	6000	95	[101]
Lemon peel	6.61	425.26	3000	92	[180]
Ligno-cellulosic waste, fruit stones	13	3410	20,000	99	[181]
Oil palm kernel shell	-	-	1000	95–97	[99]
Orange peel	23.3	2334.3	-	-	[162]
Paulownia flower (PF)	44.5~22.2	247~3781	1000	93	[182]
Pea skin	19.6	254,000	5000	75	[183]
Peanut shell and rice husk	19.3	1007	-	-	[184]
Pistachio nutshell	-	-	4000	~100	[185]
Pistachio nutshell	10–39	52,000–286,000	-	-	[186]
Potato starch	-	-	900	86	[187]
Rape flower stems	-	-	1000	96	[188]
Raw rice brans	70	1223	10,000	~97	[189]
Rice husk	-	-	10,000	97–99	[94]
Rice husk	5.11	-	10,000	90	[190]
Sago bark	5	400	1700	94	[191]
Shells of broad beans	-	-	3000	90	[192]
Soybean residue	12	2000	5000–10,000	90	[193]
Soybean Root	100.5	63,000	10,000	98	[161]
Spent coffee grounds	-	-	~2000	98	[194]
Sugarcane bagasse	5	35,000	1000	90	[132]
Sugar cane bagasse	5.9	10,000	5000	83	[143]
Sugar industry spent wash waste	-	414,000	1000	~100	[109]
Sunflower seed shell	4.8	24,000	-	-	[195]
Waste tea-leaves	-	-	2000	92	[145]
Wood sawdust	5.7–7.8	250–5000	10,000	94.2	[196]

4. Summary/Future Prospects

The demand for renewable energy sources worldwide has gained tremendous research attention over the past decades. The development and optimization of novel materials towards energy storage is essential to the push to provide clean energy through renewable sources. Materials derived from waste and for that matter biowaste have continuously gained penetration into the field of supercapacitor technology. In this review, we gathered different activated carbons derived from biowaste for electrochemical energy storage systems, discussing the various performance parameters and storage mechanisms of the various types of supercapacitors.

In particular, we presented reports on the surface area and pore size effects on the performance of supercapacitors. Specific capacitance, energy/power densities, and cyclic stability have been reviewed, discussing the requirements for an application. We also reviewed the processing of electrode materials to optimize or maximize the performance of the supercapacitor. Supercapacitor electrode

materials such as carbon and carbon-based materials offer a high specific surface area, good electrical conductivity and excellent stability in harsh environments, etc. The development of an alternative supercapacitor electrode material from biowaste serves two main purposes: (1) It helps with waste disposal; converting waste to a useful product, and (2) it provides an economic argument for the substantiality of supercapacitor technology.

Author Contributions: R.K.G. conceived the idea and finalized the manuscript. K.M.-D. wrote the first draft of the manuscript. C.Z. and P.K.K. reviewed the manuscript.

Funding: Ram K. Gupta expresses his sincere acknowledgment to the Polymer Chemistry Program, Graduate College, and Kansas Polymer Research Center at Pittsburg State University for providing financial and research support.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Singh, S.; Jain, S.; Venkateswaran, P.S.; Tiwari, A.K.; Nouni, M.R.; Pandey, J.K.; Goel, S. Hydrogen: A sustainable fuel for future of the transport sector. *Renew. Sustain. Energy Rev.* **2015**, *51*, 623–633. [CrossRef]
2. Hassmann, K.; Kühne, H.-M. Primary energy sources for hydrogen production. *Int. J. Hydrogen Energy* **1993**, *18*, 635–640. [CrossRef]
3. Fera, M.; Macchiaroli, R.; Iannone, R.; Miranda, S.; Riemma, S. Economic evaluation model for the energy Demand Response. *Energy* **2016**, *112*, 457–468. [CrossRef]
4. Gonenc, H.; Scholtens, B. Environmental and Financial Performance of Fossil Fuel Firms: A Closer Inspection of their Interaction. *Ecol. Econ.* **2017**, *132*, 307–328. [CrossRef]
5. Piao, S.; Fang, J.; Ciais, P.; Peylin, P.; Huang, Y.; Sitch, S.; Wang, T. The carbon balance of terrestrial ecosystems in China. *Nature* **2009**, *458*, 1009–1013. [CrossRef]
6. Trancoso, R.; Larsen, J.R.; McVicar, T.R.; Phinn, S.R.; McAlpine, C.A. CO2-vegetation feedbacks and other climate changes implicated in reducing base flow. *Geophys. Res. Lett.* **2017**, *44*, 2310–2318. [CrossRef]
7. Stern, N. What Is the Economics of Climate Change? *World Econ.* **2006**, *7*, 1–10. Available online: http://www.eci.ox.ac.uk/~{}dliverma/articles/Stern%20from%20World%20Economics.pdf (accessed on 12 October 2018).
8. Karl, T.R.; Trenberth, K.E. Modern Global Climate Change. *Science* **2003**, *302*, 1719–1723. [CrossRef]
9. Azcárate, C.; Mallor, F.; Mateo, P. Tactical and operational management of wind energy systems with storage using a probabilistic forecast of the energy resource. *Renew. Energy* **2017**, *102*, 445–456. [CrossRef]
10. Gondal, I.A.; Masood, S.A.; Amjad, M. Review of geothermal energy development efforts in Pakistan and way forward. *Renew. Sustain. Energy Rev.* **2017**, *71*, 687–696. [CrossRef]
11. McKone, J.R.; DiSalvo, F.J.; Abruña, H.D. Solar energy conversion, storage, and release using an integrated solar-driven redox flow battery. *J. Mater. Chem. A* **2017**, *5*, 5362–5372. [CrossRef]
12. Holze, R. F. Béguin, E. Frąckowiak (eds): Supercapacitors—Materials, Systems, and Applications. *J. Solid State Electrochem.* **2015**, *19*, 1253. [CrossRef]
13. Kötz, R.; Carlen, M. Principles and applications of electrochemical capacitors. *Electrochim. Acta* **2000**, *45*, 2483–2498. [CrossRef]
14. Zhang, Q.; Uchaker, E.; Candelaria, S.L.; Cao, G. Nanomaterials for energy conversion and storage. *Chem. Soc. Rev.* **2013**, *42*, 3127–3171. [CrossRef]
15. Liu, J.; Zhang, J.-G.; Yang, Z.; Lemmon, J.P.; Imhoff, C.; Graff, G.L.; Li, L.; Hu, J.; Wang, C.; Xiao, J.; et al. Materials Science and Materials Chemistry for Large Scale Electrochemical Energy Storage: From Transportation to Electrical Grid. *Adv. Funct. Mater.* **2012**, *23*, 929–946. [CrossRef]
16. Choi, N.-S.; Chen, Z.; Freunberger, S.A.; Ji, X.; Sun, Y.-K.; Amine, K.; Yushin, G.; Nazar, L.F.; Cho, J.; Bruce, P.G. Challenges Facing Lithium Batteries and Electrical Double-Layer Capacitors. *Angew. Chem. Int. Ed.* **2012**, *51*, 9994–10024. [CrossRef]
17. Lee, S.C.; Jung, W.Y. Analogical Understanding of the Ragone plot and a New Categorization of Energy Devices. *Energy Procedia* **2016**, *88*, 526–530. [CrossRef]
18. Christen, T.; Carlen, M.W. Theory of Ragone plots. *J. Power Sources* **2000**, *91*, 210–216. [CrossRef]
19. Christen, T.; Ohler, C. Optimizing energy storage devices using Ragone plots. *J. Power Sources* **2002**, *110*, 107–116. [CrossRef]

20. Winter, M.; Brodd, R.J. What are batteries, fuel cells, and supercapacitors? *Chem. Rev.* **2004**, *104*, 4245–4269. [CrossRef]
21. Pandolfo, A.G.; Hollenkamp, A.F. Carbon properties and their role in supercapacitors. *J. Power Sources* **2006**, *157*, 11–27. [CrossRef]
22. Wang, T.; Chen, H.C.; Yu, F.; Zhao, X.S.; Wang, H. Boosting the cycling stability of transition metal compounds-based supercapacitors. *Energy Storage Mater.* **2019**, *16*, 545–573. [CrossRef]
23. Miller, E.E.; Hua, Y.; Tezel, F.H. Materials for energy storage: Review of electrode materials and methods of increasing capacitance for supercapacitors. *J. Energy Storage* **2018**, *20*, 30–40. [CrossRef]
24. Song, Z.; Hou, J.; Hofmann, H.; Li, J.; Ouyang, M. Sliding-mode and Lyapunov function-based control for battery/supercapacitor hybrid energy storage system used in electric vehicles. *Energy* **2017**, *122*, 601–612. [CrossRef]
25. Hadjipaschalis, I.; Poullikkas, A.; Efthimiou, V. Overview of current and future energy storage technologies for electric power applications. *Renew. Sustain. Energy Rev.* **2009**, *13*, 1513–1522. [CrossRef]
26. Frackowiak, E. Carbon materials for supercapacitor application. *Phys. Chem. Chem. Phys.* **2007**, *9*, 1774–1785. [CrossRef]
27. Frackowiak, E.; Béguin, F. Carbon materials for the electrochemical storage of energy in capacitors. *Carbon N. Y.* **2001**, *39*, 937–950. [CrossRef]
28. Wang, F.; Xiao, S.; Hou, Y.; Hu, C.; Liu, L.; Wu, Y. Electrode materials for aqueous asymmetric supercapacitors. *RSC Adv.* **2013**, *3*, 13059–13084. [CrossRef]
29. Zhang, L.L.; Gu, Y.; Zhao, X.S. Advanced porous carbon electrodes for electrochemical capacitors. *J. Mater. Chem. A* **2013**, *1*, 9395–9408. [CrossRef]
30. Béguin, F.; Presser, V.; Balducci, A.; Frackowiak, E. Supercapacitors: Carbons and Electrolytes for Advanced Supercapacitors (Adv. Mater. 14/2014). *Adv. Mater.* **2014**, *26*, 2283. [CrossRef]
31. Zhao, X.; Sánchez, B.M.; Dobson, P.J.; Grant, P.S. The role of nanomaterials in redox-based supercapacitors for next generation energy storage devices. *Nanoscale* **2011**, *3*, 839–855. [CrossRef] [PubMed]
32. Dubal, D.P.; Gomez-Romero, P. All nanocarbon Li-Ion capacitor with high energy and high power density. *Mater. Today Energy* **2018**, *8*, 109–117. [CrossRef]
33. Divyashree, A.; Hegde, G. Activated carbon nanospheres derived from bio-waste materials for supercapacitor applications—A review. *RSC Adv.* **2015**, *5*, 88339–88352.
34. Fan, Z.; Yan, J.; Wei, T.; Zhi, L.; Ning, G.; Li, T.; Wei, F. Asymmetric Supercapacitors Based on Graphene/MnO2 and Activated Carbon Nanofiber Electrodes with High Power and Energy Density. *Adv. Funct. Mater.* **2011**, *21*, 2366–2375. [CrossRef]
35. El-Kady, M.F.; Strong, V.; Dubin, S.; Kaner, R.B. Laser Scribing of High-Performance and Flexible Graphene-Based Electrochemical Capacitors. *Science* **2012**, *335*, 1326–1330. [CrossRef]
36. Zhang, L.L.; Zhao, X.S. Carbon-based materials as supercapacitor electrodes. *Chem. Soc. Rev.* **2009**, *38*, 2520–2531. [CrossRef]
37. Liu, C.; Yu, Z.; Neff, D.; Zhamu, A.; Jang, B.Z. Graphene-Based Supercapacitor with an Ultrahigh Energy Density. *Nano Lett.* **2010**, *10*, 4863–4868. [CrossRef]
38. Zhang, Y.; Feng, H.; Wu, X.; Wang, L.; Zhang, A.; Xia, T.; Dong, H.; Li, X.; Zhang, L. Progress of electrochemical capacitor electrode materials: A review. *Int. J. Hydrogen Energy* **2009**, *34*, 4889–4899. [CrossRef]
39. Sun, L.; Tian, C.; Li, M.; Meng, X.; Wang, L.; Wang, R.; Yin, J.; Fu, H. From coconut shell to porous graphene-like nanosheets for high-power supercapacitors. *J. Mater. Chem. A* **2013**, *1*, 6462–6470. [CrossRef]
40. Simon, P.; Gogotsi, Y. Materials for electrochemical capacitors. In *Nanoscience and Technology*; Co-Published with Macmillan Publishers Ltd.: London, UK, 2009; pp. 320–329. ISBN 978-981-4282-68-0.
41. Peng, C.; Zhang, S.; Zhou, X.; Chen, G.Z. Unequalisation of electrode capacitances for enhanced energy capacity in asymmetrical supercapacitors. *Energy Environ. Sci.* **2010**, *3*, 1499–1502. [CrossRef]
42. Guo, C.X.; Li, C.M. A self-assembled hierarchical nanostructure comprising carbon spheres and graphene nanosheets for enhanced supercapacitor performance. *Energy Environ. Sci.* **2011**, *4*, 4504–4507. [CrossRef]
43. Cheng, Q.; Tang, J.; Ma, J.; Zhang, H.; Shinya, N.; Qin, L.-C. Graphene and carbon nanotube composite electrodes for supercapacitors with ultra-high energy density. *Phys. Chem. Chem. Phys.* **2011**, *13*, 17615–17624. [CrossRef] [PubMed]

44. Hou, L.; Shi, Y.; Wu, C.; Zhang, Y.; Ma, Y.; Sun, X.; Sun, J.; Zhang, X.; Yuan, C. Monodisperse Metallic NiCoSe2 Hollow Sub-Microspheres: Formation Process, Intrinsic Charge-Storage Mechanism, and Appealing Pseudocapacitance as Highly Conductive Electrode for Electrochemical Supercapacitors. *Adv. Funct. Mater.* **2018**, *28*, 1705921. [CrossRef]
45. Conway, B. *Electrochemical Supercapacitors: Scientific Fundamentals and Technological Applications*; Springer Science & Business Media: Berlin, Germany, 2013.
46. Zhao, Q.; Chen, J.; Luo, F.; Shen, L.; Wang, Y.; Wu, K.; Lu, M. Vertically oriented polyaniline-graphene nanocomposite based on functionalized graphene for supercapacitor electrode. *J. Appl. Polym. Sci.* **2017**, *134*. [CrossRef]
47. Khomenko, V.; Frackowiak, E.; Béguin, F. Determination of the specific capacitance of conducting polymer/nanotubes composite electrodes using different cell configurations. *Electrochim. Acta* **2005**, *50*, 2499–2506. [CrossRef]
48. Wang, H.; Pilon, L. Physical interpretation of cyclic voltammetry for measuring electric double layer capacitances. *Electrochim. Acta* **2012**, *64*, 130–139. [CrossRef]
49. Cao, P.; Fan, Y.; Yu, J.; Wang, R.; Song, P.; Xiong, Y. Polypyrrole nanocomposites doped with functional ionic liquids for high performance supercapacitors. *New J. Chem.* **2018**, *42*, 3909–3916. [CrossRef]
50. Zhang, L.; Tsay, K.; Bock, C.; Zhang, J. Ionic liquids as electrolytes for non-aqueous solutions electrochemical supercapacitors in a temperature range of 20 °C–80 °C. *J. Power Sources* **2016**, *324*, 615–624. [CrossRef]
51. Hou, Z.; Lu, H.; Yang, Q.; Zhao, Q.; Liu, J. Micromorphology-controlled synthesis of polypyrrole films by using binary surfactant of Span80/OP10 via interfacial polymerization and their enhanced electrochemical capacitance. *Electrochim. Acta* **2018**, *265*, 601–608. [CrossRef]
52. Orazem, M.E.; Tribollet, B. *Electrochemical Impedance Spectroscopy*; Wiley: Hoboken, NJ, USA, 2011.
53. Lee, H.-J.; Park, I.-J.; Choi, S.-R.; Kim, J.-G. Effect of Chloride on Anodic Dissolution of Aluminum in 4 M NaOH Solution for Aluminum-Air Battery. *J. Electrochem. Soc.* **2017**, *164*, A549–A554. [CrossRef]
54. Shang, P.; Zhang, J.; Tang, W.; Xu, Q.; Guo, S. 2D Thin Nanoflakes Assembled on Mesoporous Carbon Nanorods for Enhancing Electrocatalysis and for Improving Asymmetric Supercapacitors. *Adv. Funct. Mater.* **2016**, *26*, 7766–7774. [CrossRef]
55. Zhang, J.; Zhao, X.S. On the Configuration of Supercapacitors for Maximizing Electrochemical Performance. *ChemSusChem* **2012**, *5*, 818–841. [CrossRef]
56. Chapman, D.L. LI. A contribution to the theory of electrocapillarity. *Lond. Edinb. Dublin Philos. Mag. J. Sci.* **1913**, *25*, 475–481. [CrossRef]
57. Zhu, Z.; Wang, G.; Sun, M.; Li, X.; Li, C. Fabrication and electrochemical characterization of polyaniline nanorods modified with sulfonated carbon nanotubes for supercapacitor applications. *Electrochim. Acta* **2011**, *56*, 1366–1372. [CrossRef]
58. Laine, J.; Yunes, S. Effect of the preparation method on the pore size distribution of activated carbon from coconut shell. *Carbon N. Y.* **1992**, *30*, 601–604. [CrossRef]
59. Daud, W.M.A.W.; Ali, W.S.W. Comparison on pore development of activated carbon produced from palm shell and coconut shell. *Bioresour. Technol.* **2004**, *93*, 63–69. [CrossRef] [PubMed]
60. Wang, H.; Yoshio, M.; Thapa, A.K.; Nakamura, H. From symmetric AC/AC to asymmetric AC/graphite, a progress in electrochemical capacitors. *J. Power Sources* **2007**, *169*, 375–380. [CrossRef]
61. Fang, B.; Binder, L. Enhanced surface hydrophobisation for improved performance of carbon aerogel electrochemical capacitor. *Electrochim. Acta* **2007**, *52*, 6916–6921. [CrossRef]
62. Liu, X.; Zhang, R.; Zhan, L.; Long, D.; Qiao, W.; Yang, J.; Ling, L. Impedance of carbon aerogel/activated carbon composites as electrodes of electrochemical capacitors in aprotic electrolyte. *New Carbon Mater.* **2007**, *22*, 153–158. [CrossRef]
63. Du, J.; Liu, L.; Yu, Y.; Zhang, L.; Zhang, Y.; Chen, A. Synthesis of nitrogen doped graphene aerogels using solid supported strategy for supercapacitor. *Mater. Chem. Phys.* **2019**, *223*, 145–151. [CrossRef]
64. Zhang, G.; Song, Y.; Zhang, H.; Xu, J.; Duan, H.; Liu, J. Radially Aligned Porous Carbon Nanotube Arrays on Carbon Fibers: A Hierarchical 3D Carbon Nanostructure for High-Performance Capacitive Energy Storage. *Adv. Funct. Mater.* **2016**, *26*, 3012–3020. [CrossRef]
65. Wang, H.; Yoshio, M. Graphite, a suitable positive electrode material for high-energy electrochemical capacitors. *Electrochem. Commun.* **2006**, *8*, 1481–1486. [CrossRef]

66. Gomibuchi, E.; Ichikawa, T.; Kimura, K.; Isobe, S.; Nabeta, K.; Fujii, H. Electrode properties of a double layer capacitor of nano-structured graphite produced by ball milling under a hydrogen atmosphere. *Carbon N. Y.* **2006**, *44*, 983–988. [CrossRef]
67. Zhang, L.L.; Zhou, R.; Zhao, X.S. Graphene-based materials as supercapacitor electrodes. *J. Mater. Chem.* **2010**, *20*, 5983–5992. [CrossRef]
68. Ke, Q.; Wang, J. Graphene-based materials for supercapacitor electrodes—A review. *J. Mater.* **2016**, *2*, 37–54. [CrossRef]
69. Lu, W. Carbon Nanotube Supercapacitors. In *Carbon Nanotubes*; Marulanda, J.M., Ed.; IntechOpen: Rijeka, Croatia, 2010; Chapter 29.
70. Baughman, R.H.; Zakhidov, A.A.; de Heer, W.A. Carbon Nanotubes—The Route Toward Applications. *Science* **2002**, *297*, 787–792. [CrossRef] [PubMed]
71. Kaempgen, M.; Chan, C.K.; Ma, J.; Cui, Y.; Gruner, G. Printable Thin Film Supercapacitors Using Single-Walled Carbon Nanotubes. *Nano Lett.* **2009**, *9*, 1872–1876. [CrossRef]
72. Liu, C.; Bard, A.J.; Wudl, F.; Weitz, I.; Heath, J.R. Electrochemical Characterization of Films of Single-Walled Carbon Nanotubes and Their Possible Application in Supercapacitors. *Electrochem. Solid-State Lett.* **1999**, *2*, 577–578. [CrossRef]
73. Honda, Y.; Haramoto, T.; Takeshige, M.; Shiozaki, H.; Kitamura, T.; Ishikawa, M. Aligned MWCNT Sheet Electrodes Prepared by Transfer Methodology Providing High-Power Capacitor Performance. *Electrochem. Solid-State Lett.* **2007**, *10*, A106–A110. [CrossRef]
74. Katakabe, T.; Kaneko, T.; Watanabe, M.; Fukushima, T.; Aida, T. Electric Double-Layer Capacitors Using "Bucky Gels" Consisting of an Ionic Liquid and Carbon Nanotubes. *J. Electrochem. Soc.* **2005**, *152*, A1913–A1916. [CrossRef]
75. Xu, B.; Wu, F.; Chen, S.; Zhang, C.; Cao, G.; Yang, Y. Activated carbon fiber cloths as electrodes for high performance electric double layer capacitors. *Electrochim. Acta* **2007**, *52*, 4595–4598. [CrossRef]
76. Kim, S.-U.; Lee, K.-H. Carbon nanofiber composites for the electrodes of electrochemical capacitors. *Chem. Phys. Lett.* **2004**, *400*, 253–257. [CrossRef]
77. Chen, L.F.; Zhang, X.D.; Liang, H.W.; Kong, M.; Guan, Q.F.; Chen, P.; Wu, Z.Y.; Yu, S.H. Synthesis of nitrogen-doped porous carbon nanofibers as an efficient electrode material for supercapacitors. *ACS Nano* **2012**, *6*, 7092–7102. [CrossRef] [PubMed]
78. Kim, C.; Ngoc, B.T.N.; Yang, K.S.; Kojima, M.; Kim, Y.A.; Kim, Y.J.; Endo, M.; Yang, S.C. Self-sustained thin Webs consisting of porous carbon nanofibers for supercapacitors via the electrospinning of polyacrylonitrile solutions containing zinc chloride. *Adv. Mater.* **2007**, *19*, 2341–2346. [CrossRef]
79. Tran, C.; Kalra, V. Fabrication of porous carbon nanofibers with adjustable pore sizes as electrodes for supercapacitors. *J. Power Sources* **2013**, *235*, 289–296. [CrossRef]
80. Barranco, V.; Lillo-Rodenas, M.A.; Linares-Solano, A.; Oya, A.; Pico, F.; Ibañez, J.; Agullo-Rueda, F.; Amarilla, J.M.; Rojo, J.M. Amorphous Carbon Nanofibers and Their Activated Carbon Nanofibers as Supercapacitor Electrodes. *J. Phys. Chem. C* **2010**, *114*, 10302–10307. [CrossRef]
81. Sivakkumar, S.R.; Ko, J.M.; Kim, D.Y.; Kim, B.C.; Wallace, G.G. Performance evaluation of CNT/polypyrrole/MnO2 composite electrodes for electrochemical capacitors. *Electrochim. Acta* **2007**, *52*, 7377–7385. [CrossRef]
82. Honda, K.; Yoshimura, M.; Kawakita, K.; Fujishima, A.; Sakamoto, Y.; Yasui, K.; Nishio, N.; Masuda, H. Electrochemical Characterization of Carbon Nanotube/Nanohoneycomb Diamond Composite Electrodes for a Hybrid Anode of Li-Ion Battery and Super Capacitor. *J. Electrochem. Soc.* **2004**, *151*, A532–A541. [CrossRef]
83. Eikerling, M.; Kornyshev, A.A.; Lust, E. Optimized Structure of Nanoporous Carbon-Based Double-Layer Capacitors. *J. Electrochem. Soc.* **2005**, *152*, E24–E33. [CrossRef]
84. Chen, L.-F.; Lu, Y.; Yu, L.; Lou, X.W. Designed formation of hollow particle-based nitrogen-doped carbon nanofibers for high-performance supercapacitors. *Energy Environ. Sci.* **2017**, *10*, 1777–1783. [CrossRef]
85. Tavasoli, A.; Aslan, M.; Salimi, M.; Balou, S.; Pirbazari, S.M.; Hashemi, H.; Kohansal, K. Influence of the blend nickel/porous hydrothermal carbon and cattle manure hydrochar catalyst on the hydrothermal gasification of cattle manure for H2 production. *Energy Convers. Manag.* **2018**, *173*, 15–28. [CrossRef]
86. Zhang, Y.; Song, X.; Xu, Y.; Shen, H.; Kong, X.; Xu, H. Utilization of wheat bran for producing activated carbon with high specific surface area via NaOH activation using industrial furnace. *J. Clean. Prod.* **2019**, *210*, 366–375. [CrossRef]

87. Guardia, L.; Suárez, L.; Querejeta, N.; Pevida, C.; Centeno, T.A. Winery wastes as precursors of sustainable porous carbons for environmental applications. *J. Clean. Prod.* **2018**, *193*, 614–624. [CrossRef]
88. Manna, M.C.; Rahman, M.M.; Naidu, R.; Sahu, A.; Bhattacharjya, S.; Wanjari, R.H.; Patra, A.K.; Chaudhari, S.K.; Majumdar, K.; Khanna, S.S. Chapter Three—Bio-Waste Management in Subtropical Soils of India: Future Challenges and Opportunities in Agriculture. In *Advances in Agronomy*; Sparks, D.L., Ed.; Academic Press: Cambridge, MA, USA, 2018; Volume 152, pp. 87–148.
89. Benedetti, V.; Patuzzi, F.; Baratieri, M. Characterization of char from biomass gasification and its similarities with activated carbon in adsorption applications. *Appl. Energy* **2018**, *227*, 92–99. [CrossRef]
90. Maharjan, M.; Bhattarai, A.; Ulaganathan, M.; Wai, N.; Oo, M.O.; Wang, J.-Y.; Lim, T.M. High surface area bio-waste based carbon as a superior electrode for vanadium redox flow battery. *J. Power Sources* **2017**, *362*, 50–56. [CrossRef]
91. Azwar, E.; Mahari, W.A.W.; Chuah, J.H.; Vo, D.-V.N.; Ma, N.L.; Lam, W.H.; Lam, S.S. Transformation of biomass into carbon nanofiber for supercapacitor application—A review. *Int. J. Hydrogen Energy* **2018**, *43*, 20811–20821. [CrossRef]
92. Hill, J.M. Sustainable and/or waste sources for catalysts: Porous carbon development and gasification. *Catal. Today* **2017**, *285*, 204–210. [CrossRef]
93. Veerakumar, P.; Maiyalagan, T.; Raj, B.G.S.; Guruprasad, K.; Jiang, Z.; Lin, K.-C. Paper flower-derived porous carbons with high-capacitance by chemical and physical activation for sustainable applications. *Arab. J. Chem.* **2018**, in press. [CrossRef]
94. Sathyamoorthi, S.; Phattharasupakun, N.; Sawangphruk, M. Environmentally benign non-fluoro deep eutectic solvent and free-standing rice husk-derived bio-carbon based high-temperature supercapacitors. *Electrochim. Acta* **2018**, *286*, 148–157. [CrossRef]
95. Na, R.; Wang, X.; Lu, N.; Huo, G.; Lin, H.; Wang, G. Novel egg white gel polymer electrolyte and a green solid-state supercapacitor derived from the egg and rice waste. *Electrochim. Acta* **2018**, *274*, 316–325. [CrossRef]
96. Zhang, Y.; Gao, Z.; Song, N.; Li, X. High-performance supercapacitors and batteries derived from activated banana-peel with porous structures. *Electrochim. Acta* **2016**, *222*, 1257–1266. [CrossRef]
97. Parveen, N.; Al-Jaafari, A.I.; Han, J.I. Robust cyclic stability and high-rate asymmetric supercapacitor based on orange peel-derived nitrogen-doped porous carbon and intercrossed interlinked urchin-like NiCo2O4@3DNF framework. *Electrochim. Acta* **2019**, *293*, 84–96. [CrossRef]
98. Gong, C.; Wang, X.; Ma, D.; Chen, H.; Zhang, S.; Liao, Z. Microporous carbon from a biological waste-stiff silkworm for capacitive energy storage. *Electrochim. Acta* **2016**, *220*, 331–339. [CrossRef]
99. Misnon, I.I.; Zain, N.K.M.; Aziz, R.A.; Vidyadharan, B.; Jose, R. Electrochemical properties of carbon from oil palm kernel shell for high performance supercapacitors. *Electrochim. Acta* **2015**, *174*, 78–86. [CrossRef]
100. Rawal, S.; Joshi, B.; Kumar, Y. Synthesis and characterization of activated carbon from the biomass of Saccharum bengalense for electrochemical supercapacitors. *J. Energy Storage* **2018**, *20*, 418–426. [CrossRef]
101. Kesavan, T.; Partheeban, T.; Vivekanantha, M.; Kundu, M.; Maduraiveeran, G.; Sasidharan, M. Hierarchical nanoporous activated carbon as potential electrode materials for high performance electrochemical supercapacitor. *Microporous Mesoporous Mater.* **2019**, *274*, 236–244. [CrossRef]
102. Su, X.-L.; Li, S.-H.; Jiang, S.; Peng, Z.-K.; Guan, X.-X.; Zheng, X.-C. Superior capacitive behavior of porous activated carbon tubes derived from biomass waste-cotonier strobili fibers. *Adv. Powder Technol.* **2018**, *29*, 2097–2107. [CrossRef]
103. Nam, H.; Choi, W.; Genuino, D.A.; Capareda, S.C. Development of rice straw activated carbon and its utilizations. *J. Environ. Chem. Eng.* **2018**, *6*, 5221–5229. [CrossRef]
104. Song, M.; Zhou, Y.; Ren, X.; Wan, J.; Du, Y.; Wu, G.; Ma, F. Biowaste-based porous carbon for supercapacitor: The influence of preparation processes on structure and performance. *J. Colloid Interface Sci.* **2019**, *535*, 276–286. [CrossRef]
105. Tian, Q.; Wang, X.; Xu, X.; Zhang, M.; Wang, L.; Zhao, X.; An, Z.; Yao, H.; Gao, J. A novel porous carbon material made from wild rice stem and its application in supercapacitors. *Mater. Chem. Phys.* **2018**, *213*, 267–276. [CrossRef]
106. Genovese, M.; Wu, H.; Virya, A.; Li, J.; Shen, P.; Lian, K. Ultrathin all-solid-state supercapacitor devices based on chitosan activated carbon electrodes and polymer electrolytes. *Electrochim. Acta* **2018**, *273*, 392–401. [CrossRef]

107. Karnan, M.; Subramani, K.; Srividhya, P.K.; Sathish, M. Electrochemical Studies on Corncob Derived Activated Porous Carbon for Supercapacitors Application in Aqueous and Non-aqueous Electrolytes. *Electrochim. Acta* **2017**, *228*, 586–596. [CrossRef]
108. Han, Y.; Shen, N.; Zhang, S.; Li, D.; Li, X. Fish gill-derived activated carbon for supercapacitor application. *J. Alloys Compd.* **2017**, *694*, 636–642. [CrossRef]
109. Mahto, A.; Gupta, R.; Ghara, K.K.; Srivastava, D.N.; Maiti, P.; Kalpana, D.; Rivera, P.-Z.; Meena, R.; Nataraj, S.K. Development of high-performance supercapacitor electrode derived from sugar industry spent wash waste. *J. Hazard. Mater.* **2017**, *340*, 189–201. [CrossRef] [PubMed]
110. González, J.F.; Román, S.; Encinar, J.M.; Martínez, G. Pyrolysis of various biomass residues and char utilization for the production of activated carbons. *J. Anal. Appl. Pyrolysis* **2009**, *85*, 134–141. [CrossRef]
111. Özçimen, D.; Ersoy-Meriçboyu, A. Adsorption of Copper(II) Ions onto Hazelnut Shell and Apricot Stone Activated Carbons. *Adsorpt. Sci. Technol.* **2010**, *28*, 327–340. [CrossRef]
112. Boonpoke, A.; Chiarakorn, S.; Laosiripojana, N.; Towprayoon, S.; Chidthaisong, A. Synthesis of activated carbon and MCM-41 from bagasse and rice husk and their carbon dioxide adsorption capacity. *J. Sustain. Environ.* **2011**, *2*, 77–81.
113. Hirunpraditkoon, S.; Tunthong, N.; Ruangchai, A.; Nuithitikul, K. Adsorption Capacities of Activated Carbons Prepared from Bamboo by KOH Activation. *Int. J. Chem. Mol. Nucl. Mater. Metall. Eng.* **2011**, *5*, 477–481.
114. Zequine, C.; Ranaweera, C.K.; Wang, Z.; Singh, S.; Tripathi, P.; Srivastava, O.N.; Gupta, B.K.; Ramasamy, K.; Kahol, P.K.; Dvornic, P.R.; et al. High Performance and Flexible Supercapacitors based on Carbonized Bamboo Fibers for Wide Temperature Applications. *Sci. Rep.* **2016**, *6*, 31704. [CrossRef]
115. Cruz, G.; Pirilä, M.; Huuhtanen, M.; Carrión, L.; Alvarenga, E.; Keiski, R.L. Production of Activated Carbon from Cocoa (Theobroma cacao) Pod Husk. *Civ. Environ. Eng.* **2012**, *2*, 1–6. [CrossRef]
116. Guo, S.; Peng, J.; Li, W.; Yang, K.; Zhang, L.; Zhang, S.; Xia, H. Effects of CO2 activation on porous structures of coconut shell-based activated carbons. *Appl. Surf. Sci.* **2009**, *255*, 8443–8449. [CrossRef]
117. Li, W.; Yang, K.; Peng, J.; Zhang, L.; Guo, S.; Xia, H. Effects of carbonization temperatures on characteristics of porosity in coconut shell chars and activated carbons derived from carbonized coconut shell chars. *Ind. Crops Prod.* **2008**, *28*, 190–198. [CrossRef]
118. Nahil, M.A.; Williams, P.T. Pore characteristics of activated carbons from the phosphoric acid chemical activation of cotton stalks. *Biomass Bioenergy* **2012**, *37*, 142–149. [CrossRef]
119. Subha, R.; Namasivayam, C. Zinc chloride activated coir pith carbon as low cost adsorbent for removal of 2,4-dichlorophenol: Equilibrium and kinetic studies. *Indian J. Chem. Technol.* **2009**, *16*, 471–479.
120. ThamYee, J.; Arumugam, S.D.; Nur Hidayah, A.L.; Abdullah, A.M.; Latif, P.A. Effect of activation temperature and heating duration on physical characteristics of activated carbon prepared from agriculture waste. *Environ. Asia* **2010**, *3*, 143–148.
121. Demiral, H.; Demiral, İ.; Tümsek, F.; Karabacakoğlu, B. Pore structure of activated carbon prepared from hazelnut bagasse by chemical activation. *Surf. Interface Anal.* **2008**, *40*, 616–619. [CrossRef]
122. Zequine, C.; Ranaweera, C.K.; Wang, Z.; Dvornic, P.R.; Kahol, P.K.; Singh, S.; Tripathi, P.; Srivastava, O.N.; Singh, S.; Gupta, B.K.; et al. High-Performance Flexible Supercapacitors obtained via Recycled Jute: Bio-Waste to Energy Storage Approach. *Sci. Rep.* **2017**, *7*, 1174. [CrossRef] [PubMed]
123. Borhan, A.; Kamil, A.F. Preparation & Characterization of Activated Carbon from Rubber-seed Shell by Chemical Activation. *J. Appl. Sci.* **2012**, *12*, 1124–1129.
124. Girgis, B.S.; Yunis, S.S.; Soliman, A.M. Characteristics of activated carbon from peanut hulls in relation to conditions of preparation. *Mater. Lett.* **2002**, *57*, 164–172. [CrossRef]
125. Lua, A.C.; Yang, T.; Guo, J. Effects of pyrolysis conditions on the properties of activated carbons prepared from pistachio-nut shells. *J. Anal. Appl. Pyrolysis* **2004**, *72*, 279–287. [CrossRef]
126. Devnarain, P.B.; Arnold, D.R.; Davis, S.B. Production of activated carbon from South African sugarcane bagasse. In Proceedings of the 76th Annual Congress of the South African Sugar Technologists' Association, Mount Edgecombe, South Africa, 30 July–2 August 2002; pp. 477–489.
127. Bhoyate, S.; Ranaweera, C.K.; Zhang, C.; Morey, T.; Hyatt, M.; Kahol, P.K.; Ghimire, M.; Mishra, S.R.; Gupta, R.K. Eco-Friendly and High Performance Supercapacitors for Elevated Temperature Applications Using Recycled Tea Leaves. *Glob. Chall.* **2017**, *1*, 1700063. [CrossRef]

128. Bhadusha, N.; Ananthabaskaran, T. Adsorptive removal of methylene blue onto ZnCl2 activated carbon from wood apple outer shell: Kinetics and equilibrium studies. *E-J. Chem.* **2011**, *8*, 1696–1707. [CrossRef]
129. Mi, J.; Wang, X.R.; Fan, R.J.; Qu, W.H.; Li, W.C. Coconut-shell-based porous carbons with a tunable micro/mesopore ratio for high-performance supercapacitors. *Energy Fuels* **2012**, *26*, 5321–5329. [CrossRef]
130. Jain, A.; Tripathi, S.K. Fabrication and characterization of energy storing supercapacitor devices using coconut shell based activated charcoal electrode. *Mater. Sci. Eng. B* **2014**, *183*, 54–60. [CrossRef]
131. Yin, L.; Chen, Y.; Li, D.; Zhao, X.; Hou, B.; Cao, B. 3-Dimensional hierarchical porous activated carbon derived from coconut fibers with high-rate performance for symmetric supercapacitors. *Mater. Des.* **2016**, *111*, 44–50. [CrossRef]
132. Wahid, M.; Puthusseri, D.; Phase, D.; Ogale, S. Enhanced capacitance retention in a supercapacitor made of carbon from sugarcane bagasse by hydrothermal pretreatment. *Energy Fuels* **2014**, *28*, 4233–4240. [CrossRef]
133. Qu, W.-H.; Xu, Y.-Y.; Lu, A.-H.; Zhang, X.-Q.; Li, W.-C. Converting biowaste corncob residue into high value added porous carbon for supercapacitor electrodes. *Bioresour. Technol.* **2015**, *189*, 285–291. [CrossRef]
134. Zhang, G.; Chen, Y.; Chen, Y.; Guo, H. Activated biomass carbon made from bamboo as electrode material for supercapacitors. *Mater. Res. Bull.* **2018**, *102*, 391–398. [CrossRef]
135. Yang, C.S.; Jang, Y.S.; Jeong, H.K. Bamboo-based activated carbon for supercapacitor applications. *Curr. Appl. Phys.* **2014**, *14*, 1616–1620. [CrossRef]
136. Kishore, B.; Shanmughasundaram, D.; Penki, T.R.; Munichandraiah, N. Coconut kernel-derived activated carbon as electrode material for electrical double-layer capacitors. *J. Appl. Electrochem.* **2014**, *44*, 903–916. [CrossRef]
137. Yu, K.; Zhu, H.; Qi, H.; Liang, C. High surface area carbon materials derived from corn stalk core as electrode for supercapacitor. *Diam. Relat. Mater.* **2018**, *88*, 18–22. [CrossRef]
138. Cao, W.; Yang, F. Supercapacitors from high fructose corn syrup-derived activated carbons. *Mater. Today Energy* **2018**, *9*, 406–415. [CrossRef]
139. Hong, X.; Hui, K.S.; Zeng, Z.; Hui, K.N.; Zhang, L.; Mo, M.; Li, M. Hierarchical nitrogen-doped porous carbon with high surface area derived from endothelium corneum gigeriae galli for high-performance supercapacitor. *Electrochim. Acta* **2014**, *130*, 464–469. [CrossRef]
140. Fan, H.; Shen, W. Gelatin-Based Microporous Carbon Nanosheets as High Performance Supercapacitor Electrodes. *ACS Sustain. Chem. Eng.* **2016**, *4*, 1328–1337. [CrossRef]
141. Li, Y.-T.; Pi, Y.-T.; Lu, L.-M.; Xu, S.-H.; Ren, T.-Z. Hierarchical porous active carbon from fallen leaves by synergy of K2CO3 and their supercapacitor performance. *J. Power Sources* **2015**, *299*, 519–528. [CrossRef]
142. Du, S.; Wang, L.; Fu, X.; Chen, M.; Wang, C. Hierarchical porous carbon microspheres derived from porous starch for use in high-rate electrochemical double-layer capacitors. *Bioresour. Technol.* **2013**, *139*, 406–409. [CrossRef]
143. Rufford, T.E.; Hulicova-Jurcakova, D.; Khosla, K.; Zhu, Z.; Lu, G.Q. Microstructure and electrochemical double-layer capacitance of carbon electrodes prepared by zinc chloride activation of sugar cane bagasse. *J. Power Sources* **2010**, *195*, 912–918. [CrossRef]
144. Liu, J.; Deng, Y.; Li, X.; Wang, L. Promising Nitrogen-Rich Porous Carbons Derived from One-Step Calcium Chloride Activation of Biomass-Based Waste for High Performance Supercapacitors. *ACS Sustain. Chem. Eng.* **2016**, *4*, 177–187. [CrossRef]
145. Peng, C.; Yan, X.B.; Wang, R.T.; Lang, J.W.; Ou, Y.J.; Xue, Q.J. Promising activated carbons derived from waste tea-leaves and their application in high performance supercapacitors electrodes. *Electrochim. Acta* **2013**, *87*, 401–408. [CrossRef]
146. Fu, M.; Chen, W.; Zhu, X.; Yang, B.; Liu, Q. Crab shell derived multi-hierarchical carbon materials as a typical recycling of waste for high performance supercapacitors. *Carbon N. Y.* **2019**, *141*, 748–757. [CrossRef]
147. Ismanto, A.E.; Wang, S.; Soetaredjo, F.E.; Ismadji, S. Preparation of capacitor's electrode from cassava peel waste. *Bioresour. Technol.* **2010**, *101*, 3534–3540. [CrossRef] [PubMed]
148. Xu, B.; Chen, Y.; Wei, G.; Cao, G.; Zhang, H.; Yang, Y. Activated carbon with high capacitance prepared by NaOH activation for supercapacitors. *Mater. Chem. Phys.* **2010**, *124*, 504–509. [CrossRef]
149. Choy, K.K.H.; Barford, J.P.; McKay, G. Production of activated carbon from bamboo scaffolding waste—Process design, evaluation and sensitivity analysis. *Chem. Eng. J.* **2005**, *109*, 147–165. [CrossRef]
150. Hu, Z.; Srinivasan, M.P. Preparation of high-surface-area activated carbons from coconut shell. *Microporous Mesoporous Mater.* **1999**, *27*, 11–18. [CrossRef]

151. Kumagai, S.; Ishizawa, H.; Toida, Y. Influence of solvent type on dibenzothiophene adsorption onto activated carbon fiber and granular coconut-shell activated carbon. *Fuel* **2010**, *89*, 365–371. [CrossRef]
152. Azevedo, D.C.S.; Araújo, J.C.S.; Bastos-Neto, M.; Torres, A.E.B.; Jaguaribe, E.F.; Cavalcante, C.L. Microporous activated carbon prepared from coconut shells using chemical activation with zinc chloride. *Microporous Mesoporous Mater.* **2007**, *100*, 361–364. [CrossRef]
153. Hulicova-Jurcakova, D.; Seredych, M.; Lu, G.Q.; Bandosz, T.J. Combined Effect of Nitrogen- and Oxygen-Containing Functional Groups of Microporous Activated Carbon on its Electrochemical Performance in Supercapacitors. *Adv. Funct. Mater.* **2009**, *19*, 438–447. [CrossRef]
154. Chandra, T.C.; Mirna, M.M.; Sudaryanto, Y.; Ismadji, S. Adsorption of basic dye onto activated carbon prepared from durian shell: Studies of adsorption equilibrium and kinetics. *Chem. Eng. J.* **2007**, *127*, 121–129. [CrossRef]
155. Zhai, D.; Li, B.; Du, H.; Wang, G.; Kang, F. The effect of pre-carbonization of mesophase pitch-based activated carbons on their electrochemical performance for electric double-layer capacitors. *J. Solid State Electrochem.* **2011**, *15*, 787–794. [CrossRef]
156. Endo, M.; Kim, Y.J.; Maeda, T.; Koshiba, K.; Katayam, K.; Dresselhaus, M.S. Morphological effect on the electrochemical behavior of electric double-layer capacitors. *J. Mater. Res.* **2001**, *16*, 3402–3410. [CrossRef]
157. Alonso, A.; Ruiz, V.; Blanco, C.; Santamaría, R.; Granda, M.; Menéndez, R.; de Jager, S.G.E. Activated carbon produced from Sasol-Lurgi gasifier pitch and its application as electrodes in supercapacitors. *Carbon N. Y.* **2006**, *44*, 441–446. [CrossRef]
158. Raymundo-Piñero, E.; Leroux, F.; Béguin, F. A High-Performance Carbon for Supercapacitors Obtained by Carbonization of a Seaweed Biopolymer. *Adv. Mater.* **2006**, *18*, 1877–1882. [CrossRef]
159. Raymundo-Piñero, E.; Cadek, M.; Béguin, F. Tuning Carbon Materials for Supercapacitors by Direct Pyrolysis of Seaweeds. *Adv. Funct. Mater.* **2009**, *19*, 1032–1039. [CrossRef]
160. Li, X.; Han, C.; Chen, X.; Shi, C. Preparation and performance of straw based activated carbon for supercapacitor in non-aqueous electrolytes. *Microporous Mesoporous Mater.* **2010**, *131*, 303–309. [CrossRef]
161. Guo, N.; Li, M.; Wang, Y.; Sun, X.; Wang, F.; Yang, R. Soybean Root-Derived Hierarchical Porous Carbon as Electrode Material for High-Performance Supercapacitors in Ionic Liquids. *ACS Appl. Mater. Interfaces* **2016**, *8*, 33626–33634. [CrossRef] [PubMed]
162. Ahmed, S.; Rafat, M.; Ahmed, A. Nitrogen doped activated carbon derived from orange peel for supercapacitor application. *Adv. Nat. Sci. Nanosci. Nanotechnol.* **2018**, *9*, 35008. [CrossRef]
163. Gu, X.; Wang, Y.; Lai, C.; Qiu, J.; Li, S.; Hou, Y.; Martens, W.; Mahmood, N.; Zhang, S. Microporous bamboo biochar for lithium-sulfur batteries. *Nano Res.* **2015**, *8*, 129–139. [CrossRef]
164. Liu, B.; Zhang, L.; Qi, P.; Zhu, M.; Wang, G.; Ma, Y.; Guo, X.; Chen, H.; Zhang, B.; Zhao, Z.; et al. Nitrogen-Doped Banana Peel–Derived Porous Carbon Foam as Binder-Free Electrode for Supercapacitors. *Nanomaterials* **2016**, *6*, 18. [CrossRef] [PubMed]
165. Taer, E.; Taslim, R.; Aini, Z.; Hartati, S.D.; Mustika, W.S. Activated carbon electrode from banana-peel waste for supercapacitor applications. *AIP Conf. Proc.* **2017**, *1801*, 40004.
166. Yao, Q.; Wang, H.; Wang, C.; Jin, C.; Sun, Q. One Step Construction of Nitrogen–Carbon Derived from Bradyrhizobium japonicum for Supercapacitor Applications with a Soybean Leaf as a Separator. *ACS Sustain. Chem. Eng.* **2018**, *6*, 4695–4704. [CrossRef]
167. Wang, R.; Wang, P.; Yan, X.; Lang, J.; Peng, C.; Xue, Q. Promising Porous Carbon Derived from Celtuce Leaves with Outstanding Supercapacitance and CO2 Capture Performance. *ACS Appl. Mater. Interfaces* **2012**, *4*, 5800–5806. [CrossRef]
168. Jain, A.; Aravindan, V.; Jayaraman, S.; Kumar, P.S.; Balasubramanian, R.; Ramakrishna, S.; Madhavi, S.; Srinivasan, M.P. Activated carbons derived from coconut shells as high energy density cathode material for Li-ion capacitors. *Sci. Rep.* **2013**, *3*, 3002. [CrossRef] [PubMed]
169. Sun, K.; Leng, C.; Jiang, J.; Bu, Q.; Lin, G.; Lu, X.; Zhu, G. Microporous activated carbons from coconut shells produced by self-activation using the pyrolysis gases produced from them, that have an excellent electric double layer performance. *New Carbon Mater.* **2017**, *32*, 451–459. [CrossRef]
170. Rufford, T.E.; Hulicova-Jurcakova, D.; Zhu, Z.; Lu, G.Q. Nanoporous carbon electrode from waste coffee beans for high performance supercapacitors. *Electrochem. Commun.* **2008**, *10*, 1594–1597. [CrossRef]
171. Huang, C.; Sun, T.; Hulicova-Jurcakova, D. Wide Electrochemical Window of Supercapacitors from Coffee Bean-Derived Phosphorus-Rich Carbons. *ChemSusChem* **2013**, *6*, 2330–2339. [CrossRef]

172. Rufford, T.E.; Hulicova-Jurcakova, D.; Fiset, E.; Zhu, Z.; Lu, G.Q. Double-layer capacitance of waste coffee ground activated carbons in an organic electrolyte. *Electrochem. Commun.* **2009**, *11*, 974–977. [CrossRef]
173. Cheng, P.; Li, T.; Yu, H.; Zhi, L.; Liu, Z.; Lei, Z. Biomass-Derived Carbon Fiber Aerogel as a Binder-Free Electrode for High-Rate Supercapacitors. *J. Phys. Chem. C* **2016**, *120*, 2079–2086. [CrossRef]
174. Biswal, M.; Banerjee, A.; Deo, M.; Ogale, S. From dead leaves to high energy density supercapacitors. *Energy Environ. Sci.* **2013**, *6*, 1249–1259. [CrossRef]
175. Mondal, A.K.; Kretschmer, K.; Zhao, Y.; Liu, H.; Wang, C.; Sun, B.; Wang, G. Nitrogen-Doped Porous Carbon Nanosheets from Eco-Friendly Eucalyptus Leaves as High Performance Electrode Materials for Supercapacitors and Lithium Ion Batteries. *Chem. A Eur. J.* **2016**, *23*, 3683–3690. [CrossRef]
176. Farma, R.; Deraman, M.; Awitdrus, A.; Talib, I.A.; Taer, E.; Basri, N.H.; Manjunatha, J.G.; Ishak, M.M.; Dollah, B.N.M.; Hashmi, S.A. Preparation of highly porous binderless activated carbon electrodes from fibres of oil palm empty fruit bunches for application in supercapacitors. *Bioresour. Technol.* **2013**, *132*, 254–261. [CrossRef]
177. Selvamani, V.; Ravikumar, R.; Suryanarayanan, V.; Velayutham, D.; Gopukumar, S. Garlic peel derived high capacity hierarchical N-doped porous carbon anode for sodium/lithium ion cell. *Electrochim. Acta* **2016**, *190*, 337–345. [CrossRef]
178. Zhang, Q.; Han, K.; Li, S.; Li, M.; Li, J.; Ren, K. Synthesis of garlic skin-derived 3D hierarchical porous carbon for high-performance supercapacitors. *Nanoscale* **2018**, *10*, 2427–2437. [CrossRef] [PubMed]
179. Qian, W.; Sun, F.; Xu, Y.; Qiu, L.; Liu, C.; Wang, S.; Yan, F. Human hair-derived carbon flakes for electrochemical supercapacitors. *Energy Environ. Sci.* **2014**, *7*, 379–386. [CrossRef]
180. Senthilkumar, S.T.; Fu, N.; Liu, Y.; Wang, Y.; Zhou, L.; Huang, H. Flexible fiber hybrid supercapacitor with NiCo2O4 nanograss@carbon fiber and bio-waste derived high surface area porous carbon. *Electrochim. Acta* **2016**, *211*, 411–419. [CrossRef]
181. Huang, C.; Puziy, A.M.; Sun, T.; Poddubnaya, O.I.; Suárez-García, F.; Tascón, J.M.D.; Hulicova-Jurcakova, D. Capacitive Behaviours of Phosphorus-Rich Carbons Derived from Lignocelluloses. *Electrochim. Acta* **2014**, *137*, 219–227. [CrossRef]
182. Chang, J.; Gao, Z.; Wang, X.; Wu, D.; Xu, F.; Wang, X.; Guo, Y.; Jiang, K. Activated porous carbon prepared from paulownia flower for high performance supercapacitor electrodes. *Electrochim. Acta* **2015**, *157*, 290–298. [CrossRef]
183. Ahmed, S.; Ahmed, A.; Rafat, M. Nitrogen doped activated carbon from pea skin for high performance supercapacitor. *Mater. Res. Express* **2018**, *5*, 45508. [CrossRef]
184. He, X.; Ling, P.; Qiu, J.; Yu, M.; Zhang, X.; Yu, C.; Zheng, M. Efficient preparation of biomass-based mesoporous carbons for supercapacitors with both high energy density and high power density. *J. Power Sources* **2013**, *240*, 109–113. [CrossRef]
185. Goldfarb, J.L.; Dou, G.; Salari, M.; Grinstaff, M.W. Biomass-Based Fuels and Activated Carbon Electrode Materials: An Integrated Approach to Green Energy Systems. *ACS Sustain. Chem. Eng.* **2017**, *5*, 3046–3054. [CrossRef]
186. Xu, J.; Gao, Q.; Zhang, Y.; Tan, Y.; Tian, W.; Zhu, L.; Jiang, L. Preparing two-dimensional microporous carbon from Pistachio nutshell with high areal capacitance as supercapacitor materials. *Sci. Rep.* **2014**, *4*, 5545. [CrossRef]
187. Zhao, S.; Wang, C.-Y.; Chen, M.-M.; Wang, J.; Shi, Z.-Q. Potato starch-based activated carbon spheres as electrode material for electrochemical capacitor. *J. Phys. Chem. Solids* **2009**, *70*, 1256–1260. [CrossRef]
188. Cao, Y.; Liu, C.; Qian, J.; Chen, Z.; Chen, F. Novel 3D porous graphene decorated with Co3O4/CeO2 for high performance supercapacitor power cell. *J. Rare Earths* **2017**, *35*, 995–1001. [CrossRef]
189. Hou, J.; Cao, C.; Ma, X.; Idrees, F.; Xu, B.; Hao, X.; Lin, W. From Rice Bran to High Energy Density Supercapacitors: A New Route to Control Porous Structure of 3D Carbon. *Sci. Rep.* **2014**, *4*, 7260. [CrossRef] [PubMed]
190. Teo, E.Y.L.; Muniandy, L.; Ng, E.-P.; Adam, F.; Mohamed, A.R.; Jose, R.; Chong, K.F. High surface area activated carbon from rice husk as a high performance supercapacitor electrode. *Electrochim. Acta* **2016**, *192*, 110–119. [CrossRef]
191. Hegde, G.; Abdul Manaf, S.A.; Kumar, A.; Ali, G.A.M.; Chong, K.F.; Ngaini, Z.; Sharma, K.V. Biowaste Sago Bark Based Catalyst Free Carbon Nanospheres: Waste to Wealth Approach. *ACS Sustain. Chem. Eng.* **2015**, *3*, 2247–2253. [CrossRef]

192. Xu, G.; Han, J.; Ding, B.; Nie, P.; Pan, J.; Dou, H.; Li, H.; Zhang, X. Biomass-derived porous carbon materials with sulfur and nitrogen dual-doping for energy storage. *Green Chem.* **2015**, *17*, 1668–1674. [CrossRef]
193. Ferrero, G.A.; Fuertes, A.B.; Sevilla, M. From Soybean residue to advanced supercapacitors. *Sci. Rep.* **2015**, *5*, 16618. [CrossRef] [PubMed]
194. Ramasahayam, S.K.; Clark, A.L.; Hicks, Z.; Viswanathan, T. Spent coffee grounds derived P, N co-doped C as electrocatalyst for supercapacitor applications. *Electrochim. Acta* **2015**, *168*, 414–422. [CrossRef]
195. Li, X.; Xing, W.; Zhuo, S.; Zhou, J.; Li, F.; Qiao, S.; Lu, G. Preparation of capacitor's electrode from sunflower seed shell. *Bioresour. Technol.* **2011**, *102*, 1118–1123. [CrossRef]
196. Huang, Y.; Peng, L.; Liu, Y.; Zhao, G.; Chen, J.Y.; Yu, G. Biobased Nano Porous Active Carbon Fibers for High-Performance Supercapacitors. *ACS Appl. Mater. Interfaces* **2016**, *8*, 15205–15215. [CrossRef]