UNIVERSITI PUTRA MALAYSIA

VALORIZATION OF OIL PALM BY-PRODUCT MATERIALS AS A NEW SUSTAINABLE CARBON SOURCE FOR CARBON-BASED NANOMATERIAL SYNTHESIS AND ENERGY STORAGE APPLICATION

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ITMA 2019 5

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By

SALISU NASIR

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

April 2019

DEDICATION

This thesis is dedicated to the beloved memory of my late parents: Mrs. Fatima Binti Adam Alhassan and His Eminence Muhammad Nasir Ibn Usman Isma'il, for introducing me to the world, and setting up the right footings in my life. May Allah (S.W.T.) reward them, be pleased with them, accept all their good deeds, forgive all their shortcomings and make their graves spacious, full of light and a garden of paradise, amen.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chairman : Professor Mohd Zobir Hussein, PhD
Faculty : Institute of Advanced Technology

Energy and environmental issues are the two major problems that our world is facing today. These, combined with developing consumer demands have stirred researchers' interest in inexpensive, environmentally friendly functional materials. With Malaysia as an indicator, and based on a projected annual production of palm oil in Malaysia of over 15.4 million metric tons by 2020, it is estimated that about 46.6 tons of lignocellulosic wastes will be generated. Transforming these wastes into wealth could be integrated into a global paradigm shift towards sustainable development.

Thus, in this research, a new approach was proposed to produce reduced graphene oxide (rGO) from graphene oxide (GO), and activated carbons (AC) using various oil palm by-product materials, namely oil palm leaves (OPL), palm kernel shells (PKS) and empty fruit bunches (EFB). The effect of heating temperature on the formation of graphitic carbon and the yield was examined prior to the GO and rGO synthesis. Carbonization of the starting materials was conducted in a furnace under nitrogen gas for 3 h at temperatures ranging from 400 to 900 °C and a constant heating rate of 10 °C/min. The GO was further synthesized from the as-carbonized materials using the 'improved synthesis of graphene oxide' method. Subsequently, the GO was reduced by low-temperature annealing reduction at 300 °C in a furnace under nitrogen gas for 1 h to produce rGO.

It was found that the I_G/I_D ratio calculated from the Raman spectral analysis increases with the increasing of the degree of the graphitization in the order of rGO from oil palm leaves (rGOOPL) < rGO palm kernel shells (rGOPKS) < rGO commercial graphite (rGOCG) < rGO empty fruit bunches (rGOEFB) with the I_G/I_D values of 1.06,

1.14, 1.16 and 1.20, respectively. The surface area and pore volume analyses of the as-prepared materials were performed using the Brunauer Emmett Teller (BET) nitrogen adsorption-desorption method. The lower BET surface area of 8 and 15 m^2g^{-1} observed for rGOCG and rGOOPL, respectively could be due to partial restacking of GO layers and locally-blocked pores. Relatively, this lower BET surface area is inconsequential when compared to rGOPKS and rGOEFB, with a surface area of 114 and 117 m^2 g^{-1}, respectively.

Furthermore, electrochemical energy storage performances of the rGOs, and also the as-prepared activated carbons were also all carried out using cyclic voltametry (CV) method, and were found to be good electrode materials for supercapacitors applications. One of the OPL-based AC electrodes was found to have very high capacitance values of 434 F g^{-1} at 5 mVs^{-1}, which is much higher than the specific capacitance value (343 F g^{-1}) of the only oil palm leaf-derived porous carbon nanoparticles ever reported in the literature.

On the other hand, a novel phase change material (PCM) made of n-nonadecane infused by capillary forces in a compressed reduced graphene oxide-activated carbon composite matrix was also investigated. Reduced graphene oxide (rGOEFB) - activated carbon (AC) composite was successfully prepared and exhibited an improved thermal conduction property, and was used as a matrix or framework for the fabrication of shape-stabilized composite phase change material (SCPCM). During this SCPCM set-up, which was achieved by simple impregnation method, the pores of the rGOEFB-AC composite serves as the matrix/framework while n-nonadecane as the central envelope. The molten n-nonadecane was successfully stabilized by this porous carbon matrix via the capillary force and surface tension forces which mitigated the seepage of the molten n-nonadecane throughout the phase change cycle. The phase change temperatures and latent heats of composite SCPCM-5 were 37.25 and 25.58 ^{o}C and 82.72 and -62.22 J/g, respectively. On the whole, the novel carbon-based nanomaterials produced in this project demonstrate excellent features that enabled them to be used as both thermal and electrochemical energy storage materials.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENAMBAHAN NILAI PRODUK SAMPINGAN KELAPA SAWIT SEBAGAI SUMBER KARBON BARU YANG MAMPAN UNTUK SINTESIS BAHAN NANO BERASASKAN KARBON DAN APLIKASI PENYIMPANAN TENAGA

Oleh

SALISU NASIR

April 2019

Pengerusi : Profesor Mohd Zobir Hussein, PhD
Fakulti : Institut Teknologi Maju

Antara permasalahan besar yang dihadapi masyarakat dunia hari ini adalah isu-isu berkaitan tenaga dan alam sekitar. Di samping itu, permintaan pengguna yang semakin meningkat turut menggalakkan kajian berkaitan bahan berfungsi yang murah dan mesra alam. Dengan menggunakan Malaysia sebagai indikator dan berdasarkan jangkaan produksi minyak kelapa sawit Malaysia yang akan melebihi 15.4 juta tan matrik pada tahun 2020, dijangka bahawa sebanyak 46.6 tan sisa lignoselulosa akan dijana. Kemampuan untuk menukar sisa tersebut kepada bahan bernilai mungkin boleh diintegrasikan ke dalam usaha perubahan paradigma dunia ke arah pembangunan mampan.

Sehubungan dengan itu, kajian ini memperkenalkan kaedah baru untuk penghasilan grafen oksida terturun (rGO) daripada grafen oksida (GO) dan karbon teraktif (AC) menggunakan produk sampingan industri kelapa sawit iaitu daun kelapa sawit (OPL), tempurung sawit (PKS) dan tandang kosong kelapa sawit (EFB). Kesan suhu pemanasan terhadap penghasilan karbon grafitik dikaji sebelum proses sintesis GO dan rGO. Karbonasi bahan mentah telah dijalankan di dalam relau berisi gas nitrogen selama 3 jam pada suhu antara 400 ke 900 °C dengan kadar pemanasan 10 °C/min. Kemudian GO telah disintesis menggunakan bahan yang telah dikarbonasi dengan menggunakan kaedah Hummers' yang telah ditambah baik. Seterusnya, GO diturunkan menggunakan kaedah penurunan penyepuhlindapan suhu rendah pada suhu 300 °C di dalam relau berisi nitrogen selama 1 jam untuk menghasilkan rGO.

Didapati bahawa nisbah I_G/I_D yang dikira daripada analisis spektroskopi Raman bertambah dengan pertambahan kadar pengrafitan mengikut urutan berikut; rGO

daripada daun kelapa sawit (rGOOPL) < rGO daripada tempurung sawit (rGOPKS) < rGO daripada graphit komersil (rGOCG) < rGO daripada tandan kosong kelapa sawit (rGOEFB) dengan nilai I_G/I_D masin-masing 1.06, 1.14, 1.16 and 1.20. Analisis luas permukaan dan isipadu liang bahan-bahan yang disintesis telah dikaji menggunakan keadah penjerapan-penyahjerapan nitrogen Brunauer Emmett Teller (BET). Luas permukaan yang rendah telah didapati untuk rGOCG dan rGOOPL (8 dan 15 m^2g^{-1}) adalah berkemungkinan disebabkan oleh penyusunan semula lapisan GO serta liang yang tersumbat. Secara relatif, luas permukaan BET yang rendah ini tidak penting jika dibanding dengan nilai luas permukaan BET rGOPKS dan rGOEFB, iaitu masing-masing, 114 and 117 m^2 g^{-1}.

Di samping itu, prestasi penyimpanan kuasa elektrokimia oleh rGO dan karbon teraktif yang dihasilkan telah dikaji menggunakan kaedah voltametri berkitar (CV). Didapati bahawa semua rGO dan karbon teraktif menunjukkan prestasi baik sebagai elektrod untuk aplikasi superkapasitor. Salah satu elektrod AC berasaskan OPL menunjukkan nilai kapasiti yang tinggi iaitu 434 F g^{-1} pada 5 mVs^{-1}. Nilai ini lebih tinggi jika dibandingkan dengan nilai kapasiti bahan partikel nanokarbon berasaskan daun kelapa sawit tunggal yang pernah dilaporkan dalam literatur (343 F g^{-1}).

Selain itu, bahan berubah fasa (PCM) baru yang dihasilkan menggunakan komposit grafen oksida terturun (rGOEFB) /karbon teraktif (AC) dan n-nonadekana turut dikaji. Komposit rGOEFB-AC bertindak sebagai matrik sementara n- nonadekana bertindak sebagai bahan berubah fasa yang utama. Pencairan n- nonadekana telah berjaya distabilkan menggunakan karbon matrik berongga melalui daya kapilari dan daya tegang permukaan yang mengurangkan rembesan pencairan n- nonadekana sepanjang kitaran perubahan fasa. Perubahan fasa suhu dan pengumpulan haba komposit masing masing, SCPCM-5 adalah 37.25 dan 25.58 ºC dan 82.72 dan -62.22 J/g. Secara keseluruhannya, bahan-bahan nanokarbon baru yang dihasilkan di dalam kajian ini menunjukkan ciri-ciri unggul untuk digunakan sebagai bahan penyimpanan tenaga haba dan juga tenaga elektrokimia.

ACKNOWLEDGEMENTS

All praises, thanks and glories belong to Almighty Allah alone in whose Hands is the dominion of all things, The Omniscient, the Omnipotent and the Omnipresence for His sustenance and sparing my life to reach this milestone. Alhamdulillah!

Completion of work of this nature would not have been possible without the support of many people. For this reason, I would like to take this golden opportunity to express my heartfelt appreciation to all those people who have helped get me to this point. First and foremost, I must acknowledge my beloved late parents for their lovely support and prayers and setting up the right footings in my life, and my wife for her patience, encouragement, kind hearted support and understanding all the way through. The story of my three year Ph.D. expedition (without the comfort of my wife and son with me in Malaysia) is a one to be sympathetic and emotionally remembered forever.

Secondly, I would like to express my deepest gratitude to Prof. Dr. Mohd Zobir Hussein for his guidance and kind hearted support in this project. The technical discourse with Prof. Zobir was very helpful and incredibly insightful all the time. In fact, I will forever be grateful to him for all the knowledge he has shared with me. His quick and accelerated responses all the time, despite his busy research activities were really appreciated. His encouragement and supervision technique led the project to completion at a great speed. In the same way, I would also like to thank co-members of my supervisory committee; Prof. Dr. Zulkarnain Zainal and Prof. Dr. Nor Azah Yusof, for their tremendous help, insightful comments and marvellous contributions towards the successful completion of this project.

Furthermore, I would also like to thank my lab mates (teammates), the ''NANOMITE'' research group for their help during my laboratory works (experiments). Indeed, it has been a great pleasure and nice working with all of them. In fact, these guys have served as my immediate family here in Malaysia. I am indeed grateful for the friendship and friendly advices and support that you have rendered to me throughout my stay in this beautiful country.

The last but not the least, my sincere appreciation goes to the management and staff of ITMA and UPM at large, for giving me the enabling environment to study. More so, I would also like to forward my deepest appreciations to the Nigerian community in UPM, especially the Town House community of Musollah Al-Abrar, and many others for being sociable and supportive. My nostalgia could have been much horrible without them.

Finally, I would like to thank my employer, the Federal University Dutse (FUD), Nigeria for the Ph.D. study leave.

Eternally yours,
Salisu Nasir

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
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- this thesis has not been submitted previously or concurrently for any other degree at any institutions;
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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

Signature: ______________________________
Name of Chairman of Supervisory Committee: Professor Dr. Mohd Zobir Hussein

Signature: ______________________________
Name of Member of Supervisory Committee: Professor Dr. Zulkarnain Zainal

Signature: ______________________________
Name of Member of Supervisory Committee: Professor Dr. Nor Azah Yusof

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LIST OF ABBREVIATIONS

0-D	Zero Dimensional
1-D	One Dimensional
2-D	Two Dimensional
3-D	Three Dimensional
AC	Activated Carbon
BET	Brunauer-Emmet-Teller
BJH	Barrett– Joyner–Halenda
CG	Commercial Graphite
CV	Cyclic Voltammetry
CVD	Chemical Vapour Deposition
DSC	Differential Scanning Calorimeter
DTG	Differential Thermogravimetric
EDLCs	Electric Double Layer Capacitors
EFB	Empty Fruit Bunch
EFBAC	Empty Fruit Bunch-Derived Activated Carbon
EFB(rGOAC)-M	Reduced Graphene Oxide-Activated Carbon Matrix
EPA	Environmental Protection Agency
ESR	Equivalent Series Resistance
ETES	Electrochemical and Thermal Energy Storage
FAO	Food and Agriculture Organization of the United Nations
FESEM	Field Emission Scanning Electron Microscope
FTIR	Fourier Transforms Infrared Spectroscopy
GCD	Galvanostatic Charge and Discharge
GCE	Glassy Carbon Electrode

GO	Graphene Oxide
GOCG	Graphene Oxide Derived from Commercially Acquired Graphite
GOEFB	Graphene Oxide Derived from Empty Fruit Bunch
GOOPL	Graphene Oxide Derived from Oil Palm Leaves
GOPKS	Graphene Oxide Derived from Palm Kernel Shells
ΔH_f	Enthalpy Change of Freezing
ΔH_m	Enthalpy Change of Melting
HRTEM	High Resolution Transmission Electron Microscopy
I_D/I_G	Ratio of the Intensity of the Raman D-Peak to that of the G-Peak
I_G/I_D	Ratio of the Intensity of the Raman G-Peak to that of the D-Peak
IUPAC	International Union of Pure and Applied Chemistry
J/g	Joule Per Gram
MPOC	Malaysian Palm Oil Council
mV/s	Millivolts Per Second
MWCNT	Multiwall Carbon Nanotubes
nm	Nanometer
OPL	Oil Palm Leaf
OPLAC	Oil Palm Leaf-Derived Activated Carbon
PA	Phosphoric Acid
PCNs	Porous Carbon Nanoparticles
PKS	Palm Kernel Shell
PKSAC	Palm Kernel Shell-Derived Activated Carbon
rGO	Reduced Graphene Oxide
rGOCG	Reduced Graphene Oxide Derived from Commercial Graphite
rGOEFB	Reduced Graphene Oxide Derived from Empty Fruit Bunch

rGOOPL	Reduced Graphene Oxide Derived from Oil Palm Leaves
rGOPKS	Reduced Graphene Oxide Derived from Palm Kernel Shells
rmp	Revolution Per Minute
SEM	Scanning Electron Microscopy
SCPCM	Shape-Stabilized Composite Phase Change Material
SCPCM-1	SCPCM derived from 10 wt % of n-Nonadecane
SCPCM-2	SCPCM derived from 30 wt % of n-Nonadecane
SCPCM-3	SCPCM derived from 50 wt % of n-Nonadecane
SCPCM-4	SCPCM derived from 70 wt % of n-Nonadecane
SCPCM-5	SCPCM derived from 90 wt % of n-Nonadecane
SWCNT	Single Wall Carbon Nanotube
TCE	Thermal Conductivity Enhancer
TES	Thermal Energy Storage
TEM	Transmission Electron Microscopy
TGA	Thermogravimetric Analysis
UN	United Nations
WEC	World Energy Council
wt	Weight
w/v	Weight by Volume
XRD	X-ray Diffraction
µm	Micrometer

CHAPTER 1

INTRODUCTION

1.1 General Background of the Research

Oil palm-derived wastes are often becoming environmental problems in the Southeast Asian developing countries, especially, Malaysia, Indonesia and Thailand. The use of natural bioresources or biomass for carbon-based nanostructures fabrication as well as their energy storage-related applications are currently receiving a great deal of attention [1]. As a result, problems associated with the generation of bio-agricultural wastes are prompting researchers to find ways of utilizing them in order to protect the environment. Most of the natural components (especially those of lignocellulosic inclination) from those wastes can be utilized as carbon sources for creating innovative materials as a function of cost. Thus, high technology industries are compelled to find alternative materials to substitute the conventional materials due to economic and environmental challenges. These alternative materials are believed to hold some advantages over their counterparts (i.e. the conventional materials) in terms of availability/sustainability, renewability, cost effectiveness and compatibility with the natural environment. In summary, the establishments of sustainable and innovative solutions are required to tackle those sprouting problems. The main intention of this thesis is to contribute with new knowledge to a better understanding of the huge potentials of oil palm waste-based biomass materials for the fabrication of carbon-based nanomaterials (graphene oxide, reduced graphene oxide and activated carbons) and to explore their thermal and electrochemical energy storage potentials.

To begin with, nanomaterials (in general) are materials that have distinctive or novel properties, due to the nanoscale structuring. The materials are usually produced by integrating or structuring of nanoparticles. They are subdivided into nanopowders, nanocrystals and nanotubes and can have zero, one, two or three dimensions on the nanoscale. The current interest on nanomaterials is ascribed to the small scale dimension of the materials. Materials with nanoscale size have essentially different properties as compared to the bigger scale and this is attributed to increased surface area to volume ratios. In essence, increased interaction and reactivity is expected with these materials and thus potentially using less of the materials [2].

1.2 Graphitic Nanostructures

Typical graphitic nanostructures comprise graphene, graphene oxides (GO), reduced graphene oxide (rGO), graphene quantum dots (GQDs), carbon nanotubes (CNTs), carbon nanofibers (CNFs), carbon nanohorns and onion-like carbon (OLC). They are usually synthesized using a variety of carbon sources (as the precursors) with different methods. In the context of this thesis, we focus largely on the preparation of GO, rGO and activated carbon with renewable and economical materials (biomass) as carbon source.

1.3 Carbon Nanomaterials at a Glance

An evidence of the synthesis and application of carbon-based materials went back to several centuries ago. The material under discussion encompasses complete and diverse crystallographic structures with various shapes, dimensions, geometries and chemical bonds. A typical example of these materials are but not limited to, various sorts of graphite, synthetic and naturally occurring diamond, activated carbon, carbon-based aerogels, carbon fibres, and their composites, carbon nanotubes, fullerenes, graphene and other graphene-related and derived materials, etc. In recent times, the controlled manipulation, reduction and modification of sample dimension into a small number of nanometers is getting so much attention. Researchers are captivated in the nanoscale due to the fact that physical and chemical properties of materials at nanoscale change considerably from those at a larger scale. Therefore, nanoscaled materials could be designed and developed through the modified, controlled and size-selective production of nanoscale building block with tunable and enhanced physical and chemical properties.

1.4 Carbon Nanomaterials on the Global Energy Perspective

According to world energy council report (WEC) [3], it is projected that the world's population will expand from nearly 7 billion in 2013 to about 8.7 billion in the Jazz scenario and around 9.4 billion in the Symphony scenario in 2050, respectively, which is equivalent to a 26% boost up (36% respectively). As a result, the world energy demand will keep on increasing. It is forecasted that the demand may double by 2050. This calls for a new and efficient means to also double the energy supply in order to meet the challenges that forge ahead. Carbon nanomaterials are believed to be appropriate and promising (when used as energy materials) to cushion the threat. Consequently, the need and the challenge to expand and revolutionize the energy future to clean and sustainable one is enormous and necessary. The future outlook for major energy intermingles in 2050 demonstrates that increase rates will be supreme for renewable energy sources. The contribution of renewable energy supply will rise from approximately 15% in 2010 to about 20% in Jazz in 2050 and nearly 30% in Symphony in 2050. For clarity, ''Jazz as an energy scenario, has a focus on energy equity with priority given to achieving individual access and affordability of energy through economic growth. Symphony as an energy scenario on the other hand has a focus on achieving environmental sustainability through internationally coordinated policies and practices''.

In an attempt to offer a substantial solution to those challenges, to achieve the global aspiration of affordable, sustainable, and secure energy supply for all, this thesis has explored the potential valorization of by-product materials from oil palm to be an alternative and sustainable carbon sources of carbon-based nanomaterials synthesis and energy storage applications.

1.5 Carbon-based Supercapacitors

Energy storage systems are a central pillar for the success of the energy revolution. They contribute significantly to the integration of renewable energies and ensure a stable grid. The field of materials science and nanotechnology has witnessed a significant expansion in recent years across virtually all industrial sectors. This is due to number of key advantages that traditional manufacturing cannot offer. These include mass customization, geometrical complexity, etc. Historically, the first supercapacitor based on double layer mechanism was developed in 1957 by Becker H. I. (an engineer at General Electric) using a porous carbon electrode. Although the mechanism was not known at that time until 1966, however, it was believed that the energy was stored in the pores of the carbon material and it exhibited high capacitance value. Thus, for quite long time, carbon has garnered substantial attention due to its unique properties. It has been identified to comprise of different low-dimension allotropes including graphite, activated carbon, carbon nanotubes, and the C_{60} family of buckyballs, polyaromatic molecules and graphene. This distinctive ability for existence under diverse forms (i.e. from powders to fibres, forms, fabrics and composite) denotes an excellent material for electrochemical applications, particularly for the storage of energy in supercacitors. More so, the amphoteric nature of carbon also allows use of the rich electrochemical properties of this element from donor to acceptor state. In addition, carbon-based materials are eco-friendly. In the last couple of years, a huge attention has been directed on the application of renewable and sustainable carbons sources for electrode materials owing to their accessibility, transformation operational simplicity and inexpensiveness. Mostly, carbon-based materials are chemically stable in different solutions (from strongly acidic to basic) and able for performance in a wide range of temperatures. A well-established chemical and physical method of preparation and activation (as the case may be) allow fabricating materials with a developed surface area and a controlled distribution of pores that influence the electrode/electrolyte interface for electrochemical applications.

In recent times, carbon-based electrode materials for electrochemical capacitors (EC) have been successfully developed owing to the growing demand for an innovative type of accumulators of electrical energy with a high specific power and a long durability. The fundamental benefit of this storage appliance is the capacity of a high dynamic of charge transmission which is essential in the hybrid power sources for electrical vehicles, digital telecommunication systems, UPS for computers, etc. Another important benefits of the EC device is a likelihood of full discharge, and a short-circuit between the two electrodes is also not harmful [4].

In general, carbon nanomaterials (when used as electrode materials for supercapacitors) are very efficient energy conversion and storage devices owing to their good thermal, electrical, mechanical and chemical properties [5–7]. Therefore, they are generally believed to be the potential materials that could solve the global energy demand by 2050. Energy conversion and storage ability could be enhanced using materials with excellent morphological, electrical, optical and mechanical properties. In this study, carbon nanomaterials have been experimentally tested and proven to possess all the requisite qualities needed to be used in this course. It should be emphasized that carbon-based materials were and still are the primary supplier of energy consumed by mankind. In sum, the amazing properties of these materials and greatest potentials towards greener and environment friendly synthesis methods and industrial scale production of carbon nanostructured materials is undoubtedly crucial and can therefore be glimpsed as the focal point of many researchers in science and technology in the 21st century.

1.6 Synthesis, Properties and Applications of carbon nanomaterials

The two foremost approaches employed for the fabrication of carbon nanomaterials like graphene and other graphene-related materials are generally known as the bottom-up and top-down approaches. The quality and the yield of the graphene produced via these methods have a contrasting stance which entirely relies on the how the processes are used. In bottom-up approach, for example the graphene or graphene related materials are mainly generated using uncomplicated carbon molecule such as alkanes (e.g. methane) and alkanols (e.g. ethanol). However, in top-down approach (as employed in this work), graphene or graphene-like material layers are extracted from graphite. The materials produced in this thesis, and their corresponding application, could be extended to address the rising demand of new types of clean and sustainable energy storage systems, especially for electric vehicles with minor or no exhaust emissions.

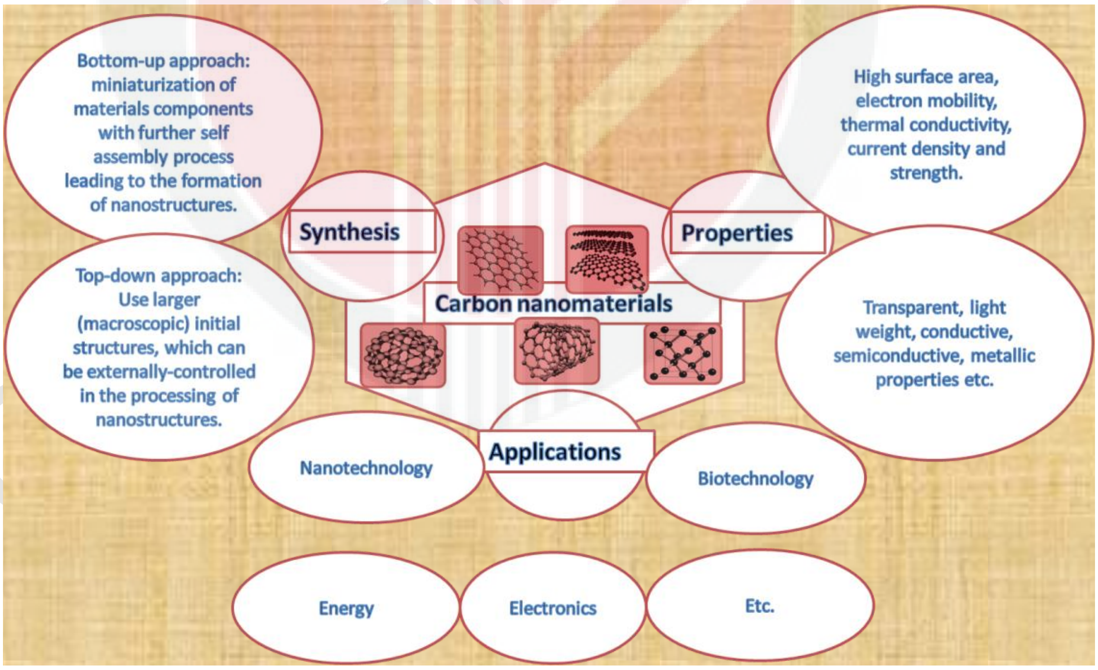

Figure 1.1 : Schematic illustration of synthesis, properties and applications of carbon nanomaterials

1.7 Problem Statement

There is an increasing demand for carbon-based materials, particularly activated carbon, graphene and other graphene-related and derived nanomaterials globally, such as in the automotive, aerospace, energy storage and consumer product industries, etc.

Secondly, Malaysia is one of the world's largest palm oil producers with over 950,000 ha of oil palm land cultivated. It is estimated that annual production of palm oil in Malaysia may reach about 15.4 million tonnes between 2016 to 2020. In essence, a lot of lignocellulosic biomass are generated every day from the oil palm industries. These include oil palm trunks (OPT), oil palm fronds (OPF), empty fruit bunches (EFB) and palm pressed fibres (PPF), palm shells and palm oil mill effluent palm (POME) etc.

It is alarming that the waste generated from oil palm activities is posing major disposal problems concerns.

Consequently, there is a need for technological, cost-effective, energy balance and environmental considerations in a balanced proportion in order to resolve utilization of oil palm wastes.

For this reason and coupled by the researcher's inquisitiveness to explore new knowledge, I felt it was essential to devise an experimental means of enhancing the utilization and production of profitable materials from those 'green wastes' generated by oil palm industries that can match the trendy from 'Wastes to wealth' mantra which is focused towards zero waste industry. This is believed to stimulate economic growth more especially in the developing countries and mitigate environmental degradation, and there by heading towards green technology, which is integrated into global paradigm shift towards sustainable development.

1.8 Objectives

Herein, four objectives were set and will follow the general objective as presented below:

1.8.1 General Objective

The main goal of this project is to produce carbon-based nanomaterials particularly graphene oxide (GO), reduced graphene oxide (rGO) and activated carbon from a low-cost natural carbon feedstock (exclusively oil palm waste precursors) using unique, improved and highly novel process (i.e. energy saving reactions) and explore their new potentials in thermal and electrochemical energy storage applications. This is targeted towards stimulating economic growth (i.e. creating wealth from waste) and mitigating environmental degradation to corroborate with the global paradigm shift towards sustainable development.

1.8.2 Specific Objectives

1. To use a scalable and cost-effective feedstocks and synthetic pathway to produce carbon nanomaterials (graphene oxide, reduced graphene oxide and activated carbon) all from various oil palm waste precursors.
2. To characterize the as-synthesized materials using modern characterization techniques.
3. To assess the appropriate reaction conditions for the synthetic pathways and compare the physico-chemical properties of the as-prepared carbon-based nanomaterials.
4. To evaluate the electrochemical and thermal energy storage (ETES) potentials of the as-prepared materials.

1.9 Hypothesis

Natural precursors as a source of hydrocarbon (which are renewable and inexpensive), have the potentials to be the green alternative for laboratory and industrial scale production of carbon nanomaterials such as graphene, GO, rGO and activated carbon for ETES applications. The perception behind using natural precursors as a carbon feedstock for synthesizing the aforementioned materials is they are cheap, commonly available and have no likelihood of scarcity in the near future. Hence, this work will test the possibility of using oil palm wastes to synthesize carbon-nanostructured materials, particularly GO and rGO (as these materials have never been synthesized from those class of waste before), and AC and test their potential application as electrochemical and thermal energy storage materials

1.10 Scope of the Thesis

This project covered only a selective synthesis and characterization of some carbon nanomaterials (i.e. GO, rGO, and AC) from oil palm-derived byproduct materials. Thermal and electrochemical energy storage system of rGO and the activated carbon were also studied.

1.11 Thesis Layout

This thesis format is organized into six chapters. The first chapter (introduction) gives the general background on carbon nanomaterials; this was followed by a problem statement of this project, general and specific objectives of the work, hypothesis, scope and the thesis layout. The second chapter (Literature review) begins with extensive review of relevant available literature in the area. The first part of this chapter begins with the description of oil palm activities in Malaysia in relation to ligocellulosic waste generation. The second part of the chapter talks about the potential valorization of the by-product materials from oil palm as an alternative carbon sources for carbon-based nanomaterials synthesis, current global energy crisis and the role of carbon-based materials as a useful materials to mitigate this problem. The last part of this chapter describes the commonest synthetic pathways to prepare carbon nanomaterials.

The third chapter focused mainly on the synthesis of graphene oxides and reduced graphene oxides from different oil palm precursors. The results of the synthetic pathways and the conditions were interpreted and discussed under this chapter. This chapter also reported the utility of the as-prepared reduced graphene oxides as carbon-electrode materials for supercapacitors application.

The fourth chapter describes mainly the synthesis and characterization of activated carbon from oil palm leaf and palm kernel shell precursors, and their use as electrode materials for electrochemical energy storage application.

The fifth chapter described the synthesis and application of new, inexpensive framework/ matrix based on n-nonadecane/biomass wastes-derived reduced graphene oxide-activated carbon composites for the preparation of shape–stabilized phase change material. The thermal energy storage potential of the composite material was studied under this chapter.

The sixth or the last chapter is dedicated to the general conclusion and recommendation. Summary of all the results was given here and future recommendations were suggested under this chapter.

REFERENCES

[1] M. Biswal, A. Banerjee, M. Deo, and S. Ogale, “From dead leaves to high energy density supercapacitors,” *Energy Environ. Sci.*, vol. 6, no. 4, pp. 1249–1259, 2013.

[2] M. Kuno, “Introduction to Nanoscience and Nanotechnology: A Workbook,” University of Notre Dame, South Bend, Indiana, USA, 2005.

[3] W. Christoph Frei, Rob Whitney, Hans-Wilhelm Schiffer, Karl Rose, Dan A. Rieser, Ayed Al-Qahtani, Philip Thomas, “World Energy Scenarios: Composing energy futures to 2050,” London W1B 5LT United Kingdom, 2013.

[4] E. Frackowiak and F. Béguin, “Carbon materials for the electrochemical storage of energy in capacitors,” *Carbon N. Y.*, vol. 39, no. 6, pp. 937–950, 2001.

[5] S. Yu, S. G. Jeong, O. Chung, and S. Kim, “Bio-based PCM/carbon nanomaterials composites with enhanced thermal conductivity,” *Sol. Energy Mater. Sol. Cells*, vol. 120, no. PART B, pp. 549–554, 2014.

[6] L. . Dai, D. W. . Chang, J.-B. . Baek, and W. . Lu, “Carbon nanomaterials for advanced energy conversion and storage,” *Small*, vol. 8, no. 8, pp. 1130–1166, 2012.

[7] M. Notarianni, J. Liu, K. Vernon, and N. Motta, “Synthesis and applications of carbon nanomaterials for energy generation and storage,” *Beilstein J. Nanotechnol.*, vol. 7, no. 1, pp. 149–196, 2016.

[8] H. C. Ong, T. M. I. Mahlia, and H. H. Masjuki, “A review on energy scenario and sustainable energy in Malaysia,” *Renew. Sustain. Energy Rev.*, vol. 15, no. 1, pp. 639–647, 2011.

[9] FAO, *The State of Food and Agriculture 2007*, vol. 38. 2007.

[10] R. Corley and P. Tinker, *The Oil Palm*, 4th ed. Oxford, UK: Blackwell Science Ltd., 2003.

[11] E. Barcelos, S. D. A. Rios, R. N. V Cunha, and R. Lopes, “Oil palm natural diversity and the potential for yield improvement,” *Front. Plant Sci.*, vol. 6, no. March, pp. 1–16, 2015.

[12] K. Kiple, Kenneth F.; Conee Ornelas, *The Cambridge World History of Food*. Cambridge, UK: Cambridge University Press, 2000.

[13] F.I. Obahiagbon, “A Review: Aspects of the African Oil Palm (Elaeis Guineensis jacq.) and the Implications of its Bioactives in Human Health,” *Am. J. Biochem. Mol. Biol.*, vol. 2, pp. 106–119, 2012.

[14] C. W. S. Hartley, *The oil palm (Elaeis guineensis Jacq.).*, Third edit. London, United Kingdom: Harlow, Essex, England : Longman Scientific & Technical ; New York : Wiley, 1988, 1988.

[15] Malaysian Government, “The Oil Palm in Malaysia: Report published by the Ministry of Agriculture and Cooperatives, Kuala Lumpur, Government of Malaysia,” 1966.

[16] L. P. Koh and D. S. Wilcove, “Is oil palm agriculture really destroying tropical biodiversity?,” *Conserv. Lett.*, vol. 1, no. 2, pp. 60–64, 2008.

[17] A. S. A. Ferdous Alam, A. C. Er, and H. Begum, “Malaysian oil palm industry: Prospect and problem,” *J. Food, Agric. Environ.*, vol. 13, no. 2, pp. 143–148, 2015.

[18] B. G. Smith, “The Effects of Soil-Water and Atmospheric Vapor-Pressure Deficit on Stomatal Behavior and Photosynthesis in the Oil Palm,” *J. Exp. Bot.*, vol. 40, no. 215, pp. 647–651, 1989.

[19] P. B. Corley, R.H.V., and Tinker, *The Oil Palm*. Oxford: John Wiley& Sons., 2003.

[20] D. J. Murphy, “The future of oil palm as a major global crop: Opportunities and Challenges,” *J. Oil Palm Res.*, vol. 26, no. March, pp. 1–24, 2014.

[21] N. Abdullah and F. Sulaiman, “The oil palm wastes in Malaysia,” in *Biomass Now – Sustainable Growth and Use*, 2013, pp. 75–100.

[22] F. Sulaiman, N. Abdullah, H. Gerhauser, and A. Shariff, “An outlook of Malaysian energy, oil palm industry and its utilization of wastes as useful resources,” *Biomass and Bioenergy*, vol. 35, no. 2011, pp. 3775–3786, 2011.

[23] M. S. Umar, P. Jennings, and T. Urmee, “Generating renewable energy from oil palm biomass in Malaysia: The Feed-in Tariff policy framework,” *Biomass and Bioenergy*, vol. 62, pp. 37–46, 2014.

[24] W. P. Q. Ng, H. L. Lam, F. Y. Ng, M. Kamal, and J. H. E. Lim, “Waste-to-wealth: Green potential from palm biomass in Malaysia,” *J. Clean. Prod.*, vol. 34, no. September 2011, pp. 57–65, 2012.

[25] A. Memari, R. Ahmad, A. R. Abdul Rahim, and M. R. Akbari Jokar, “An optimization study of a palm oil-based regional bio-energy supply chain under carbon pricing and trading policies,” *Clean Technol. Environ. Policy*, vol. 20, no. 1, pp. 113–125, 2018.

[26] M. R. MJ Salifairus, SB Abd Hamid, Salman AH Alrokayan, Haseeb A Khan, “The effect of synthesis time on graphene growth from palm oil as green carbon precursor,” in *AIP Conference Proceedings*, 2016, vol. 1733, p. 020066.

[27] S. Fadzli Abd Rahman, M. R. Mahmood, and A. M. Hashim, "Growth of graphene on nickel using a natural carbon source by thermal chemical vapor deposition," *Sains Malaysiana*, vol. 43, no. 8, pp. 1205–1211, 2014.

[28] N. A. A. M. Robaiah, M. Rusop, S. Abdullah, Z. khusaimi, H. Azhan, "Synthesis of graphene layer at different waste cooking palm oil temperatures," in *4th International Conference on the Advancement of Materials and Nanotechnology*, 2017, p. 010001.

[29] N. U. Tahir, Noor Ayuma Mat, Mohd Fadzli Bin Abdollah, Noreffendy Tamaldin, Hilmi Amiruddin, Takayuki Tokoroyama, "Potential of growing graphene from solid waste products," *Proc. SAKURA Symp. Mech. Sci. Eng. Cent. Adv. Res. Energy*, no. November, pp. 26–28, 2017.

[30] S. Nasir, M. Z. Hussein, N. A. Yusof, and Z. Zainal, "Oil Palm Waste-Based Precursors as a Renewable and Economical Carbon Sources for the Preparation of Reduced Graphene Oxide from Graphene Oxide," *Nanomaterials*, vol. 7, pp. 1–18, 2017.

[31] A. Yogi *et al.*, "Synthesis of Cellulose Nanocrystals from Oil Palm Empty Fruit Bunch by Using Phosphotungstic Acid," in *ICNSE 2017 : 19th International Conference on Nanomaterials Science and Engineering*, 2017, vol. 4, no. 10, p. 74549.

[32] A. A. Azira *et al.*, "Malaysian Palm Oil For Carbon Nanotubes Preparation," *Adv. Mater. Res.*, vol. 667, pp. 343–348, 2013.

[33] A. B. Suriani, A. A. Azira, S. F. Nik, R. Md Nor, and M. Rusop, "Synthesis of vertically aligned carbon nanotubes using natural palm oil as carbon precursor," *Mater. Lett.*, vol. 63, no. 30, pp. 2704–2706, 2009.

[34] A. Khalil, H. P. S. A. Khalil, H. M. Fizree, M. Jawaid, and O. S. Alattas, "Preparation and Characterization of Nano- Structured Materials From Oil Palm Ash: a Bio- Agricultural Waste From Oil Palm Mill," *BioResources*, vol. 6, no. 4, pp. 4537–4546, 2011.

[35] H. M. Abdul Khalil, H.P.S., Md. Sohrab Hossain, Nur Amiranajwa, A.S., Nurul Fazita, M.R., Mohamad Haafiz, M.K., Suraya, N.L.M., Dungani, R. & Fizree, "Production and Characterization of the Defatted Oil Palm Shell Nanoparticles," *Sains Malaysiana*, vol. 45, no. 5, pp. 833–839, 2016.

[36] H. P. S. Abdul Khalil, H. M. Fizree, A. H. Bhat, M. Jawaid, and C. K. Abdullah, "Development and characterization of epoxy nanocomposites based on nano-structured oil palm ash," *Compos. Part B Eng.*, vol. 53, pp. 324–333, 2013.

[37] M. J. N. S. Lani, N. Ngadi, A. Johari, "Isolation, Characterization and Application of nanoCellulose from Oil Palm Empty Fruit Bunch," *J. Nanomater.*, vol. 2014, pp. 1–9, 2014.

[38] C. K. A. H. P. S. Abdul Khalil, Rus Mahayuni A. R., Irshad-ul-Haq Bhat, Rudi D., M. Z. Almulali, "Characterization of Various Organic Waste Nanofillers Obtained from Oil Palm Ash," *Bioresources*, vol. 7, no. 4, pp. 5771–5780, 2012.

[39] H. Kristianto, C. D. Putra, A. A. Arie, M. Halim, and J. K. Lee, "Synthesis and Characterization of Carbon Nanospheres Using Cooking Palm Oil as Natural Precursors onto Activated Carbon Support," *Procedia Chem.*, vol. 16, no. 2015, pp. 328–333, 2015.

[40] H. P. S. Abdul Khalil, M. Jawaid, P. Firoozian, E. S. Zainudin, and M. T. Paridah, "Dynamic Mechanical Properties of Activated Carbon-Filled Epoxy Nanocomposites," *Int. J. Polym. Anal. Charact.*, vol. 18, no. 4, pp. 247–256, 2013.

[41] G. A. M. Ali, S. A. B. A. Manaf, A. Kumar, K. F. Chong, and G. Hegde, "High performance supercapacitor using catalysis free porous carbon nanoparticles," *J. Phys. D. Appl. Phys.*, vol. 47, no. 49, p. 495307, 2014.

[42] R. Farma, M. Deraman, A. Awitdrus, I. A. Talib, E. Taer, and N. H. Basri, "Preparation of highly porous binderless activated carbon electrodes from fibres of oil palm empty fruit bunches for application in supercapacitors," *Bioresour. Technol.*, vol. 132, pp. 254–261, 2013.

[43] K. S. Novoselov, A. K. Geim, S. V Morozov, and D. Jiang, "Electric Field Effect in Atomically Thin Carbon Films," *Science (80-.).*, vol. 306, pp. 666–669, 2004.

[44] S. Iijima, "Helical microtubules of graphitic carbon," *Nature*, vol. 354, pp. 56–58, 1991.

[45] H. W. Kroto, J. R. Heath, S. C. O'Brien, R. F. Curl, and R. E. Smalley, "C 60: buckminsterfullerene," *Nature*, vol. 318, pp. 162–163, 1985.

[46] R. E. Smalley, "Great Balls of Carbon: The Story of Buckminsterfullerene," *Sciences (New. York).*, vol. 31, no. 2, pp. 22–28, 1991.

[47] V. Georgakilas, J. A. Perman, J. Tucek, and R. Zboril, "Broad Family of Carbon Nanoallotropes : Classification, Chemistry, and Applications of Fullerenes, Carbon Dots, Nanotubes, Graphene, Nanodiamonds, and Combined Superstructures," *Chem. Rev.*, vol. 115, pp. 4744–4822, 2015.

[48] F. J. Heiligtag and M. Niederberger, "The fascinating world of nanoparticle research," *Mater. Today*, vol. 16, no. 7–8, pp. 262–271, 2013.

[49] S. Vaddiraju, I. Tomazos, D. J. Burgess, F. C. Jain, and F. Papadimitrakopoulos, "Emerging synergy between nanotechnology and implantable biosensors: A review," *Biosens. Bioelectron.*, vol. 25, no. 7, pp. 1553–1565, 2010.

[50] R. P. Feynman, "There's plenty of room at the bottom," *Eng. Sci.*, vol. 22, pp. 22–36, 1960.

[51] K. E. Drexler, *Engines Of Creation: The coming Era of Technology*, First. New York: Anchor Press, New York, 1986.

[52] L. A. Weiyou Yang, Zhipeng Xie, Hezhuo Miao, Ligong Zhang, Hang Ji, "Synthesis of Single-Crystalline Silicon Nitride Nanobelts Via Catalyst-Assisted Pyrolysis of a Polysilazane," *J. Am. Ceram. Soc.*, vol. 88, no. 2, pp. 466–469, 2005.

[53] L. C. Chen *et al.*, "Crystalline silicon carbon nitride: A wide band gap semiconductor," *Appl. Phys. Lett.*, vol. 72, no. 19, pp. 2463–2465, 1998.

[54] Z. C. M.-J. S. Xinrui Cao, "Si(C≡C)4-Based Single-Crystalline Semiconductor: Diamond-like Superlight and Superflexible Wide-Bandgap Material for the UV Photoconductive Device," *ACS Appl. Mater. Interfaces*, vol. 8(26), pp. 16551–16554, 2016.

[55] C. Lee Ventola, "The Nanomedicine Revolution: Part 3: Regulatory and Safety Challenges," *Pharm. Ther.*, vol. 37, no. 11, pp. 631–639, 2012.

[56] S. Nasir, M. Z. Hussein, Z. Zainal, N. A.Yusof, "Carbon-Based Nanomaterials / Allotropes : A Glimpse of Their Synthesis, Properties and Some Applications," *Materials*, vol. 11, no. 295, pp. 1–24, 2018.

[57] F. Rodríguez-Reinoso, "The role of carbon materials in heterogeneous catalysis," *Carbon N. Y.*, vol. 36, no. 3, pp. 159–175, 1998.

[58] K. S. W. Sing, "Reporting physisorption data for gas/solid systems with special reference to the determination of surface area and porosity (Recommendations 1984)," *Pure Appl. Chem.*, vol. 57, no. 4, pp. 603–619, 1985.

[59] X. Chen, G. Wu, Y. Jiang, Y. Wang, and X. Chen, "Graphene and graphene-based nanomaterials: the promising materials for bright future of electroanalytical chemistry," *Analyst*, vol. 136, pp. 4631–4640, 2011.

[60] Y. Yang, A. M. Asiri, Z. Tang, D. Du, and Y. Lin, "Graphene based materials for biomedical applications," *Mater. Today*, vol. 16, no. 10, pp. 365–373, 2013.

[61] V. P. D. Mrinmoy De, Stanley S. Chou, "Graphene Oxide as an Enzyme Inhibitor: Modulation of Activity of α-Chymotrypsin," *J. Am. Chem. Soc.*, vol. 133, no. 44, pp. 17524–17527, 2011.

[62] J. Liu, L. Cui, and D. Losic, "Graphene and graphene oxide as new nanocarriers for drug delivery applications," *Acta Biomaterialia*, vol. 9, no. 12. pp. 9243–9257, 2013.

[63] M. Pumera, "Graphene in biosensing," *Mater. Today*, vol. 14, no. 7–8, pp. 308–315, 2011.

[64] C. Cha, S. R. Shin, N. Annabi, and M. R. Dokmeci, “Carbon-Based Nanomaterials : Multifunctional Materials for Engineering,” *ACSNano*, vol. 7, no. 4, pp. 2891–2897, 2013.

[65] H. Liu, Y. Zhang, Q. Ke, K. H. Ho, Y. Hu, and J. Wang, “Tuning the porous texture and specific surface area of nanoporous carbons for supercapacitor electrodes by adjusting the hydrothermal synthesis temperature,” *J. Mater. Chem. A*, vol. 1, no. 41, pp. 12962–12970, 2013.

[66] I. A. Khan, A. Badshah, A. A. Altaf, N. Tahir, N. Haider, and M. A. Nadeem, “Acid base co-crystal converted into porous carbon material for energy storage devices,” *RSC Adv.*, vol. 5, no. 12, pp. 9110–9115, 2015.

[67] C. Liu, Z. Yu, D. Neff, A. Zhamu, and B. Z. Jang, “Graphene-based supercapacitor with an ultrahigh energy density,” *Nano Lett.*, vol. 10, no. 12, pp. 4863–4868, 2010.

[68] T. Chen and L. Dai, “Carbon nanomaterials for high- performance supercapacitors,” *Biochem. Pharmacol.*, vol. 16, no. 7–8, pp. 272–280, 2013.

[69] A. Ambrosi, C. K. Chua, A. Bonanni, and M. Pumera, “Electrochemistry of Graphene and Related Materials,” *Chem. Rev.*, vol. 114, p. 7150−7188, 2014.

[70] H. Kim, K.-Y. Park, J. Hong, and K. Kang, “All-graphene-battery: bridging the gap between supercapacitors and lithium ion batteries.,” *Sci. Rep.*, vol. 4, p. 5278, 2014.

[71] Y. Zhu *et al.*, “Carbon-based supercapacitors produced by activation of graphene,” *Science (80-.).*, vol. 332, no. 6037, pp. 1537–1541, 2011.

[72] A. Ramesh, M. Jeyavelan, and M. S. Leo Hudson, “Electrochemical properties of reduced graphene oxide derived through camphor assisted combustion of graphite oxide,” *Dalt. Trans.*, vol. 47, no. 15, pp. 5406–5414, 2018.

[73] S. Nasir, M. Z. Hussein, Z. Zainal, N. A.Yusof, S. A. Mohd Zobir, I. A. Mustapha, “Potential Valorization of By-product Materials from Oil Palm: A review of Alternative and Sustainable Carbon Sources for Carbon-based Nanomaterials Synthesis,” *BioResources*, vol. 14, no. 1, pp. 2352–2388, 2019.

[74] L. Xia, P. Zhang, and R. Z. Wang, “Preparation and thermal characterization of expanded graphite/paraffin composite phase change material,” *Carbon N. Y.*, vol. 48, no. 9, pp. 2538–2548, 2010.

[75] T. Khadiran, M. Z. Hussein, Z. Zainal, and R. Rusli, “Activated carbon derived from peat soil as a framework for the preparation of shape-stabilized phase change material,” *Energy*, vol. 82, pp. 468–478, 2015.

[76] B. Zalba, J. M. Marín, L. F. Cabeza, and H. Mehling, “Review on thermal energy storage with phase change: Materials, heat transfer analysis and applications,” *Appl. Therm. Eng.*, vol. 23, no. 3, pp. 251–283, 2003.

[77] Dincer Ibrahim and M.A. Rosen, *Thermal energy storage systems and applications*, 2nd ed. London: John Wiley & Son, 2011.

[78] M. Kenisarin and K. Mahkamov, "Solar energy storage using phase change materials," *Renew. Sustain. Energy Rev.*, vol. 11, no. 9, pp. 1913–1965, 2007.

[79] P. Schossig, H. M. Henning, S. Gschwander, and T. Haussmann, "Micro-encapsulated phase-change materials integrated into construction materials," *Sol. Energy Mater. Sol. Cells*, vol. 89, no. 2–3, pp. 297–306, 2005.

[80] A. Kürklü, "Energy storage applications in greenhouses by means of phase change materials (PCMs): A review," *Renew. Energy*, vol. 13, no. 1, pp. 89–103, 1998.

[81] M. M. Farid, A. M. Khudhair, S. A. K. Razack, and S. Al-Hallaj, "A review on phase change energy storage: Materials and applications," *Energy Convers. Manag.*, vol. 45, no. 9–10, pp. 1597–1615, 2004.

[82] C. Alkan and A. Sari, "Fatty acid/poly(methyl methacrylate) (PMMA) blends as form-stable phase change materials for latent heat thermal energy storage," *Sol. Energy*, vol. 82, no. 2, pp. 118–124, 2008.

[83] H. Inaba and P. Tu, "Evaluation of thermophysical characteristics on shape-stabilized paraffin as a solid-liquid phase change material," *Heat Mass Transf.*, vol. 32, no. 4, pp. 307–312, 1997.

[84] S. Grandi, A. Magistris, P. Mustarelli, E. Quartarone, C. Tomasi, and L. Meda, "Synthesis and characterization of SiO2-PEG hybrid materials," *J. Non. Cryst. Solids*, vol. 352, no. 3, pp. 273–280, 2006.

[85] S. Jiang, C. Qiao, S. Tian, X. Ji, L. An, and B. Jiang, "Confined crystallization behavior of PEO in organic networks," *Polymer (Guildf).*, vol. 42, no. 13, pp. 5755–5761, 2001.

[86] K. Pielichowski and K. Flejtuch, "Thermal properties of poly(ethylene oxide)/lauric acid blends: A SSA-DSC study," *Thermochim. Acta*, vol. 442, no. 1–2, pp. 18–24, 2006.

[87] G. Song, S. Ma, G. Tang, Z. Yin, and X. Wang, "Preparation and characterization of flame retardant form-stable phase change materials composed by EPDM, paraffin and nano magnesium hydroxide," *Energy*, vol. 35, no. 5, pp. 2179–2183, 2010.

[88] Y. Hong, "Preparation of polyethylene-paraffin compound as a form-stable solid-liquid phase change material," *Sol. Energy Mater. Sol. Cells*, vol. 64, no. 1, pp. 37–44, 2000.

[89] Z. Zhang, N. Zhang, J. Peng, X. Fang, X. Gao, and Y. Fang, "Preparation and thermal energy storage properties of paraffin/expanded graphite composite phase change material," *Appl. Energy*, vol. 91, no. 1, pp. 426–431, 2012.

[90] Z. Chen, F. Shan, L. Cao, and G. Fang, "Synthesis and thermal properties of shape-stabilized lauric acid/activated carbon composites as phase change materials for thermal energy storage," *Sol. Energy Mater. Sol. Cells*, vol. 102, pp. 131–136, 2012.

[91] G. Fang, Z. Chen, and H. Li, "Synthesis and properties of microencapsulated paraffin composites with SiO2shell as thermal energy storage materials," *Chem. Eng. J.*, vol. 163, no. 1–2, pp. 154–159, 2010.

[92] L. Feng, J. Zheng, H. Yang, Y. Guo, W. Li, and X. Li, "Preparation and characterization of polyethylene glycol/active carbon composites as shape-stabilized phase change materials," *Sol. Energy Mater. Sol. Cells*, vol. 95, no. 2, pp. 644–650, 2011.

[93] M. Mehrali, S. T. Latibari, M. Mehrali, H. S. C. Metselaar, and M. Silakhori, "Shape-stabilized phase change materials with high thermal conductivity based on paraffin/graphene oxide composite," *Energy Convers. Manag.*, vol. 67, pp. 275–282, 2013.

[94] B. Li, T. Liu, L. Hu, Y. Wang, and S. Nie, "Facile preparation and adjustable thermal property of stearic acid-graphene oxide composite as shape-stabilized phase change material," *Chem. Eng. J.*, vol. 215–216, pp. 819–826, 2013.

[95] A. Sari, A. Karaipekli, and C. Alkan, "Preparation, characterization and thermal properties of lauric acid/expanded perlite as novel form-stable composite phase change material," *Chem. Eng. J.*, vol. 155, no. 3, pp. 899–904, 2009.

[96] Y. Wang, H. Zheng, H. X. Feng, and D. Y. Zhang, "Effect of preparation methods on the structure and thermal properties of stearic acid/activated montmorillonite phase change materials," *Energy Build.*, vol. 47, pp. 467–473, 2012.

[97] W. Li *et al.*, "Preparation of activated carbon from coconut shell chars in pilot-scale microwave heating equipment at 60 kW," *Waste Manag.*, vol. 29, no. 2, pp. 756–760, 2009.

[98] H. P. Nurten Şahan, Magali Fois, "The effects of various carbon derivative additives on the thermal properties of paraffin as a phase change material," *Int. J. Energy Res.*, vol. 40, no. 2, pp. 198–206, 2016.

[99] S. I. Hussain, R. Dinesh, A. A. Roseline, S. Dhivya, and S. Kalaiselvam, "Enhanced thermal performance and study the influence of sub cooling on activated carbon dispersed eutectic PCM for cold storage applications," *Energy Build.*, vol. 143, pp. 17–24, 2017.

[100] G. H. Zhang, S. A. F. Bon, and C. Y. Zhao, "Synthesis, characterization and thermal properties of novel nanoencapsulated phase change materials for thermal energy storage," *Sol. Energy*, vol. 86, no. 5, pp. 1149–1154, 2012.

[101] S. H. Shuit, K. T. Tan, K. T. Lee, and A. H. Kamaruddin, "Oil palm biomass as a sustainable energy source: A Malaysian case study," *Energy*, vol. 34, no. 9, pp. 1225–1235, 2009.

[102] J. Deng, Y. You, V. Sahajwalla, and R. K. Joshi, "Transforming waste into carbon-based nanomaterials," *Carbon N. Y.*, vol. 96, pp. 105–115, 2016.

[103] J. Deng, M. Li, and Y. Wang, "Biomass-derived carbon: synthesis and applications in energy storage and conversion," *Green Chem.*, vol. 18, no. 18, pp. 4824–4854, 2016.

[104] F. Bonaccorso *et al.*, "2D materials. Graphene, related two-dimensional crystals, and hybrid systems for energy conversion and storage," *Science (80-.).*, vol. 347, no. 6217, pp. 1246501–9, 2015.

[105] S. Gilje, S. Han, M. Wang, K. L. Wang, and R. B. Kaner, "A chemical route to graphene for device applications," *Nano Lett.*, vol. 7, no. 11, pp. 3394–3398, 2007.

[106] X. Wang and Y. Shi, "Fabrication Techniques of Graphene Nanostructures," *Nanofabrication its Appl. Renew. Energy*, no. 32, pp. 1–30, 2014.

[107] A. C. Ferrari *et al.*, "Raman spectrum of graphene and graphene layers," *Phys. Rev. Lett.*, vol. 97, no. 18, pp. 1–4, 2006.

[108] T. Xing *et al.*, "Ball milling: a green mechanochemical approach for synthesis of nitrogen doped carbon nanoparticles.," *Nanoscale*, 2013.

[109] Z. Q. Li, C. J. Lu, Z. P. Xia, Y. Zhou, and Z. Luo, "X-ray diffraction patterns of graphite and turbostratic carbon," *Carbon N. Y.*, vol. 45, no. 8, pp. 1686–1695, 2007.

[110] S. Bae *et al.*, "Roll-to-roll production of 30-inch graphene films for transparent electrodes," *Nat. Nanotechnol.*, vol. 5, no. 8, pp. 574–578, 2010.

[111] A. K. Geim and K. S. Novoselov, "The rise of graphene.," *Nat. Mater.*, vol. 6, no. 3, pp. 183–91, 2007.

[112] U. K. Sur, "Graphene: A Rising Star on the Horizon of Materials Science," *Int. J. Electrochem.*, vol. 2012, pp. 1–12, 2012.

[113] M. J. Sun, X. Cao, and Z. Cao, "Si(C∼C)4-Based Single-Crystalline Semiconductor: Diamond-like Superlight and Superflexible Wide-Bandgap Material for the UV Photoconductive Device," *ACS Appl. Mater. Interfaces*, vol. 8, no. 26, pp. 16551–16554, 2016.

[114] M. V. Jacob *et al.*, "Catalyst-Free Plasma Enhanced Growth of Graphene from Sustainable Sources," *Nano Lett.*, vol. 15, no. 9, pp. 5702–5708, 2015.

[115] G. Ruan, Z. Sun, Z. Peng, and J. M. Tour, "Growth of graphene from food, insects, and waste," *ACS Nano*, vol. 5, no. 9, pp. 7601–7607, 2011.

[116] A. V Kretinin *et al.*, "Electronic properties of graphene encapsulated with different 2D atomic crystals," *Nano Lett.*, 2014.

[117] B. Yuan *et al.*, "A facile method to prepare reduced graphene oxide with a large pore volume," *Mater. Lett.*, vol. 162, pp. 154–156, 2016.

[118] B. C. Brodie, P. Trans, and R. S. Lond, "On the Atomic Weight of Graphite," *Philos. Trans. R. Soc. London*, vol. 149, pp. 249–259, 1859.

[119] W. S. Hummers and R. E. Offeman, "Preparation of Graphitic Oxide," *J. Am. Chem. Soc.*, vol. 80, p. 1339, 1958.

[120] Y. Jiang *et al.*, "Versatile Graphene Oxide Putty-Like Material," *Adv. Mater.*, no. 03284, pp. 1–6, 2016.

[121] L. Liao *et al.*, "High-speed graphene transistors with a self-aligned nanowire gate," *Nature*, vol. 467, no. 7313, pp. 305–308, 2010.

[122] C. Berger *et al.*, "Electronic confinement and coherence in patterned epitaxial graphene," *Science (80-.).*, vol. 312, pp. 1191–1196, 2006.

[123] A. Dimiev and S. Eigler, *Graphene Oxide-Fundamentals and Applications*, First Edit. The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom For: John Wiley & Sons, Ltd, 2017.

[124] Z. Tian *et al.*, "Facile electrochemical approach for the production of graphite oxide with tunable chemistry," *Carbon N. Y.*, vol. 112, pp. 185–191, 2017.

[125] P. Yu *et al.*, "Mechanically-assisted electrochemical production of graphene oxide," *Chem. Mater.*, vol. 28, no. 22, pp. 8429–8438, 2016.

[126] C. Yu *et al.*, "Graphene oxide deposited microfiber knot resonator for gas sensing," *Opt. Mater. Express*, vol. 6, no. 3, pp. 727–733, 2016.

[127] J. W. Han, E. Kim, J. Kim, J. W. Han, and J. Kim, "Reduction of graphene oxide by resveratrol : A novel and simple biological method for the synthesis of an effective anticancer nanotherapeutic molecule," *Int. J. Nanomedicene*, vol. 10, pp. 2951–2969, 2015.

[128] N. Morimoto, T. Kubo, and Y. Nishina, "Tailoring the Oxygen Content of Graphite and Reduced Graphene Oxide for Specific Applications," *Nat. Publ. Gr.*, pp. 4–11, 2016.

[129] M. Salimian *et al.*, "Synthesis and characterization of reduced graphene oxide / spiky nickel nanocomposite for nanoelectronic applications," *J. Mater. Chem. C*, no. 3, pp. 11516–11523, 2015.

[130] M. S. Usman, M. Z. Hussein, S. Fakurazi, and F. F. Ahmad Saad, "Gadolinium-based layered double hydroxide and graphene oxide nano-carriers for magnetic resonance imaging and drug delivery," *Chem. Cent. J.*, vol. 11, no. 1, p. 47, 2017.

[131] R. R. Thangavelu, "Synthesis and Characterization of Reduced Graphene Oxide," *Adv. Mater. Res.*, vol. 678, pp. 56–60, 2013.

[132] D. R. Dreyer, S. Park, W. Bielawski, and R. S. Ruoff, "The chemistry of graphene oxide," *Chem. Soc. Rev.*, vol. 39, pp. 228–240, 2010.

[133] S. Pei and H. Cheng, "The reduction of graphene oxide," *Carbon N. Y.*, vol. 50, no. 9, pp. 3210–3228, 2012.

[134] H. Feng, R. Cheng, X. Zhao, X. Duan, and J. Li, "reduced graphene oxide," *Nat. Commun.*, vol. 4, pp. 1537–1539, 2013.

[135] S. Stankovich *et al.*, "Synthesis of graphene-based nanosheets via chemical reduction of exfoliated graphite oxide," *Carbon N. Y.*, vol. 45, no. 7, pp. 1558–1565, 2007.

[136] B. H. Shin *et al.*, "Efficient Reduction of Graphite Oxide by Sodium Borohydride and Its Effect on Electrical Conductance," *Adv. Funct. Mater.*, vol. 19, pp. 1987–1992, 2009.

[137] Z. Bo *et al.*, "Green preparation of reduced graphene oxide for sensing and energy storage applications," *Sci. Rep.*, pp. 1–8, 2014.

[138] L. Guardia, J. I. Paredes, P. Solı, and J. M. D. Tasco, "Vitamin C is an Ideal Substitute for Hydrazine in the Reduction of Graphene Oxide Suspensions," *J. Phys. Chem. C*, vol. 114, pp. 6426–6432, 2010.

[139] D. Yang *et al.*, "Chemical analysis of graphene oxide films after heat and chemical treatments by X-ray photoelectron and Micro-Raman spectroscopy," *Carbon N. Y.*, vol. 47, no. 1, pp. 145–152, 2009.

[140] D. C. Marcano *et al.*, "Improved Synthesis of Graphene Oxide," *ACSNano*, vol. 4, no. 8, pp. 4806–4814, 2010.

[141] O. Akhavan, K. Bijanzad, and A. Mirsepah, "Synthesis of graphene from natural and industrial carbonaceous wastes," *RSC Adv.*, vol. 4, pp. 20441–20448, 2014.

[142] K. H. Adolfsson, S. Hassanzadeh, and M. Hakkarainen, "Valorization of cellulose and waste paper to graphene oxide quantum dots," *RSC Adv.*, vol. 5, no. 34, pp. 26550–26558, 2015.

[143] Z. Sun, Z. Yan, J. Yao, E. Beitler, Y. Zhu, and J. M. Tour, "Growth of graphene from solid carbon sources," *Nature*, vol. 468, no. 7323, pp. 549–552, 2010.

[144] T. Somanathan, K. Prasad, K. Ostrikov, A. Saravanan, and V. Krishna, “Graphene Oxide Synthesis from Agro Waste,” *Nanomaterials*, vol. 5, no. 2, pp. 826–834, 2015.

[145] Z. G. Zhuangnan Li, Srinivas Gadipelli, Yuchen Yang, “Design of 3D Graphene-Oxide Spheres and Their Derived Hierarchical Porous Structures for High Performance,” *Small*, vol. 1702474, pp. 1–9, 2017.

[146] W. Peng, S. Liu, H. Sun, Y. Yao, L. Zhi, and S. Wang, “Synthesis of porous reduced graphene oxide as metal-free carbon for adsorption and catalytic oxidation of organics in water,” *J. Mater. Chem. A*, vol. 1, no. 19, p. 5854, 2013.

[147] M. Nasar and N. Salisu, “Investigation of Effect of KBr Matrix on Drift Infrared Spectra of Some Minerals,” *ChemSearch J.*, vol. 5, no. 2, pp. 14–19, 2014.

[148] S. Nasir, M. Hussein, Z. Zainal, N. Yusof, and S. Mohd Zobir, “Electrochemical Energy Storage Potentials of Waste Biomass: Oil Palm Leaf- and Palm Kernel Shell-Derived Activated Carbons,” *Energies*, vol. 11, no. 12, p. 3410, 2018.

[149] A. C. Ferrari, “Raman spectroscopy of graphene and graphite : Disorder , electron – phonon coupling , doping and nonadiabatic effects,” *Solid State Commun.*, vol. 143, pp. 47–57, 2007.

[150] F. Tuinstra and L. Koenig, “Raman Spectrum of Graphite,” *J. Chem. Phys.*, vol. 53, no. 1970, pp. 1126–1130, 1970.

[151] A. Ferrari and J. Robertson, “Interpretation of Raman spectra of disordered and amorphous carbon,” *Phys. Rev. B*, vol. 61, no. 20, pp. 14095–14107, 2000.

[152] N. H. Cho *et al.*, “Effects of substrate temperature on chemical structure of amorphous carbon films carbon of substrate films temperature on chemical structure of amorphous,” *J. Appl. Phys.*, vol. 71, pp. 2243–2248, 1992.

[153] B. K. Tay, X. Shi, E. J. Liu, H. S. Tan, and L. K. Cheah, “Effects of substrate temperature on the properties of tetrahedral amorphous carbon films,” *Thin Solid Films*, vol. 346, no. 6090, pp. 155–161, 1999.

[154] H. Budde *et al.*, “Raman Radiation Patterns of Graphene,” *ACS Nano*, vol. 10, p. 1756−1763, 2016.

[155] D. Rudi, P. Aditiawati, S. Aprilia, K. Yuniarti, T. Karliati, I. Suwandhi, and I. Sumardi “Biomaterial from Oil Palm Waste: Properties, Characterization and Applications,” in *Palm Oil*, Rijeka, Crotia: IntechOpen Limited, 2018, pp. 31–51.

[156] X. Zhang, Q. Yan, W. Leng, J. Li, J. Zhang, and Z. Cai, “Carbon Nanostructure of Kraft Lignin Thermally,” *Materials (Basel).*, vol. 10, no. 975, pp. 1–14, 2017.

[157] B. Gupta, N. Kumar, K. Panda, V. Kanan, S. Joshi, and I. Visoly-Fisher, “Role of oxygen functional groups in reduced graphene oxide for lubrication,” *Sci. Rep.*, vol. 7, p. 45030, 2017.

[158] A. M. Dimiev, L. B. Alemany, and J. M. Tour, “Graphene oxide. Origin of acidity, its instability in water, and a new dynamic structural model,” *ACS Nano*, vol. 7, no. 1, 2013.

[159] R. P. Antony, L. K. Preethi, B. Gupta, T. Mathews, S. Dash, and A. K. Tyagi, “Efficient electrocatalytic performance of thermally exfoliated reduced graphene oxide-Pt hybrid,” *Mater. Res. Bull.*, vol. 70, no. October, pp. 60–67, 2015.

[160] W. Chen and P. Kuo, “A study on torrefaction of various biomass materials and its impact on lignocellulosic structure simulated by a thermogravimetry,” *Energy*, vol. 35, no. 6, pp. 2580–2586, 2010.

[161] L. Aziz, A.M., Sabil, M.K., Uemura, Y., and Ismail, “A study on Torrefaction of Oil Palm Biomass,” *J. Appl. Sci.*, vol. 12, no. 11, pp. 1130–1135, 2012.

[162] K. H. Kim, M. Yang, K. M. Cho, Y.-S. Jun, S. B. Lee, and H.-T. Jung, “High quality reduced graphene oxide through repairing with multi-layered graphene ball nanostructures.,” *Sci. Rep.*, vol. 3, p. 3251, 2013.

[163] Z. Lin, G. H. Waller, Y. Liu, M. Liu, and C. ping Wong, “3D Nitrogen-doped graphene prepared by pyrolysis of graphene oxide with polypyrrole for electrocatalysis of oxygen reduction reaction,” *Nano Energy*, vol. 2, no. 2, pp. 241–248, 2013.

[164] K. S. W. Sing, “Reporting physisorption data for gas/solid systems with special reference to the determination of surface area and porosity (Provisional),” *Pure Appl. Chem.*, vol. 54, no. 11, 1982.

[165] X. Zhao *et al.*, “Interconnected 3 D Network of Graphene-Oxide Nanosheets Decorated with Carbon Dots for High-Performance Supercapacitors,” *ChemSusChem*, vol. 10, no. 12, pp. 2626–2634, 2017.

[166] J. Wang, *Analytical Electrochemistry, Second Edition*, vol. 3. New York, USA: John Wiley & Sons, Inc., Publication, 2000.

[167] Y.-Q. Dang, S.-Z. Ren, G. Liu, J. Cai, Y. Zhang, and J. Qiu, “Electrochemical and Capacitive Properties of Carbon Dots/Reduced Graphene Oxide Supercapacitors,” *Nanomaterials*, vol. 6, no. 11, p. 212, 2016.

[168] A. M. Abioye, Z. A. Noorden, and F. N. Ani, “Synthesis and Characterizations of Electroless Oil Palm Shell Based-Activated Carbon/Nickel Oxide Nanocomposite Electrodes for Supercapacitor Applications,” *Electrochim. Acta*, vol. 225, pp. 493–502, 2017.

[169] A. Liverani, "Climate change and individual behavior: considerations for policy," *World Bank Policy Res. Work. Pap. Ser.*, no. September 2009, pp. 1–16, 2009.

[170] N. Oreskes, "E SSAY on Climate Change," *Science (80-.).*, vol. 306, no. January, pp. 2004–2005, 2005.

[171] P. Kalyani and A. Anitha, "Biomass carbon & its prospects in electrochemical energy systems," *Int. J. Hydrogen Energy*, vol. 38, no. 10, pp. 4034–4045, 2013.

[172] R. Kumar, R. K. Singh, and D. P. Singh, "Natural and waste hydrocarbon precursors for the synthesis of carbon based nanomaterials: Graphene and CNTs," *Renew. Sustain. Energy Rev.*, vol. 58, pp. 976–1006, 2016.

[173] J. Deng, M. Li, and Y. Wang, "Biomass-derived Carbon: Synthesis and Application on Energy Storage and Conversion," *Green Chem.*, vol. 18, pp. 4824–4854, 2016.

[174] H. Wang *et al.*, "Supercapacitors based on carbons with tuned porosity derived from paper pulp mill sludge biowaste," *Carbon N. Y.*, vol. 57, pp. 317–328, 2013.

[175] H. Demiral, I. Demiral, B. Karabacakoĝlu, and F. Tümsek, "Production of activated carbon from olive bagasse by physical activation," *Chem. Eng. Res. Des.*, vol. 89, no. 2, pp. 206–213, 2011.

[176] M.-M. Titirici *et al.*, "Sustainable carbon materials.," *Chem. Soc. Rev.*, vol. 44, pp. 250–290, 2015.

[177] M. Z. Hussein, M. B. Abdul Rahman, A. H. Yahaya, Y. H. Taufiq-Yap, and N. Ahmad, "Oil palm trunk as a raw material for activated carbon production," *J. Porous Mater.*, vol. 8, no. 4, pp. 327–334, 2001.

[178] N. S. Nasri, U. D. Hamza, S. N. Ismail, M. M. Ahmed, and R. Mohsin, "Assessment of porous carbons derived from sustainable palm solid waste for carbon dioxide capture," *J. Clean. Prod.*, vol. 71, pp. 148–157, 2014.

[179] M. Jagtoyen and F. Derbyshire, "Activated carbons from yellow poplar and white oak by H3PO4 activation," *Carbon N. Y.*, vol. 36, no. 7–8, pp. 1085–1097, 1998.

[180] M. K. B. Gratuito, T. Panyathanmaporn, R. A. Chumnanklang, N. Sirinuntawittaya, and A. Dutta, "Production of activated carbon from coconut shell: Optimization using response surface methodology," *Bioresour. Technol.*, vol. 99, no. 11, pp. 4887–4895, 2008.

[181] G. M. J.F. Gonza´lez, S. Roma´n, J.M. Encinar, "Pyrolysis of various biomass residues and char utilization for the production of activated carbons," *J. Anal. Appl. Pyrolysis*, vol. 85, pp. 134–141, 2009.

[182] N. A. B. Jabit, “The Production and Characterization of Activated Carbon Using Local Agricultural,” *Carbon N. Y.*, no. June, 2007.

[183] H. Dolas, O. Sahin, C. Saka, and H. Demir, “A new method on producing high surface area activated carbon: The effect of salt on the surface area and the pore size distribution of activated carbon prepared from pistachio shell,” *Chem. Eng. J.*, vol. 166, no. 1, pp. 191–197, 2011.

[184] H. Benaddi, D. Legras, J. N. Rouzaud, and F. Beguin, “Influence of the atmosphere in the chemical activation of wood by phosphoric acid,” *Carbon N. Y.*, vol. 36, no. 3, pp. 306–309, 1998.

[185] E.-S. A. R. Nour T. Abdel-Ghani, Ghadir A. El-Chaghaby, Mohamed H. ElGammal, “Optimizing the preparation conditions of activated carbons from olive cake using KOH activation,” *New Carbon Mater.*, vol. 31, no. 5, pp. 2–10, 2016.

[186] M. Molina-Sabio and F. Rodríguez-Reinoso, “Role of chemical activation in the development of carbon porosity,” *Colloids Surfaces A Physicochem. Eng. Asp.*, vol. 241, no. 1–3, pp. 15–25, 2004.

[187] F. Karacan, U. Ozden, and S. Karacan, “Optimization of manufacturing conditions for activated carbon from Turkish lignite by chemical activation using response surface methodology,” *Appl. Therm. Eng.*, vol. 27, no. 7 SPEC. ISS., pp. 1212–1218, 2007.

[188] M. Thommes *et al.*, “Physisorption of gases, with special reference to the evaluation of surface area and pore size distribution (IUPAC Technical Report),” *Pure Appl. Chem.*, vol. 87, no. 9–10, pp. 1051–1069, 2015.

[189] M. Wu, P. Li, Y. Li, J. Liu, and Y. Wang, “Enteromorpha based porous carbons activated by zinc chloride for supercapacitors with high capacity retention,” *RSC Adv.*, vol. 5, no. 21, pp. 16575–16581, 2015.

[190] S. Bhati, J. S. Mahur, S. Dixit, and O. N. Chobey, “Study on effect of chemical impregnation on the surface and porous characteristics of activated carbon fabric prepared from viscose rayon,” *Carbon Lett.*, vol. 15, no. 1, pp. 45–49, 2014.

[191] M. A. Yahya, Z. Al-Qodah, and C. W. Z. Ngah, “Agricultural bio-waste materials as potential sustainable precursors used for activated carbon production: A review,” *Renew. Sustain. Energy Rev.*, vol. 46, no. November 2016, pp. 218–235, 2015.

[192] Y. Song, J. Liu, K. Sun, and W. Xu, “Synthesis of sustainable lignin-derived mesoporous carbon for supercapacitors using a nano-sized MgO template coupled with Pluronic F127,” *RSC Adv.*, vol. 7, no. 76, pp. 48324–48332, 2017.

[193] R. Wang, P. Wang, X. Yan, J. Lang, C. Peng, and Q. Xue, "Promising porous carbon derived from celtuce leaves with outstanding supercapacitance and CO2 capture performance," *ACS Appl. Mater. Interfaces*, vol. 4, no. 11, pp. 5800–5806, 2012.

[194] K. Wang *et al.*, "Promising biomass-based activated carbons derived from willow catkins for high performance supercapacitors," *Electrochim. Acta*, vol. 166, pp. 1–11, 2015.

[195] Z. Li, D. Wu, Y. Liang, F. Xu, and R. Fu, "Facile fabrication of novel highly microporous carbons with superior size-selective adsorption and supercapacitance properties," *Nanoscale*, vol. 5, no. 22, pp. 10824–10828, 2013.

[196] Y. Hu, X. Tong, H. Zhuo, L. Zhong, and X. Peng, "Biomass-Based Porous N-Self-Doped Carbon Framework/Polyaniline Composite with Outstanding Supercapacitance," *ACS Sustain. Chem. Eng.*, vol. 5, no. 10, pp. 8663–8674, 2017.

[197] A. Kumar, G. Hegde, S. A. B. A. Manaf, Z. Ngaini, and K. V. Sharma, "Catalyst free silica templated porous carbon nanoparticles from bio-waste materials," *Chem. Commun.*, vol. 50, no. 84, pp. 12702–12705, 2014.

[198] C. Zequine *et al.*, "High Per formance and Flexible Supercapacitors based on Carbonized Bamboo Fibers for Wide Temperature Applications," *Sci. Rep.*, vol. 6, no. 1, p. 31704, 2016.

[199] H. Li *et al.*, "Lignin-derived interconnected hierarchical porous carbon monolith with large areal/volumetric capacitances for supercapacitor," *Carbon N. Y.*, vol. 100, pp. 151–157, 2016.

[200] Y. Fang *et al.*, "Two-Dimensional Mesoporous Carbon Nanosheets and Their Derived Graphene Nanosheets: Synthesis and Efficient Lithium Ion Storage," *J. Am. Chem. Soc.*, vol. 135, no. 4, pp. 1524–1530, 2013.

[201] C. Y. Su *et al.*, "Highly efficient restoration of graphitic structure in graphene oxide using alcohol vapors," *ACS Nano*, vol. 4, no. 9, pp. 5285–5292, 2010.

[202] Y. Sun, J. Shen, G. Rice, P. Atanassova, and G. D. Moeser, "High surface area graphitized carbon and processes for making same," 9017837, 2015.

[203] G. Z. Chen, "Understanding supercapacitors based on nano-hybrid materials with interfacial conjugation," *Prog. Nat. Sci. Mater. Int.*, vol. 23, no. 3, pp. 245–255, 2013.

[204] M. Danish, R. Hashim, M. N. M. Ibrahim, and O. Sulaiman, "Optimized preparation for large surface area activated carbon from date (Phoenix dactylifera L.) stone biomass," *Biomass and Bioenergy*, vol. 61, no. 320, pp. 167–178, 2014.

[205] S. R. S. Prabaharan, R. Vimala, and Z. Zainal, "Nanostructured mesoporous carbon as electrodes for supercapacitors," *J. Power Sources*, vol. 161, no. 1, pp. 730–736, 2006.

[206] A. Elmouwahidi, Z. Zapata-Benabithe, F. Carrasco-Marín, and C. Moreno-Castilla, "Activated carbons from KOH-activation of argan (Argania spinosa) seed shells as supercapacitor electrodes," *Bioresour. Technol.*, vol. 111, pp. 185–190, 2012.

[207] Lin G, Jiang J, Wu K, Sun K, "Preparation and characterization of bamboo-based activated carbon by phosphoric acid activation," *Carbon N. Y.*, vol. 70, p. 321, 2014.

[208] V. Subramanian, C. Luo, A. M. Stephan, K. S. Nahm, S. Thomas, and B. Wei, "Supercapacitors from activated carbon derived from banana fibers," *J. Phys. Chem. C*, vol. 111, no. 20, pp. 7527–7531, 2007.

[209] M. P. Bichat, E. Raymundo-Piñero, and F. Béguin, "High voltage supercapacitor built with seaweed carbons in neutral aqueous electrolyte," *Carbon N. Y.*, vol. 48, no. 15, pp. 4351–4361, 2010.

[210] A. E. Ismanto, S. Wang, F. E. Soetaredjo, and S. Ismadji, "Preparation of capacitor's electrode from cassava peel waste," *Bioresour. Technol.*, vol. 101, no. 10, pp. 3534–3540, 2010.

[211] J. Y. and H. F. Li Sun, Chungui Tian, Meitong Li, Xiangying Meng, LeiWang, RuihongWang, "From coconut shell to porous graphene-like nanosheets for highpower supercapacitors supercapacitors," *J. Mater. Chem. A*, vol. 1, pp. 6462–6470, 2013.

[212] M. S. Balathanigaimani, W. G. Shim, M. J. Lee, C. Kim, J. W. Lee, and H. Moon, "Highly porous electrodes from novel corn grains-based activated carbons for electrical double layer capacitors," *Electrochem. commun.*, vol. 10, no. 6, pp. 868–871, 2008.

[213] F. C. Wu, R. L. Tseng, C. C. Hu, and C. C. Wang, "Physical and electrochemical characterization of activated carbons prepared from firwoods for supercapacitors," *J. Power Sources*, vol. 138, no. 1–2, pp. 351–359, 2004.

[214] F. C. Wu, R. L. Tseng, C. C. Hu, and C. C. Wang, "Effects of pore structure and electrolyte on the capacitive characteristics of steam- and KOH-activated carbons for supercapacitors," *J. Power Sources*, vol. 144, no. 1, pp. 302–309, 2005.

[215] Y. Luan, L. Wang, S. Guo, B. Jiang, D. Zhao, H. Yan, C. Tian, H. Fu, "A Hierarchical Porous Carbon Material from a Loofah Sponge Network for High Performance Supercapacitors," *RSC Adv.*, vol. 5, pp. 42430–42437, 2015.

[216] X. Wang *et al.*, “Electrochemical energy storage and adsorptive dye removal of Platanus fruit-derived porous carbon,” *RSC Adv.*, vol. 5, no. 21, pp. 15969–15976, 2015.

[217] M. C. Liu, L. Bin Kong, P. Zhang, Y. C. Luo, and L. Kang, “Porous wood carbon monolith for high-performance supercapacitors,” *Electrochim. Acta*, vol. 60, pp. 443–448, 2012.

[218] B. Chang, Y. Guo, Y. Li, and B. Yang, “Hierarchical porous carbon derived from recycled waste filter paper as high-performance supercapacitor electrodes,” *RSC Adv.*, vol. 5, no. 88, pp. 72019–72027, 2015.

[219] Y. Guo, J. Qi, Y. Jiang, S. Yang, Z. Wang, and H. Xu, “Performance of electrical double layer capacitors with porous carbons derived from rice husk,” *Mater. Chem. Phys.*, vol. 80, no. 3, pp. 704–709, 2003.

[220] E. Raymundo-Piñero, M. Cadek, and F. Béguin, “Tuning carbon materials for supercapacitors by direct pyrolysis of seaweeds,” *Adv. Funct. Mater.*, vol. 19, no. 7, pp. 1032–1039, 2009.

[221] T. E. Rufford, D. Hulicova-Jurcakova, K. Khosla, Z. Zhu, and G. Q. Lu, “Microstructure and electrochemical double-layer capacitance of carbon electrodes prepared by zinc chloride activation of sugar cane bagasse,” *J. Power Sources*, vol. 195, no. 3, pp. 912–918, 2010.

[222] X. Li *et al.*, “Preparation of capacitor’s electrode from sunflower seed shell,” *Bioresour. Technol.*, vol. 102, no. 2, pp. 1118–1123, 2011.

[223] T. E. Rufford, D. Hulicova-Jurcakova, Z. Zhu, and G. Q. Lu, “Nanoporous carbon electrode from waste coffee beans for high performance supercapacitors,” *Electrochem. commun.*, vol. 10, no. 10, pp. 1594–1597, 2008.

[224] D. Kalpana, S. H. Cho, S. B. Lee, Y. S. Lee, R. Misra, and N. G. Renganathan, “Recycled waste paper—A new source of raw material for electric double-layer capacitors,” *J. Power Sources*, vol. 190, no. 2, pp. 587–591, May 2009.

[225] W. H. Chen and P. C. Kuo, “A study on torrefaction of various biomass materials and its impact on lignocellulosic structure simulated by a thermogravimetry,” *Energy*, vol. 35, no. 6, pp. 2580–2586, 2010.

[226] U.S. Energy Information Administration, “International Energy Outlook,” Washington, DC, USA, 2016.

[227] H. Yang, S. A. Memon, X. Bao, H. Cui, and D. Li, “Design and preparation of carbon based composite phase change material for energy piles,” *Materials (Basel).*, vol. 10, no. 4, pp. 1–15, 2017.

[228] H. Cui, W. Liao, S. A. Memon, B. Dong, and W. Tang, “Thermophysical and mechanical properties of hardened cement paste with microencapsulated phase change materials for energy storage,” *Materials (Basel).*, vol. 7, no. 12, pp. 8070–8087, 2014.

[229] Z. Dong, H. Cui, W. Tang, D. Chen, and H. Wen, “Development of hollow steel ball macro-encapsulated PCM for thermal energy storage concrete,” *Materials (Basel).*, vol. 9, no. 1, 2016.

[230] T. Abbasi and S. A. Abbasi, “Decarbonization of fossil fuels as a strategy to control global warming,” *Renew. Sustain. Energy Rev.*, vol. 15, no. 4, pp. 1828–1834, 2011.

[231] R. J. White, *The Search for Functional Porous Carbons from Sustainable Precursors*, RSC Green. Universität Freiburg, FMF - Freiburger Materialforschungszentrum, Stefan-Meier-Straße 21, 79104 Freiburg im Breisgau. Institut für Anorganische und Analytische Chemie, Albertstrasse 21, 79104 Freiburg, Germany E-mail: robin.white@fmf.uni-freiburg.de: © The Royal Society of Chemistry 2015, 2015.

[232] P. Zhang, Y. Hu, L. Song, H. Lu, J. Wang, and Q. Liu, “Synergistic effect of iron and intumescent flame retardant on shape-stabilized phase change material,” *Thermochim. Acta*, vol. 487, no. 1–2, pp. 74–79, 2009.

[233] T. Khadiran, M. Z. Hussein, Z. Zainal, and R. Rusli, “Advanced energy storage materials for building applications and their thermal performance characterization: A review,” *Renew. Sustain. Energy Rev.*, vol. 57, pp. 916–928, 2016.

[234] M. Z. Hussein, T. Khadiran, Z. Zainal, and R. Rusli, “Properties of N-Octadecane-Encapsulated Activated Carbon Nanocomposite for Energy Storage Medium : The Effect of Surface Area and Pore Structure Properties of N-Octadecane-Encapsulated Activated Carbon Nanocomposite for Energy Storage Medium : The Effect,” *Aust. J. Basic Appl. Sci.*, vol. 9, no. 8, pp. 82–88, 2015.

[235] P. González-garcía, T. A. Centeno, E. Urones-garrote, D. Ávila-brande, and L. C. Otero-díaz, “Microstructure and surface properties of lignocellulosic-based activated carbons,” *Appl. Surf. Sci.*, vol. 265, pp. 731–737, 2013.

[236] T. R. Whiffen and S. B. Riffat, “A review of PCM technology for thermal energy storage in the built environment: Part I,” *Int. J. Low-Carbon Technol.*, vol. 8, no. 3, pp. 147–158, 2013.

[237] M. Mehrali *et al.*, “From rice husk to high performance shape stabilized phase change materials for thermal energy storage,” *RSC Adv.*, vol. 6, no. 51, pp. 45595–45604, 2016.

[238] M. A. Pimenta, G. Dresselhaus, M. S. Dresselhaus, L. G. Cançado, A. Jorio, and R. Saito, "Studying disorder in graphite-based systems by Raman spectroscopy," *Phys. Chem. Chem. Phys.*, vol. 9, no. 11, pp. 1276–1291, 2007.

[239] L. Zhang, J. Zhu, W. Zhou, J. Wang, and Y. Wang, "Thermal and electrical conductivity enhancement of graphite nanoplatelets on form-stable polyethylene glycol/polymethyl methacrylate composite phase change materials," *Energy*, vol. 39, no. 1, pp. 294–302, 2012.

[240] A. S. L. M.J. Mochane, "The effect of expanded graphite on the thermal stability, latent heat, and flammability properties of EVA/wax phase change blends," *Polym. Eng. Sci.*, pp. 1–8, 2015.

BIODATA OF STUDENT

The researcher was born and grew up in a small rural town called Babura, on the north edge of Jigawa State, Nigeria. At the age of five in 1989 he was enrolled into Babura Arewa Primary School (BAPS) and finished in 1995. From BAPS, he proceeded to a Government Secondary School for his junior school education in the same town. Upon completion of junior school education at the age of fourteen, he moved to Science Secondary School Kafin-Hausa also in Jigawa State, where he completed his secondary school education at the age of seventeen. After finishing secondary school, Nasir worked as a clerical officer at the Jigawa State Investment and Property Development Company Ltd., before he moved to Kano, where he gained a first degree in Chemistry from the famous Bayero University, Kano (a.k.a. BUK) in 2009. Upon successful completion of one year mandatory National Youth Service (NYSC) in 2010 at the Nigerian National Petroleum Corporation (NNPC), he was awarded a Scholarship by the Petroleum Technology Development Fund (PTDF) to study in the United Kingdom. Under this award (Scholarship), he earned a master's degree in Petroleum Geochemistry from the University of Newcastle upon Tyne in 2011. He started a lecturing career as assistant lecturer in January 2013 at the Department of Chemistry, Faculty of Science, Federal University Dutse, Nigeria. He continued his postgraduate at the PhD level in April 2016 at the Institute of Advanced Technology (ITMA), University Putra Malaysia, under the able supervision of Prof. Dr. Mohd Zobir Hussein. His research topic was ''Valorization of oil palm by-product materials as a new sustainable carbon source for carbon-based nanomaterials synthesis and energy storage applications''. He's happily married to Rahmah binti Sabo Yusuf and blessed with a child named Muhammad Nasir II (a.k.a. Affan).

LIST OF PUBLICATIONS

Publications

Nasir Salisu, Hussein Mohd Zobir, Yusof Nor Azah and Zainal Zulkarnain. Oil Palm Waste-Based Precursors as a Renewable and Economical Carbon Sources for the Preparation of Reduced Graphene Oxide from Graphene Oxide. ***Nanomaterials*** **2017**, *7*, 1–18. Doi: 10.3390/nano7070182. **Q1, IF: 4.034**

Nasir Salisu, Hussein Mohd Zobir, Zainal Zulkarnain and Yusof Nor Azah. Carbon-Based Nanomaterials / Allotropes : A Glimpse of Their Synthesis, Properties and Some Applications. ***Materials*** **2018**, *11* (295), 1–24. Doi: 10.3390/ma11020295. **Q2, IF: 2.972**

Nasir Salisu, Hussein Mohd Zobir, Zainal Zulkarnain, Yusof Nor Azah and Mohd Zobir, Syazwan Afif. Electrochemical Energy Storage Potentials of Waste Biomass: Oil Palm Leaf- and Palm Kernel Shell-Derived Activated Carbons. ***Energies*** **2018**, *11*, 3410. Doi.org/10.3390/en11123410. **Q2, IF: 2.707**

Nasir Salisu, Hussein Mohd Zobir, Zainal Zulkarnain, Yusof Nor Azah, Mohd Zobir, Syazwan Afif and Alibe Mustapha Ibrahim. Potential valorization of by-product materials from oil palm: A review of alternative and sustainable carbon sources for carbon-based nanomaterials synthesis. ***BioResources*** **2019**, 14(1), 2352-2388. Doi: 10.15376biores.14.1.Nasir. **Q2, IF: 1.396**

Nasir Salisu, Hussein Mohd Zobir, Zainal Zulkarnain and Yusof Nor Azah. Preparation of Shape-Stabilized Phase Change Material by Valorization of Oil Palm Waste: Reduced Graphene Oxide-Activated Carbon Derived Carbon Matrix for Thermal Energy Storage. ***BioResources*** **2019**, manuscript accepted for publication. **Q2, IF: 1.202**

Nasir Salisu, Hussein Mohd Zobir, Zainal Zulkarnain and Yusof Nor Azah. Development of New Carbon-based Electrode Material from Oil Palm Wastes-derived Reduced Graphene Oxide and Its Capacitive Performance Evaluation. ***Journal of Nanomaterials*** **2019**, manuscript submitted. **Q3, IF: 2.233**

Proceedings/Oral/Poster Presentation

Nasir Salisu and Mohd Zobir Hussein. Raman spectroscopy and X-ray diffraction studies of graphite-like materials produced by Pyrolysis of oil palm byproducts. *Workshop on Advanced Materials and Nanotechnology (WAMN 2016): Co-organised by the National Nanotechnology Directorate, Ministry of Science, Technology and Innovation Malaysia and ITMA. Held on 24th -25th August 2016.* **Poster Presentation**

Nasir Salisu, Hussein Mohd Zobir, Yusof Nor Azah and Zainal Zulkarnain. Oil palm waste-based precursors as a sustainable, economical and renewable carbon sources in the preparation of graphene oxide. *Symposium on Advanced Materials and Nanotechnology (SAMN 2017)*: *Organized by Functional Devices Laboratory (FDL), Institute of Advanced Technology (ITMA), UPM, 18th -19th July 2017.* **Oral Presentation**