# Electroactive textile supercapacitor electrodes for renewable energy storage

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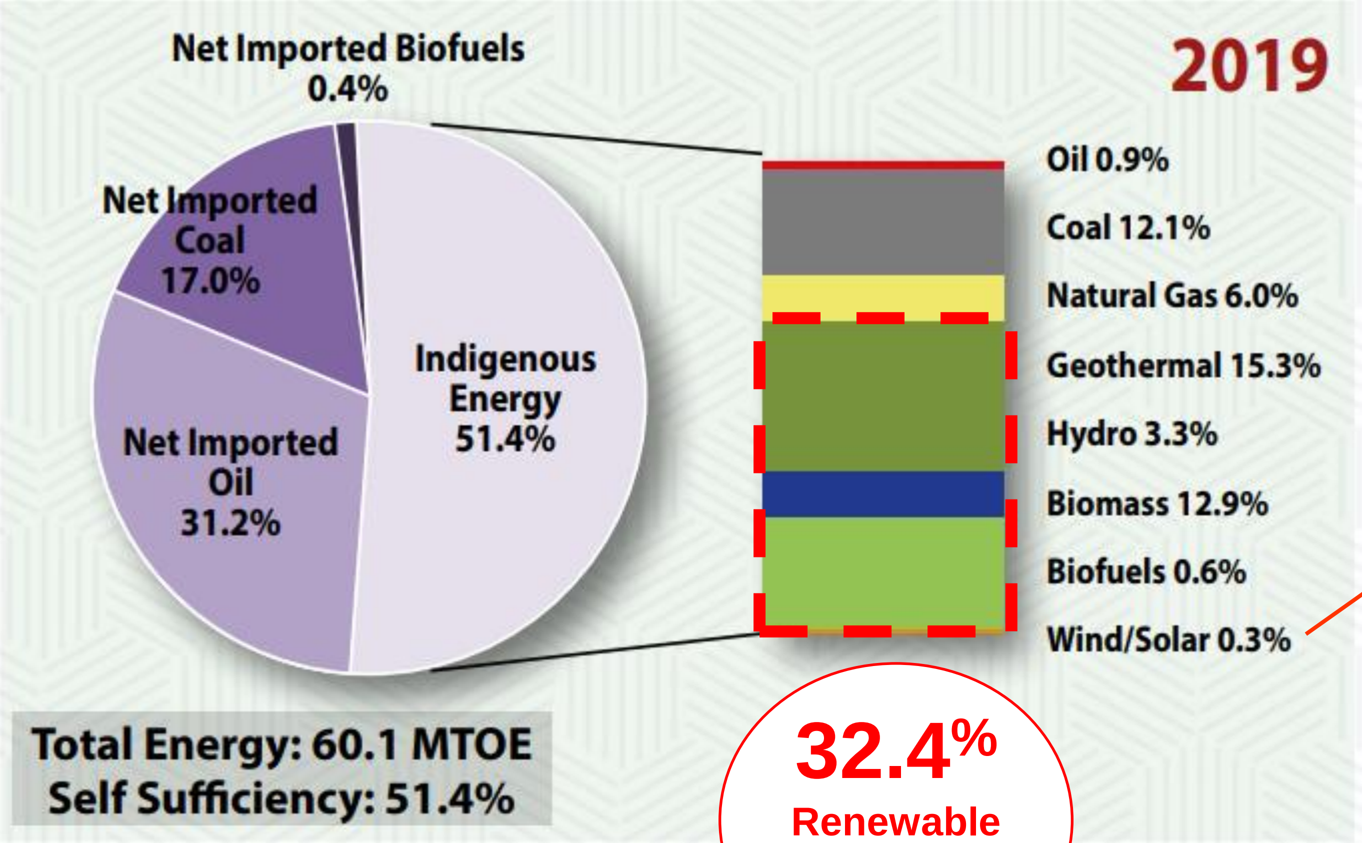
*Science for Change: Niche Centers in the Regions for R&D (NICER)*

# Philippine Energy Industry Background

## Sources of Energy Supply




DOE, *Philippine Energy Situationer & Key Energy Statistics*, **2019**

**32.4%**
**Renewable Sources of Energy**


PhilSolar, n.d.

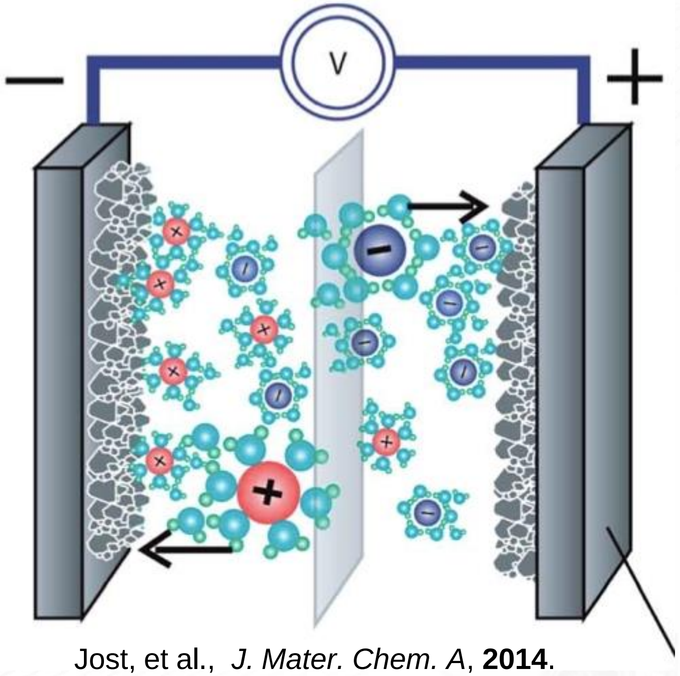
## Problems

- Not available during high energy demand
- Highly variable and provides uneven power
- Batteries charge slowly and have short lifespan

# Supercapacitors

**Solution:**
**Improve Energy Storage Devices**
✓ **Batteries**
✓ **Supercapacitors**

## Supercapacitor
- **Stores energy by charge separation on the surface of its electrodes**
- **Quick charge and discharge cycles (seconds)**
- **Can easily adjust to current variations**



Jost, et al., *J. Mater. Chem. A*, **2014**.

## Supercapacitor Parts
- **Current Collector**
- **Electrolyte**
- **Separator**
- **Electrode Material**

## Ideal Electrode Material
- **Conducting**
- **High surface area & porosity**
- **High capacitance**

(Wang et al., *Chem.Soc.Rev.*, **2012**)

# Solution: Composite Materials

## Natural Fiber-Polyester Blended Textiles

- ✓ Flexible and porous (Hu et al., *Nano Letters*, **2010)**
- ✓ High surface area, 3D materials (Firoz Babu et al., *Carbohydr. Polym.*, **2013)**
- x Insulators

### Natural Fibers

- Cellulosic in nature
- hydrophillic

### Polyester Fibers

- Poly(ethylene terephthalate)
- hydrophobic

## Carbon Materials

- MWCNTs or biochar

- ✓ Modest to excellent conductivity
- ✓ High surface area
- ✓ Durable
- ✓ Good chemical stability
- ✓ Long cycle life

- x Moderate capacitance values (~10 to 100x lower than CPs and metal oxides) (Wang et al., *Chem.Soc.Rev.*, 2012)

## Conducting Polymers

- Polyaniline or Polypyrrole

- ✓ Interesting redox properties
- ✓ Low cost
- ✓ High theoretical capacitance
- ✓ Good conductivity
- ✓ Easy to synthesize

- x Poor cyclic stability
- x Poor mechanical properties
- x Brittle

(Luo et al., 2020; Ryu et al., 2021; Yilmaz Erdogan et al., 2020; Liu et al., 2018; D. Sun et al., 2020; Yang et al., 2018)

# Pineapple- and Water Hyacinth-Polyester Composite Fabrics as Supercapacitor Electrode Materials

Felicidad Christina Ramirez,[1,2,3] Sangaraju Shanmugam,[4] and Christina A. Binag[1,2,3]

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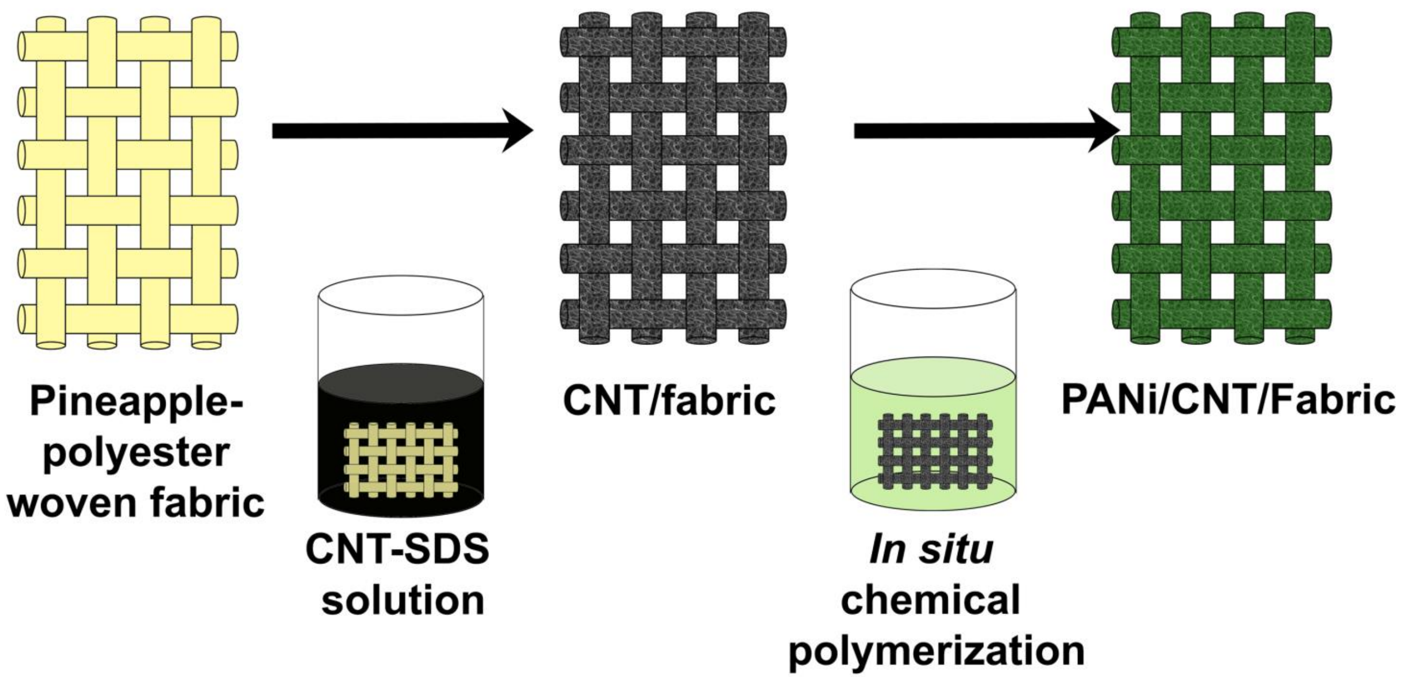
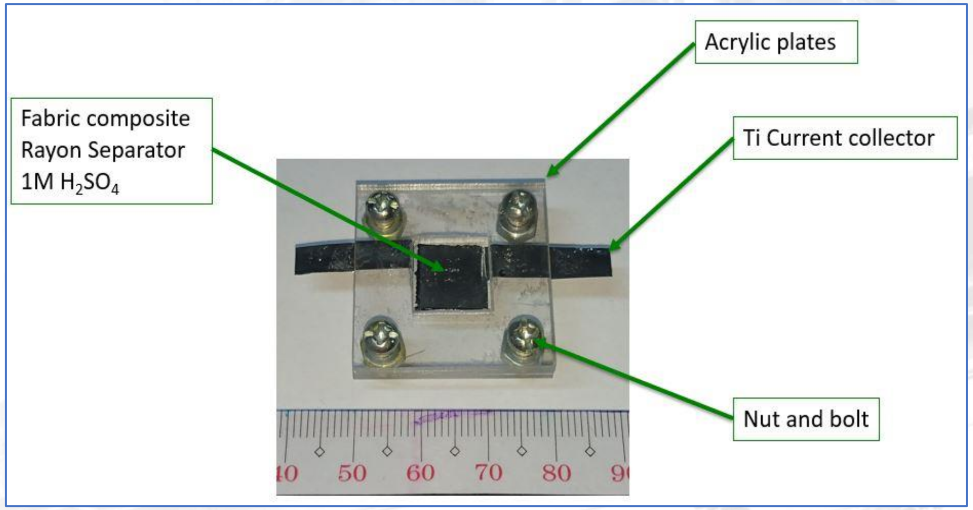
*University of Santo Tomas, Manila 1015, Philippines*
[4]*Department of Energy Systems Engineering, Daegu Gyeongbuk Institute of Science and Technology, Daegu, 711873 South Korea*

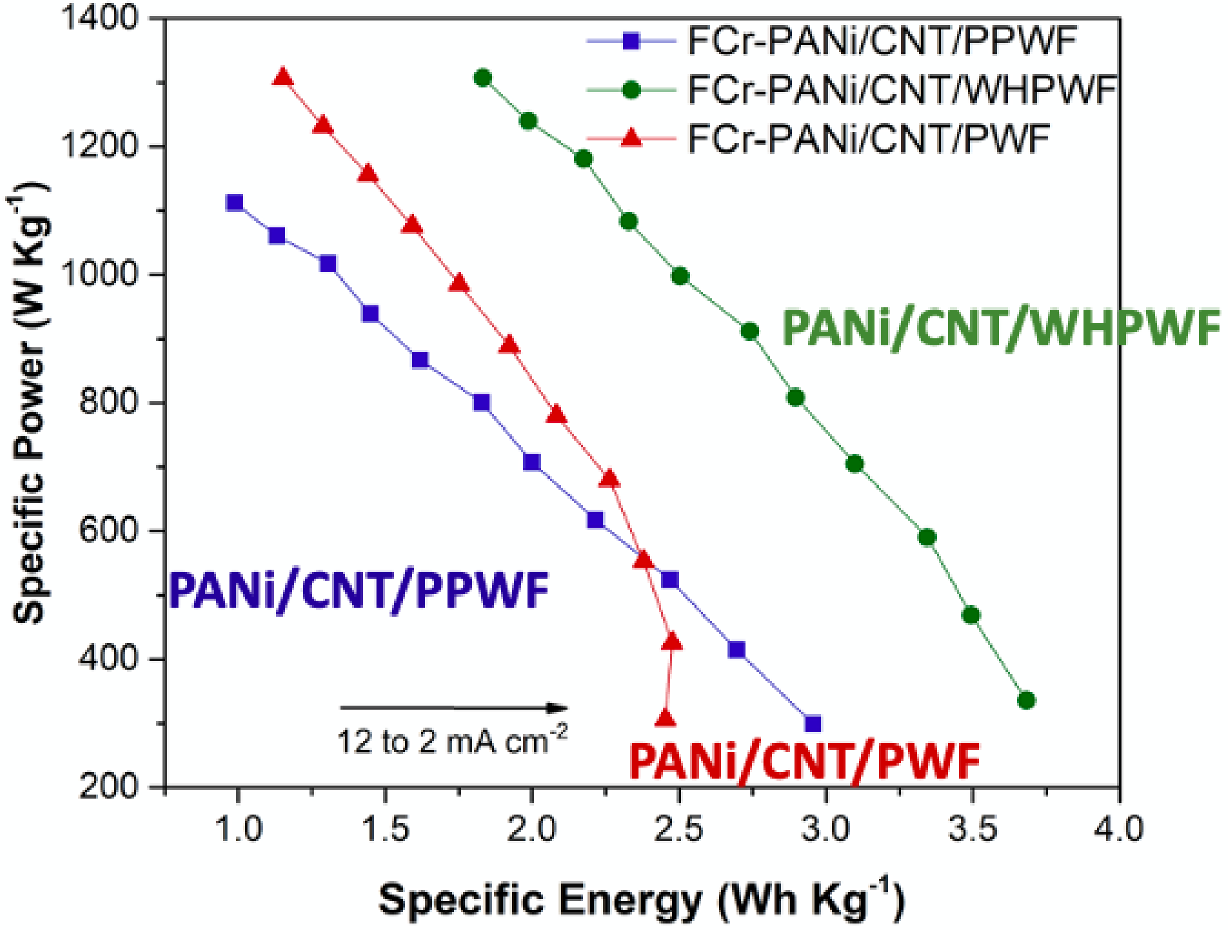
# Preparation of Composite Fabrics



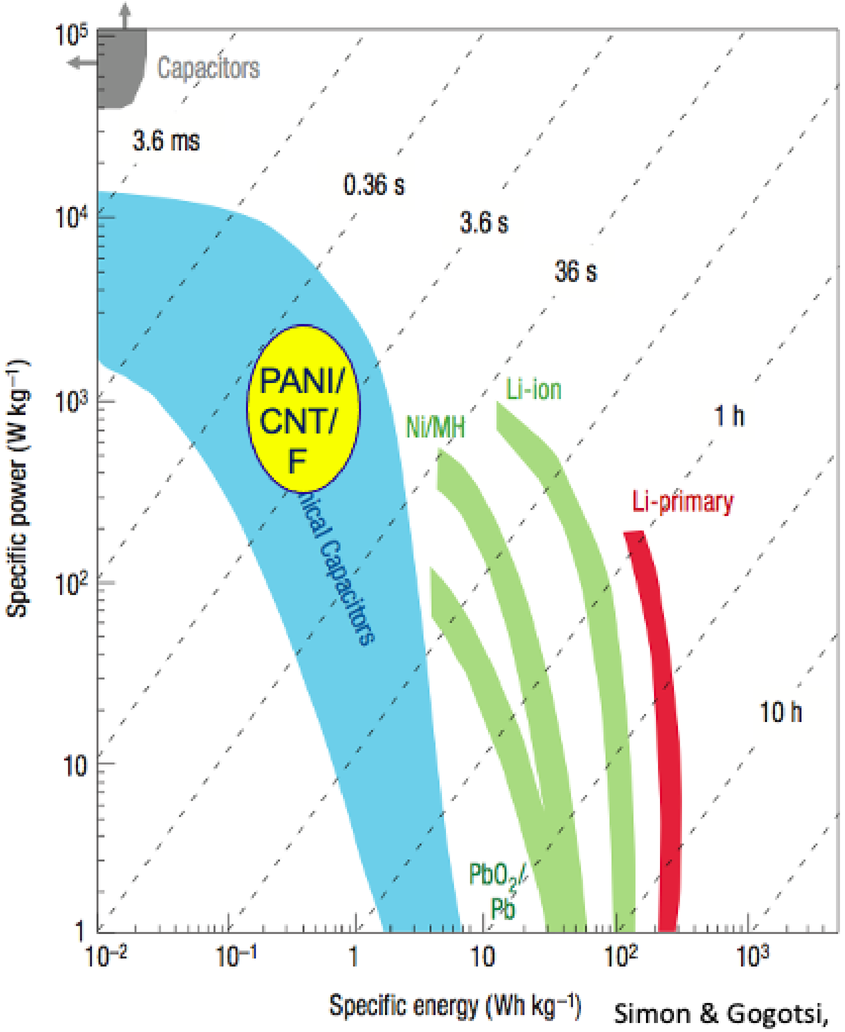




Ramirez, F. C., Ramakrishnan, P., Flores-Payag, Z. P., Shanmugam, S., & Binag, C. A. (2017). Polyaniline and carbon nanotube coated pineapple-polyester blended fabric composites as electrodes for supercapacitors. *Synthetic Metals*, *230*, 65–72. https://doi.org/10.1016/j.synthmet.2017.05.005

# GCD Characterization of Device

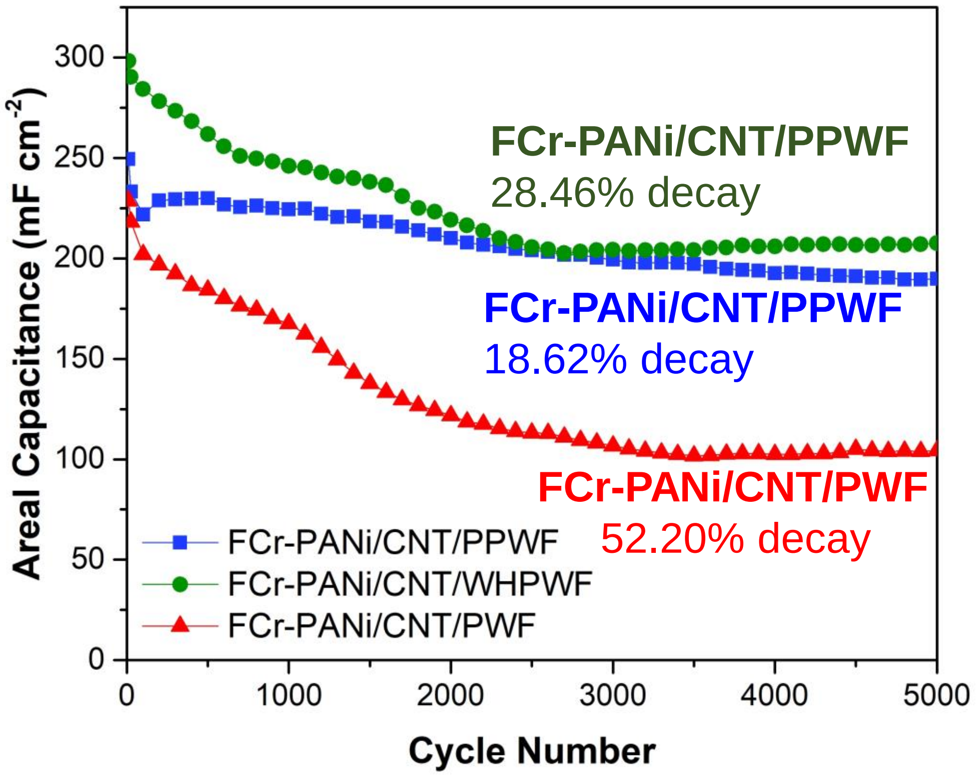



## Ragone Plot



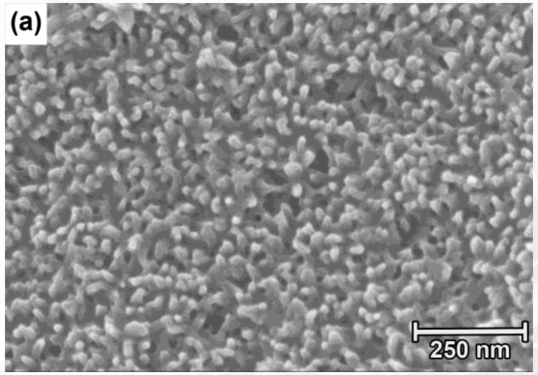

Simon & Gogotsi, *Nature Materials*, **2008**

# Cycling Stability after 5000 cycles

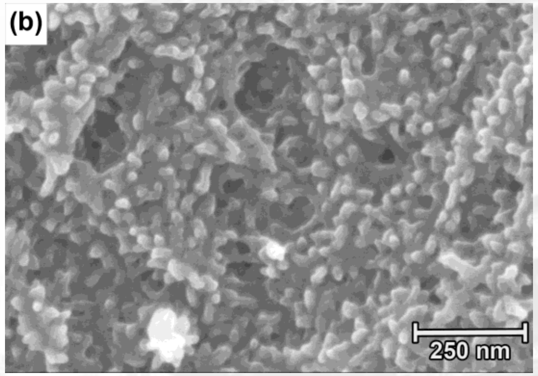



- **FCr-PANi/CNT/PPWF exhibited the lowest areal capacitance decay after 5000 GCD cycles at 4 mA $cm^{-2}$.**

**PANi/CNT/PPWF**




**Before 5000 cycles**




**After 5000 cycles**

# Highly Porous Carbon from Abaca Fibers for Supercapacitor Electrode Applications

Felicidad Christina Ramirez-Peñafiel[1,2], Christina A. Binag[1,2,3], and Sangaraju Shanmugam[4]

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[2]Advanced and Nano Materials Laboratory, Research Center for the Natural and Applied Sciences, University of Santo Tomas, España, Manila 1015, Philippines

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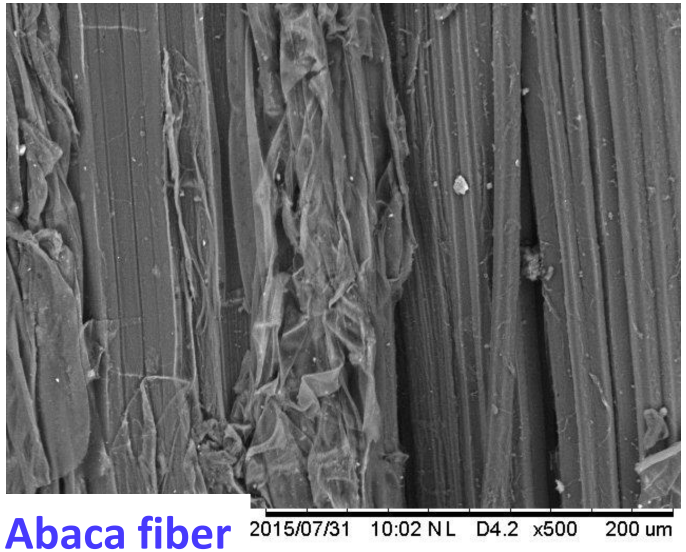
[4]Department of Energy Science and Engineering, Daegu Gyeongbuk Institute of Science and Technology (DGIST), 50-1, Sang-Ri, Hyeonpung-Myeon, Dalseong-Gun, Daegu 42988, Republic of Korea

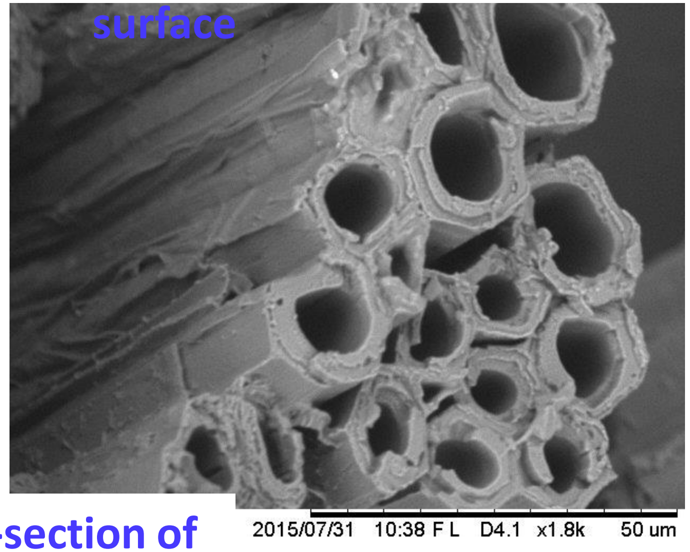
# Abaca Fiber

- Leaf fiber of *Musa textilis*
- Excellent mechanical properties, saltwater resistance, and **high porosity**
- Used in the production of ropes, specialty papers, textiles, furniture, composites, handicrafts, and industrial applications
- The Philippines supplies **87%** of the world's demand and produced **52,962 tons** in 2020 (PhilFida, Fiber Statistics, 2020)
- SEM images show the **rough** surface of the fibers and composed of **tubes** clustered together

**SEM Images**

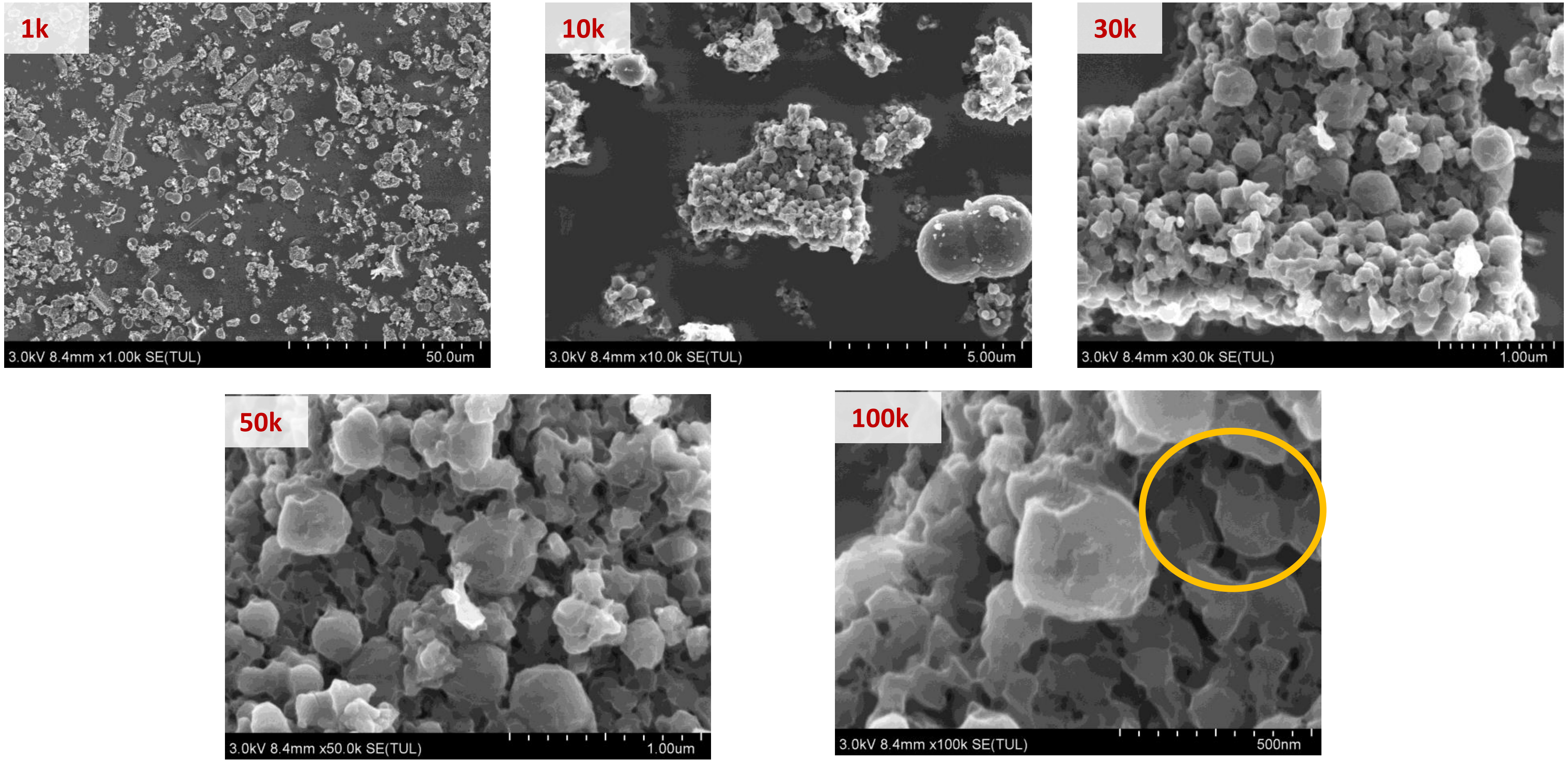



**Abaca fiber surface**



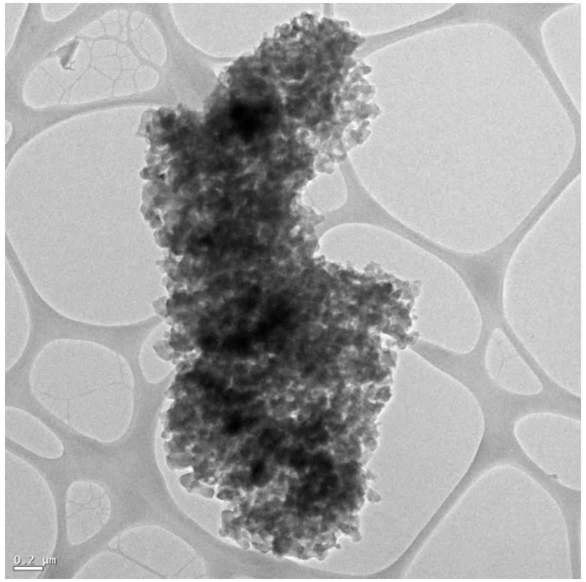

**Cross-section of Abaca fiber**

# Surface Morphology

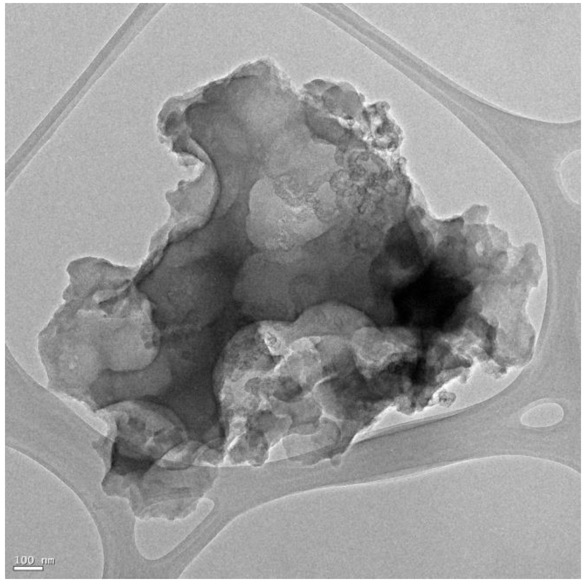



- Globular structure with multiple pores

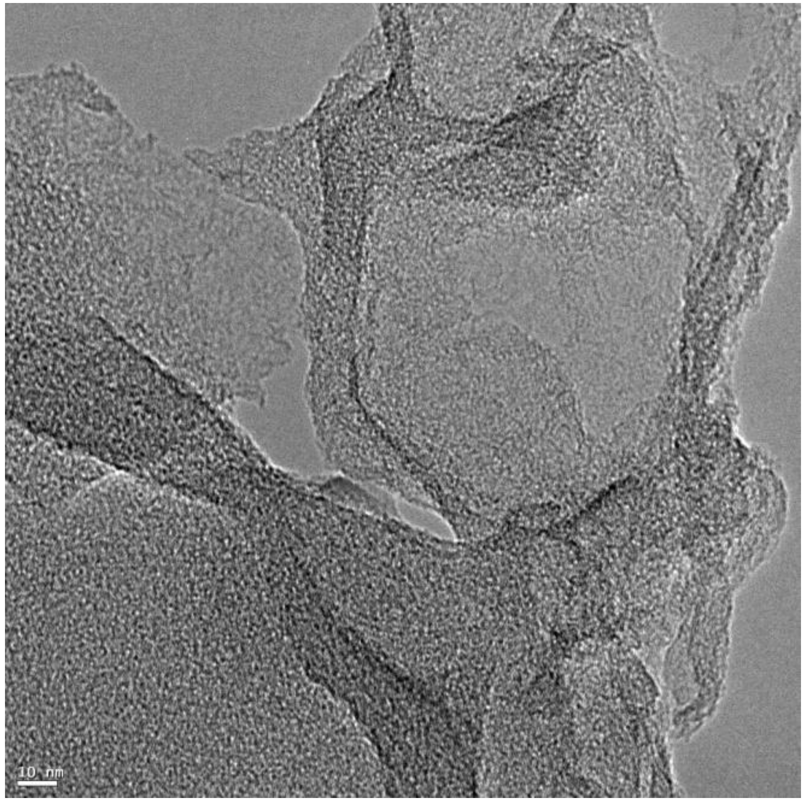
# TEM Micrographs



0.2 um



100 nm



10 nm

- Highly porous internal structure following a honeycomb-like arrangement
- Composed of thin sheet-like structures

# Comparison with Other Studies

| Carbon Material | SSA ($m^2/g$) | Specific Capacitance (F/g) | Electrolyte & Cell Configuration | Reference |
|---|---|---|---|---|
| Abaca Carbon | 1915 | 184 at 1 A/g | 1M $H_2SO_4$, 6M KOH, 3E-GCD | **This study** |
| **Hemp Carbon Nanosheets** | **2287** | **106** at 10 A/g | Ionic liquid, 2E-GCD | Wang et al., *ACS Nano*, 2013 |
| **Poplar Carbon Nanosheets** | **1612** | **508** at 1 A/g | 6M KOH, 3E-GCD | Liu et al., *Carbon*, 2019 |
| ***Syzygium oleana* leaves Carbon Nanosheets** | **1138** | **188** at 1 mV/s | 1M $H_2SO_4$, 2E-CV | Taer et al., *Journal of Materials Research and Technology*, 2020 |
| **Peanut Shells Porous Carbons** | **3246** | **280** at 1 A/g | 6M KOH, 3E-GCD | Zhan et al., *Journal of Alloys and Compounds*, 2021 |
| ***Metaplexis japonica* microporous active carbon** | **2210** | **287** at 1 A/g | 6M KOH, , 3E-GCD | Li et al., *Diamond & Related Materials*, 2021 |

RCNAS
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# Polypyrrole / Rice Straw Biochar / Natural Fiber – Cotton Fabrics for Supercapacitor Applications

David Joseph G. Alzate[1,2], Angelico Tolentino[2], Hidenori Tomimatsu[2], Felicidad Christina R. Peñafiel[2,3], and Christina A. Binag[1,2,3]

[1]The Graduate School; [2]Research Center for the Natural and Applied Sciences;
[3]Department of Chemistry, College of Science; University of Santo Tomas, España, Manila, Philippines

# Preparation

Rice straw

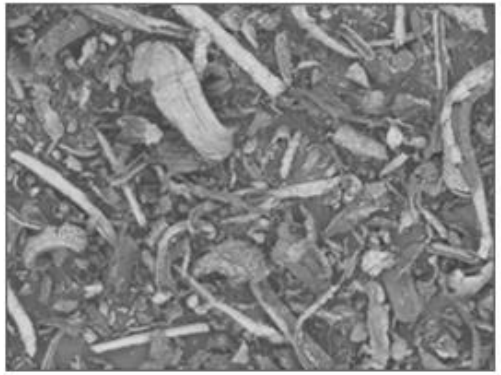
- Sourced from Nueva Ecija
- Sun-dried
- Crushed and sieved finely

Pyrolyzed under inert atmosphere

Post treatment

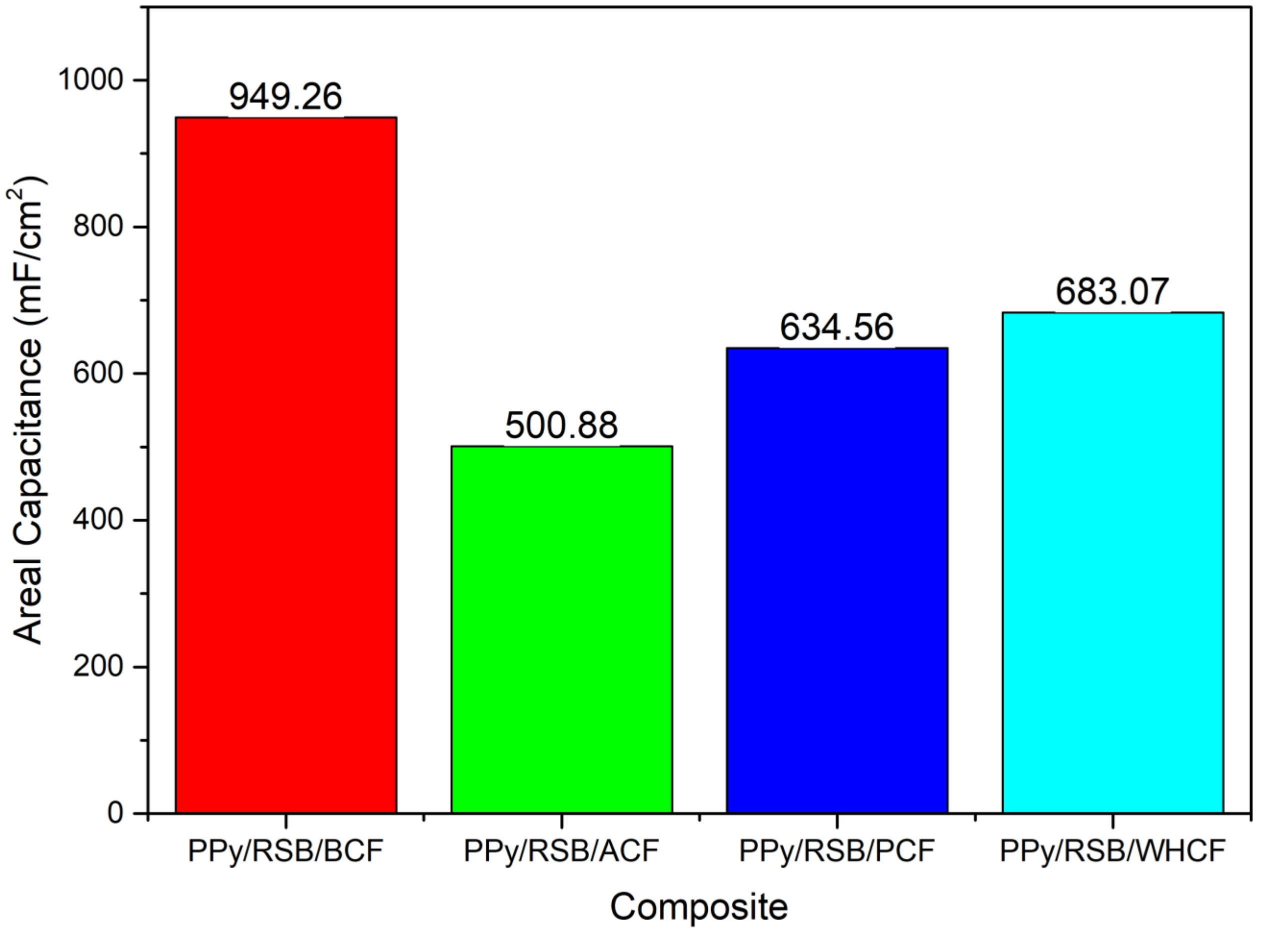
- $HNO_3$

Rice Straw Biochar (RBC)



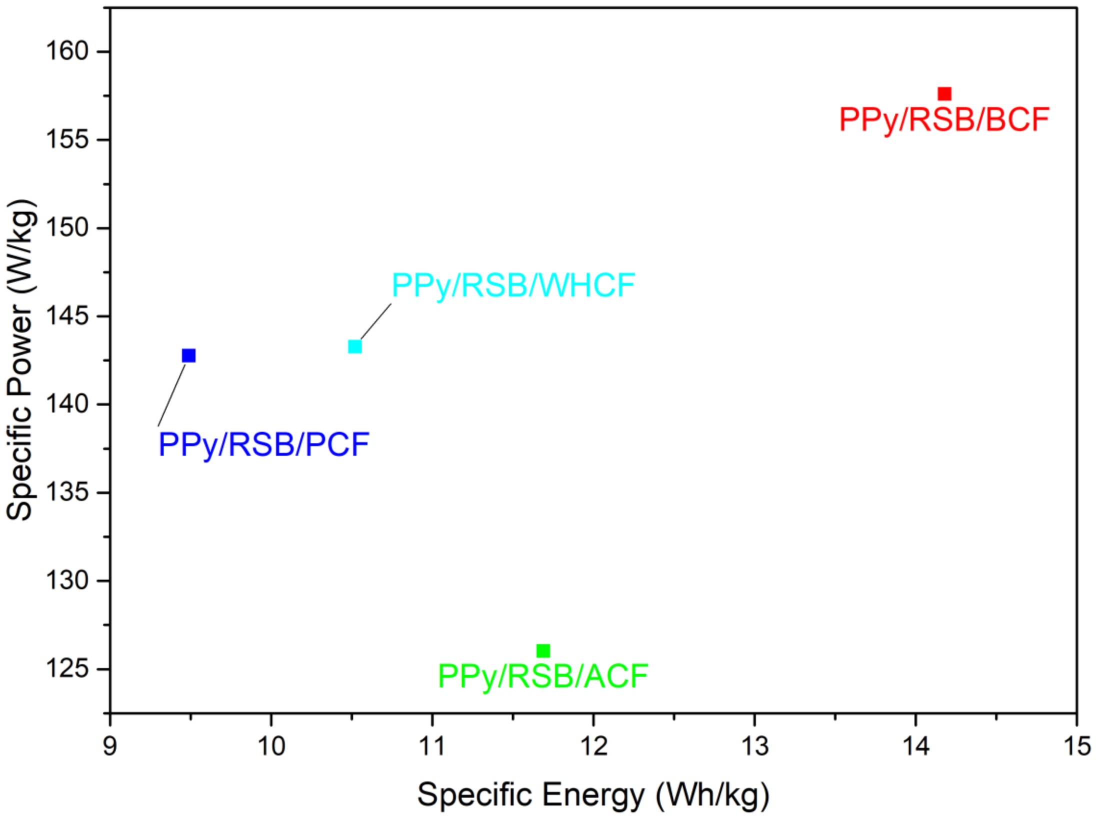

Two-electrode analysis

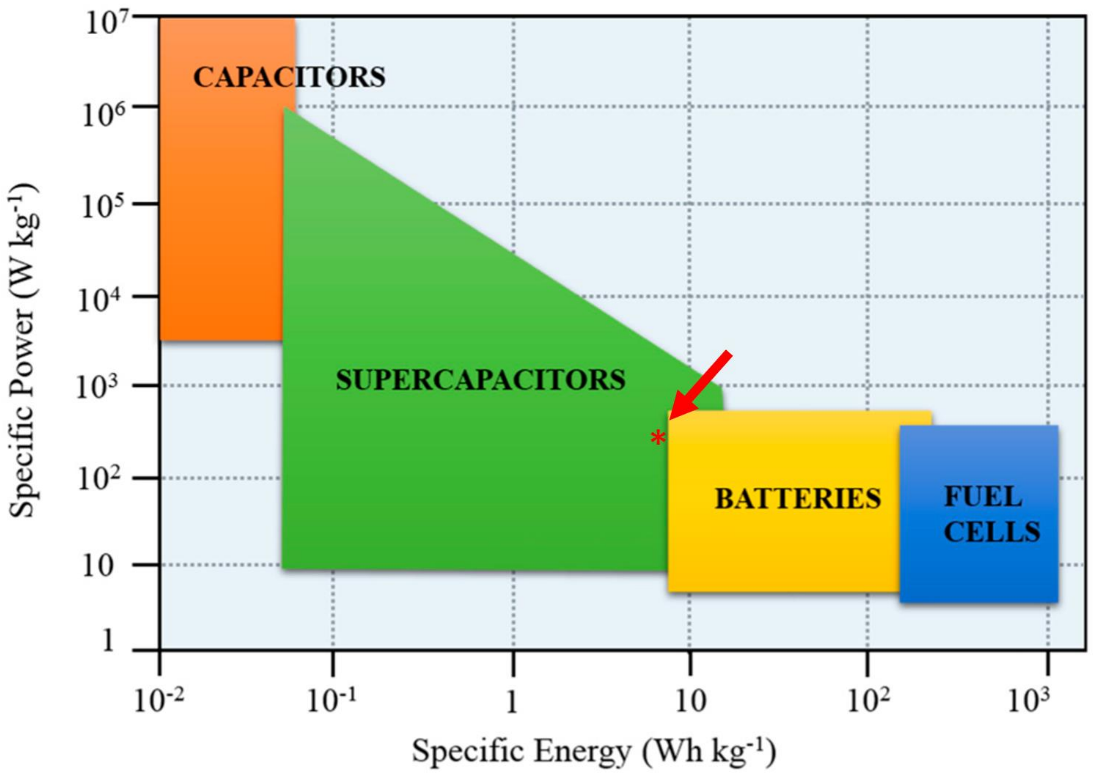
# Areal Capacitance (2E GCD)



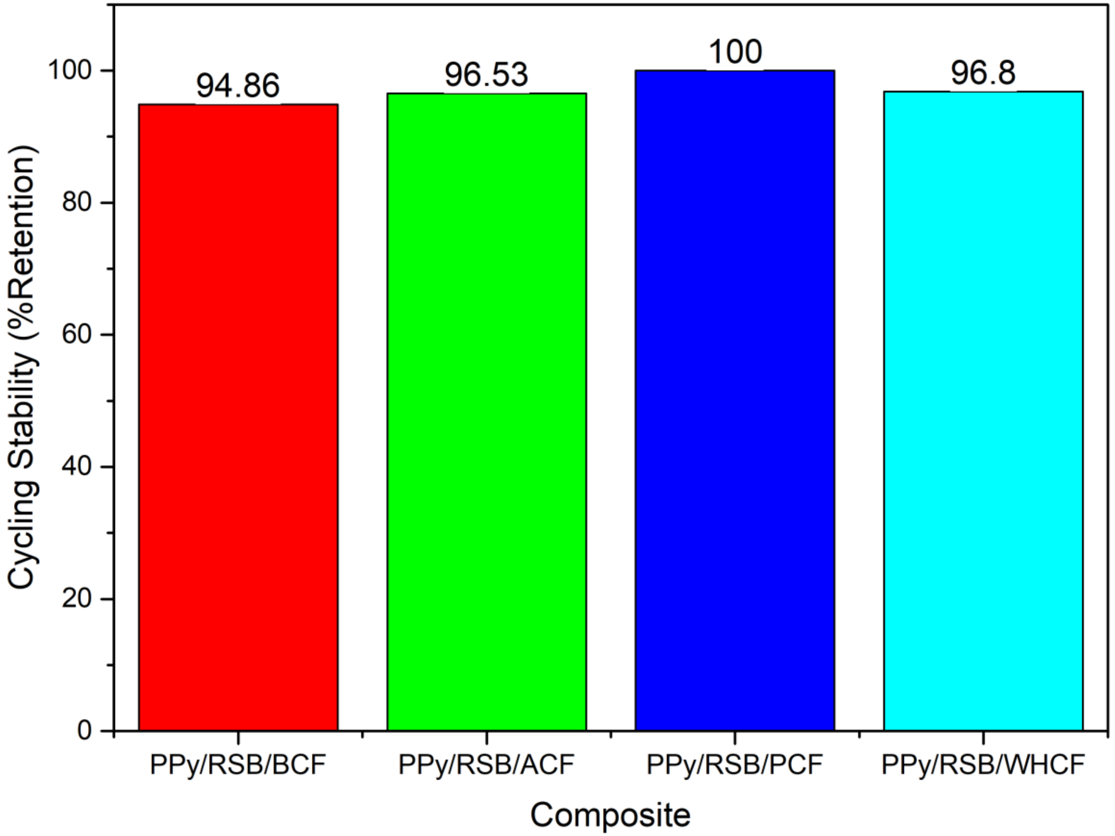

- 2E studies produced higher areal capacitance values compared to previous studies due to coin cell configuration

## Ragone Plot


Specific Power (W/kg)
Specific Energy (Wh/kg)
160
155
150
145
140
135
130
125
9
10
11
12
13
14
15
PPy/RSB/BCF
PPy/RSB/WHCF
PPy/RSB/PCF
PPy/RSB/ACF

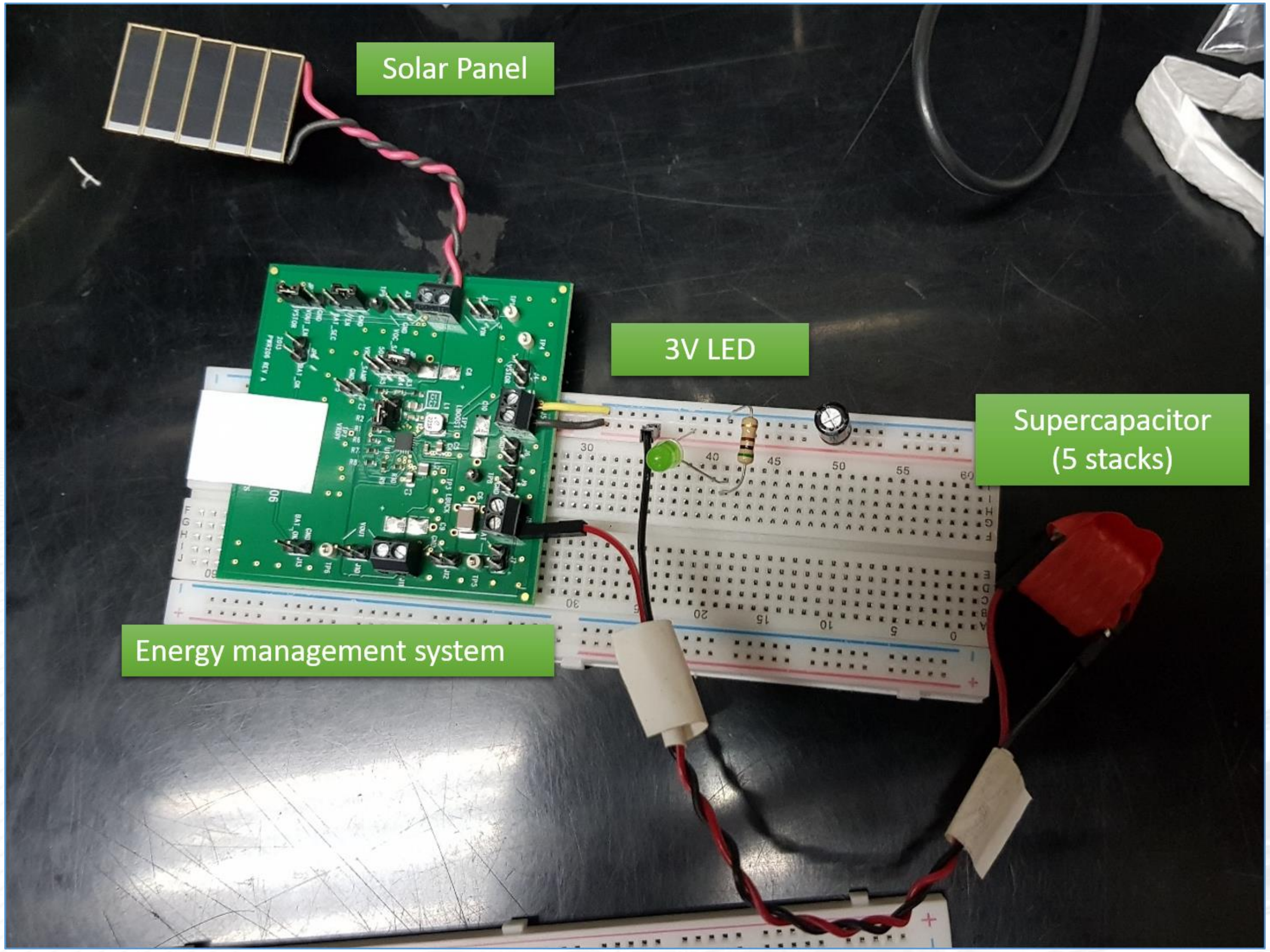

CAPACITORS
SUPERCAPACITORS
BATTERIES
FUEL CELLS
Specific Power (W kg-1)
Specific Energy (Wh kg-1)
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^-2
10^-1
1
10
10^2
10^3

# Cycling Stability after 10,000 cycles

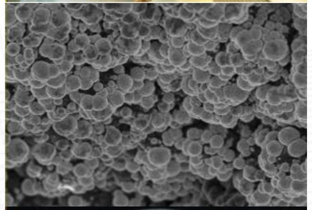
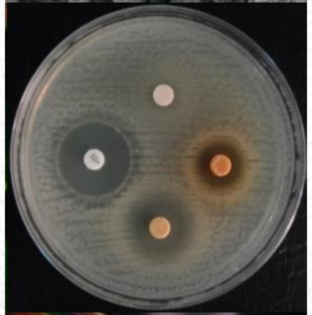
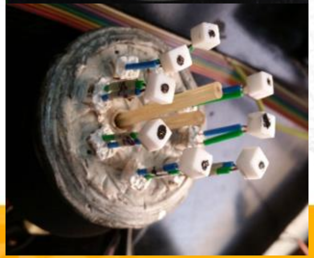



- Composites exhibited excellent cycling stability after 10,000 cycles

# Application





## Research Programs

### Natural Products for Health & Wellness / Drug Discovery & Development

- Natural products chemistry and synthesis
- Natural products formulations
- Natural products pharmacology and toxicity
- Drug delivery systems

### Molecular Diagnostics and Therapeutics

- Molecular Biology & Biochemistry
- Immunology
- Clinical diagnostic methods

### Chemical Sensors and Biosensors

- Innovative analytical and sensing devices (i.e. optical, piezoelectric, chemoresistive and electrochemical) for:
  - ✓ food safety
  - ✓ environment
  - ✓ health

### Advanced Materials

- Synthesis and characterization of new materials and nanomaterials for:
  - ✓ electrochemical energy conversion (e.g. fuel cells) and storage (e.g. supercapacitors and batteries)
  - ✓ thermal energy storage

### Pure and Applied Microbiology

- Characterization and utilization of microorganisms for:
  - ✓ health
  - ✓ environmental applications

### Process Design, Intelligent and Embedded Systems, Automation

- Process design
- Wearable technologies
- Intelligent systems
- Multimedia signal processing and communications

# Acknowledgements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- Science Education Institute of the Department of Science and Technology (DOST – SEI)
- Philippine Textile Research Institute of the Department of Science and Technology (DOST – PTRI)
- Department of Energy Systems Engineering, Daegu Gyeongbuk Institute of Science and Technology