Technological carbon from biomass

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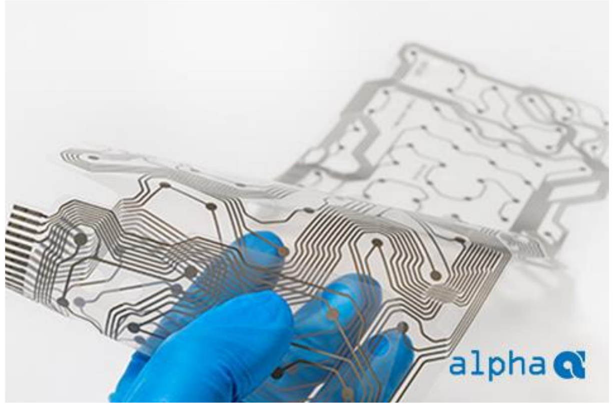
Content

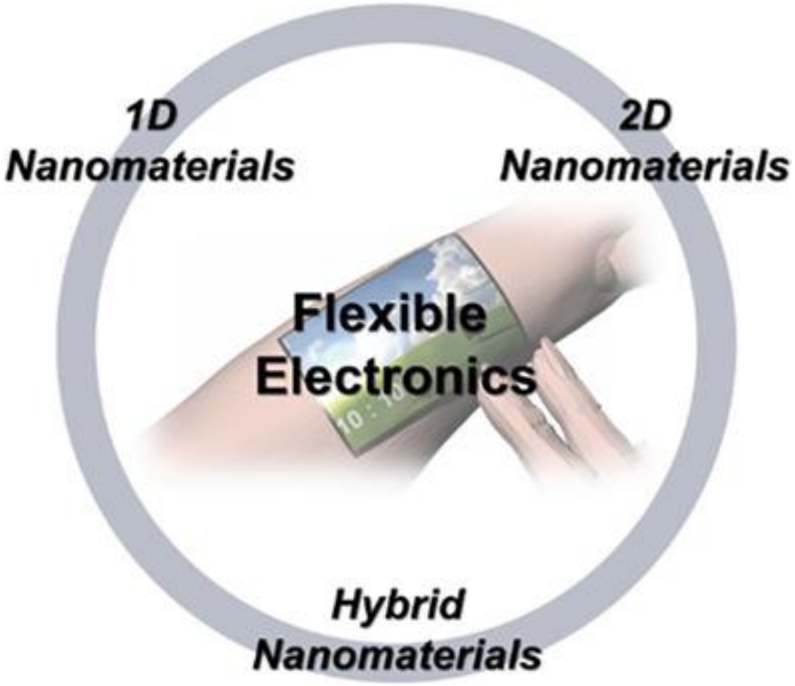
- Motivation
- Biomass as value-added carbon resource
- From amorphous to ordered nano carbon structures
- Technological carbon;
  - Nano biochar
  - Biochar cartridge
  - Electrical conductive carbon
  - Energy storage materials in supercapacitors
  - Electromagnetic emission shielding material
  - Bioelectrochemical systems
- Planned experimental study
- Conclusion

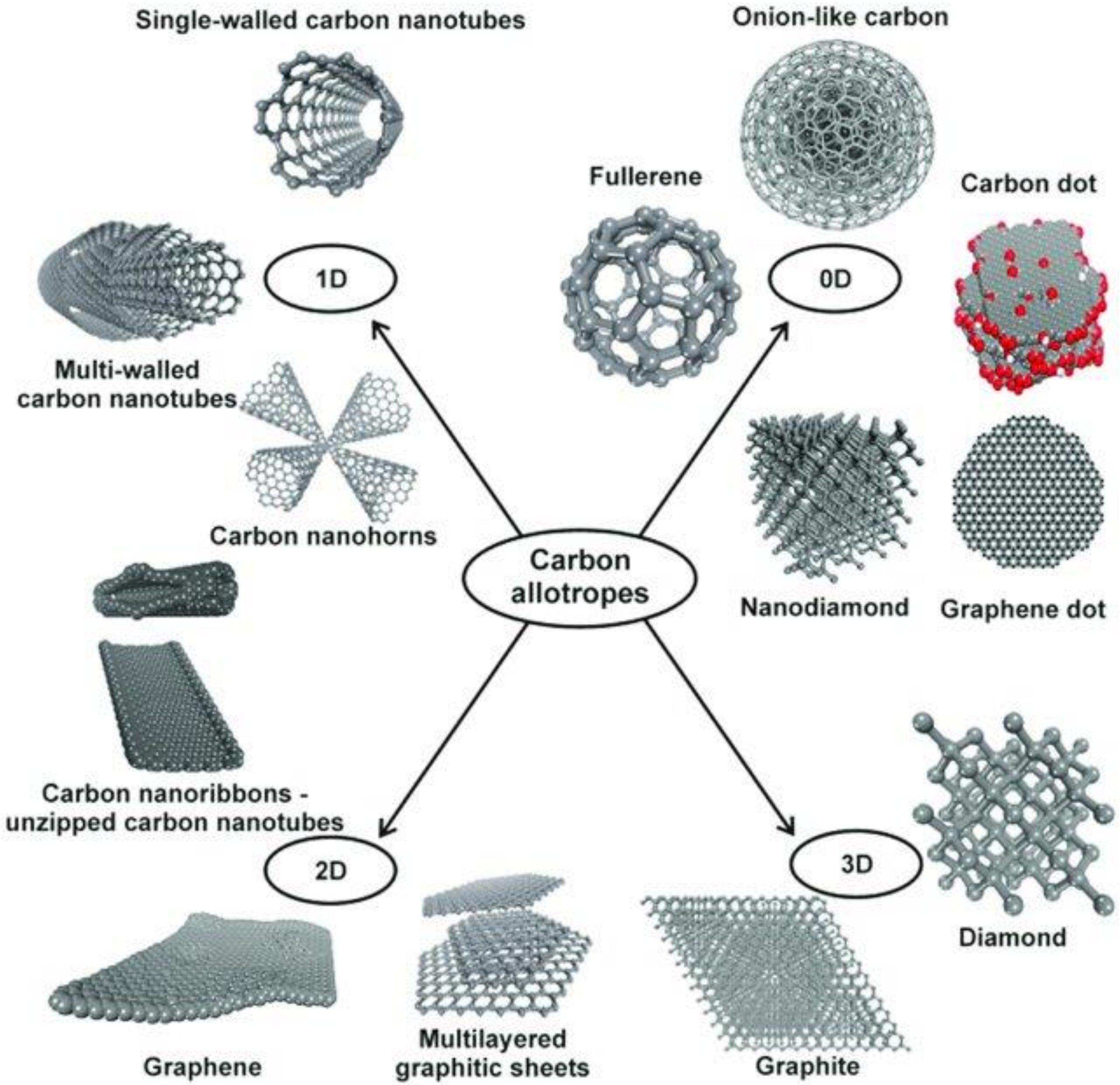
Motivation

- Flexible electronic devices are involved in the development of portable technologies
- Carbon nanomaterials play a key role in electronic devices and their applications
  - Foldable TVs, phones, computers, circuit boards (PCBs)
  - Printable sensors, collectors, solar cells
  - Wearable gadgets
  - …
  - Electrochemical devices
  - Catalysts
  - Sensors
  - …



Motivation


1D
Nanomaterials
2D
Nanomaterials
Flexible
Electronics
Hybrid
Nanomaterials


Single-walled carbon nanotubes
Onion-like carbon
Fullerene
Carbon dot
1D
0D
Multi-walled
carbon nanotubes
Carbon nanohorns
Carbon
allotropes
Nanodiamond
Graphene dot
Carbon nanoribbons -
unzipped carbon nanotubes
2D
3D
Diamond
Graphene
Multilayered
graphitic sheets
Graphite

Motivation

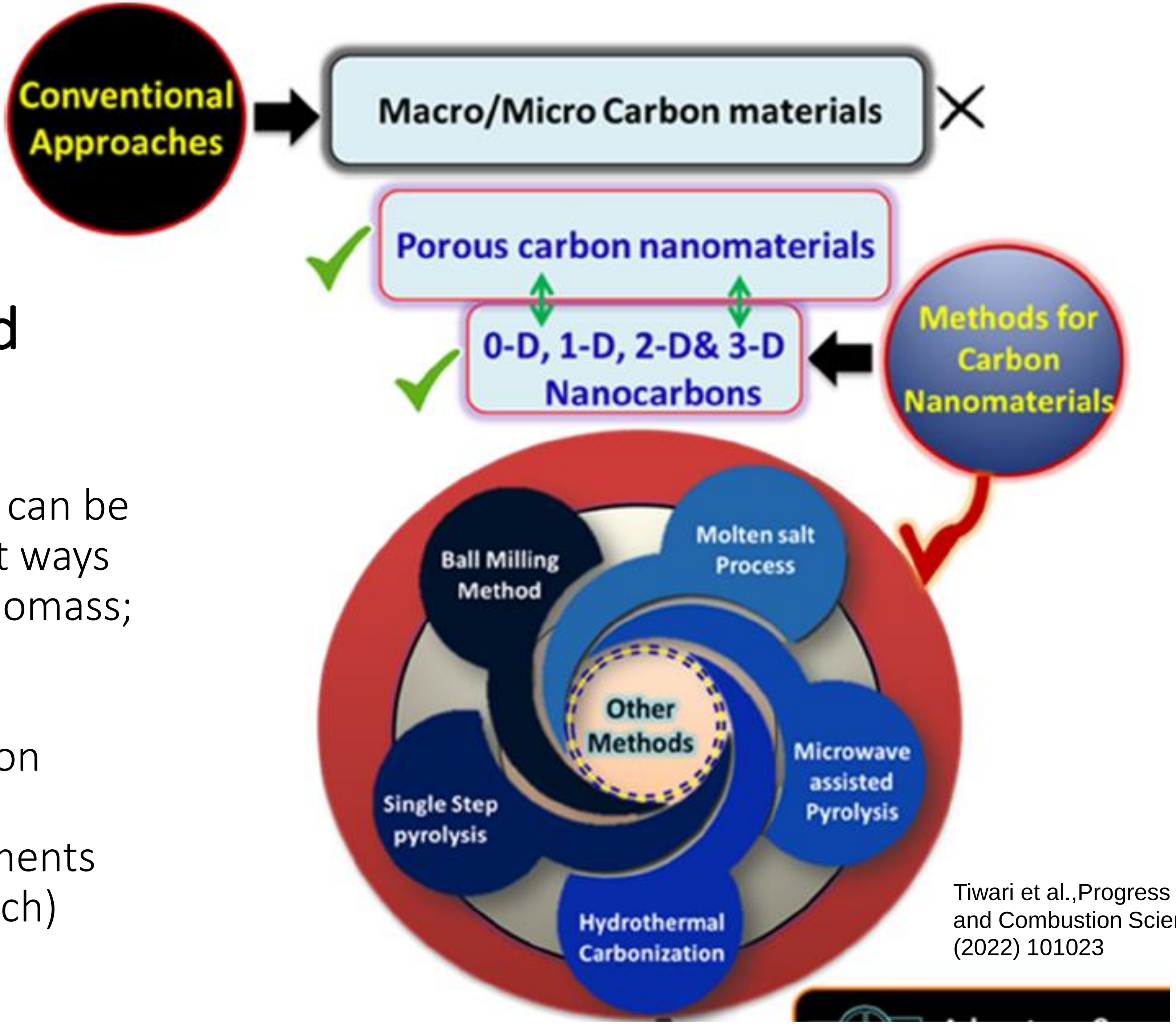
- They are primarily of fossil origin
- Defects in the crystal structures influence negatively the electronic properties
- Expensive to mass production

- Considering the depletion of fossil resources and their negative effects on climate change, there is a need for alternative, clean, renewable and sustainable carbon sources.

Biomass; value-added carbon resource

Nanocarbons from biomass can be developed in many different ways depending on the type of biomass;

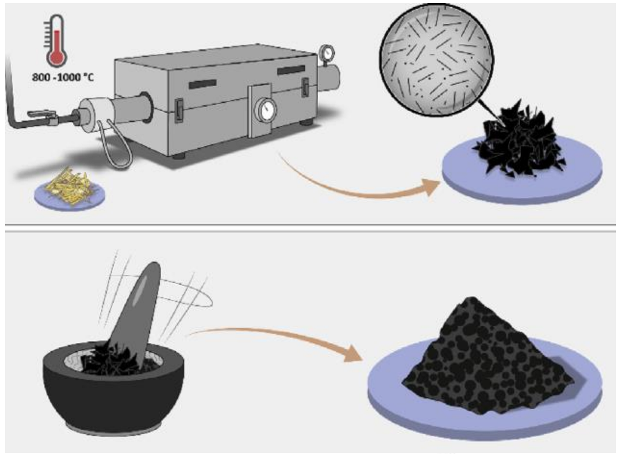
pyrolysis,
catalytic carbonization
chemical activation
hydrothermal treatments
...(Top-down approach)

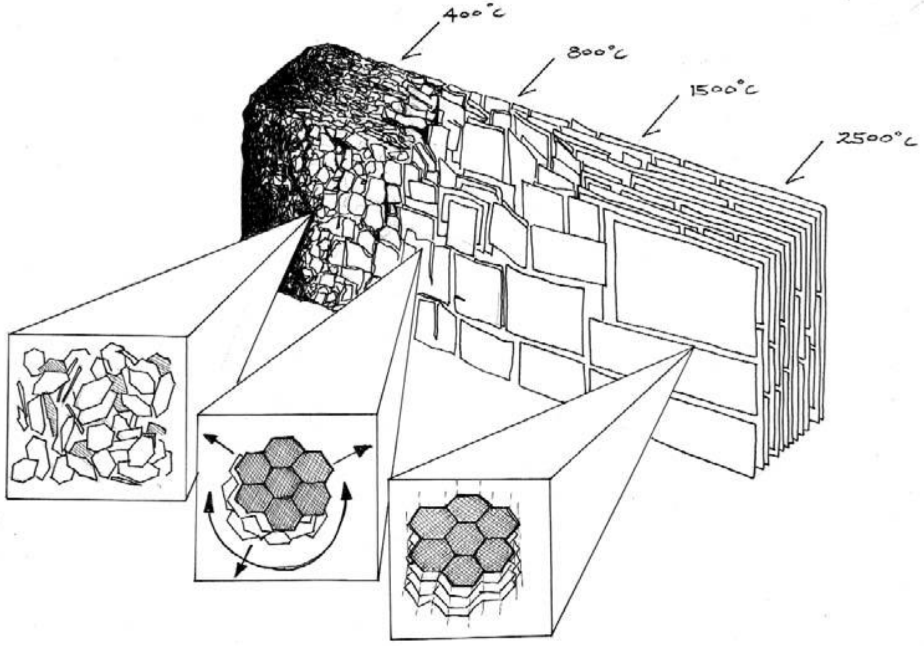


Tiwari et al.,Progress in Energy and Combustion Science 92 (2022) 101023

Biomass; value-added carbon resource

- Electrical conductivity of biomass derived carbon is highly dependent on its degree of carbonization/graphitization.
- Structural evolution is reached by the effect of temperature





From amorphous to ordered nano carbon from biomass

- **Graphitization/activation:** Organic precursor is subjected to structural changes
  - Heat treatment (pyrolysis); T>1000 °C, low heating rate (3-5 °C/min), inert Ar, N_2, limited O_2 atmosphere
    - Through heat treatment, the low density and disordered carbon of nonconductive hemicellulose, cellulose and lignin are transformed into high density and conductive graphitic sheets, and the sp3 carbon can also change into sp2 carbon.
    - The removal of oxygen containing functional groups can reduce the gallery spacing of graphene sheet and producing the p-conjugated structure
  - Catalytic pyrolysis with graphitization agents; $FeCl_3$, $NiCl_2$, H_3BO_3, Fe, KCl,K_2FeO_4, $Fe(NO_3)_3$,Mg etc.
  - Activation with KOH, NaOH, K_2CO_3, etc.
  - Hydrothermal treatments
  - Microwave treatments
  - Arch discharge
  - Plasma
  - Laser induction
  - Molten salt process

From amorphous to ordered nano carbon from biomass

- Physical; Ultrasonic treatments, milling
- Chemical; Hummers methods
- Electrochemical exfoliation

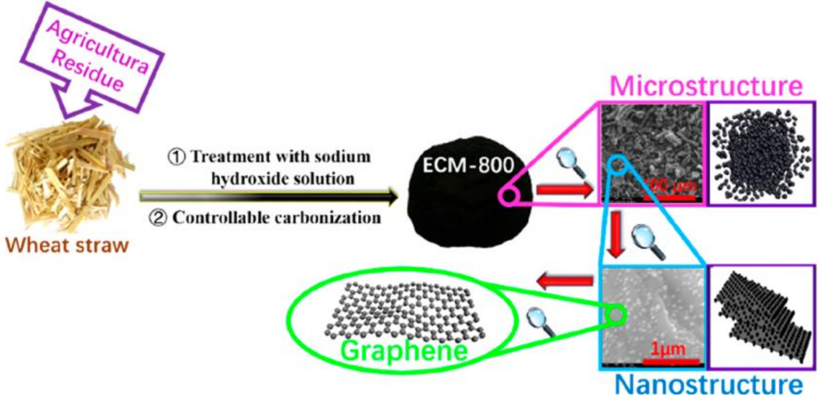
From amorphous to ordered nano carbon from biomass

Biomass derived graphene, carbon nanotubes and like nanomaterials.

S. N	Biomass Sources & Year	Methods and conditions	Product	Applications
1	Wheat straw & sawdust	Utilizing waste pyrolysis gases and waste heat	3D graphene foams	Environmental &energy-storage applications.
2	Waste pomelo peel	Hydrothermal process	Graphene-like nano- sheets	Microwave absorption & thermal infrared properties
3	Biomass-loofah	Chemical activation and graphitization	N-doped graphene like nanomaterials	Asymmetric supercapacitors
4	Agricultural Waste	Chemical synthesis	Amine- functionalized bio graphene	Ciprofloxacin adsorption in water-modelling
5	Chitosan	Pyrolysis at 900 °C in Ar atm	N-doped, defective graphene	Catalyst for conversion CO_2 to methane
6	Alginic acid & chitosan	Pyrolysis at 1100 °C	Few-layers graphene	Hydrogen generation
7	Pear waste	Chemical synthesis	Graphene-based aerogels	Environmental remediation & energy storage
8	Guanine and colloidal silica	Hydrothermal carbonization	Graphene-like carbons	Electrocatalytic oxygen reduction
9	Populus wood biomass	Chemical activation using KOH and carbonization	Highly porous graphene	Cost effective CO_2 capture at atmospheric pressure
10	Kelp	Facile chemical synthesis	Cobalt encapsulated multilayer-graphene	Electrocatalyst for versatile renewable energy
11	[illegible]	[illegible]	[illegible]	[illegible]

Tiwari et al., Progress in Energy and Combustion Science 92 (2022) 101023

Nano biochar

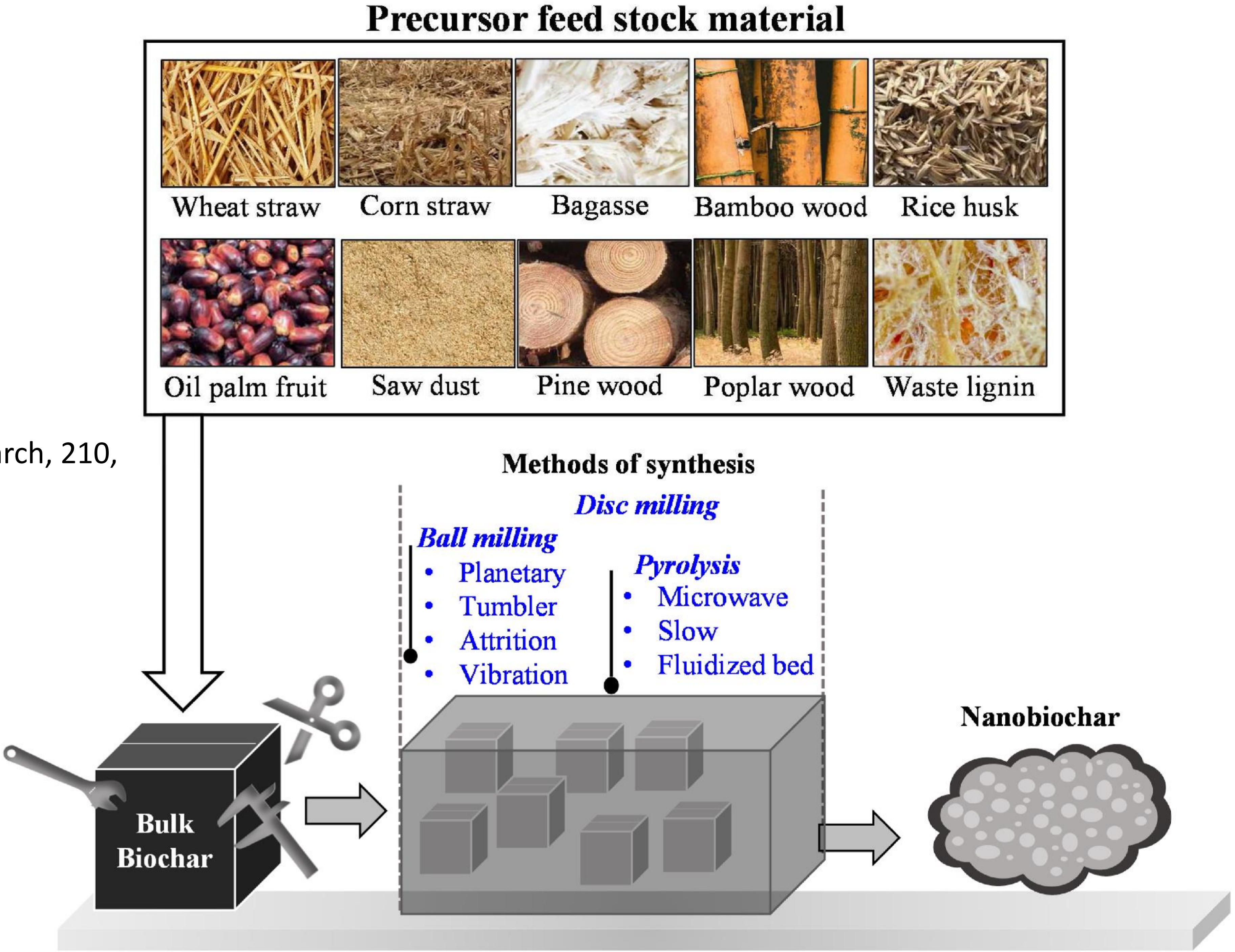


- The conventional biochar obtained from biomass are normally in micron or millimeter size with irregular shapes
- With size reduced to nano scale
  - more superior for easy and stable applications
  - enable fast electron transfer
  - provide more adsorption sites for target binding and enrichment
  - spherical structures
- **Biomass →pyrloysis, hyrdothermal, microwave heating… → X g biochar/Y L water (solution suspension)→ultrasonication, centrifugation→supernatant consisting nano biochar**

Ramanayaka et al., Nanobiochar: Production, Properties, and Multifunctional Applications, Environ. Sci.: Nano 7, 11, (2020) 3279-3302

Nano biochar

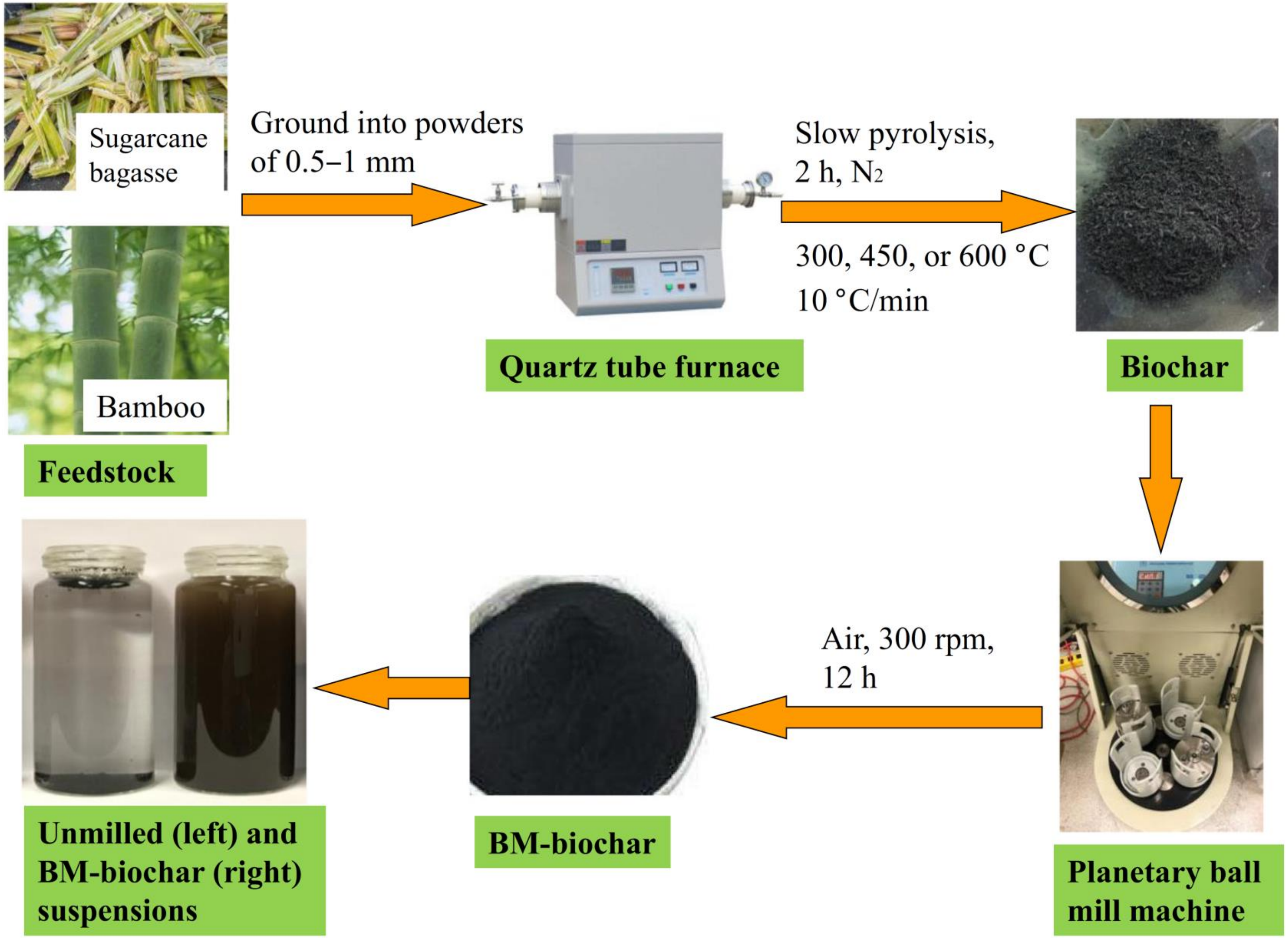
Rajput et al., Environmental Research, 210, (2022) 112891



Nano biochar

Lyu et al., Ball-milled biochar for alternative carbon electrode, Environmental Science and Pollution Research 26 (2019) 14693–14702

Substitute for rubber industry ; Jiang et al., Converting waste lignin into nano-biochar as a renewable substitute of carbon black for reinforcing styrene-butadiene rubber, Waste Management 102 (2020) 732–742



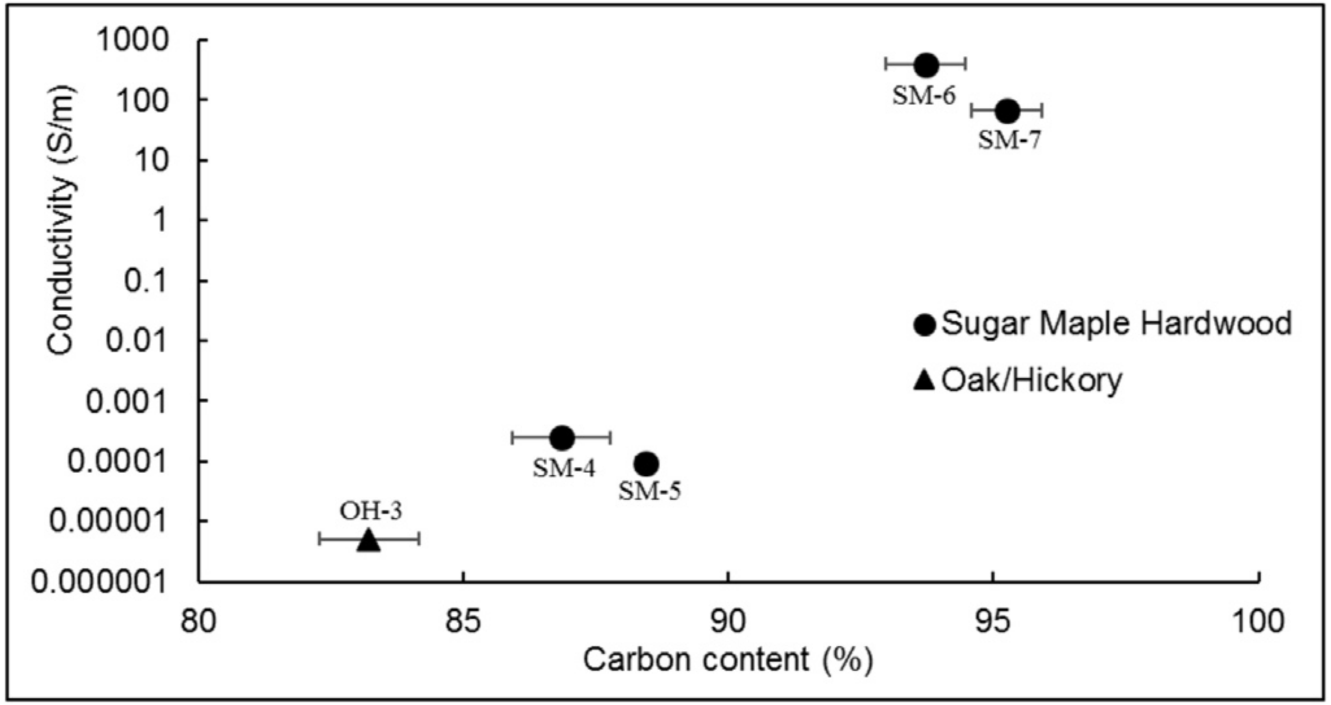
Biochar cartridge

- Worldwide sell of carbon black derived from combustion of hydrocarbon based fuels will reach $23 billion by 2023.
- Significant contribution to climate change
- Black pigments derived from renewable biomass
- Replicate all the key physical properties (e.g. particle size, hue, durability, etc.)
- Biochar for sustainable printing products
- Oil-Based Ink

Goh et al., Cleaner production of flexographic ink by substituting carbon black with biochar, Journal of Cleaner Production, 324, 15 (2021) 129262

Electrical conductive carbon from biomass

Precursor	Code	Conductivity (S/m)	Carbon (wt%)
Oak/Hickory	OH-3	5.15E-06	83.22 ± 1.86
Sugar Maple	SM-4	2.47E-04	86.85 ± 0.32
	SM-5	9.30E-05	88.43 ± 1.52
	SM-6	399.67	93.72 ± 1.33
	SM-7	67.31	95.26 ± 2.13



R.S. Gabhi et al. / Carbon 116 (2017) 435-442

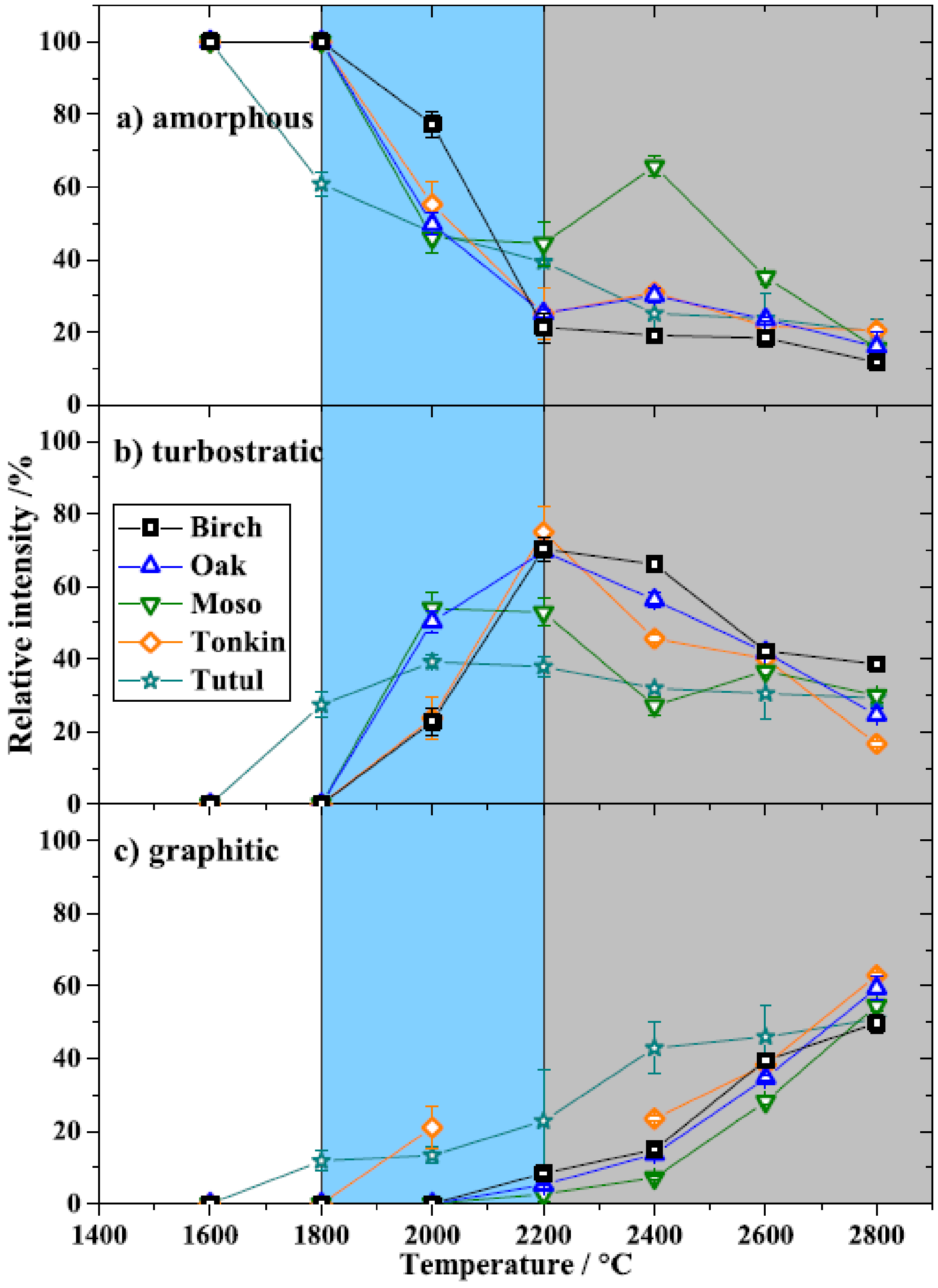
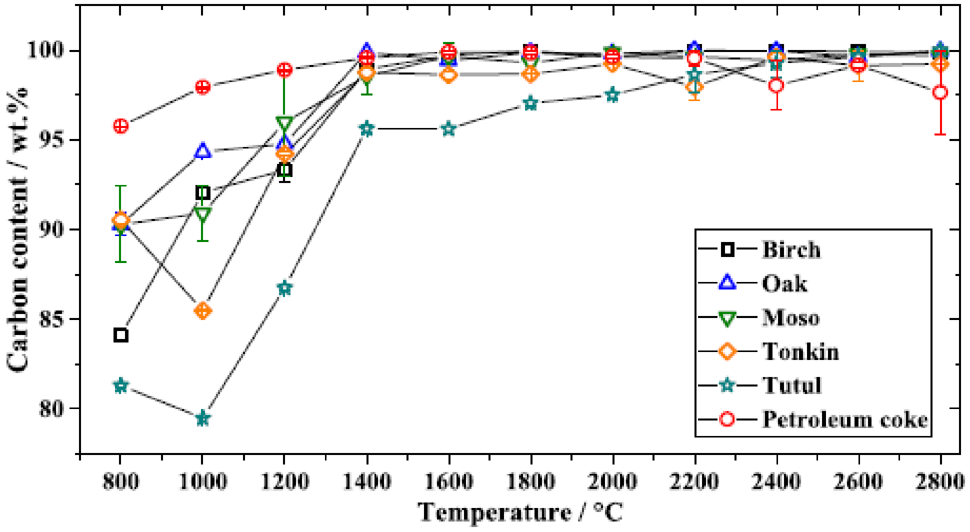


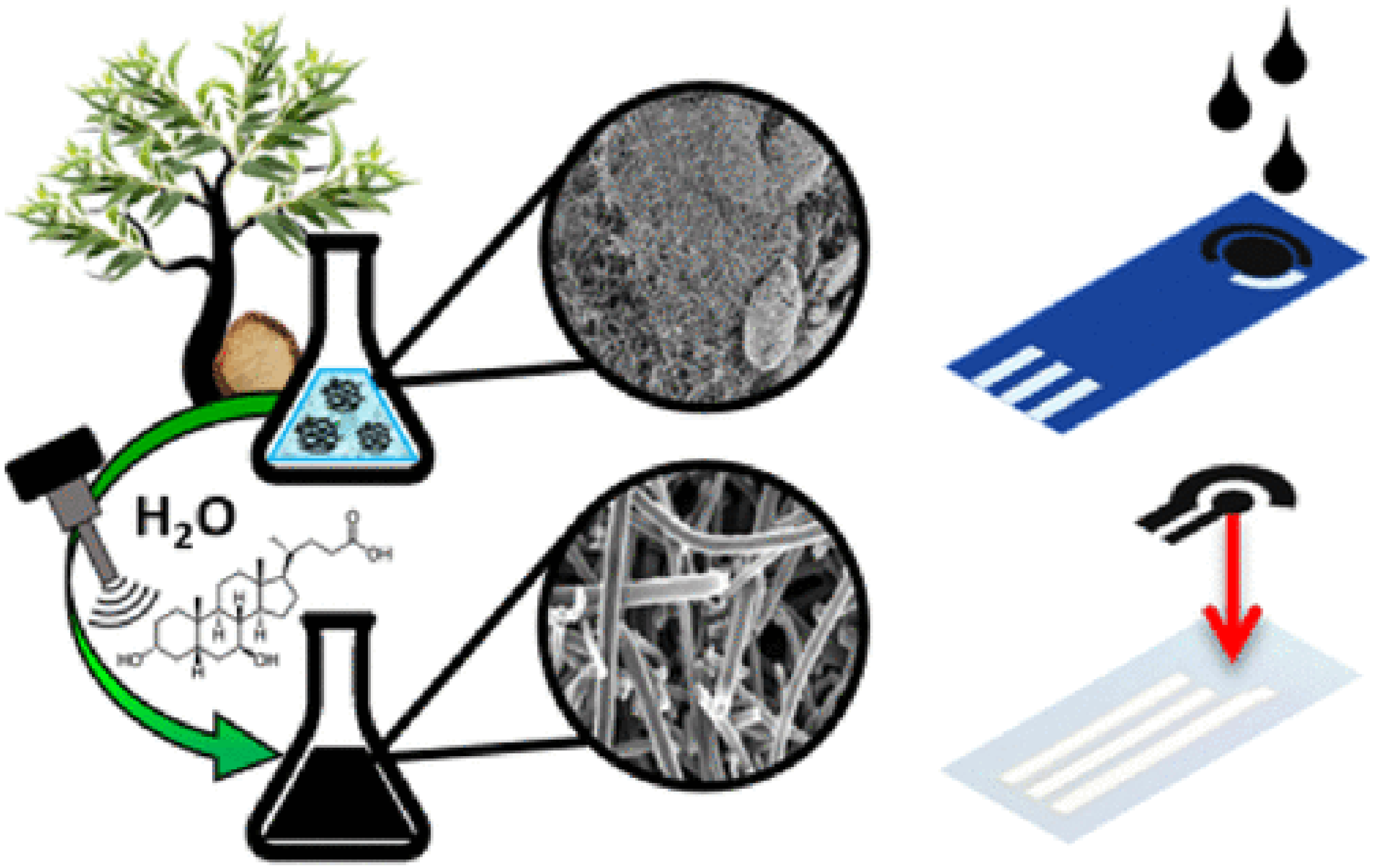
Fig. 9. Relative intensity of the five biomass-derived carbons. Petroleum coke-derived

Electrical conductive carbon from biomass



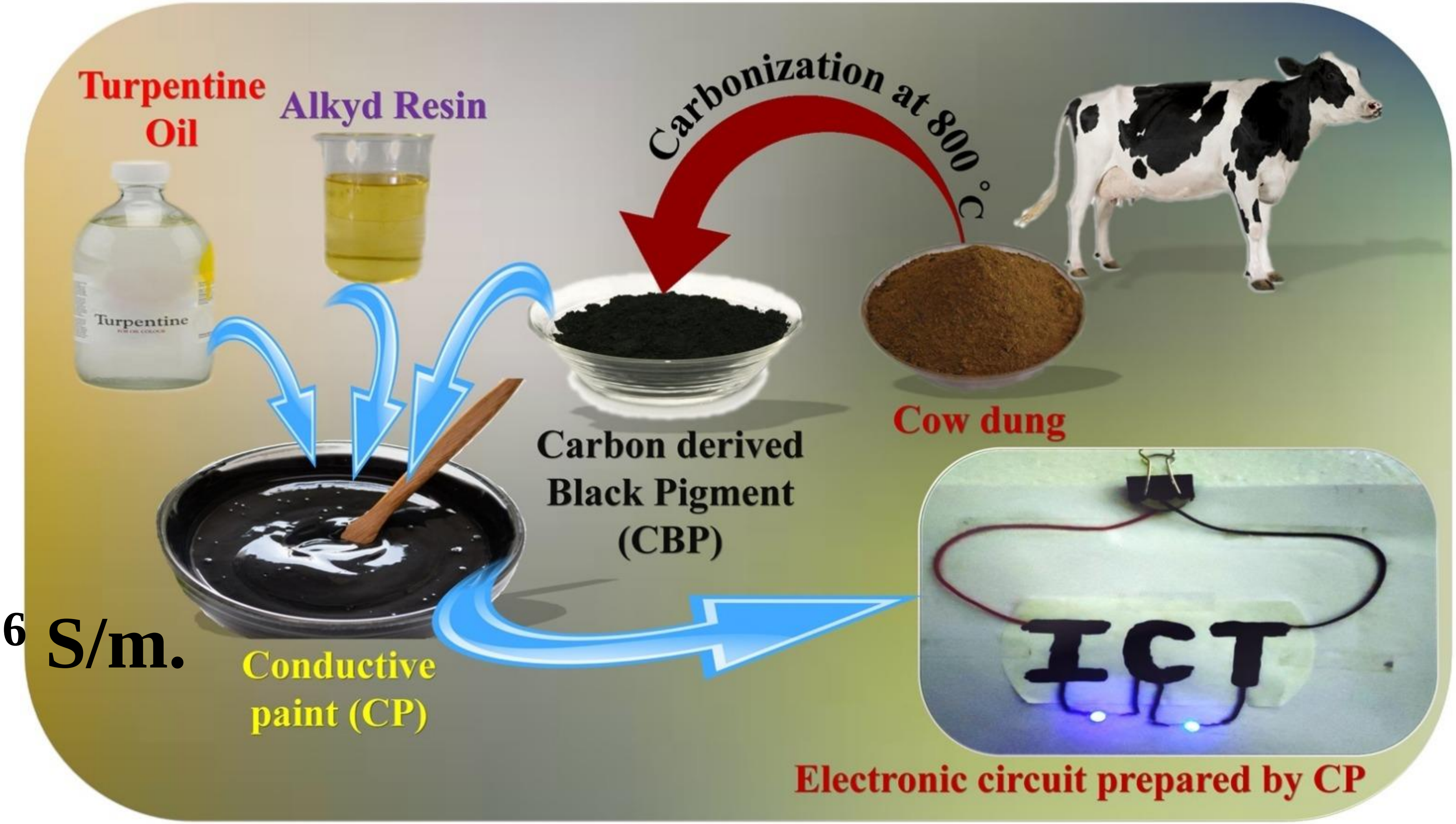
Fromm et al., Carbon 128 (2018) 147-163

Electrical conductive carbon from biomass



Bukhari, et al., Water-Phase Exfoliated Biochar Nanofibers from Eucalyptus Scraps
for Electrode Modification and Conductive Film Fabrication, ACS Sustainable Chem. Eng. 9 (2021) 13988−13998

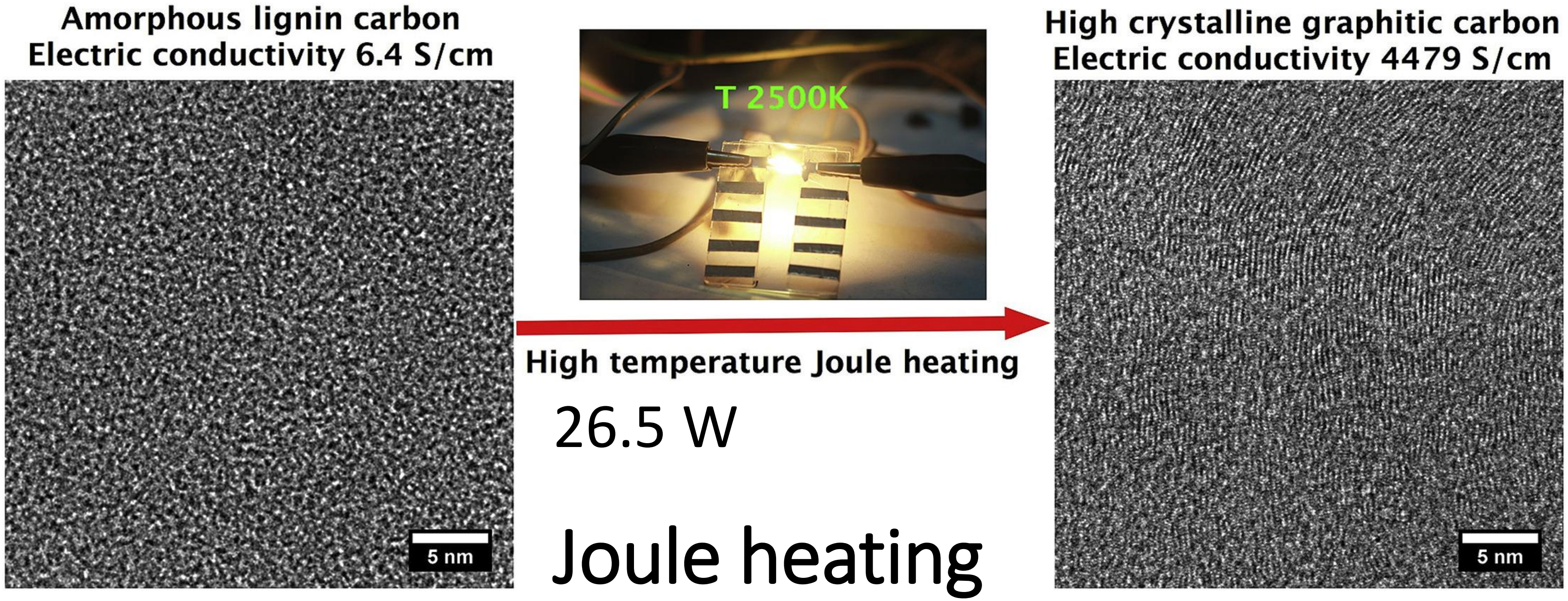
Electrical conductive carbon from biomass



6.84×10^{6} S/m.

Bhakare et al., Eco-friendly biowaste-derived graphitic carbon as black pigment for conductive paint, Progress in Organic Coatings. 147 (2020) 105872

Electrical conductive carbon from biomass



26.5 W

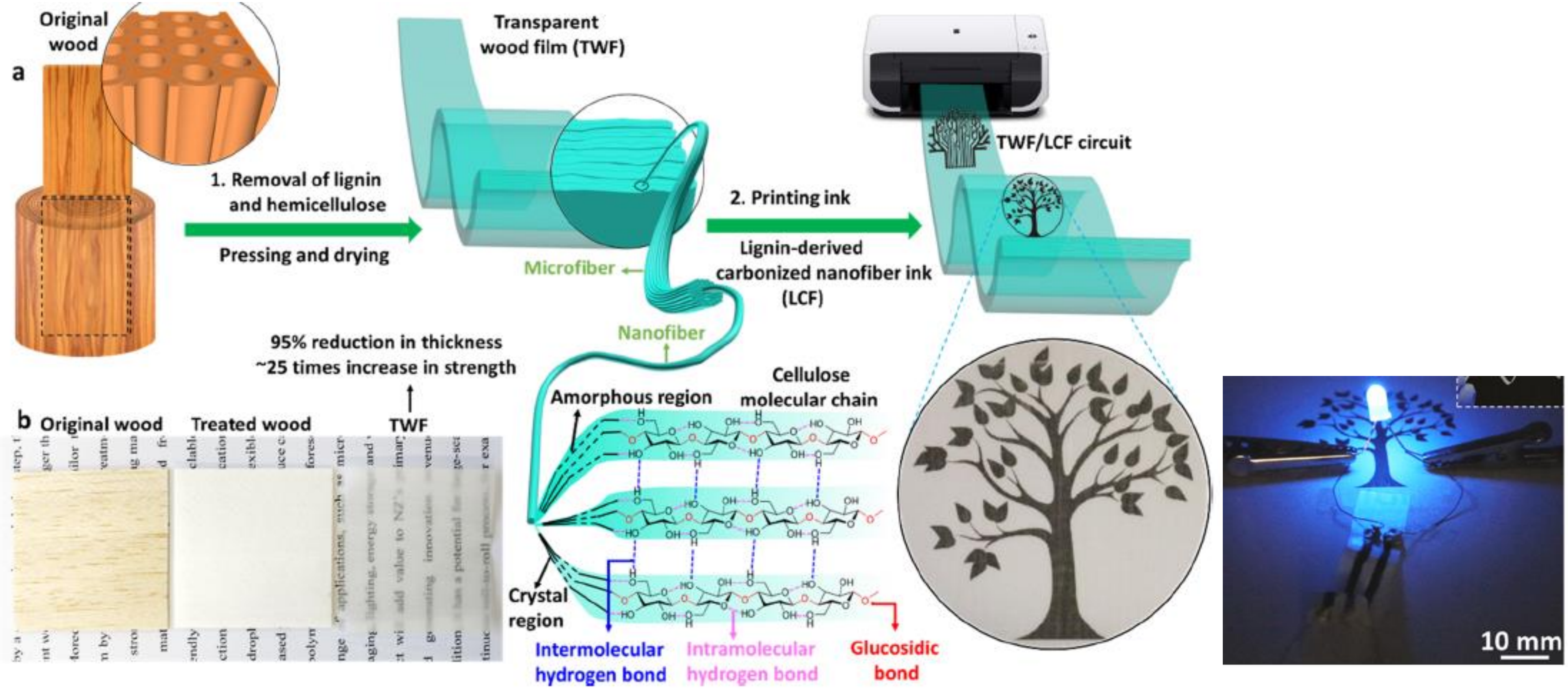
Joule heating

Jiang et al., Ultrahigh-temperature conversion of biomass to highly conductive graphitic carbon, Carbon 144 (2019) 241-248

Electrical conductive carbon from biomass

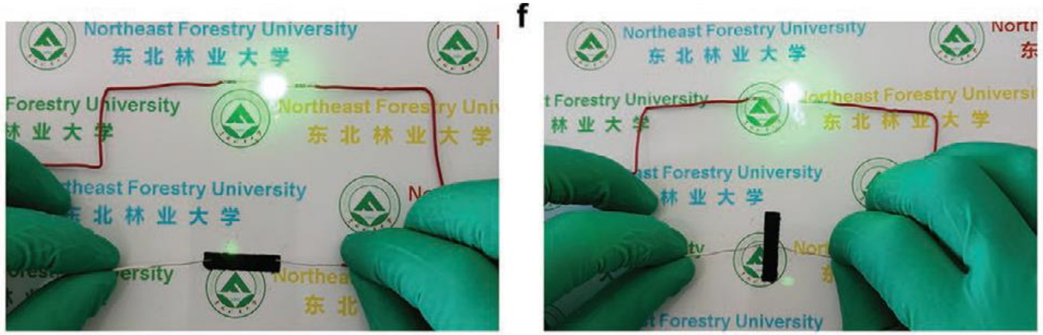
Wood-Based Flexible Electronics

Fu et al., ACS Nano 2020, 14, 3528–3538

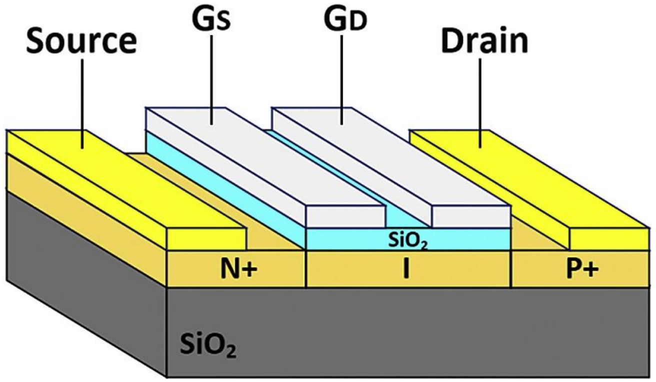


Electrical conductive carbon from biomass

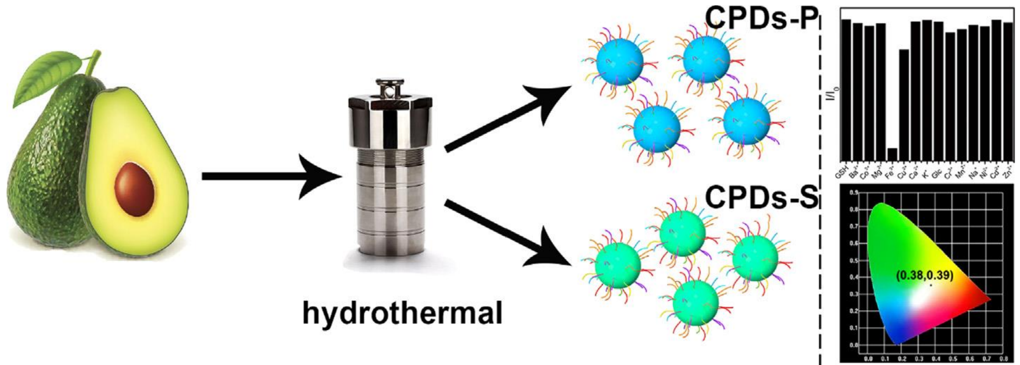
Printed circuits, diodes, transistors



Sun et al., Flexible, Strong, Anisotropic Wood-Derived Conductive Circuit, Adv. Sustainable Syst. 5 (2021) 2100040

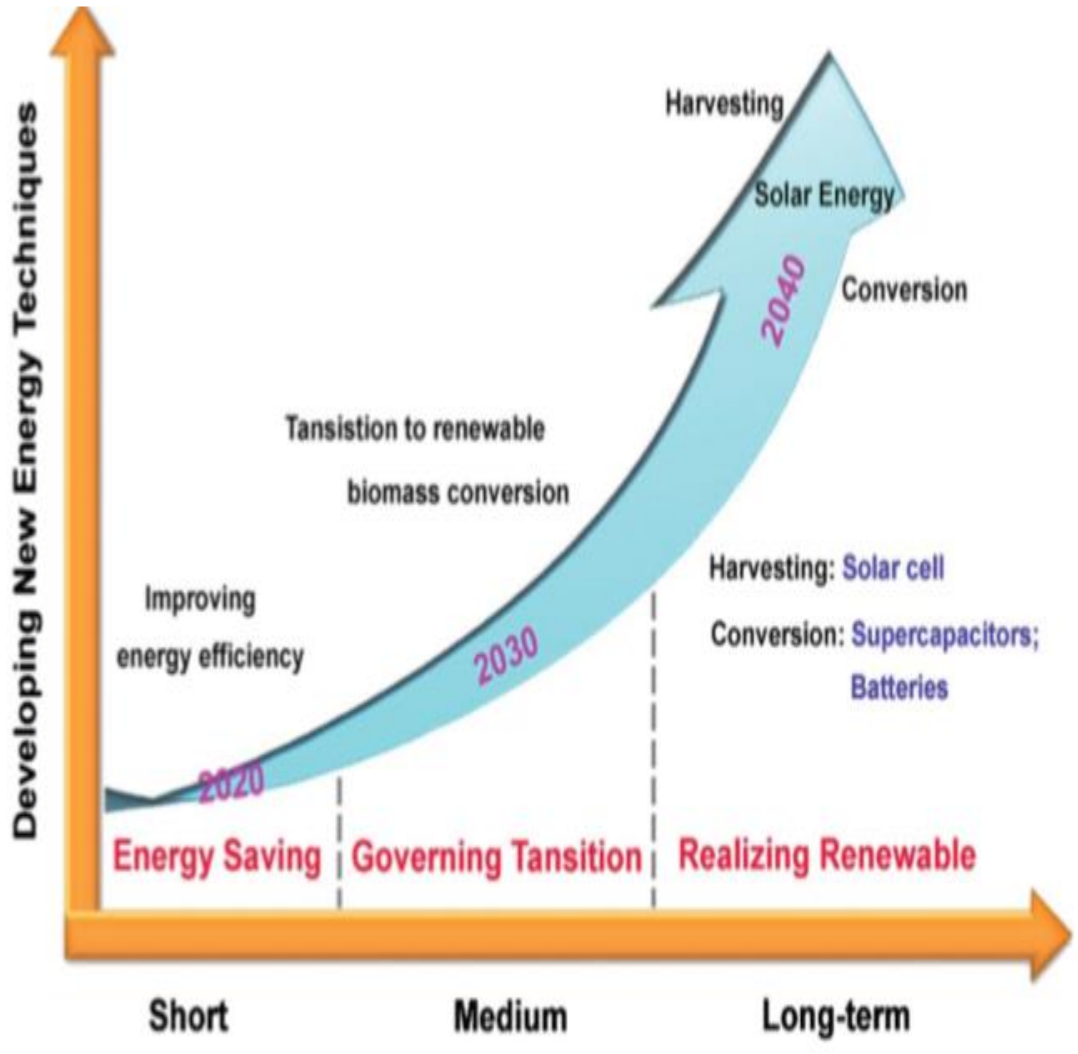


Bıçakçı and Akgül, Application of high performance carbon derived from tea waste into transistor as a conduction channel material. Journal of Polytechnic 23,3 (2020) 909-914

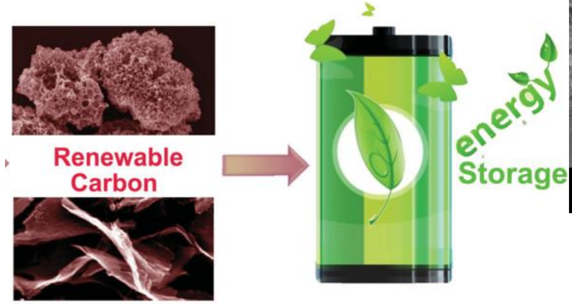


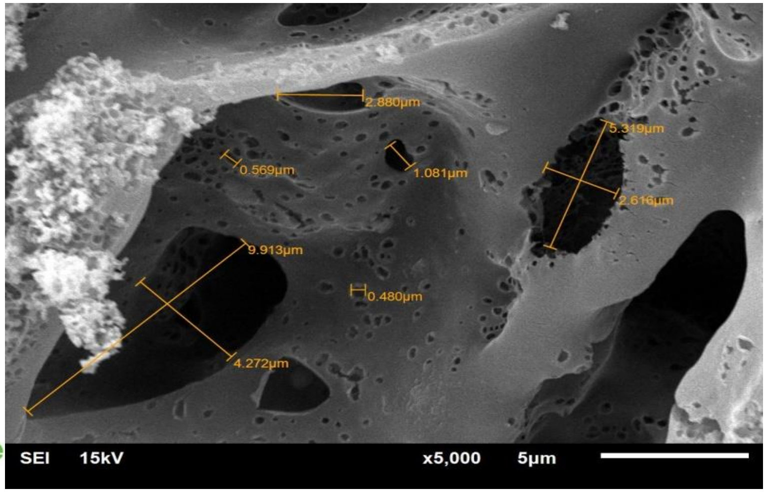
Meng et al., Engineering white light-emitting diodes with high color rendering index from biomass carbonized polymer dots. Journal of Colloid and Interface Science 598 (2021) 274–282

Energy storage materials in Supercapacitors



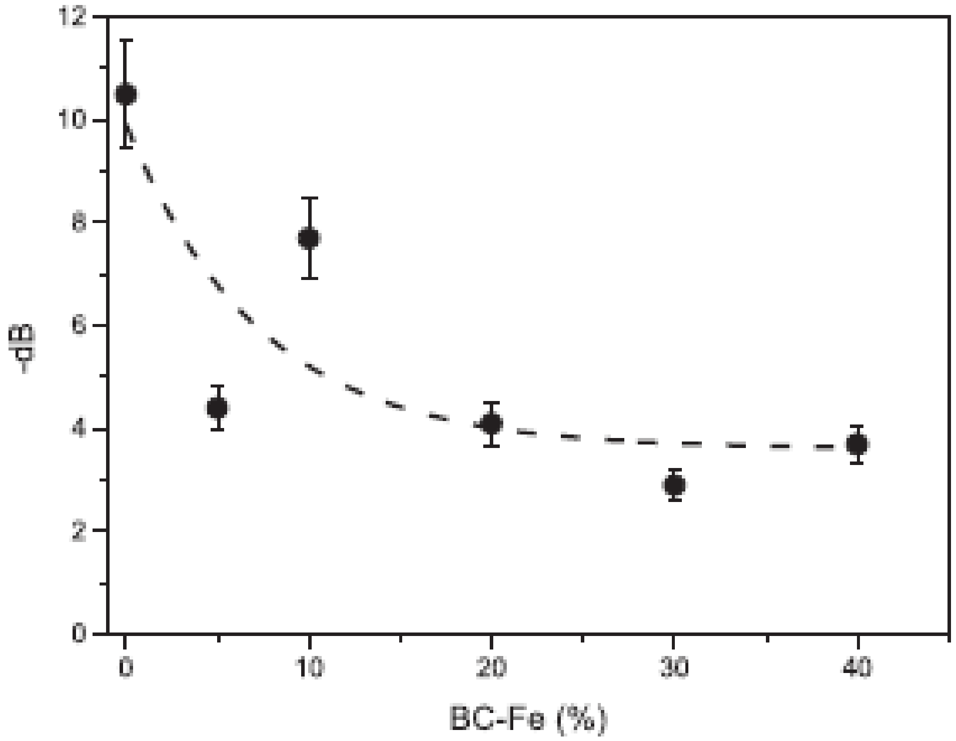
- Porous carbon from biomass
- In situ micropore formation
- Porosity is more important than surface area
- Doping; MnO_2, B_2O_3, Ru_2O…
- N doping increases the conductivity
- Kinetics depend on:
  - Diffusion
  - Adsorption
  - Charging





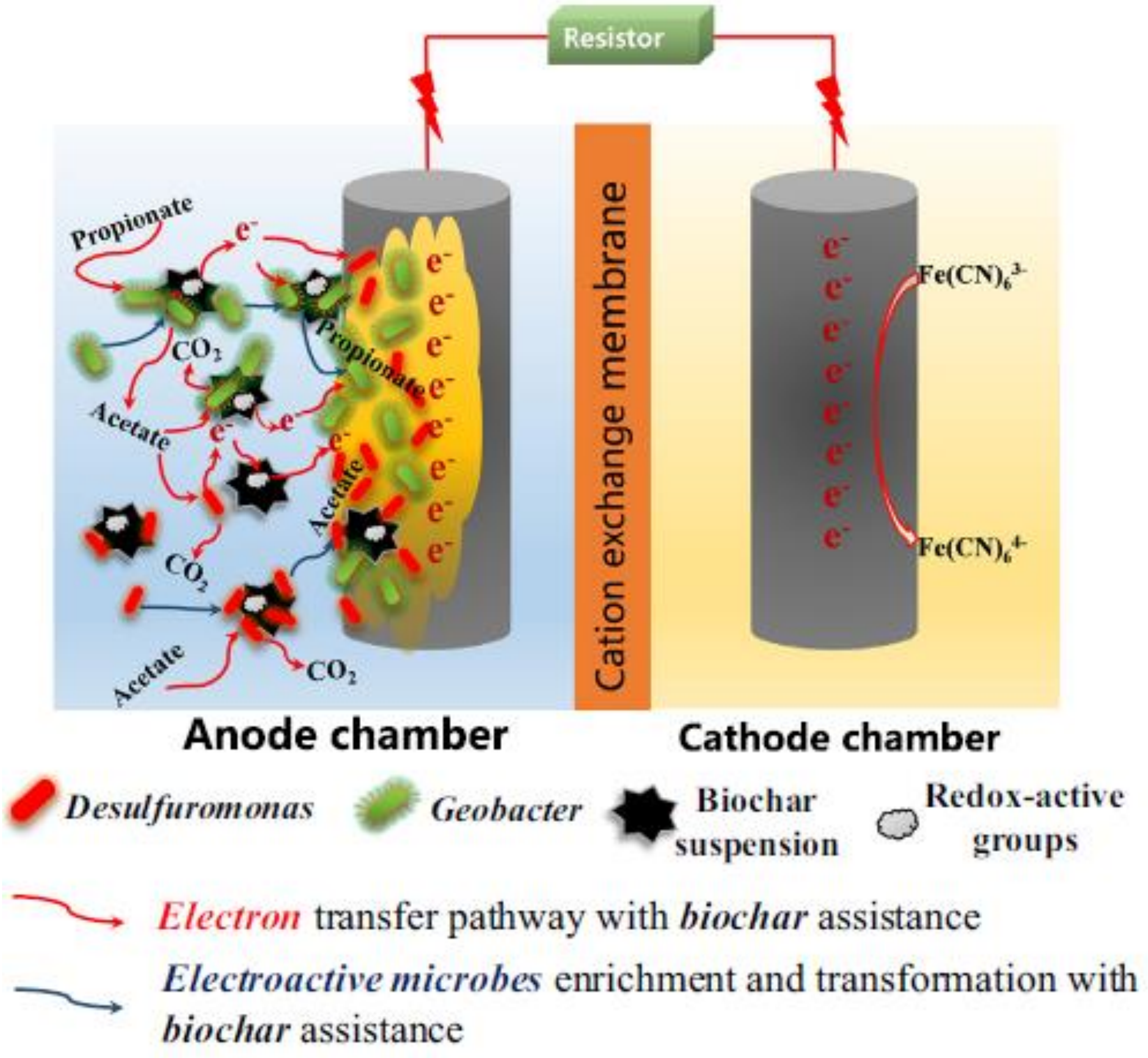
EMI shielding

Akgül et al., Biochar-iron composites as electromagnetic interference shielding Material. Mater. Res. Express 7 (2020) 015604



Bioelectrochemical systems

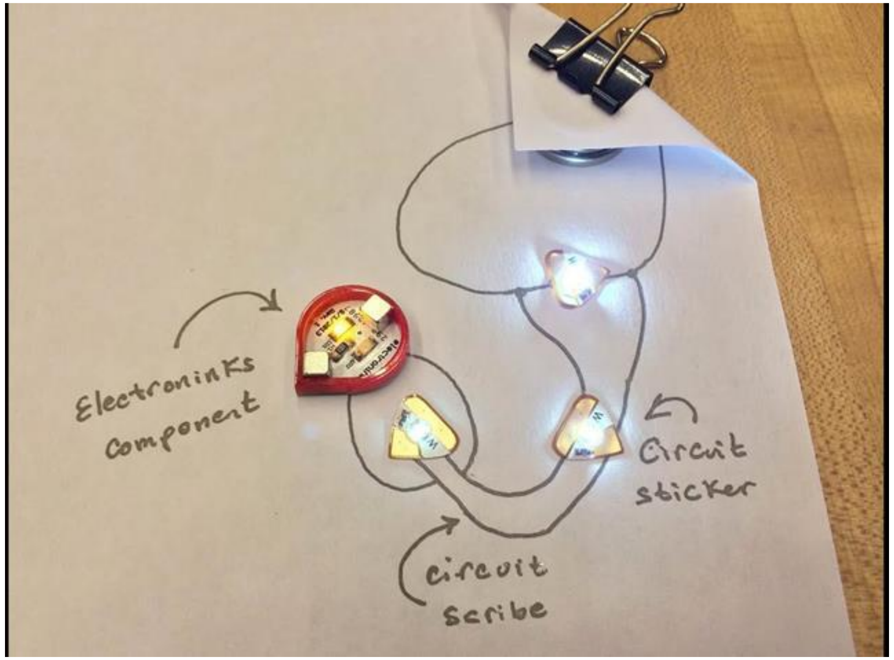
- In a bioelectrochemical system, adding biochar suspension remarkably enhanced electricity generation
- The abundant redox-active functional groups of quinone, phenol, and phenazine, generated during pyrolysis made biochar show excellent electron exchange capacity and redox based media



Wang et al., Science of the Total Environment 809 (2022) 151113

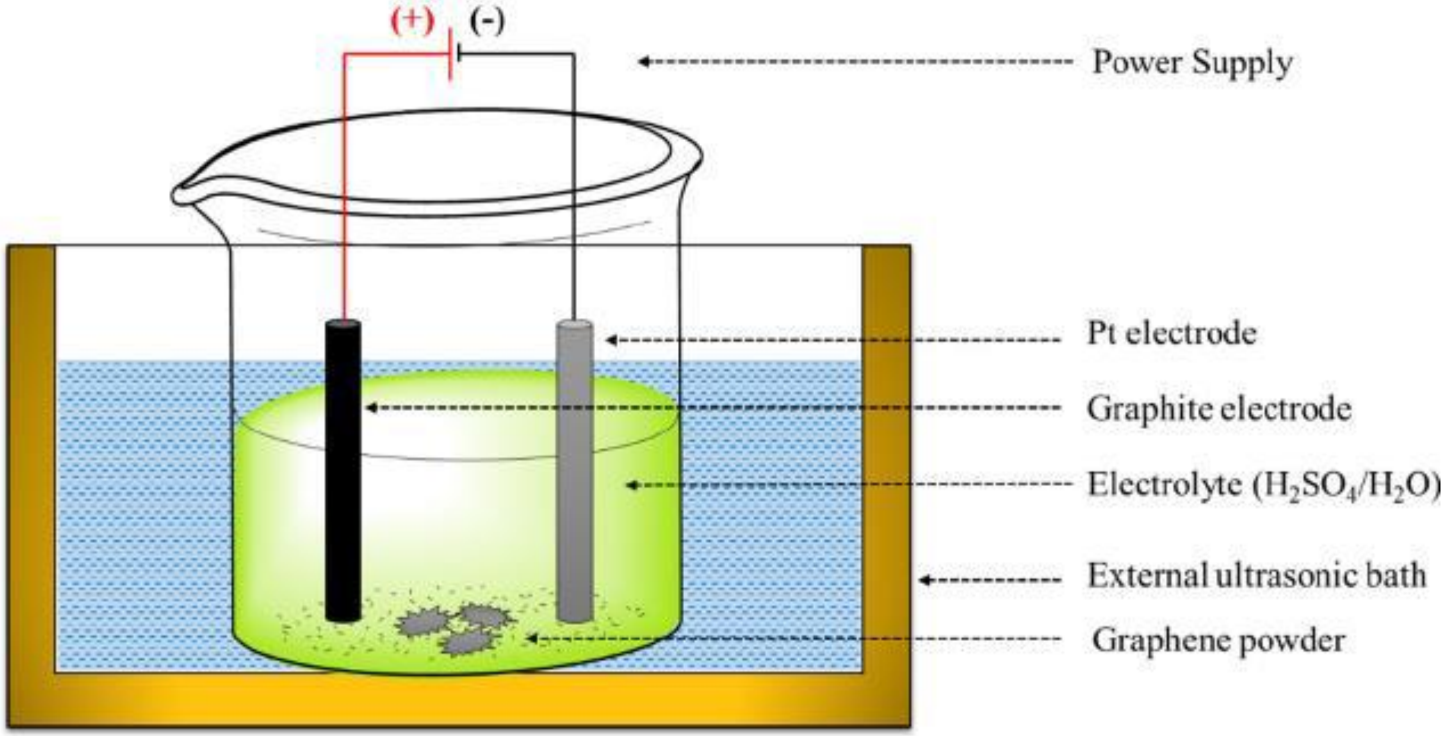
Other studies on technological carbon from biomass

- Fuel cells
- Different allotropes from biomass
- Catalysts
- Composite materials
- Conductive pens
- Printed circuit boards (PCBs)
- Carbon aerogels
- Solar cells
- Optoelectronics
- …



Planned experimental study

1. Catalytic carbonization of insudtrial tea waste biomass
2. Electrochemical exfoliation of the graphitized carbon to graphitic carbon
3. Preperation a conductive carbon ink
4. Application of the ink for printed circuits



Conclusion

- Biomass can be used as a technological carbon resource
- Carbonization is the first step
- Structural developed and nano sized carbon from biomass has various technological appliation areas
- Further researches are required