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Green Waste to Green Energy: Harnessing the Power of Agricultural Waste

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India generates ~998 million tonnes of crop residues annually, much of which is underutilised or burned, contributing to greenhouse-gas emissions and soil degradation. At the same time, the country's clean-energy push is driving rapid adoption of lithium-ion and sodium-ion batteries for electric vehicles, grid storage and electronics. However, conventional anodes rely on mined graphite and other raw materials whose extraction, processing and low recycling rates (~6% of battery waste) impose major environmental and resource costs.pib. This article argues that crop residues—rice husk, straw, sugarcane bagasse, maize and cotton stalks, fruit peels, and nut shells—can serve as sustainable precursors for carbon-based anodes. Their cellulose–hemicellulose–lignin matrix, upon carbonisation (pyrolysis or hydrothermal treatment) and chemical activation, yields porous, heteroatom-doped carbons with capacities that can match or exceed graphite's theoretical 372 mAh g^{-1}. We outline a practical route from field to cell and highlight environmental and economic benefits, including reduced residue burning, lower mining impacts and additional farmer income. Key challenges include feedstock variability, relatively low initial Coulombic efficiency and the need for industrial-scale implementation. We conclude that even partial replacement of conventional anode materials with residue-derived carbon is a strategic step toward a cleaner, more self-reliant and sustainable energy future for India.

Key woeds: Crop residues, energy, waste, battery, raw materials

Introduction

Agriculture being the primary sector industry in India, not only provide food, fodder, fees but also generates a considerable amount of crop residues. These residues generated are estimated to 998 million tonnes per year, from which a large share contibutes to greenhouse gas emmisions along with soil and ecosystem degradation. Also, the nutrients taken up by these plant parts remain underutilised or get wasted. At the same time due to the ongoing non-renewable energy crisis & geopolitical conflicts, India needs an alternative source for its energy needs. The source that can help India to shape a cleaner future by rapidly growing its clean energy technologies – from solar panels and electricity networks to electric vehicles. This need leads to use of batteries such as Lithium-ion batteries, Sodium-ion batteries for energy storage and electricity generation. However, the widespread use of these batteries also possess certain challenges like availability of raw materials, their extraction and purification, low recycling percentage of the batteries (only 6% of the total waste generated), impact of these processess on enviornment and lastly their disposal can lead to release of toxic substances into the enviornment. To adress such problems, alternatives to the raw materials are necessary that can promise a sustainable energy production without compromising the environmental concerns. What if we address the problem of clean energy from the green waste generated from our fields.

What makes these batteries important

1. Batteries are important because of its use in cleaner energy technologies: -

- electric vehicles
- energy storage(renewable)
- portable electronic gadgets etc.

Why we need an alternative resource for battery making

1.The extraction and processing of its raw materials are highly dangerous as this can cause: -

- Degradation of landmass
- Utilization of water
- Environmental pollution
- Emission of greenhouse gases
- Depletion of other resources

2.The recycling of these batteries include highly sophisticated process of hydrometallurgy and pyrometallurgy that needs high energy use and possess safety challenges.

Can crop residues act as an alternative source of raw materials?

In Lithum ion batteries, the anode is made up of graphite that stores the lithium ions during charging. During discharging these lithium ions again move to cathode. So for the preparation of anode raw materials made up of carbon and having high porosity to facilitate diffusion of the ions is necessary. Therefore, carbon derived from crop residues can be used for making anode and the heteroatom containing functional groups present in it will act as additional storage site for lithium ions. According to Dagwar *et al.* the carbon derived from residues have higher capacitiy than the theoritical capacity of graphite (372 mAh g−1). So, yes crop residues can act as an alternative source of raw materials for battery making.

What properties make crop residues valuable

Rice husk, rice straw, wheat straw, sugarcane bagasse, maize stalks, soybean residues, cotton stalks, fruit peels, coconut and groundnut shells are the main faces of the crop residues generated in India. These materials being derived from the plants are mainly composed of cellulose (40-50%), hemicellulose (25-35%) and lignin (15-20%). These natural plant components upon carbonization will produce carbon structures that are more organized with closed pores and structural defects, facilitating additional lithium ion storage and improved structural stability. Other heteroatoms such as oxygen, nitrogen, sulphur etc. present in crop residues can provide additional active sites for the adsorption and charge transfer of lithium-ion. The properties and components of crop residues vary from crop to crop and also depends on the climate, soil and overall management practices which make some crop residues more favourable and acceptable.

How to convert crop residues into electrodes?

It includes:

1. Collection of crop residues
2. Cleaning and drying of residues
3. Grinding to increase surface area
4. Carbonization (pyrolysis/hydrothermal carbonization)
5. Chemical activation of carbon obtained
6. Cleaning and resizing of carbon obtained
7. Electrode slurry preparation
8. Coating the metal
9. Drying and processing
10. Incorporation to a lithium-ion battery

Explaining the above procedure in deatil:

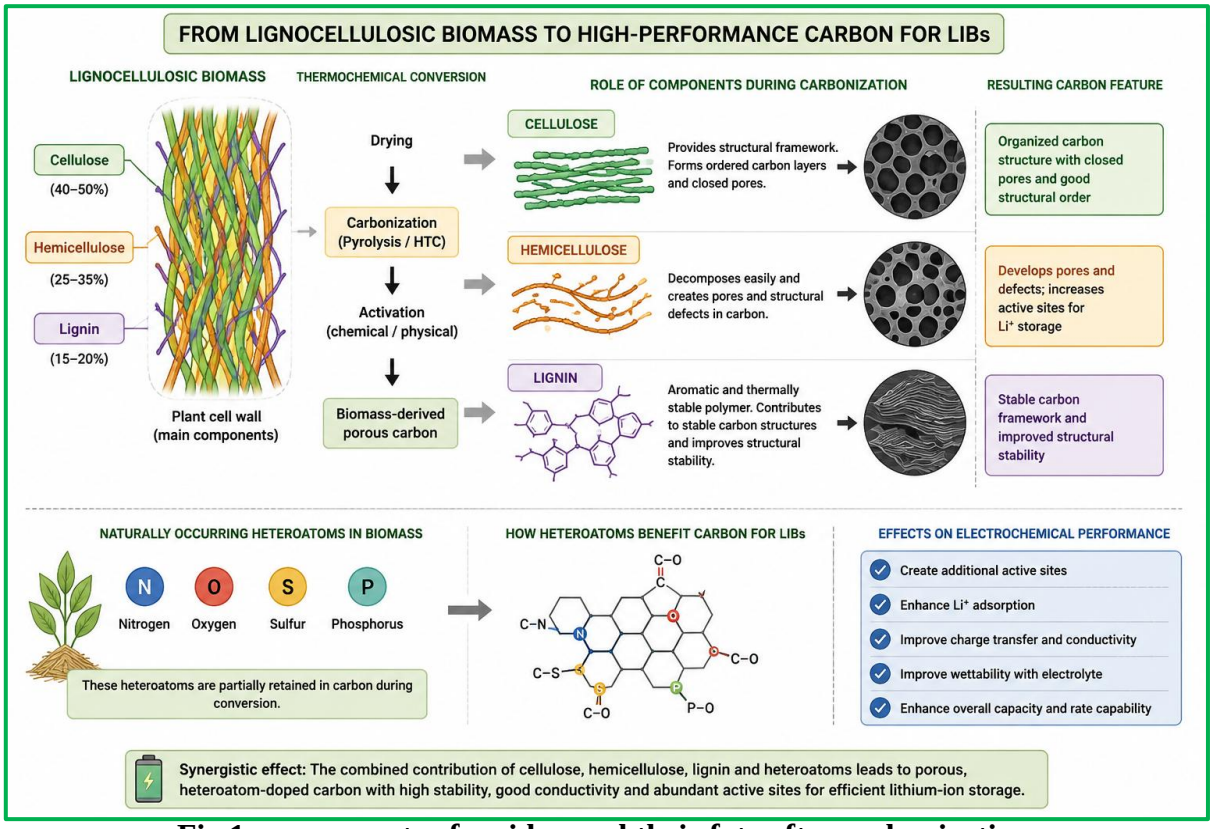

Fig 1, components of residue and their fate after carbonization

The raw materials i.e. the crop residues are first collected from the field, followed by thorough cleaning, drying and grinding into suitable size. Which are then subjected to pyrolysis (heating the residues at 500-1200°C in the absence or limited oxygen) or hydrothermal carbonization (processing residues in water at approximately 180-250°C) depending on whether the residues are dry or wet respectively. Following the carbonization, the porous carbon that are formed are chemically activated using KOH, NaOH or HCl in order to increase their surface area and modify their pore space. The carbon is then washed to remove the treated chemicals and processed to obtain a uniform size of materials to facilitate electrode fabrication. The residue derived carbon along with a conductive additive (to improve electrical conductivity) and binder (to hold the particles together) are then formulated to an electrode slurry which is coated on a conductive metal current collector. After this the electrode is dried and processed to get assembled with other components to form a lithium-ion battery.

Benefits of using crop residues

A. Environmental benefits

- Reduces the carbon footprint generated by using non-renewable energy sources
- Adresses the problem of crop residue management
- Checks resource consumption and depletion
- Converts low value residues into high value products
- Can establish a zero waste model for agriculture
- Can help India achieve the goal of cleaner energy
- Reduce greenhouse gas emission due to burning of residues
- Check the enviornmental pollution caused due to unmanaged residues

B. Economic benefits

- Reduces cost of mining, transportaion and processing of graphites
- Generates additional income from low value crop residues
- Builds a circular economy

Challenges

- Variability in composition of crop residues can cause variability in the carbon produced
- Initial coloumbic efficiency of residue derived carbon is low as compared to that of graphite
- Actual implementaion of idea in industries

Future prospects

- To carry out research to replace more battery parts with available, low cost, sustainable resources that are environment friendly
- To implement these ideas on large-scale in industries
- To carry out more research to harness the hidden potential of crop residues

Conclusion

Using the agricultural waste as a source to produce carbon for electrodes of batteries provides a way forward to efficiently divert the potential of crop residues towards a sustainable and clean energy production. This divertion will reduce the dependency on traditional graphite electrodes and there by reducing ecological degradation during its mining. It can also reduce the emission of greenhouse gases and pollution. Though each and every part of a battery can not be replaced by sustainable alternatives still, replacing a part of it in first step represents a critical step for India that is growing resiliently towards an independent, cleaner, sustainable and efficient energy producing nation.

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