Li-Ion Batteries and Sodium-Ion Batteries

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Batteries are the backbones of the sustainable energy transition for stationary off-grid, portable electronic devices, and plug-in electric vehicle applications. Both lithium-ion batteries (LIBs) and sodium-ion batteries (NIBs), most commonly rely on carbon-based anode materials and are usually derived from non-renewable sources such as fossil deposits.

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1. Introduction

With the earth's human population growing to 8 billion, the energy demand is increasing at alarming rates. The depletion of global natural resources and the environmental crisis, opt for the development of low-cost renewable, and sustainable high-energy and power-density energy storage systems, such as batteries as these natural sources are intermittent. Due to their high energy density and power output, outstanding safety, and long cycle life, lithium-ion battery (LIBs) is the most used technology revolutionizing the portable electronic world and is now being pursued to develop plug-in electric vehicles [1][2][3][4]. For example, the global grid-battery energy storage market has been forecast an annual growth rate of 23% or even more by 2030. However, lithium (Li) is a very limited resource in the earth's crust containing only 0.0017 wt.%, and their mining deposits are situated in politically unstable countries making them very expensive to cast as "white gold" [5].

Therefore, the focus is directed towards developing energy storage devices with earthly abundant and sustainable elements such as sodium-ion batteries (NIBs) that are believed to be the most suitable battery technology to replace LIBs, because of stationary applications such as wind energy storage. Sodium (Na) is cheaper and more abundant than Li, with an estimated 2.8 wt.% of total Na concentration in the earth's crust [6][7]. In addition, Na and Li have similar physical and chemical properties but differ in their energy density due to their standard electrode potentials: −2.71 V vs. SHE (Na^+/Na) and −3.04 V vs. SHE (Li^+/Li) and different atomic radii [8]. However, NIBs have sluggish kinetics and lower energy/power density compared to LIBs which slows down their massive employment in mobile devices and electric vehicles; but allows NIBs to be employed in massive stationary storage applications (e.g., grid energy storage) where energy density and battery size are not critical factors [9][10].

One of the key parameters for efficient battery technologies (NIBs or LIBs) is the right development of sustainable and high-capacity anode materials. Nowadays, graphite (Gr) is the most common anode material for LIBs [11][12][13]. Carbon nanotubes and graphene appear as important anode materials as well [14][15]. However, these types of carbonaceous materials face serious drawbacks including high production costs, extremely complex large-scale fabrication, and or non-sustainable routes/processes [16]. Then, it is highly necessary to develop novel, eco-friendly, cheap carbon-based functional materials with sustainable and scalable synthesis/fabrication processes [17]. Considering this statement, carbon anode materials from biomass resources have gathered huge interest due to their easy processing and handling, non-toxicity, and worldwide availability and abundance of biomass resources [18][19][20][21][22]. Also, biomass carbon materials can be easily turned into hierarchically porous structures to be employed in battery technologies due to their excellent cycling stability and rate performance.

The scientific society has responded to the request for sustainable bio-based electricity storage devices through a tenfold increase in scientific publications over the last decade [19][21][23]. To date, plenty of research has dealt with biomass-derived carbon anodes for batteries application [18][19][20][21][22]. Some main advantages of using bio-based carbon anodes for batteries can be simplified into some main characteristics such as (i) large interlayer spaces that provide excellent physical-mechanical stability during ion intercalation/de-intercalation process [24]; (ii) different and large amounts of surface functionalities that boost the charge transfer [25]; (iii) high specific surface area (SSA), well developed pore structures with different nano-sizes, and good thermal stability, fast mass transports; (iv) the surface and structure of the bio-based carbons can be easily modified/tailored, in terms of its chemical structure and surface functionalities, e.g., by heteroatom doping (Nitrogen, Oxygen, Sulphur, etc) to boost the electrochemical performance (e.g., lifetime, capacity and safety) [26]; (v) wide availability/accessibility facilitate the developing of multiple carbon anodes using different types of biomass carbons and composites by simple synthesis methods [20][21][22].

2. Li-Ion Batteries (LIBs)

Lithium-ion batteries (LIBs) are the well-established and more dominating battery technology and are already the most widely used in our society. It has been an enabling technology for portable electronic devices and is revolutionizing the automotive industry [3][27]. To achieve a better energy transition, high energy density batteries are intensively researched worldwide, LIBs having emerged as one of the most promising energy storages [28]. LIBs are increasing in popularity despite rising prices and uncertainty around sourcing component materials. However, due to the rising demand and unequal geographic distribution, Li and Gr are becoming ever-increasing strategic resources [17]. LIB uses $Li_4Ti_5O_{12}$ (LTO) or Gr as the anode and lithium cobalt oxide (LCO), lithium iron phosphate (LFP), lithium manganese oxide (LMO), lithium nickel-manganese-cobalt (NMC), lithium nickel-cobalt-aluminum oxide (NCA) as cathode materials [28][29]. Almost 95% of the world’s LIBs are produced in Asian countries like Japan, South Korea, China, and Taiwan. However, Gr has been used widely as anode materials for LIBs and could not meet the requirements due to the limitations in energy capacity and reliable operation. Alternatively, several anode materials have been widely investigated and tried to replace Gr, such as silicon, tin, and simple binary transition metal oxides [30][31][32], even Li metal for solid-state batteries, and especially, biomass-derived carbon materials with special morphologies and structures because these, generally, exhibit high specific capacity.

3. Sodium-Ion Batteries (NIBs)

Sodium-ion battery (NIB) is a type of rechargeable battery like the LIB but uses sodium ions (Na^+) as the charge carrier. NIBs have several advantages over competing for battery technology, but furthermore, research and development are still needed to fully exploit them [33][34][35]. Several companies are developing commercially viable NIBs for different applications, but NIBs with high energy densities, excellent electrochemical performance, and high stability are not yet commercialized though a couple of companies have announced imminent productions (for example, CATL and BYD). If the cost of NIBs is further reduced, they will be favored for energy storage in grids, where battery weight is not important [35][36][37][38]. The NIBs are electrochemical energy storage devices like LIBs because both are working in the same principle (intercalation and deintercalation). Then the question is why we should concentrate on NIBs rather than LIBs, even though they have lower energy density [39][40][41]. LIBs materials, mainly Li, are not abundant in nature. However, researchers are looking for alternative batteries for electric vehicles to protect against energy crises and global warming. Once the demand for electric vehicles increases. It can automatically increase the demand for batteries. Hence, it should create a big problem in the supply chain process due to the deficiency of Li sources. It is noted that the solution to this Li shortage problem has been fulfilled by NIBs because of their abundant nature, low cost, etc. Therefore, the research on NIBs might capture more attention [42][43].

NIBs were originally developed in the early 1980s, approximately over the same time period as LIBs. During this time intercalation process of TiS_2 could be tested for both LIBs and NIBs. In 1990, low-cost, moderate-capacity graphite anode was also tested for both battery chemistries. The LIBs battery shows a better output than NIBs. This was the reason for ignoring NIB. Then, development based on Na metal batteries is highly focused because of their energy density. These devices are only working at elevated temperatures (300 to 350 °C) for ensuring the liquid state Na (melting point 98 °C). Here, (sodium β“ alumina) solid-state electrolytes (“-alumina”) were used as the ion transport medium. However, the poor power density, security issues, and more expansive implementation of the batteries again stop its development. Room temperature NIBs are widely recognized as the alternative candidates for LIBs [44]. NIB comprises of cathode, electrolyte, separator, and anode. The cathode should be reversibly accommodated Na^+ at a voltage greater than 2 V vs. Na/Na^+. In oxide-based cathode compounds, Na^+ occupies only octahedral or prismatic sites because the large size of Na^+ exhibits less stability with four coordinates (tetrahedral) than Li-ion. On the other hand, polyanionic materials have octahedral interstitials in their structures. These cathodes look promising candidates for NIBs [42]. At room temperature, organic electrolytes have superior electrochemical properties for NIBs. This organic solvent is a mixture of propylene carbonate (PC), ethylene carbonate (EC), diethyl carbonate (DEC), and ethyl methyl carbonate (DMC) with sodium salt $NaPF_6$. It can have good ionic conductivity, chemical stability, and potential window. The successfull anode must have a lower voltage (less than 2 V) and act as a good host for Na^+ [42].

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