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Review

A Novel Biogenic Silicon-Based Anode Material for Lithium-Ion Batteries: A Review

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Abstract: Silicon possesses a 10-fold specific capacity compared to commonly used carbon-based anodes. The volume instability, among other impediments for practical use of silicon anodes, leads to the rapid decay of the capacity because of poor cyclability. Urgent mechanisms are required to improve lithium-ion storage during cycling and prevent volume variation in the silicon structure. Biogenic silicon derived from sugarcane bagasse can be used in nanoelectronic devices. Over the years, electrode materials have been an essential part of battery components. Moreover, electrode materials are favourable for highly portable nanoelectronics, hybrid as well as pure electric vehicles, etc. Furthermore, the biogenic silicon chosen for this study was based on natural abundance, environmental friendliness, and affordability. However, most silicon anodes are hindered by unstable volume expansion, variation in solid electrolyte interface films, and poor electrical conductivity. The focus is on silicon anodes, recent developments, and the potential of biogenic silicon from sugarcane waste, exploring its physicochemical properties to meet the requirements of a suitable anode material.

Keywords: energy storage; biogenic silicon; nanostructured; lithium-ion battery; anode

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1. Introduction

Renewable energy has been used to maintain life on Earth since the dawn of humanity. Humans used renewable energy sources such as solar, wind, and biomass to power fires and heat homes so that they could eat and survive. Currently, non-renewable energy sources, such as fossil fuels, dominate electricity generation. These resources take longer to replenish, making it difficult to meet energy demand. The growing population has led to an increased demand for energy supply. Non-renewable energy sources not only meet the rising demand, but also create greenhouse gases such as carbon dioxide, which contributes significantly to global warming. As a result, there is a growing desire to transition to a state entirely powered by renewable energy [1,2].

Carbon abatement across the world is a hot topic, mostly for the investigation of the energy mix. Energy storage technologies are receiving extensive research attention, especially LIBs in a range of portable nanoelectronics, electric cars, etc. The performance of these batteries can be affected by several factors, such as electrode materials, SEI, and binders, which are the critical components of the battery. The negative electrode over the years has been graphite, which has a considerable market share [2,3].

Around a decade ago, there was a huge breakthrough in anode materials, and silicon was intensively studied for use in LIBs. This research is currently in its early stages because of difficulties with silicon materials, such as volume increase, instability, and decreasing rate performance. The trade-offs between these factors make it extremely difficult to achieve high-rate performance in silicon anodes [4–8].

Biogenic silicon as an anode addresses these trade-offs and achieves considerable improvements in total battery performance. Furthermore, the proposed biogenic silicon is derived from sugarcane bagasse and is completely compatible with electrochemical methods, reducing volume fluctuation while improving solid electrolyte interphase and binder synergies. This makes it an inexpensive and user-friendly anode material [9–14].

In addition, future directions for the research and development of silicon anode materials for practical use are discussed, providing details regarding a rational inquiry of silicon anode material based on biomass. One kind of biomass anode material that may offer stable production and cooperate to improve the electrochemical properties of LIB anodes is biogenic silicon, which is derived from sugarcane bagasse. Biogenic silicon with mesoporous characteristics may be able to overcome the challenges that silicon anode materials face.

2. Silicon Anodes

Because silicon provides excellent application properties, the nature of the material design is crucial in establishing suitable anode material (Figure 1a). This typically drives up asking prices in the areas where silicon is mined. It is a semiconductor that cycles with large volume fluctuations and low conductivity [12].

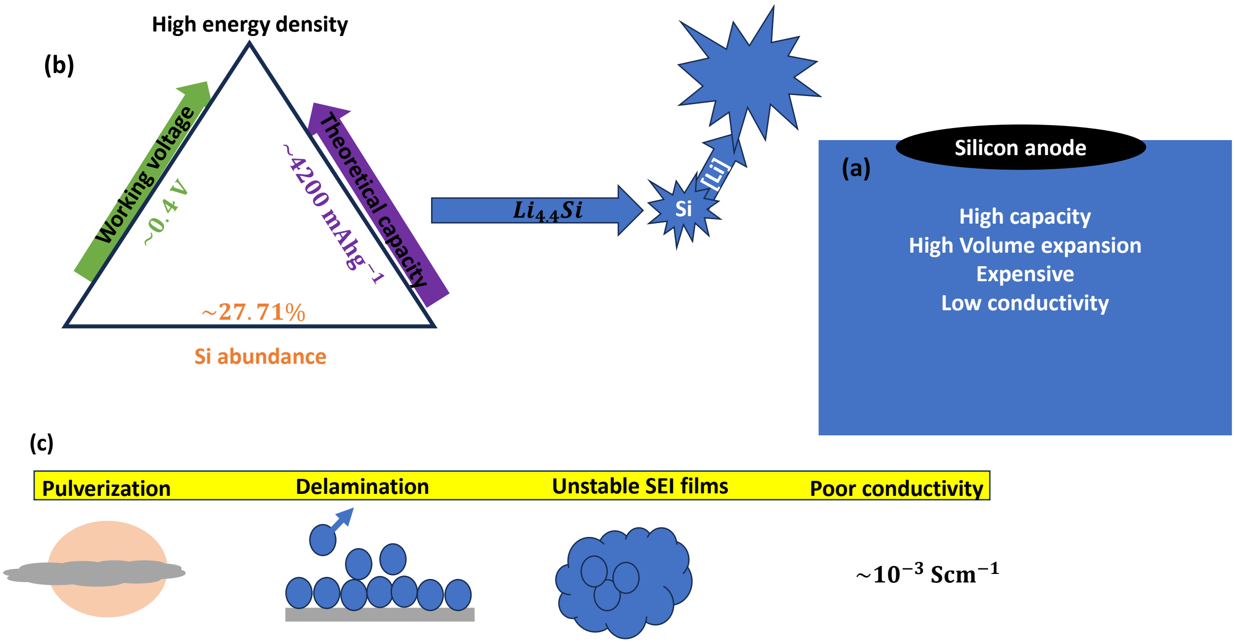

Figure 1. Schematic illustration of anodes for silicon (**a**) a description of (**b**) the benefits and (**c**) underlying difficulties associated with the electrode material is provided.

As Figure 1b illustrates, to identify the alloyed anode based on Si, a widely used material that has moderate electrochemical potential, an average theoretical capacity ten times higher than graphite, is readily available. The undesirable effects of the silicon volume change during cycling include (Figure 1c) (i) instability during SEI cycles, (ii) poor conductivity, and (iii) pulverisation. Previous studies have indicated that these problems lead to a reduction in capacity [12,13].

Sugarcane bagasse is known to be a renewable feedstock that can be used to make nanostructured silicon. The tuneable characteristics of nanosilicon offer many benefits over those of bulk counterparts. The most widely used techniques for producing nanosilicates in nanotechnology are chemical vapour deposition and etching. Figure 2a shows that the optimum route for practical application in silicon anode materials is low-cost, customised silicon [12,14].

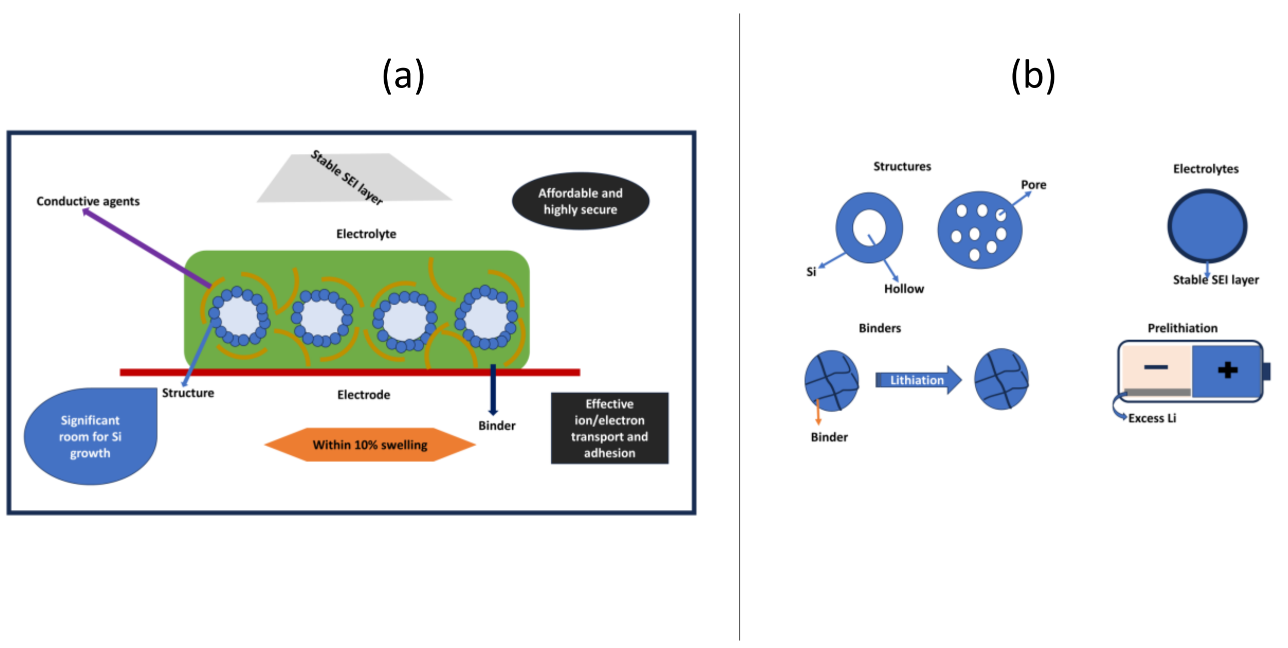

Figure 2. Diagram demonstrating the probable growth of a (**a**) silicon anode; an overview of (**b**) Si-based LIB anode strategies for developing the structure, binder, electrolyte, and Si.

It is improbable for existing approaches to solve all three issues at once. To achieve reduced electrode swelling and homogeneous Si distribution, future research should focus on developing practical and scalable preparation procedures for Si-based anodes as well as efficient manufacturing techniques for Si/graphite composites [12–14].

In commercialisation, the concurrent use of inexpensive, natural resources for silicon and production techniques is frequently an indispensable factor. There are five key parts that can further adjust the Si anode to attain application-specific features and commercial progress. To decrease mechanical characteristics, significant Si nanocomposites, electrolytes, and structural designs are recognised. Performance is the synergistic interaction of electrolytes, binders, and core architectures (Figure 2b). The design of the structure is crucial, especially in establishing the most precise method for reducing the volume growth of Si during cycling. These materials' structures differ from those of silicon nanostructures (which include nanoparticles, nanotubes, nanowires, and nanolayers) [12–15].

The yolk shell, porosity structure, and core are examples of structures inspired by morphology. Doping techniques, heterostructure, and lattice deformation are also used on an atomic basis. Since the binder is essential to the active material, it should typically occupy less than 10%. Many features of modern binders, including conductive additives, work against volume expansions through ionic and electronic conduction, good dispersion function, and SEI contribution. Their special qualities include being inexpensive, safe for the environment, and possessing a broad electrochemical range in addition to being chemically and electrochemically stable [16–18].

The reactivity of materials in chemistry gives an umbrella of three divisions of lithium anode materials. Classes consist of intercalation, conversion, and alloying materials. Among the materials Sb, Sn, Ge, SiO, and SnO_2, Si has received considerable attention in alloyed material studies over the years. Although these alloyed materials beat graphite in terms of theoretical capacities, their irreversible capacity fading after the first cycle and volume instability have hindered their avenues. Another interesting mechanism involves conversion of materials such as metal oxides. The following general reaction, Equation (1), denotes the displacement reaction, showing the conversion reaction mechanism [19–21]:

$$M_aX_b + (bn)\ Li^+ + (bn) \rightarrow aM + bLi_nX \quad (1)$$

The transitional metal is denoted by M, and chalcogenides, halogen, and oxygen are denoted by X, etc. Presently, graphite material is the predominant commercial anode in lithium-ion battery half-cells. Graphite and titanium oxide are intercalating compounds in these devices that are found worldwide. Research is ongoing to optimise the three mechanisms to store maximum Li capabilities, which, in turn, significantly increase electrochemical properties [22]. An illustration of intercalation can be seen in Equation (2):

$$TiO_2 + x\,(Li^+ + e^-) \leftrightarrow Li_xTiO_2 \quad (2)$$

3. Recent Developments in Research on Silicon Anodes

The main point of the given text is that Xie [23] and Zhou [24] have developed different methods to produce porous Si nanoparticles with high anode capacities (3762 and 2000 mA/g) and improved electrochemical kinetics, demonstrating their potential for use in electrochemical devices.

Figure 3 depicts the structural evolution of porous silicon produced from bulk metallurgical silicon during ball milling [25]. Figure 3B,C demonstrate no particle size distribution nor distinct shape; the material is strongly aggregated. The main point of the given text is that Zhang successfully created nanoporous Si networks and porous Si electrodes with high discharge capacities and cycle stability. Another study developed a cost-effective method for preparing nano-Cu coated porous Si powder and acid-etched porous Si powder, both showing promising electrochemical performance as anodic materials for lithium-ion batteries. These methods have the potential for practical application in the high-energy lithium-ion battery field [26].

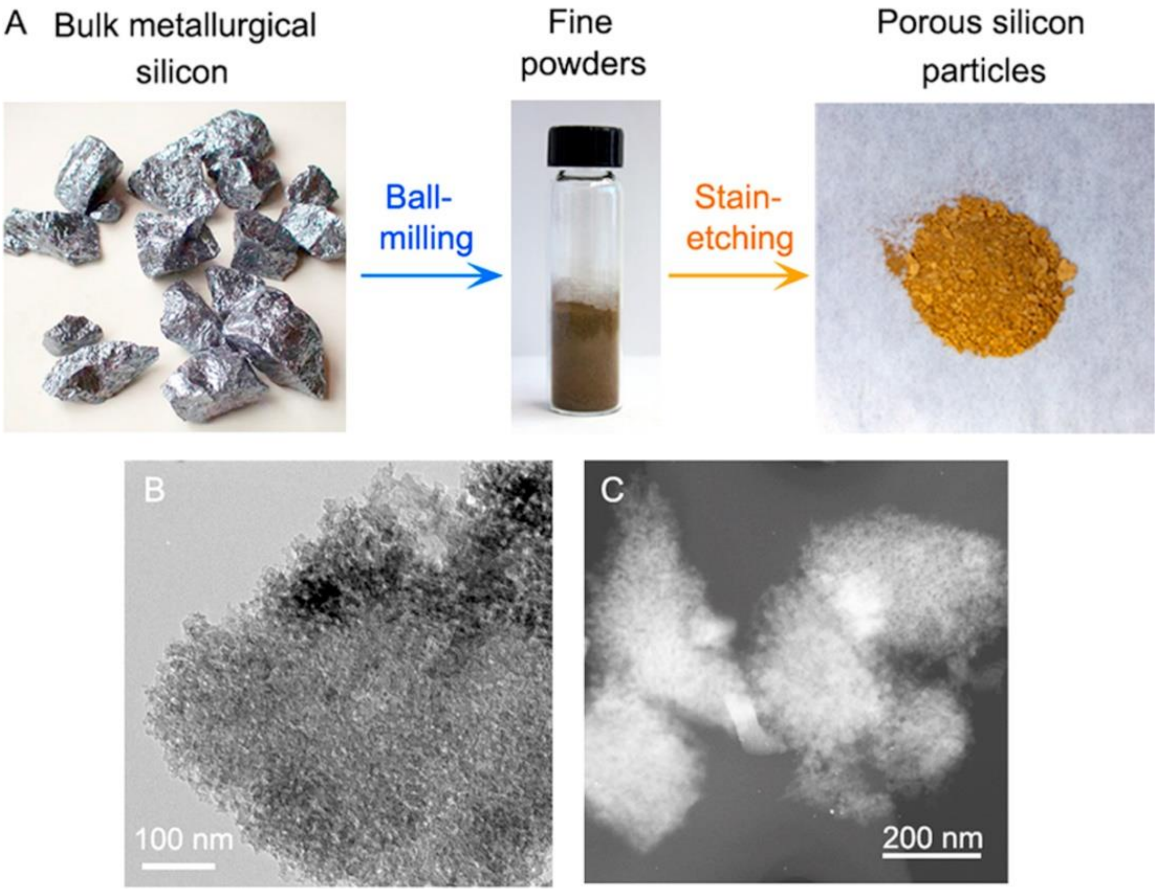

Figure 3. (**A**) Preparation and (**B**,**C**) morphological properties of silicon. Reproduced with permission from Ref. [25]. Copyright 2014, American Chemical Society.

A facile and large-scale approach for preparing microsized porous silicon from metallurgical Fe-Si alloy can lead to a high-performance anode in lithium-ion batteries, with excellent reversible capacity and coulombic efficiency, offering a promising route for large-scale production. Another work reported on the successful synthesis of mesoporous nanosilicon and monodisperse porous silicon spheres, showcasing their exceptional electrochemical properties in terms of capacity, rate performance, and cycling stability for lithium-ion battery anodes [27–29].

Silicon matrix, including various forms of silicon, such as particles, nanowires, films, and porous structures, show promise as anodes due to their straightforward synthesis methods. In addition, the use of SiO and polymerised furfuryl alcohol has been explored to improve the cyclability of silicon composites. Research was carried out and highlighted the successful development of nanosilicon composite anodes with high capacities and cyclic retention rates, highlighting the potential for advanced energy storage systems in the field of battery technology, listed in Table 1 [30].

Table 1. Multiple component Si-based lithium-ion battery anodes.

Electrode	**Synthesis Route**	**Capacity [mAh g^{-1}]**	**Cycle no.**	**Current [mA g^{-1}]**	**Ref.**
Silicon composites	Disproportionation and polymerisation of furfuryl alcohol	700	200	1	[31]
Silicon mono-oxide composites	Disproportion with graphite	1061	100	100	[32]
3D porous silicon mono-oxide composites	Chemical and thermal-assisted disproportionation	1600	100	0.1	[33]
Silicon multicomponent	High-temperature annealing process	1280	200	0.2	[34]
Structured nanotubular silicon multicomponent	Coaxial electrospinning technique and, metallothermic reduction reaction	765	280	0.5	[35]
Nanostructured silicon composites	Sol–gel process	650	1000	1	[36]
Nickel–silicon alloys	Spray drying and facile pyrolysis treatment	1261	50	210	[37]

The main point for the development of advanced electrolytes is crucial for improving the electrochemical performance of Si-based anodes, as the degradation and reforming of the SEI film on the electrode surface can lead to an increase in impedance and a decrease in battery capacity. The research community became interested in Si-based anodes due to the significant impact of the structure, properties, and composition of the SEI on the surface of the electrode, particularly the reduced SEI film caused by the decomposition of electrolytes [36,37].

The composition of the electrolyte plays a crucial role in determining the structural properties of the SEI film, making it vital to optimise the electrolyte for enhancing the performance of silicon negative electrodes. Enhancing the electrolyte composition with foreign species can help address volume variation and low initial coulombic efficiency caused by electrolyte decomposition. Functional electrolyte nano additives, as described in Table 2, have shown promising results and are extensively studied [38].

Table 2. Irreversible capacity from cathode and anode electrode materials.

Electrode	Anode (%)	Cathode (%)	Ref
HCMR (High-capacity manganese-rich)	-	~15%	[34]
NCM (Mickel Cobalt Manganese)	-	~10%	[35]
LFP (Lithium Iron Phosphate)	-	~10%	[36]
LCO (Lithium Cobalt Oxide)	-	<3%	[37]
SiOx	~30%	-	[38]
LTO (Lithium Titanium Oxide)	<3%	-	[39]
Carbon	>10%	-	[40]
Graphite	~7%	-	[41]

The concept of prelithiation is to improve energy efficiency (density), simply because of the irreversible capacity loss from initial coulombic efficiency. The silicon anode benefits greatly from the prelithiation process to promote reversibility. During formation, the Li will be poured into the anode as shown in Figure 4A, without prelithiation, since the cathode is Li^+ the source. Furthermore, not all the Li^+ in the anode will be reversible, and thus, energy leaks during the first cycle. Hence, during discharge (a), there will be less Li^+ due to the irreversible Li^+ reaction in the anode. This results in permanent energy loss. Therefore, in Figure 4B, the preloaded energy is offset by the prelithiation even though the leak is still experienced in the first cycle. No permanent energy loss is observed [33–36].

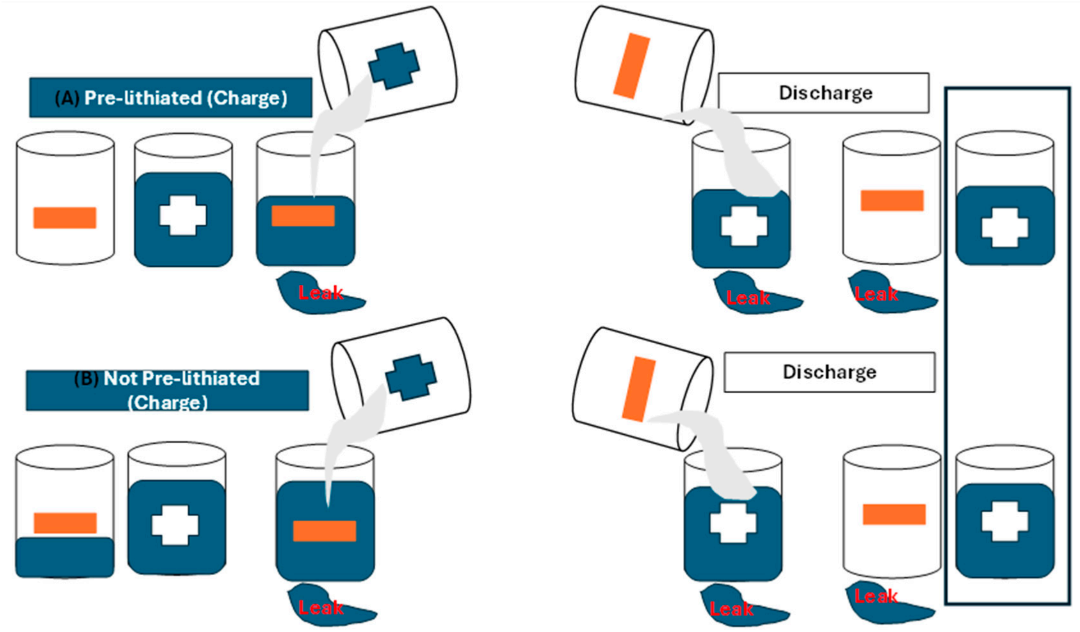

Figure 4. Effect of prelithiation on energy density.

Determining the merits of prelithiation in addressing the irreversible capacity loss is shown in Table 2, with graphite exhibiting the least irreversible capacity of 7% and LCO about less than 3%. Therefore, the prelithiation promotes Li^+ preservation and facilitates an optimum reversible process. This substantiates the preload energy as effective, since it will increase the initial columbic efficiency with an excess amount of Li^+. The right amount of prelithiation will consume oxygen in SiO_x, participate in the formation of a stable SEI layer, and mitigate Si particle expansion. Additionally, the energy density will be preserved via reversible Li^+ in the cathode and anode. However, the specific capacity of an anode is not affected or increased [34,35].

One method of understanding and evaluation of the electrochemical performance of half coin cells is such that the assembly involves the working electrode as the active material and metallic Li foil as the counter electrode. The design of the commercial anode plays a crucial role in the performance of batteries, and factors such as structure, shape, and connection state have an impact on energy density and capacity. The balance between conductivity and energy density remains a challenge in electrode design to meet the evolving market demands for battery shape and flexibility, as shown in Figure 5. The electrodes are normally counter electrode (CE), reference electrode (RE), and working electrode (WE). The main point of a previous study was that electrode materials can negatively impact battery capacity by falling off the current collector or clogging ion channels, and the connection state and flexibility of the electrode are important factors in electrode design to meet the demand for battery shape and flexibility [42].

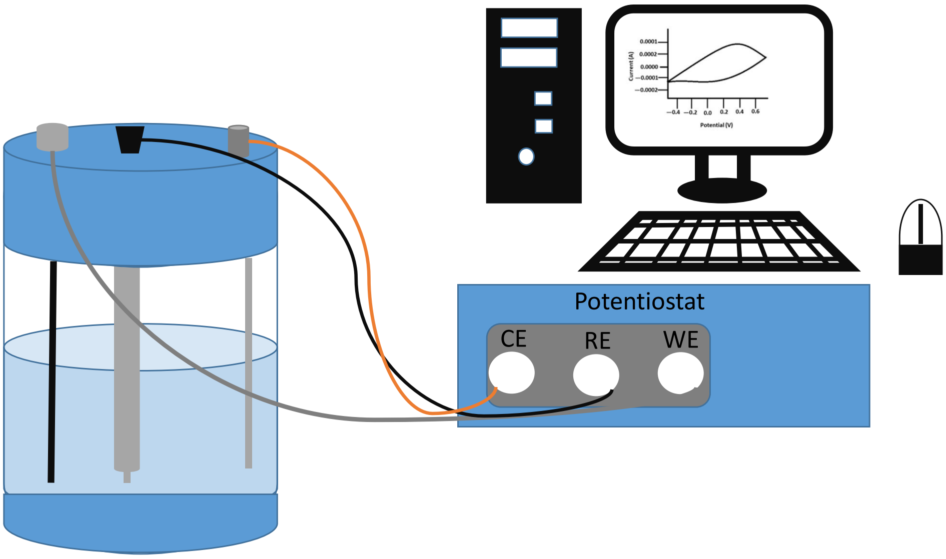

Figure 5. Schematic representation of electrochemical testing.

Cyclic voltammetry was conducted to test the activity of porous silicon and doped silicon with boron on double layer of carbon, in the Li reaction. The CV scan in Figure 6a shows strong activity towards the Li insertion during subsequent cycles. The broad peak cathodic current density at 0.6–0.8 V is due to the irreversible decomposition of electrolyte and the formation of stable solid electrolyte interphase (SEI) films. The ratio of peak current densities is important as it is an indication of the Li insertion in the polysilicon to form a matrix of Li silicide alloy. The de-intercalation process is observed from the presence anodic peaks at 0.34 and 0.53V. Figure 6c shows an initial coulombic efficiency of about 78.38% that is also observed between the first and second cycle in 6e. The stable SEI formation facilitates the plateau observed at 0.37 and 0.62V during the extraction process. The variation in current rates in Figure 6e further indicates that the electrode material composite doped with boron possesses superior rate capability during lithiation and delithiation process. The main issue preventing silicon anodes from full commercialization is the current material technology used in industry. The current silicon anodes face two main issues: the price of the material, and the volume stability and poor reaction kinetics with Li-ion batteries. As a panacea to volume stability, a study found that doping silicon material with boron in a heat treatment can help alleviate silicon volume variation, as evidenced by the absence of SEI, with satisfactory specific capacities (see Figure 6b,d,f). In Figure 6b, it is quite evident that porous silicon suffers from volume instability and, thus, an irreversible Li reaction, hence the low specific capacity. The electrode material with a carbon core–shell structure and boron doping showed improved electrochemical performance by improving electron kinetics and lithium-ion movement through porous silicon channels. The authors were able to report cycling stability after 600 cycles. They were able to emphasise that the delithiation process is essential for immediately witnessing a plateau, recording a specific capacity value of 1941 mAh/g [43].

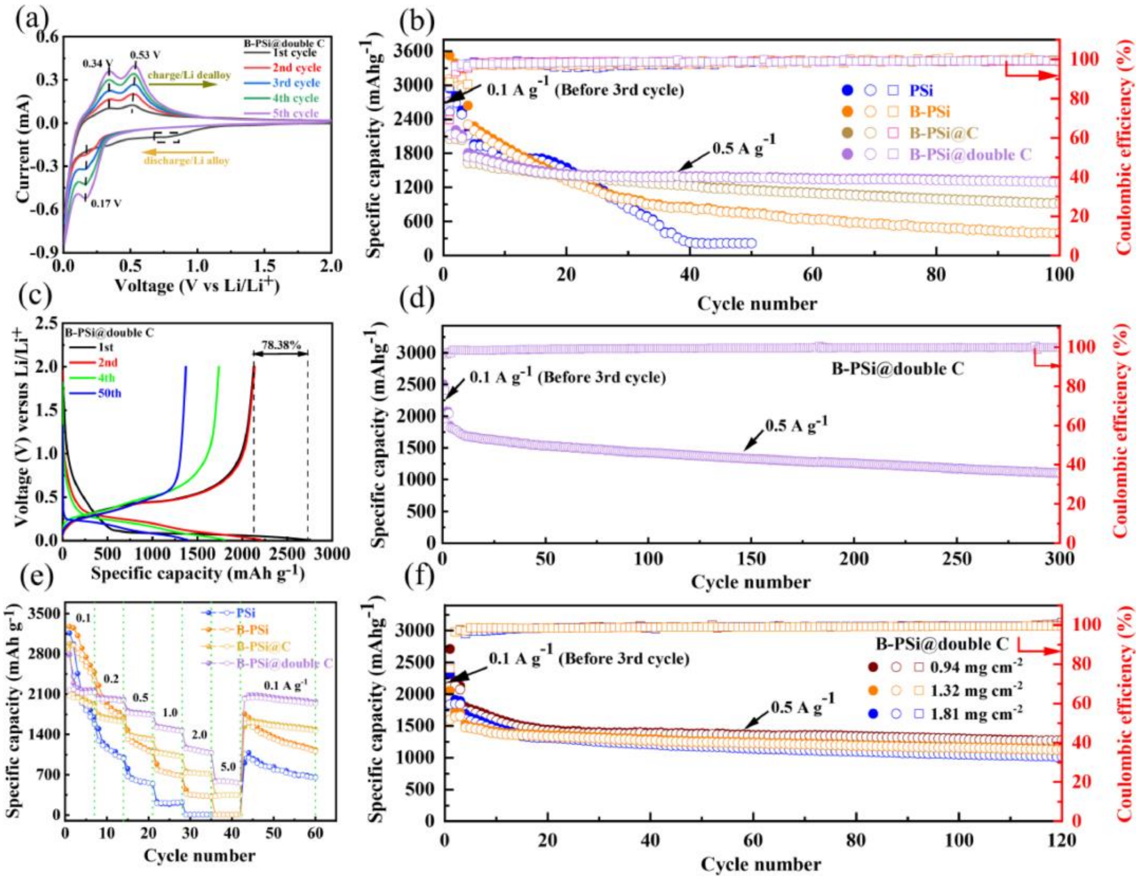

Figure 6. Electrochemical performance of silicon functionalised with boron as electrode material, (**a**) CV profiles, (**b**) cycle test, (**c**) Voltage vs capacity, (**d**) cycle test at a rate of 0.5 A g^{-1}, (**e**) Specific capacity at different rates as a function of cycle number and (**f**) Specific capacity of the active electrode with different energy densities. Reproduced with permission from [38], 2023 Elsevier.

Another study found that nanostructured materials could be excellent electrode materials. The study focuses on the specific capacity curves and differential capacity of the materials examined. The results clearly demonstrate that structural dimensions (0D−1D hybrid) have more channels for Li intercalation capabilities. The energy storage qualities shown here demonstrate that hybrid electrode materials match the criteria for a viable anode material in LIBs, as seen by the large capacity of 1200 mAh/g observed after 500 cycles [44]. The study discovered that alloyed electrodes outperformed a mixture of SiNW and smaller SiNP in terms of capacity, reaching up to 1200 mAh/g even after 500 cycles, despite electrode degradation factors. As a result, nanosilicon anodes have outstanding stability and high capacity when compared to state-of-the-art electrodes, making alloyed-based anode materials an attractive choice [39,44].

An interesting correspondence is that crystalline Si (c-Si) on alloyed Li to form amorphous LixSi is given by the following reaction shown in Equation (3):

$$\text{c-Si} + \text{xLi} \rightarrow \text{a-LixSi} \tag{3}$$

Then, the peak transition occurs between two phases.

$Li_{15}Si_4$ is delithiated to form a-Si, as demonstrated in Equation (4):

$$Li_{15}Si_4 \rightarrow 4Si + 15Li \tag{4}$$

The study shows that when silicon anodes are coupled with MXenes, a plateau of lithium-ion insertion occurs and is observed at voltages between 0.1 and 0.5 V. The 2D nanocomposite silicon anode material displayed outstanding stability and enhanced capacity, specific capacity, cycling, energy density, and overall battery performance, as shown in Table 3 [44].

Electrochemical investigations were carried out on silicon anode materials. Silicon was infused with silica, and new surface terminations produced a sequence of samples labelled S1, S3, S5, and S8. The produced materials were then carbonised with lignin. The cycle profiles used to report the S1 samples had a high specific capacity for the initial discharge. This relates to S1's core–shell structure. Although downward and continuous cycling was detected for the same sample, its counterparts, S3, S5, and S8, contained voids in their structures. Rate investigations were also conducted, and the performance was satisfactory for sample S5. The high-rate performance is ascribed to the channels supplied by silica construction in the sample, which facilitates the high-speed movement of ions and electrons. Here, S5 and S8 samples obtained a successful cycling curve results from the channels created by the insertion of the silica core–shell structure, which allows for high and smooth passage of ions and electrons in the electrode material. The structural degradation of silica in S1 and S3 cannot prevent the structural degradation of silicon, resulting in lower specific capabilities (see Table 3) [45].

Table 3. Electrode output of silicon as anode material in LIBs.

Electrode	Capacity (mA h/g)	Cycles (mA h/g)	ICE (%)	Ref.
Si-bPOD	1065	800	99.5	[46]
Si-PAPA	2312	100	94	[47]
Si@N-P-LiPN	2021	500	93.18	[48]
S5	759	1300	31	[49]
Si-M1	2522.6	100		[50]

The study found that applying a thin layer of carbon content to silicon improved the electroactive sites of the sample indicated S5, as shown in Table 3. The structural integrity of this material was reported to have shown excellent electron and ion mobility and ions within the electrode material. In another study, silicon was incorporated into 2D nanomaterial MXenes and produced excellent electrochemical results, namely Si-M1. These results show that silicon anodes are still future materials for energy storage and that a compatible trifunctional binder thus proved to be suitable for this purpose. The anode material (Si@N-P-LiPN) serves as a trifunctional binder, enhancing electrochemical performance by reducing volume changes within the silicon structure. In the search for the best binder to alleviate volume expansion, other researchers used a multifunctional binder Si- polyacrylic acid:phytic acid (PAPA) and achieved remarkable results (see Table 3). The use of biphenyl-polyoxadiazole (bPOD) as a carbon source for silicon coating has shown promising stability and lithium insertion capabilities, opening possibilities for material synthesis with varied structural properties [46].

4. Strategies to Overcome Pulverisation

There is a dearth of information on the structural and mechanistic analysis of silicon-based composite electrode materials. This study aims to use silicon anodes coated with carbon from traditional biomass-based activated carbon in a half coin cell in LIBs. These silicon-based nanocomposites will aim to decrease the amount of irreversibly coulombic efficiency and benefit from novel carbon nanomaterial supports. The nanocomposite will offer a synergistic combination of the individual constituent's properties to boost the reversible reaction of silicon and Li performance. Strategies to overcome issues associated with silicon-based anode materials have been proposed, as well as designs that maintain silicon stability for a few hundred cycles. One example is the synthesis of nanoscale porous silicon particles, doping with foreign elements, and surface modification (coating). Innovative and strategic designs (Figure 7A) are essential to achieve enhanced capacity, rapid charging capabilities, and cyclic stability (Figure 7C) in battery technology (Figure 7B). The nanoscale silicon properties from a material synthesis point of view are one way of understanding the relevance of the latest breakthroughs in these technologies.

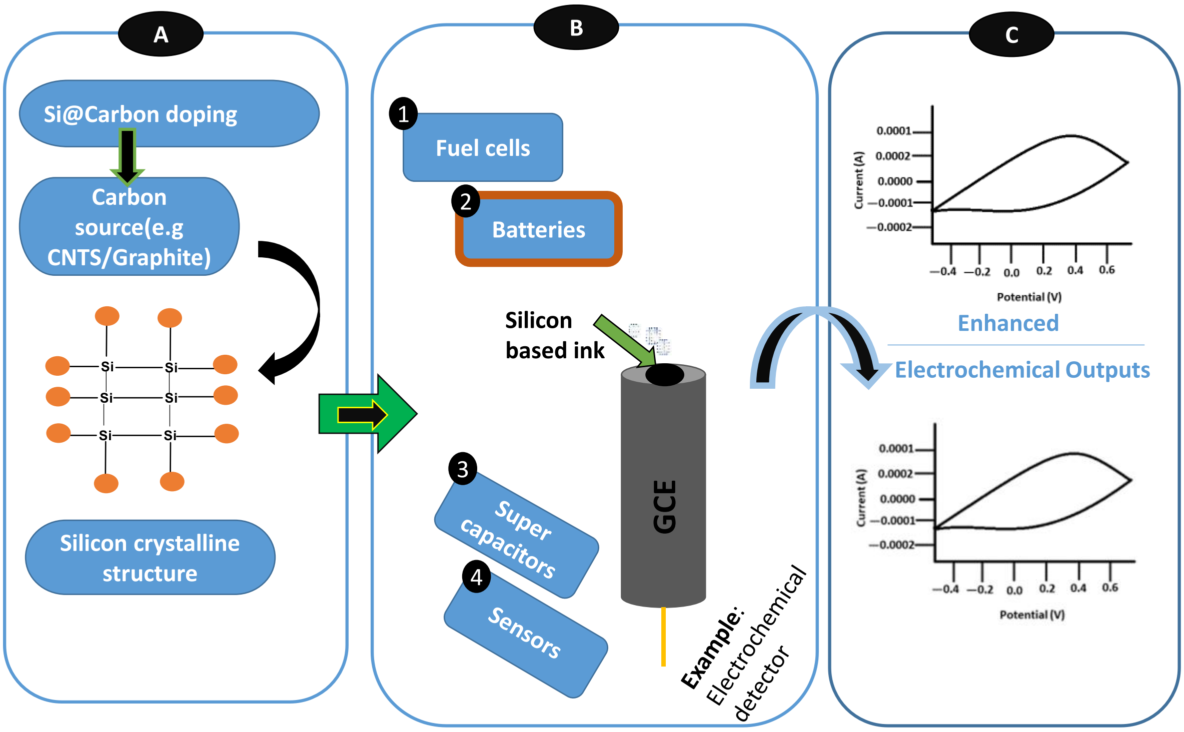

Figure 7. (**A**) Silicon structure, (**B**) electrochemical technologies, most preferable batteries, and (**C**) output.

The challenges faced by silicon-based materials in terms of significant volume expansions and poor conductivity hinder their commercial viability in technology applications. This study suggests using silicon composites and synthesising silicon nanomaterials from renewable sources to strengthen the conductive networks and prevent capacity loss. This review recommends the use of silicon anode material because of its exceptional structural designs, which offer solutions to the challenges faced in this field and open new possibilities in energy storage technologies. In terms of novelty, having both micropores (<2 nm) and mesopores (2 to 50 nm) is preferable to having only micropores. Mesopores provide low-resistance pathways for the diffusion of the reactant and product, allowing Li to easily intercalate into and out of the silicon matrix.

The main challenges in this context include the instability of the SEI, corrosion of electrode materials due to the pulverisation of active materials, and debonding, which can result in the failure of maximum current collection from the copper foil surface. The addition of a carbon coating to silicon surfaces has been shown to possess enhanced electrical properties and satisfactory charge and discharge processes, as reported in studies by Ng et al. and Gattu et al. Functionalisation with a thin layer of carbonaceous material is beneficial in surface area reduction and promotes the formation of stable SEI film [39,40]. The introduction of voids through a yolk shell structure using silica as a template and polydopamine as a carbon source is a promising strategy for generating a high capacity and excellent cyclic stability in battery cycling, allowing a flexible volume expansion without compromising structural integrity [51,52].

5. Future Perspectives

Utilizing up-to-date knowledge, market insights, access to cutting-edge resources, commercialization expertise, and infrastructure development to create portable, convenient devices with high capacity, fast charging, stable volume, rate capacity, and high area capacity are the fundamental elements for real-world applications (see Figure 8). There are many solutions achieved through high areal mass loading, which can bring about cyclic stability. These include new polymeric binders, porous structures, and free-standing electrode fabrication. However, there are a few difficulties with silicon anodes that keep them from being widely employed. The process by which silicon is created has a significant impact on its qualities. The various reactor designs and reaction circumstances utilised for silicon precursor materials have a direct impact on the chemical and physical qualities that are unique to that specific silicon, hence influencing material affordability. The most typical technique of obtaining silicon is by a process known as pyrolysis, in which the biomass is thermochemically decomposed. Silica is then removed and converted into nanostructured silicon using metallic and/or carbothermic reduction. Nanoscale, porous, and crystalline Si materials synthesised from biomass resources show enhanced electrochemical performance compared to bulk Si powders but may still face challenges in silicon structure collapse during prolonged cycling. To overcome these limitations, mesoporous derived from sugarcane bagasse has been proposed for the current study [53,54].

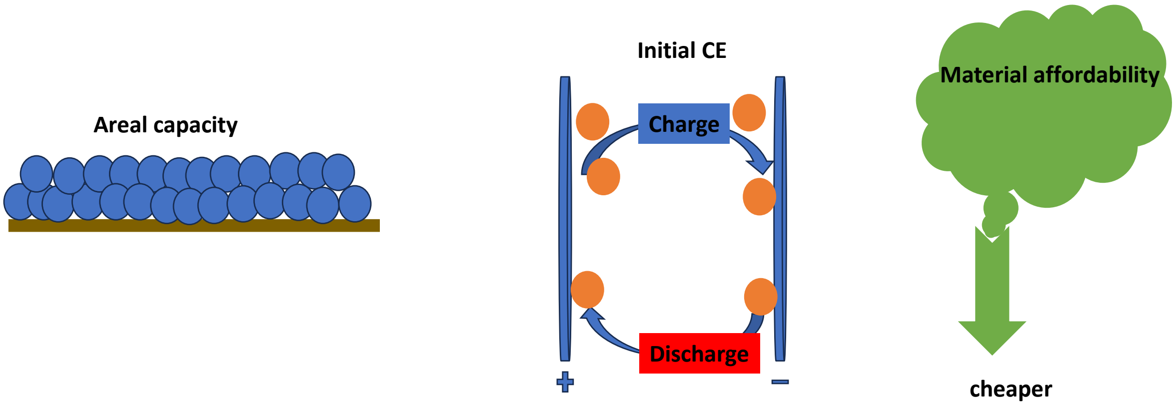

Figure 8. Prerequisite for real-world implementation.

As already mentioned, prelithiation is one way to reduce the expansion of silicon volume. It is anticipated that the procedure will help with oxygen content consumption, producing Si, and guarantee stability over the long run while maintaining capacity.

Since it is yet unclear where to draw the lines between the structural designs and anticipated electrochemical performance of these anodes, more comparative studies examining the impact of nano silicon on sodium-ion batteries are clearly needed. Over the next few years, the biogenic silicon landscape will undergo a significant transformation as boundaries become more clearly defined and novel material synthesises with advanced material characterisation techniques to better understand silicon reaction mechanisms and sodiation will be introduced. Numerous research that examined the usage of silicon and silicon-based composites in sodium-ion batteries have been thoroughly examined. Excellent reversible capacities of 954 mAh/g (NaSi) and 847 mAh/g ($Na_{15}Sn_4$), respectively, have been obtained by doping silicon with tin, although this method suffers from poor practical capacity and a short lifespan [55,56].

Since there is still a dearth of information on silicon carbides in sodium-ion batteries, it is still difficult to comprehend the fundamentals of energy storage. Therefore, by fine-tuning the sodiation process at the atomic level, amorphous silicon can be used as a substitute for sodium anode material, which experiences a volume growth of roughly 114%. It is strongly advised to use biomass for biogenic silicon with a known composition as a precursor material for sodium-ion batteries.

For future studies, these points should be looked at: (i) The intercalation of lithium and silicon oxide should be investigated further, and new characterisation techniques such as particle-induced X-ray emission (PIXE) and Rutherford backscattering spectroscopy (RBS) can be used to investigate the evolution of phase changes and new surface states, elemental composition. A greater knowledge of these mechanism can lead to better material production and the introduction of foreign atoms/molecules, particularly when using X-ray photoelectron spectroscopy (XPS). (ii) More novel strategies should be used to create nanostructures and optimise fabrication conditions for Si-based anode materials. Structural design and finer materials will be critical for improving cycle performance and lifespan. (iii) The anodes of silicon and silicon-based nanocomposites should undergo hybridization with heteroatoms (N, S) using a carbon-rich substance called biochar. (iv) Silicon precursor materials and innovative preconditioning methods should be used to increase the initial coulombic efficiency. (v) Cost analysis and the circular economy should be included while further dissecting the electrode material's synergistic effects. (vi) Exploration of metamaterials for mechanical and geometrical properties: The influence of loading makes lithium-ion batteries the dominant technology in electric vehicles. They possess one of the best combinations of physical, chemical, and mechanical properties. Flexible, efficient, and adaptable impact-resistant metamaterials may adapt to complicated engineering needs, breaking free from the constraints of traditional protective devices whose mechanical properties cannot be modified flexibly after construction. To prevent mechanical breakdown, an understanding of mechanical aspects should be approached with prudence to avoid poor performance [57,58].

6. Conclusions

In this study, we were able to disseminate that there are various ways to prevent silicon volume expansion. One way is using a chemical prelithiation strategy. The strategy is versatile in anode materials such as SiO, hard carbon, Si, P, etc. It is the case that the silicon cycleability is increased, not its specific capacity. Also included is the formation of a stable SEI from the conversion of SiO to Si. Another strategy is the production of silicon nanostructured material from renewable sources, such as biomass source. Porous architectures in Si-based materials have been shown to effectively address volume changes and enhance ion and electron transport, as demonstrated by previous research.

The synthesis of nanostructured mesoporous silicon from sugarcane bagasse has the potential to be an electrode material in LIBs. The structural integrity of the material is poised to be beneficial in terms of chemical and physical properties for electrochemical applications. For real-time applications, silicon anodes are primarily in the nano-realm, necessitating a more in-depth study on the electrochemical activity of innovative binders and electrolytes that will improve the strength and flexibility of these anodes. For safety concerns, as well as to improve initial coulombic efficiency and promote reversible coulombic efficiency, these are critical results areas that require immediate attention. More in-depth analysis could benefit from an examination of the mechanistic failures in silicon anodes utilising PIXE and RBS spectroscopies.

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Conflicts of Interest: The authors declare no conflict of interest.

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