POLICY BRIEF

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Powering South Africa's future: Can zinc-ion batteries revolutionise grid storage?

Executive summary

Investments into research and development (R&D) have played an important role in the emergence and prominence of energy storage technologies, which are now key to achieving global decarbonisation targets. These technologies are central to developing lasting and affordable energy storage systems (ESSs), which are critical within the sustainable development agenda. Over the past two decades, the growing global population has driven a significant demand for clean energy, the integration of renewable energy sources, rapid technological advancements, a rising demand for electrical vehicles (EVs), as well as supportive policies and investment. In South Africa (SA), 80% of its energy comes from fossil fuels; therefore, investment in modern energy storage systems is critical. With the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) aiming to increase renewable energy capacity in SA to 6,725 MW by 2030, which will mainly come from solar and wind, cost-effective and efficient energy storage devices are crucial. Comparatively, zinc-ion batteries (ZIBs) offer a cost-effective solution by reducing manufacturing costs by an estimate of up to 30%, while simultaneously promoting local manufacture and mineral beneficiation. However, the South African Renewable Energy Masterplan (SAREM) overlooks the investment and integration of ZIBs in favour of lithium-ion batteries, which indicates a gap in addressing the potential of ESSs. Against the backdrop of ongoing electricity demand and supply challenges, incorporating ZIBs could greatly assist in mitigating load-shedding, stabilising the grid, and supporting South Africa's energy and industrial goals. As a preferred emerging option, ZIBs align strongly with South Africa's mineral beneficiation strategies, as outlined in key national documents such as the Minerals Policy Review (2024) and the White Paper on a Minerals and Mining Policy for South Africa. These policies emphasize the need to leverage the country's abundant and strategic mineral resources, particularly manganese and zinc, for local value addition and sustainable industrial development. In ZIBs, zinc serves as the anode, while the most widely studied cathode materials are manganese-based, making this technology exceptionally well-suited to South Africa's mineral endowment. With the country being one of the world's leading producers of manganese and possessing notable zinc

reserves, adopting ZIBs not only supports environmental goals but also advances economic empowerment, beneficiation, and regional integration within the SADC framework. This brief highlights the congruence of factors that place ZIBs as key options for residential, commercial and industrial clients. These factors include the global expansion of the battery market, ZIBs low manufacturing costs, the safety benefits of ZIBs, the abundance of production materials, the reusability of ZIB elements, high energy density potential, overall affordability (accessibility) and targeted investments on ZIB research and development. The aforementioned factors point towards a growing public acceptability of ZIBs as a viable contender in the grid energy storage sector.

Introduction

South Africa's energy sector has historically depended on coal, with Eskom, the national power utility, producing over 80% of the country's electricity from coal-based sources [1]. This reliance has put immense pressure on Eskom's ability to meet the rising energy demands of a growing population, resulting in frequent load-shedding, grid instability, and environmental pollution. In the current decarbonisation discourse, the country's energy landscape is set to undergo a significant transformation, with coal's share in the energy mix expected to decrease, while renewable energy sources gain prominence [2]. The National Development Plan (NDP) envisions that, by 2030, South Africa will have achieved an environmentally sustainable society, enhanced resilience to climate change, and a robust low-carbon economy with significantly reduced emissions [3].

Policy context

As part of this transition, policy initiatives are driving the integration of renewable sources, like wind, solar, and hydroelectric power into the energy grid. This shift not only aligns with global efforts to combat climate change but also highlights the critical role that energy storage systems (ESS) play in stabilising the grid and ensuring the efficient use of intermittent renewable energy. By embracing this transition, South Africa can reduce its dependence on coal, lower emissions, and build a sustainable, low-carbon future. Energy Storage Systems (ESS) are designed to store energy produced at one point in time for utilisation later. These systems play a crucial role in balancing supply and demand within the power grid, particularly as the use of renewable energy sources like solar and wind – both of which are intermittent by nature – become more widespread. In practical terms, ESS can store excess energy generated during periods of low demand or high renewable energy production and release the energy when needed, ensuring a stable and reliable power supply. There are several types of ESS, including batteries, supercapacitors, pumped hydro storage, compressed air energy storage, and thermal energy storage, to name a few. However, this brief focuses on batteries, as they tend to be more versatile and flexible compared to options like pumped hydro. Various battery technologies are available, such as lithium-ion batteries (LIBs), lead-acid batteries (LABs), vanadium flow batteries (VFBs), rechargeable zinc-air batteries (RZABs), and ZIBs.

While LIBs and LABs are the most widely utilised due to their high-energy density, efficiency and technological maturity, there are growing concerns over their high costs, safety risks, toxicity, and the limited availability of lithium. These issues, compounded by increasing global demand and dependence on these minerals, have prompted a shift towards exploring more sustainable energy storage options [4,5]. This is where ZIBs offer a compelling solution. Unlike the more expensive and environmentally harmful LIBs, ZIB technology has the potential to significantly reduce costs, with projections targeting around USD 10 per kWh [1] at the pack level [6]. In addition to being more affordable, ZIBs offer clear advantages in terms of safety, material abundance, and environmental sustainability. While global leaders like Eos Energy Enterprises and Zinc8 Energy Solutions have demonstrated promising pilot-scale systems primarily for grid storage, large-scale manufacturing is still in development. This places ZIBs in the innovation-to-demonstration phase, presenting South Africa with a strategic opportunity to lead through research-driven piloting and localized value chain development.

By adopting a focused research and development agenda, aligned with South African policies, the country can leverage its rich manganese and zinc reserves to advance ZIB technologies. This approach promotes local production, creates skilled jobs, stimulates industrial growth, and strengthens national energy resilience. Ultimately, this can empower South Africa to meet its renewable energy targets while tackling energy poverty and ensuring affordable, equitable access to power across the nation.

South Africa grapples with perpetual energy poverty, marked by limited access and affordability, particularly in rural areas. This challenge is compounded by frequent load-shedding, an unreliable power supply, and a heavy dependence on coal, which not only impacts the environment, but the economy as well. Addressing these issues requires a transition to cleaner energy and highlights the critical need for effective energy storage to ensure a stable power supply. While LIBs dominate the global market, their high cost and dependence on rare minerals present challenges for large-scale deployment. ZIBs provide a more sustainable, cost-effective alternative, leveraging South Africa's abundant zinc and manganese reserves to create local manufacturing and employment opportunities. Therefore, increasing efforts in energy storage solutions is crucial to achieving the goals of the SAREM, which include creating 36,500 jobs, boosting the GDP by R420 billion, and maintaining adequate grid stability. Furthermore, by adopting the integration of ZIBs as one of the alternative energy storage devices, South Africa will decrease its import dependence on battery technologies, such as LIBs, promote industrial growth, and meet the Just Energy Transition (JET) target of 40% renewable electricity by 2030.

Research method and approach

This policy brief emerges from an in-depth analysis of existing data sources, such as strategies, annual progress reports, other official publications of the relevant entities and respective policies and strategies.

Results and policy implications

Broadly, emerging insights from the synthesis and analysis of data reveal a wider range of associated issues. These insights create opportunities for the consideration of ZIBs as investments advance into clean energy production solutions. Table 1 below presents a comparative analysis, illustrating why ZIBs would be favoured instead of LIBs which are often unsafe, non-renewable, and costly in various aspects.

Key performance metrics for various battery chemistries include cost, safety, environmental impact, energy density, power density, cycle life and Coulombic efficiency at the cell level. The values for ZIBs are projected for future commercialised cells operating under practical conditions, based on available references [7, 8].

Table 1 below illustrates a more detailed comparative analysis of different battery systems. ZIBs not only outperform LIBs and VFBs in terms of cost and safety but, due to the availability of zinc and manganese resources, they also offer unique advantages for South Africa's local economy. Furthermore, ZIBs are made from non-toxic and fully recyclable materials, in contrast to LIBs, which contain hazardous chemicals. The well-established zinc recycling process further decreases the environmental impact of battery disposal, supporting South Africa's goals of a circular economy and the reduction of the carbon footprint.

On the other hand, the localisation of ZIBs production could create an estimate of over 10,000 jobs in manufacturing, and related industries by 2030. This supports the government's Operation Phakisa initiative, which focuses on fast-tracking economic growth through industrialisation. Local zinc and manganese beneficiation could stimulate growth in South Africa's mining sector and contribute significantly to the growth of the national GDP.

Table 1: Comparative analysis of battery technologies

Specifications	Zinc-ion batteries	Lithium-ion batteries	Vanadium flow batteries
Cost	Low	High	Moderate
Safety	High (non-flammable)	Moderate (flammable)	High (non-flammable)
Environmental impact	Low (recyclable)	High (toxic materials)	Low (recyclable)
Energy density (Wh/L)	100–450	150–250	16–35
Power density (W/L)	100–300	1.5K–10K	~2
Cycle life	5,000+	1,200–2,000	5,000–15,000
Coulombic efficiency	80–95%	95–99%	60–80%

Policy alignment with South Africa's strategic goals

The recognition of zinc-ion batteries as a promising solution for grid energy storage aligns closely with several key South African policies, including:

Just Energy Transition (JET)

- ZIBs support South Africa's commitment to a low-carbon future by enabling the integration of renewable energy sources and phasing out coal-fired plants. This transition will not only reduce greenhouse gas emissions but will also foster the creation of green jobs in manufacturing and technology development.

National Development Plan (NDP) 2030

- The production and deployment of ZIBs align with the NDP's emphasis on local manufacturing, employment opportunities, and sustainable development. By leveraging domestic zinc resources, South Africa can focus on reducing its reliance on imported technologies, promoting industrial growth, and meeting its energy security objectives.

Paris Agreement

- By adopting ZIBs technology, South Africa can further its contributions to global climate change mitigation efforts under the Paris Agreement, reducing its overall carbon emissions.

Policy recommendations

Given that ZIBs are currently at the pre-commercialisation stage, it is critical that South Africa focuses its strategy on demonstration projects, technological validation, and building bankable business cases before committing to large-scale grid integration. The following phased approach is recommended:

Short-term (1–3 Years): Allocate R500 million to R&D and pilot demonstration projects. Targeted funding must be channelled toward applied research, material optimisation (especially MnO2 cathodes and Zn anodes), and early-stage demonstrations to validate technical performance and economic feasibility.

Departmental alignment: The Department of Science, Technology and Innovation (DSTI) should lead this phase by promoting academic-industry partnerships. Universities and research counsels should be funded to advance ZIB chemistry, prototype development, and real-world testing, especially in regions with renewable energy potential like the Northern Cape.

Medium-term (3–5 Years): De-risk and prepare for local production:

Rather than immediate plant construction, this phase should focus on establishing pre-production supply chains, conducting techno-economic feasibility studies, and supporting technology readiness assessments to determine when and how to scale manufacturing.

The Department of Trade, Industry, and Competition (DTIC): In collaboration with DSTI, the DTIC should launch industrial readiness programmes, including skills development, investor outreach, and support for SMMEs involved in component production.

Long-term (5–10 Years): Enable commercialisation and market integration Full-scale commercialisation should only follow successful pre-commercial deployment and cost-competitiveness validation. The long-term vision includes the deployment of ZIBs for grid-level storage and rural electrification projects.

Conclusion

This brief has highlighted the potential of ZIBs as a solution to South Africa's unique energy storage challenges. However, South Africa must prioritise a research-led, demonstration-first approach to de-risk ZIB technology and build a robust case for investment and localisation. In addition, beyond their immediate utility, research and development of ZIBs could boost diverse local manufacturing, create employment opportunities, strengthen socioeconomic resilience and promote environmental sustainability by conserving natural resources. By aligning with national policies and leveraging domestic resources, ZIBs could play a pivotal role in South Africa's transition to a low-carbon economy, ensuring a more stable and long-term secure energy future. Such an outcome would undoubtedly drive positive economic development and promote market stability, by ensuring a sustained and balanced supply electricity to consumers.

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References

1. Hanto, J., Schroth, A., Krawielicki, L. and Oei, P.Y. and Burton, J. (2022). South Africa's energy transition – Unravelling its political economy. Energy for Sustainable Development, 69, pp. 164–178. Available at https://doi.org/10.1016/j.esd.2022.06.006
2. Manyane, T., and Nembahe, R. (2023). The South African Energy Sector Report, 2023. Pretoria
3. National Development Plan, 2030. Our future – make it work. National Planning Commission, 2012
4. Chen, Y., Kang, Y., Zhao, Y., Wang, L., Liu, J., Li, Y., Liang, Z., He, X., Li, X.,Tavajohi, N. and Li, B. (2021). A review of lithium-ion battery safety concerns: The issues, strategies, and testing standards. Journal of Energy Chemistry, 59, pp. 83–99. Available at https://doi.org/10.1016/j.jechem.2020.10.017
5. Schismenos, S., Chalaris, M., and Stevens, G. (2021). Battery hazards and safety: A scoping review for lead acid and silver-zinc batteries. Safety Science,140. Available at https://doi.org/10.1016/j.ssci.2021.105290
6. Pross-Brakhage, J., Fitz, O., Bischoff, C. Biro D. and Birke, K.P. (2023). Post-Lithium Batteries with Zinc for the Energy Transition. Batteries, 9. Available at https://doi.org/10.3390/batteries9070367
7. Luo, X., Wang, J., Dooner, M., and Clarke, J. (2015). Overview of current development in electrical energy storage technologies and the application potential in power system operation. Applied Energy, 137, pp. 511–536. Available at https://doi.org/10.1016/j.apenergy.2014.09.081
8. Gourley, S.W.D., Brown, R., Adams, B.D. and Higgins, D. (2023). Zinc-ion batteries for stationary energy storage. Joule 7, pp. 1415–1436. Available at https://doi.org/10.1016/j.joule.2023.06.007

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