



Advancements in Raw Material Availability, Development Strategies, and Industrial Prospects for Zinc-Carbon Dry Cell Production in Nigeria and Uganda

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ABSTRACT

Nigeria could boast of at least six functioning dry cell manufacturing industries. Unfortunately, today, these industries have gone into oblivion with only one trying, epileptically, to survive. One major factor responsible for this is the higher cost of production than the sales price of imported ready-made cells. This, in turn, is due to almost zero local material content of Nigeria-made cells. This paper therefore addresses the issues of raw materials required to produce Zn-C dry cell and the level of availability of such materials in Nigeria. In addition, Uganda presents a relevant parallel, albeit at a smaller industrial scale. Official mineral-occurrence sources indicate lead-zinc, graphite and other industrial minerals in several Ugandan districts, while current national planning emphasizes value addition, industrialization and environmental sustainability. Uganda's e-waste framework, including policy, guidelines, EPR-oriented provisions and collection infrastructure, strengthens the regional relevance of this study by showing that battery-material development in Africa must link mineral endowment with downstream processing and safe end-of-life management. Strategies of improving the local raw materials content of the dry cells are also explored in both countries. Furthermore, key components and the toxic materials have been explained and finally survey of some other countries on the use of Zinc dry battery have been explained.

1. INTRODUCTION

A dry cell is an electromechanical energy power source that converts chemical energy into electrical energy. It consists of two electrodes and an electrolyte. Among the most common dry-cell types are zinc-carbon, most alkaline cells, nickel cadmium, and zinc-chlorine cells. Only the zinc-carbon dry cells are being produced in Nigeria.

The zinc-carbon (Zn-C) dry cell, the commonest of the dry-cell types, is a non-rechargeable direct current (dc) source. It consists basically of a negative electrode of

zinc, a positive electrode of carbon rod, and electrolyte of a paste of salt ammoniac. Manganese dioxide is also added to act as depolarizer. The Zn-C cell is used in operating common household portable appliances such as radio receivers, touch lights, camera flash, etc.

Local production of Zn-C dry cells (in Nigeria) has today gone into the oblivion. Investigations carried out showed that it is absolutely economically unviable to produce dry cells in Nigeria due to high production cost. No wonder the country is now dumping ground for all sorts of dry cells, particularly from Asian countries. The main reason that could be adduced to the

almost extinction state of the dry-cell industry is the total dependence by the manufacturers on imported raw materials when, in fact, such materials could be sourced locally [1].

Uganda reflects part of this challenge from a different scale. The country has documented lead-zinc occurrences at Kitaka, Kampono and Kanyambogo, graphite-bearing rocks in Karamoja, West Nile and Kitgum, and emerging policy interest in minerals-based value addition. As in Nigeria, the strategic issue is therefore not only geological occurrence, but beneficiation, intermediate-material processing, standards infrastructure and industrial coordination required to convert mineral potential into a viable battery-materials value chain [2-4].

2.0 PRODUCTION PROCESS

Figure 1 shows the typical stages involved in the production of a standard Zn-C dry cell. The production process starts with the preparation of the cathode-mix which is composed of electrolytic manganese (MnO_2), natural manganese, acetylene, graphite powder and ammonia. The cathode mix is used in making the bobbin which also comprises the carbon rod (positive electrode) and DHM gum as a binding agent. Meanwhile, the zinc can, which also serves as the negative electrode, is produced and fed with paper seal and zinc-carbon alloy coin at the bottom. Also, the electrolyte, composed of de-ionized water, zinc chloride, maize starch, ammonium chloride and, sometimes, zinc oxide and mercuric oxide, is prepared. The electrolyte, in liquid form, is poured into the zinc can and the tamped bottom placed and centralized. The can is then placed in boiled water-bath to solidify the electrolyte in order to avoid spillage and to prevent positive and negative electrodes touching each other. Insulation washer is placed on the bobbin and asphalt poured on it to seal the bobbin and to prevent air from seeping into the bobbin. Metal (brass) cap is then placed on the carbon rod to form the positive terminal (or cathode).

Essentially, the cell assembly is now complete, leaving only the finishing aspect which takes place after allowing the cells for one or two days to age. The finishing process involves, amongst others,

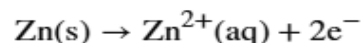
- cleaning of the zinc-can bottom for good electrical contact, and
- testing the cell for 1.5 volt/4.5 ampere rating and withdrawal of non-conforming ones.

2.1 Chemical reactions for carbon zinc battery

Zinc carbon dry cell working reactions involves electricity production due to redox reactions approximately 1.5V. the constituent elements are zinc electrode, manganese dioxide cathode and an ammonium chloride-zinc chloride electrolyte. General chemical reactions consist of anode and cathode as presented below:

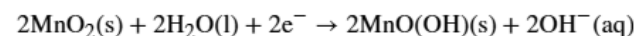
Anode

In the anode reaction, Zinc is oxides to zinc ions, releasing electronics,



Carbon

In this case, manganese dioxide is usually, reduced in the presence of water and electrons, thereby hydrogen ions are consumed from the electrolyte.



2.2 Feature of zinc carbon batteries

- ✓ Availability and inexpensive
- ✓ The discharge curve is poor (sloping)
- ✓ The performance is low at high temperatures

Advantages of the zinc carbon batteries

- ✓ Higher energy density
- ✓ Battery low temperatures service
- ✓ Good leak resistance
- ✓ High efficiency under heavy discharge loads

Disadvantages zinc carbon batteries

- ✓ High gassing rate
- ✓ Requires excellent sealing system due to increased oxygen sensitivity

Section 2.3: Methodology and Basis of Comparative Survey

This study adopts a mixed-methods comparative framework integrating literature review, secondary datasets, and expert validation across Nigeria and

Uganda. Indicators include resource occurrence, processing readiness, policy environment, and infrastructure. Multi-criteria evaluation and

triangulation ensure robustness and enable evidence-based benchmarking [5-6].

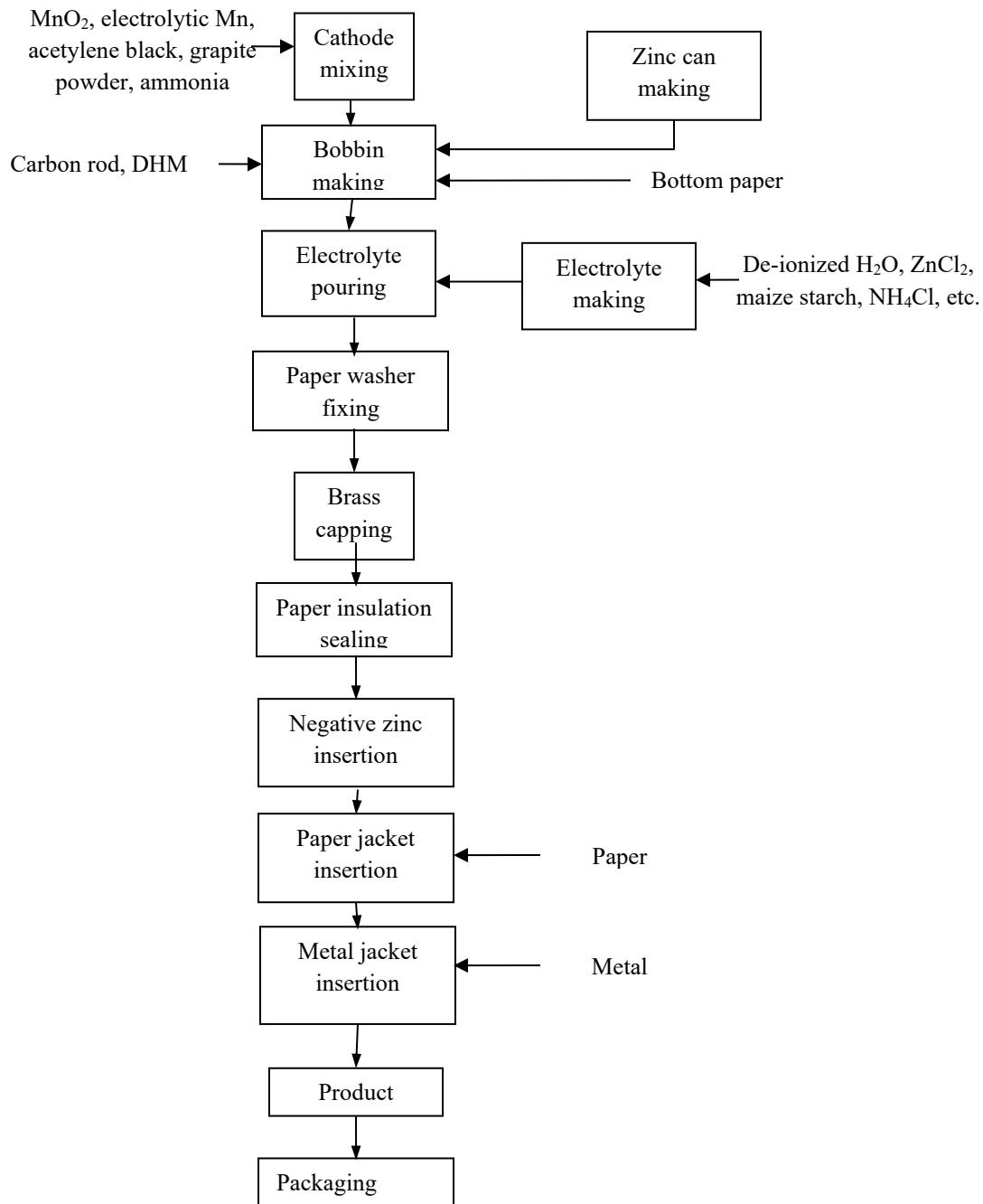


Fig. 1: Production process of a Zinc-carbon dry cell

3.0 RAW MATERIAL REQUIREMENTS

The main raw materials required in the production of Zn-C dry cell as well as their local availability levels

(where available) are shown in Table 1. One obvious deduction from the Table is that, apart from manganese, all other raw materials needed to produce Zn-C dry

cells are readily available in Nigeria. It is, however, saddening to note that the only surviving dry cell manufacturing company, at the time of investigation, was sourcing only maize starch locally. This is less than 1% of the raw material cost of a standard Zn-C dry cell. All other materials were being imported. This automatically makes the unit cost of production high, even higher than the sales price of an imported dry cell in the open market.

For Uganda, the resource picture is complementary rather than identical. Available geological sources report lead-zinc occurrences in south-western Uganda, graphite in Karamoja, West Nile and Kitgum, and manganese occurrences in western Uganda, although no commercial-grade manganese deposit has yet been confirmed. Uganda is therefore best treated as a regional comparator with selective raw-material potential for zinc- and graphite-linked battery inputs, but with a similar need for beneficiation, reserve upgrading and industrial supply-chain coordination before large-scale Zn-C battery production becomes economically realistic [2-3].

A study carried out by Raw Materials Research and Development Council (RMRDC) showed that of the N408.3 million national demand of materials needed for the production of automotive batteries and dry cells, N58.5 million worth (or 14%) were locally sourced while the country still had the potential to locally source additional materials worth N104.5 million [7].

From a harmonized Nigeria-Uganda perspective, the central policy lesson is that raw-material occurrence alone does not guarantee industrial competitiveness. The decisive variables are processing capacity, standards, logistics, investment incentives and protection against indiscriminate import dependence. Uganda's current industrialization agenda under NDPIV reinforces this argument and supports a regional battery-materials strategy anchored in mineral upgrading, SME linkage development, standards compliance and circular-economy safeguards for spent batteries and related waste streams [4], [8-9].

Figure 2 was validated through cross-country expert review and industry data triangulation in Nigeria and Uganda, confirming technical coherence of extraction, beneficiation, and processing stages. Stakeholders verified material flow accuracy, value-addition pathways, and industrial feasibility, ensuring robustness, regional relevance, and alignment with emerging battery value chain development strategies.

Table 4 presents a comparative assessment of raw material availability, processing readiness, and industrial relevance in Nigeria and Uganda. It highlights resource complementarities, identifies beneficiation gaps, and underscores strategic opportunities for regional value chain integration, supporting scalable and sustainable Zn-C battery manufacturing development across both countries. Equation defined the Local Content Ratio (LCR) as

$$LCR = \left(\frac{C_{LOCAL}}{C_{TOTAL}} \right) \times 100 \quad (1)$$

where LCR = Local Content Ratio (%) representing the proportion of domestically sourced raw materials in total material inputs,

C_{LOCAL} = Cost of locally sourced raw materials (USD or local currency units), including zinc ore, manganese, graphite, and auxiliary inputs obtained within the national or regional economy.

C_{TOTAL} = Total cost of raw material inputs (USD or local currency units), including both domestic and imported components.

The LCR quantifies the degree of domestic value retention within the Zn-C battery supply chain, serving as a critical indicator of industrial self-reliance, import substitution potential, and alignment with national beneficiation and local content policies in Nigeria and Uganda.

Table 1: Raw materials list for Zn-C dry cell production [10]

Component	Raw material base	States of occurrence	Level of occurrence	Local annual demand (MT)
Natural Mn	Manganese ores	None		4307
Electrolytic Mn	Manganese ores	None		
Acetylene black	Carbon black	Crude oil areas	Substantial	1840
Graphic powder	Carbon			372
Metal jacket	Iron ore	Kogi	Substantial	
Ammonia	Coal, natural gas			14
Zinc can	Zinc ingots	Anambra, Imo, Benue, Plateau, Nasarawa	Substantial with lead	11,000
Carbon rod	Carbon, coal	Many south-eastern states	Substantial	439
Starch	Maize, cassava	Abundantly available all over Nigeria	Substantial	635
Solder	Lead and tin	Lead: Anambra, Enugu, Imo, Benue, Nasarawa Tin: Plateau	Adequate	N/A
Asphalt	Coal	South-eastern states	Substantial	N/A

*N/A: Not Available



Fig. 2: Comparative Nigeria-Uganda Zn-C battery raw-material value chain and beneficiation pathway)

3.1 Key Components & Their Roles

Looking at the circuit diagram of the battery it's clear that zinc can is the electrode and a central carbon rod is the cathode surrounded by the paste of manganese dioxide. Ammonium chloride is the electrolyte and having a separator layer and outer construction of insulation for casing structure. However, more details

of the key components and their functions can be seen in Table 2.

Table 2: components of battery and their key functions

S/No	components	Function(s)
1	Zinc container	it is acting as negative electrode, allow oxidations to take place
2	Carbon Rod	This is positive electrode, and collecting electrons, it is a central rod.
3	Electrolyte Paste	It is acting as a depolarizer.
4	Separator	It is main function is to prevent direct contact between the anode and a cathode, thereby preventing a short circuit in the system
5	Insulation Outer Casing	It protects the cell and provides insulation; it's usually a cardboard or metal jacket.
6	Brass Cap	Provides the positive terminal connection, and is a metal cap on top of the battery.

3.2 Hazardous Component in Zinc Battery Storage

Dry carbon battery can be hazardous if mismanaged due the chemical constituents that covert the chemical elements into electricity [11], due to the number of people without regular/non access to electricity in Africa, it clear that many of the populace rely on the use of dry carbon battery as source of energy for daily life. Unfortunately, there many hazards as a result of its usage and improper handling of it especially after useful life. Therefore, stakeholders are expected to do

the needful in order to prevent the continent from these hazards. Some of the hazardous elements can results in lead poisoning of the soil that could eventually affects plants we used [12-14]. Furthermore, it can result into higher lead also in human body [15-16]. Other elements that are making hazardous includes manganese (Mn),

nickel (Ni), silver (Ag) mercury (Hg) zinc (Zn); lithium (Li), and cadmium (Cd) [17-18]. Furthermore, the chemical includes ammonium chloride (CH_4Cl) and dichloroisocyanuric acid ($\text{C}_3\text{HCl}_2\text{N}_3\text{O}_3$). Details of the risk and end of life as presented in Table 3

Table 3: Environmental-Risk Matrix for Zn–C Battery Production, Use and End-of-Life Management in Nigeria and Uganda

Lifecycle Stage	Risk Category	Specific Environmental Risk	Severity (Low–High)	Likelihood (Low–High)	Nigeria: Risk Context	Uganda: Risk Context	Mitigation Measures (Best Practice)	Residual Risk (Post-Mitigation)
Raw Material Extraction	Land Degradation	Soil erosion, habitat destruction from mining	High	High	Widespread artisanal and semi-mechanised mining impacts	Emerging mining zones with limited environmental controls	Enforce Environmental Impact Assessments (EIAs); land reclamation policies	Moderate
	Water Pollution	Heavy metal leaching (Zn, Mn) into water bodies	High	Medium–High	Weak monitoring in informal mining areas	Limited wastewater control infrastructure	Tailings management systems; water treatment technologies	Moderate
Material Processing & Beneficiation	Air Pollution	Emission of particulate matter and chemical vapours	Medium–High	Medium	Industrial emissions with limited advanced filtration	Minimal industrial base but growing processing activities	Installation of scrubbers, emission control systems	Low–Moderate
	Chemical Contamination	Improper handling of reagents (e.g., NH_4Cl , ZnCl_2)	High	Medium	Existing chemical handling gaps in SMEs	Limited chemical industry regulation capacity	Chemical safety standards; hazardous material handling protocols	Moderate
Battery Manufacturing	Industrial Waste	Solid and liquid waste generation from production lines	Medium	Medium	Expanding industrial clusters with waste challenges	Nascent manufacturing sector with limited waste systems	Waste minimisation and circular production techniques	Low–Moderate
	Occupational Exposure	Worker exposure to toxic substances (Zn, Mn dust)	High	Medium	Weak enforcement of occupational safety standards	Limited industrial safety infrastructure	PPE enforcement; occupational health monitoring	Low
Distribution & Use Phase	Improper Handling	Leakage or misuse of batteries	Medium	Medium–High	High informal market penetration	Growing consumer use with limited awareness	Consumer education; product labelling standards	Low–Moderate
	Environmental Dispersion	Disposal in open environments	High	High	Poor waste collection systems in urban areas	Limited formal waste collection coverage	Strengthen municipal waste systems; awareness campaigns	Moderate

End-of-Life (E-Waste Stage)	Toxic Release	Release of Zn, Mn, electrolytes into soil and water	High	High	Informal recycling and dumping prevalent	Emerging e-waste management systems but limited scale	Formal recycling facilities; Extended Producer Responsibility (EPR)	Moderate
	Air Emissions	Open burning releasing toxic fumes	High	Medium–High	Common in informal recycling hubs	Occasional informal burning practices	Ban on open burning; controlled recycling technologies	Low–Moderate
Recycling & Recovery	Inefficient Recovery	Low material recovery efficiency	Medium	High	Limited advanced recycling technologies	Very limited recycling infrastructure	Invest in modern recycling plants; technology transfer	Low
	Secondary Pollution	Pollution from poorly managed recycling processes	High	Medium	Informal sector dominance	Early-stage recycling systems	Formalisation of recycling sector; regulatory enforcement	Moderate
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Table 3 presents a comprehensive environmental-risk matrix across the Zn–C battery lifecycle in Nigeria and Uganda. It evaluates severity, likelihood, and mitigation pathways, highlighting critical environmental vulnerabilities and guiding the development of sustainable, policy-aligned, and circular battery management systems in both national contexts.

3.3 Internal resistance of battery storage

There is a strong relationship between internal resistance of a battery and the battery state of charge. The relationship is an inverse function such that the internal resistance of a battery is low the when the battery is fully charged, and therefore become critical when the state of charge is near zero. Also, the internal resistance, increases with decrease in temperature, and usually, as a result of change in resistance of the electrolyte. In order to determine the impedance of a battery storage, it is important to note that, the battery behave as a complex impedance Z_b contain a resistance

R_b and reactance X_b , and mathematically, can be related as

$$Z_b = R_b - jZ_b \quad (2)$$

Therefore, from the relationship, it can be seen that the complex impedance can be defined as the ratio of absolute values of two signal

$$[Z_b] = \frac{V_b}{I_b} \quad (3)$$

3.4 Efficiency of Battery Storage

In this case, there are two types of load efficiency are defined, these are faradic efficiency and energetic efficiency. Faradaic efficiency is the ability of the battery to store charges. It does not concern joule losses in the internal resistance. On the other hand, energy efficiency, takes into the Columbian efficiency and losses considering joules effects and can be express as

$$\eta = 1 - \text{Exp} \left[\frac{[20.73]}{\frac{I_{batt}}{I_{10}} + 0.55} (SOC - 1) \right] \quad (4)$$

A comparative assessment reveals Nigeria's advantage in resource volume and industrial base, contrasted with Uganda's strengths in graphite and policy-driven industrialization. Key gaps include limited beneficiation infrastructure and weak chemical processing capacity. Targeted investments and regional integration are essential to bridge readiness disparities and enable scalable battery manufacturing ecosystems [6], [19-20].

4.0 STRATEGIES FOR RAW MATERIAL REQUIREMENTS

It has been earlier stated that most of the raw materials requirements for Zn-C dry cell production could be locally sourced, either in raw form or in intermediate form. The current industrial policy of Nigeria has, among its objectives, an increase in the local content of industrial output and increased export of manufactured goods [20].

Uganda provides an instructive policy parallel because its current development framework strongly emphasizes value addition, industrialization and efficient utilization of production factors. For a comparative Nigeria-Uganda reading of this paper, the implication is that battery-sector strategy must move beyond extraction toward upgrading ores and industrial minerals into process-ready inputs, supported by fiscal incentives, infrastructure, standards, skills and environmentally sound waste controls. This broader framing strengthens the paper from a country-specific discussion into a regional industrial-development model for strategic battery materials [4].

In order to achieve these objectives, a number of strategic incentives were introduced, among which were:

- establishment of Raw Materials Research and Development Council (RMRDC),
- encouraging new industries with greater linkages to the rest of the country, and
- encouraging existing industries to pursue further backward integration.

In a sample survey carried out by the Manufacturers, Association of Nigeria (MAN) for the Economic

Affairs Office of the Presidency, it was shown that the country depended heavily on imported raw materials to the tune of 60.72% in the pre-Structural Adjustment Programme (SAP era [21]). The situation improved with the introduction of SAP as there was an upward trend in local sourcing of raw materials from 1987. Today, the situation is worse, particularly for the battery industry which almost totally collapsed. There is therefore the urgent need to take some strategic steps in order to bring back the closed down industries into production and also to pave way for new entrants to venture into dry cell production. The steps being proposed by this paper focuses on the review of the industrial policy in order to remove implementation bottlenecks and bureaucracy. Equation (5) presented Beneficiation Readiness Index (BRI)

$$BRI = \frac{\sum_{i=1}^n \omega_i S_i}{\sum_{i=1}^n \omega_i} \quad (5)$$

where BRI is Beneficiation Readiness Index (dimensionless), representing the overall preparedness of a country or region to undertake mineral beneficiation and value addition; ω_i is the Weight assigned to the i^{th} indicator, reflecting its relative importance in the beneficiation ecosystem (e.g., infrastructure may carry higher weight than occurrence); S_i is the Standardized score of the i^{th} indicator (typically scaled 0–1 or 0–100), capturing performance across key dimensions; and n is Total number of evaluation indicators considered in the model.

Indicator dimensions (Typical components of S_i):

- Resource occurrence and geological availability
- Processability and mineral quality
- Industrial infrastructure (energy, transport, processing facilities)
- Standards, regulatory, and institutional readiness

The BRI provides a composite, weighted assessment of beneficiation capability, enabling comparative evaluation of industrial readiness between Nigeria and Uganda, and supporting evidence-based prioritization of investments and policy interventions.

4.1 Tax incentives

The 1989 National Industrial Policy introduced many incentives to investors, particularly to industries involved in raw materials processing and to those industries with high local value-added. For example, tax concessions are made available to industries which take initiatives in local raw material development. There is also tax relief for industrial establishments engaged in R & D for improvement of processes and products. Also related to raw material development is the seven-year income tax relief for entrepreneurs investing in economically disadvantaged local government areas where understandably, most of the raw materials abound in their natural states.

A corresponding lesson for Uganda is that fiscal incentives should be tied to beneficiation performance, environmental compliance and localization targets. Given Uganda's mineral-based industrialization drive and e-waste policy architecture, tax reliefs and import-duty structuring can be designed to favor battery-material processing equipment, laboratory certification, cleaner production and producer take-back systems rather than continued dependence on finished imported products. This would align industrial competitiveness with environmental stewardship in both Nigeria and Uganda [4], [8], [22].

The issue of multiple taxation has been a long-drawn battle between various levels of government on one hand, and the manufacturers on the other. Taxes and levies are being continuously slammed on the manufacturers by various levels of government (federal, state and local government). There is therefore the need to harmonize payment of taxes and levies by all levels of government in order to control multiple taxation that has made Nigeria-made products more expensive than imported ones. This measure will also forestall crippling the few industries that still remain in business.

In the Ugandan context, harmonized taxation and predictable regulatory charges would likewise be important for nascent mineral-processing and battery-related enterprises. This is especially relevant where firms must invest in laboratory testing, quality assurance, waste handling and standards compliance before achieving scale. The comparative policy implication is that both countries need a clearer fiscal environment that lowers avoidable transaction costs while still enforcing environmental obligations across the battery life cycle [4], [9]. Both Nigeria and Uganda have instruments guiding the policy, and some of them as detained in Table 4.

Table 4: Policy, Tax, Standards and Institutional Instruments for Battery Value Chain Development in Nigeria and Uganda

Policy / Instrument Category	Nigeria: Framework & Instruments	Uganda: Framework & Instruments	Implementation Maturity (Comparative)	Implications for Zn-C Battery Value Chain	Strategic Harmonization Opportunity
National Industrial Policy	Nigerian Industrial Revolution Plan (NIRP); Mineral & Metals Policy	Uganda Vision 2040; National Development Plan IV (NDP IV)	Nigeria: Moderate; Uganda: Emerging-Moderate	Provides strategic direction for mineral beneficiation and manufacturing	Align industrial policies to prioritize battery value chains as strategic sectors
Mining & Raw Materials Policy	Nigerian Minerals and Mining Act; Raw Materials Research & Development Council (RMRDC)	Mining and Minerals Act (2022); Directorate of Geological Survey and Mines	Nigeria: Moderate; Uganda: Strengthening	Supports exploration, extraction, and value addition of Zn, Mn, graphite	Joint frameworks for resource mapping and cross-border beneficiation
Fiscal Incentives (Taxation)	Pioneer Status Incentives; tax holidays; import duty waivers for equipment	Tax exemptions for industrial inputs; investment incentives via UIA	Nigeria: Moderate-Advanced; Uganda: Moderate	Reduces capital costs for battery manufacturing and processing plants	Harmonised tax incentives to attract regional battery investors

Standards & Quality Infrastructure	Standards Organisation of Nigeria (SON); National Environmental Standards	Uganda National Bureau of Standards (UNBS); environmental compliance frameworks	Nigeria: Moderate; Uganda: Moderate	Ensures product quality, safety, and export competitiveness	Develop regional battery standards (EAC/ECOWAS alignment)
Environmental & E-Waste Regulation	National Environmental Regulations; emerging battery waste policies	National Environment Management Authority (NEMA) e-waste guidelines	Nigeria: Emerging; Uganda: Emerging–Moderate	Enables circular economy and safe disposal of spent batteries	Establish Extended Producer Responsibility (EPR) frameworks jointly
Institutional Coordination	Federal Ministry of Mines and Steel Development; RMRDC; Energy Commission	Ministry of Energy and Mineral Development; NEMA; UIA	Nigeria: Moderate; Uganda: Moderate	Coordinates policy implementation and sector development	Create inter-ministerial battery taskforces in both countries
Research & Innovation Systems	Universities, RMRDC, Energy Commission research initiatives	Makerere University, research institutes, innovation hubs	Nigeria: Moderate; Uganda: Emerging–Strong	Drives local technology development and beneficiation processes	Promote joint R&D programmes and technology transfer platforms
Trade & Export Promotion	Export Expansion Grant (EEG); AfCFTA participation	Uganda Export Promotion Board; AfCFTA participation	Nigeria: Moderate; Uganda: Moderate	Facilitates regional and global battery market access	Leverage AfCFTA for integrated battery supply chains
Infrastructure Support	Industrial parks; power sector reforms; transport networks	Industrial parks (Namanve); energy expansion initiatives	Nigeria: Moderate; Uganda: Emerging–Moderate	Supports manufacturing scale-up and logistics efficiency	Co-develop regional industrial clusters for battery production
Financial & Investment Instruments	Development Bank of Nigeria; sovereign funds; PPP frameworks	Uganda Development Bank; PPP frameworks; investment incentives	Nigeria: Moderate–Advanced; Uganda: Moderate	Enables financing of large-scale battery manufacturing projects	Establish regional green financing mechanisms for battery sector

Table 4 provides a comparative analysis of policy, fiscal, institutional, and regulatory instruments shaping battery value chain development in Nigeria and Uganda. It highlights implementation maturity, identifies policy gaps, and reveals strategic harmonization opportunities necessary to catalyze investment, industrialization, and sustainable Zn–C battery sector growth.

4.2 Development of small- and medium-scale entrepreneurs (SMEs)

In the developed countries, the SMEs constitute about 70 per cent of the production sector in terms of

employment offered, hence are the engine of growth in their economies. In the United States of America, for example, over 70 per cent of the input of their automobile industries is the products of their small firms [13], [23]. The situation is similar for India and, particularly, the emerging Asian economies, known as the "Asian Tigers". Encouragement of SMEs has been regarded, in these countries, as an integral part of industrialization of most other less developed countries (LDCs). India, in particular, has been able to make a giant stride in her industrialization process through the development of small-scale industries.

It is not an understatement that a promising and flourishing SME system would solve some of the raw material problems of the country. Since the raw materials for most of the component parts are readily available, all that is needed are small-scale and medium-scale industries to produce component parts for the battery industry.

In Nigeria, over a thousand previously established SMEs have been forced out of business in recent past because of lack of sufficient capital base resulting from colossal devaluation of the Naira, and inaccessibility of investors to readily available sources of funds. These form part of the issues to be resolved in bringing back the SMEs into business. As a result, the battery industries that have gone out of business would also be able to come back on stream. The grids, the plates, the inter-cell connectors, terminal posts and containers can all be produced by individual small-scale industries. All the battery assemblers need do is to ensure the quality of such component parts so that the product would meet the required quality standard.

Uganda's SME ecosystem could play a similar role in a modular battery value chain, particularly in graphite upgrading, metal fabrication, packaging materials, assembly support and end-of-life collection services. However, as in Nigeria, access to finance, process technology, standards certification and quality-assurance infrastructure remain binding constraints. A Nigeria-Uganda framework therefore supports cluster-based SME development linked to universities, mineral laboratories, industrial parks and repair-recycling networks rather than isolated micro-enterprises without technical upgrading pathways [4], [8].

The role the government has to play would encompass the determination of the forms of economic activities to be encouraged, the identification of those SMEs justifying financial assistance, and the organization of package of support system to the entrepreneurs. Financial institutions, on their own part, also need to be encouraged to promote more rigorously the SMEs through attractive incentives such as proactive lending. The SMIES programme, whereby the SMEs can borrow money from financial houses to set up or improve their companies, has been virtually shunned by

prospective investors. There is therefore the need to find out the cause(s) of this development.

4.3 Restructuring of research institutions

At present, Nigeria can boast of about thirty research institutes scattered all over the country. Unfortunately, however, most of them are purely agro-based or agro-allied. As a result, not enough emphasis is laid on core technological research. For example, there is an urgent need for a separate research institute to cater solely for solid mineral processing technology. Its function would include taking inventory of the types and quantities of various solid minerals available in the country, and the cost-effective technological means of exploiting and processing them.

For Uganda, the same argument points to stronger coupling between the Directorate of Geological Survey and Mines, Universities, standards institutions and private processors so that mineral-occurrence data are translated into bankable beneficiation projects. This is particularly relevant for lead-zinc, graphite and associated industrial minerals that may support battery-related value chains. A regional Nigeria-Uganda perspective therefore justifies specialized mineral-processing research, pilot plants and materials-characterization laboratories as prerequisites for evidence-based investment decisions [2-3].

The assistance of governments at federal, state and local government levels is also faithfully needed in solid mineral mining and processing. This has to come in form of adequate geological and exploration data and direct capitalization in the mining and processing industry. A World Bank study estimated that more than 250 billion would be required to develop and overhaul the solid mineral mining in Nigeria up to the year 2020 while the industry would need between 500 million and 1 billion US dollars to fully develop the sector on the African continent [1], [17], [24].

4.4 Research & development information flow

Africa is reported to be carrying out relatively little research, including raw material research and development (R & D). According to Badran, (1994), as low as 0.9 per cent of the world's scientific publications come from Africa despite the fact that 8.5 per cent of

the world's population live on the continent. It is also saddening that even the little R & D outputs are prematurely abandoned and not further developed into usable technologies. One main reason for this position can be attributed to the nonexistence of effective communication between the research laboratories and the industries which are the end-users and beneficiaries. Onyekwelu and Nwosah (1988) have identified five problems associated with further development and commercialization of research results. These are

1. Lack of Complete Packages required by an investor to start off the project with little or no technical problem;
2. Lack of Engineering Design Data that would have avoided going through pilot plant stage;
3. Non-availability of local machinery and equipment;
4. Unavailability of semi-processed or intermediate raw materials to convert abundantly available raw materials to intermediate ones; and
5. Lack of adequate publicity between research centers and end-users.

There is, therefore, the need to forge working collaborative partnerships between research laboratories and industries. The research laboratories have to do more public relations work to educate the industries on their capabilities. The industries themselves should sponsor meaningful and the relevant R & D activities and, this should be considered as long-term investment. The country's universities and research institutes' consultancy units may be of help in such publicity campaign. If our battery industry had started investing in research and development of battery technology, say two decades ago, the raw materials problem killing the industry would not have reared their ugly heads.

The role of governments in enhancing effective and efficient information flow between research laboratories and industry is clear. The institutional framework outlined in the industrial policy will have to be critically reviewed and faithfully implemented thereafter. It is not enough for RMRDC to identify the available raw materials, the fund for prospecting and processing these materials must be provided to

government research laboratories whose performance must be well monitored and adequately publicized.

Uganda's e-waste governance experience adds an important downstream dimension to this discussion. The country has a policy, strategy, guidelines, EPR-oriented legal provisions and a national e-waste collection centre in Kampala, but financing, specialized training and recycling infrastructure are still developing. For both Nigeria and Uganda, effective information flow should therefore cover not only upstream raw materials, but also design-for-recycling, take-back systems, hazardous-material control and secondary resource recovery from spent batteries [8], [22].

Figure 3 was validated through expert consultations and policy document analysis across Nigeria and Uganda, confirming coherence of institutional roles, fiscal incentives, and regulatory frameworks. Stakeholders affirmed its strategic relevance, feasibility, and alignment with industrialization agendas, strengthening its applicability for guiding Zn-C battery sector revitalization and investment prioritization [14], [25].

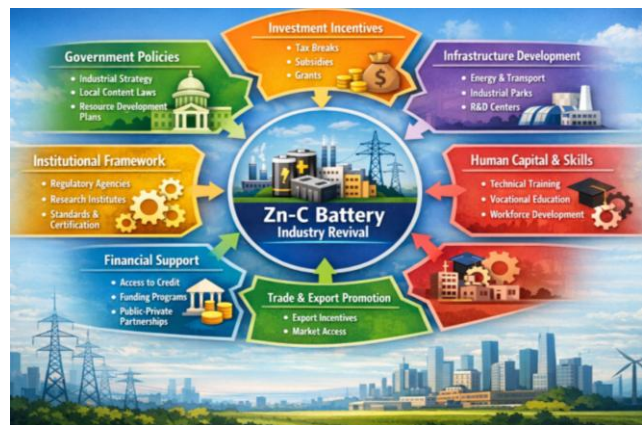


Fig. 3: Policy, institutional and fiscal ecosystem for Zn-C battery industrial revival in Nigeria and Uganda

4.5 Circular economy, EPR and end-of-life battery management framework

A circular economy framework anchored on Extended Producer Responsibility (EPR) is proposed to enhance collection, recycling, and recovery efficiency in Nigeria and Uganda. The model integrates formalized recycling systems, policy enforcement, and stakeholder incentives, reducing environmental risks and enabling

sustainable resource recovery [5], [6], [26-28]. Equation (6) defined End-of-Life Recovery Efficiency (ERE), ERE evaluates the effectiveness of recycling and circular economy systems, reflecting technological efficiency, environmental performance, and resource recovery potential. It is a key metric for assessing sustainability outcomes and informing policy design for e-waste and battery management systems in Nigeria and Uganda.

$$ERE = \left(\frac{M_{Zn}^{REC} + M_{Mn}^{REC} + M_C^{REC}}{M_{TOTAL}^{RECOV}} \right) \times 100 \quad (6)$$

where ERE = End-of-Life Recovery Efficiency (%) indicating the proportion of recoverable materials successfully reclaimed from spent Zn-C batteries.

M_{Zn}^{REC} = Mass of recovered zinc (kg or tonnes).

M_{Mn}^{REC} = Mass of recovered manganese compounds (kg or tonnes).

M_C^{REC} = Mass of recovered carbonaceous materials (e.g., graphite/carbon rod) (kg or tonnes).

M_{TOTAL}^{RECOV} = Total recoverable material input from spent batteries (kg or tonnes), representing the theoretical maximum recoverable fraction.

5.0 SURVEY IN OTHER COUNTRIES

In this case, company in Chinese experienced is used to show the penetrations level of this battery storage in African countries. One of the famous among the leading companies' ins Guangzhou Products called Tiger head, it actually called the best seller in Africa. The company management had declared that, there four products that can be termed as a life of the company, among them is 555 batteries. This product is No1 brands in China dry battery industry, especially in term of export volume for more than 20 years consecutively. This company is ranked among the top 500 energy companies globally; all these are due to the volume shipments in the battery section of the company that has been in operational since 1928. In addition, this battery is one of the first products that brought new China appearing in the world stage. However, is still sold in many parts of the world such as Africa, Middle east, America, Europe, and Asia. This battery was able to break the world market due to the unique technology

that allow it to cross the red sea without losing its properties, unlike other similar products [29-30].

In African continent, this battery is very popular among the populace. Generally, people see it as the most qualitative product to the extent they used hand to test its quality due to its penetration ability. The product is termed it is No 1 battery brand in Africa. Due to this, it is market penetration in some African countries such as Uganda, Congo, Zambia, Chad and Sierra Leone is about 50%. In Nigeria and Tanzania, it's more than 70%, and 2013 ranking of top chines exports enterprises to Africa has shown that it is ranked. In among the top 7 products. In another development, the production this product is now monitored in real time through the application of new technology. This has reduced cost, management efficiency and strengthen product quality [15], [18]. All these strategies allow, and let the other parts of the world to become assembly points as against manufacturing plants. Other efforts can be seen in Table 5.

Figure 4 was validated through comparative expert consultations and secondary data triangulation across Nigeria and Uganda, confirming technical feasibility of collection, sorting, recovery, and disposal pathways. Stakeholder inputs affirmed operational relevance, environmental compliance, and circularity potential, ensuring robustness, scalability, and policy alignment within emerging battery waste management ecosystems.



Fig. 4: Circular end-of-life flow for spent Zn-C batteries showing collection, sorting, material recovery and safe disposal in both countries

Table 5: Efforts in other countries by manufacturers of zinc carbon batteries.

S/No.	Country(s)	Efforts
1	Uganda	New process and formular, enable the company to achieved low and mercury-free requirements for battery production 5 years earlier than national expectations. The company promote a new product that is environmentally friendly.
2	Zambia	The product is expanding from the familiar dry battery series to the strategies battery series, raw material series, lighting series, emergency power supply to mentioned just a few
3	Manila-Philippines	The company responded to one belt one road initiative, and also responded to the new situation a requirement of opening up with more active attitudes.
4	Sierra Leone, Congo, Uganda and other African countries	During Ebola and coronavirus epidemic in Africa, the company donated many battery units for the use in medical equipment.

6.0 CONCLUSION

Nigeria is well blessed with natural resources that could enable her to be one of the manufacturing giants in Africa. Most of the raw materials required in the production of Zn-C dry cells are locally available, at least in the raw form. These only need to be processed to the intermediate state required by the manufacturers. The 1989 Industrial Policy of the country, if not reviewed, should be implemented. Unless the problems of bureaucratic bottlenecks and inconsistencies in the implementation of the industrial policy are removed, Nigeria may still be far from achieving much in terms of local raw materials development. Furthermore, there is need for the development of policies that could assist developing nations in the management of toxic elements from the used of zinc carbon batteries for environmental sustainability. For Uganda, the comparable policy opportunity lies in converting documented mineral occurrences and emerging e-waste governance into a smaller but strategic battery-materials ecosystem grounded in value addition, environmental compliance and regional supply-chain participation. Accordingly, the combined Nigeria-Uganda lens strengthens the argument that future competitiveness in Zn-C batteries will depend not merely on mineral presence, but on beneficiation, standards infrastructure, SME integration, research commercialization and circular end-of-life management [3-4], [8].

REFERENCES

- [1] Bakare Mutiu Shola, Abubakar Abdulkarim; Aliyu Nuhu Shuaibu; Mundu Mustafa Muhamad; Venkataramana Guntreddi; Oladimeji Ibrahim (2026) Enhancing Energy Harvesting in Wireless Sensor Networks: Strategies, Challenges, and Future Trends, in Handbook of Sustainable Wireless Communication Systems published by CRC Press.
- [2] Nagudi B. (2011): Status of Geological Resources in Uganda. Ministry of Energy and Mineral Development, Uganda.
- [3] DGSM (2017): Mineral Occurrences of Uganda. Directorate of Geological Survey and Mines, Entebbe, Uganda.
- [4] NPA (2025): Fourth National Development Plan (NDP), 2025/26-2029/30. National Planning Authority, Republic of Uganda.
- [5] Forti, V., Baldé, C.P., Kuehr, R., & Bel, G. (2024). The Global E-Waste Monitor 2024. United Nations.
- [6] African Development Bank (2023). Africa Circular Economy Outlook.
- [7] RMRDC (1989): Report of the multidisciplinary task force on raw materials for chemical and pharmaceutical industries, Raw Materials Research and Development Council Table 23.
- [8] MoICT&NG (2023): Status of Electronic Waste Management in Uganda. Ministry of ICT and National Guidance / ITU presentation, Uganda.
- [9] NESREA (2024): National Environmental (Battery Control) Regulations, 2024. National Environmental Standards and Regulations Enforcement Agency, Nigeria.

- [10] Aribisala O.A. (1993): Raw materials revolution and impact on industrialisation in Nigeria. Mednet Publications, 325 pp.
- [11] Rupani, P. F., Delarestaghi, R. M., Abbaspour, M., Rupani, M. M., EL-Mesery, H. S., & Shao, W. (2019). Current status and future perspectives of solid waste management in iran: A critical overview of Iranian Metro Politan cities. *Environmental Science and Pollution Research*, 26(32), 32777–32789/10754 50
- [12] Adediran Y.A. and Abdulkarim A. (2012) Challenges of Electronic Waste Managements in Nigeria, Published by the International Journal of Advances in Engineering &Technology (IJAET) Vol. 4, Issue 1, pp. 640-648
- [13] Zulfiqar, U., Farooq, M., Hussain, S., Maqsood, M., Hussain, M., Ishfaq, M., Ahmad, M., & Anjum, M. Z. (2019). Lead toxicity in plants: Impacts and remediation. *Journal of Environmental Management*, 250(November), 109557. <https://doi.org/10.1016/j.jenvm.2019.109557>
- [14] Kohli, S.K., Handa, N., Bali, S., Khanna, K., Arora, S., Sharma, A., & Bhardwaj, R. (2020). Current scenario of Pb toxicity in plants: Unraveling plethora of physiological responses. In P. de Voogt (Ed.), *Reviews of environmental contamination and toxicology*, 249:153–197. Cham: Springer International Publishing. https://doi.org/10.1007/978-1-4939-9825-2_25
- [15] Ondayo, M. A., Simiyu, G. M., Raburu, P. O., & Hussein, F. (2016). Child exposure to lead in the vicinities of informal used lead-acid battery recycling operations in Nairobi Slums, Kenya. *Journal of Health and Pollution*, 6(12), 15–25.
- [16] Etiang, N., Arvelo, W., Galgalo, T., Anyangu, A., Gura, Z., Kioko, J., Omondi, G., Patta, S., Lowther, S., & Brown, M. J. (2018). Environmental assessment and blood lead levels of children in Owino Uhuru and Bangladesh settlements in Kenya. *Journal of Health and Pollution*, 8(June), 180605.
- [17] Dehghani-Sanij, A. R., Tharumalingam, E., Dusseault, M. B., & Fraser, R. (2019). Study of energy storage systems and environmental challenges of batteries. *Renewable and Sustainable Energy Reviews*, 104(April), 192–208. <https://doi.org/10.1016/j.rser.2019.01.023>
- [18] Ouyang, D., Liu, J., Chen, M., & Wang, J. (2017). Investigation into the ire hazards of lithium-ion batteries under overcharging. *Applied Sciences*, 7(12), 1314
- [19] Uganda Communications Commission (2023). Market Performance Report. United Nations Industrial Development Organization (2022). E-Waste Management in Developing Countries: Uganda.
- [20] FMI (1989): Industrial Policy of Nigeria (Policies, Incentives, Guidelines and Institutional Framework), Federal Ministry of Industry, Abuja, pp. 48.
- [21] MAN (1990): Sample Survey performance of the Nigeria manufacturing sector 1987-1989, Annual Report of Manufacturing Association of Nigeria., pp 2-19.
- [22] MoICT (2012): Electronic Waste Management Policy for Uganda. Ministry of Information and Communications Technology, Kampala, Uganda.
- [23] Nwite P. (1996): Rescuing small and medium scale enterprises (SMEs) in the march towards economic development, 29th AGM of Manufacturers Association of Nigeria, July 1996.
- [24] Onowu M.A. (1997): Solid minerals mining: aiding private sector participation. *Daily Times* 1/5/97, pp 27.
- [25] Kang, Z., Huang, Z., Peng, Q., Shi, Z., Xiao, H., Yin, R., Fu, G., & Zhao, J. (2023). Recycling technologies, policies, prospects, and challenges for spent batteries. *iScience*, 26, 108072.
- [26] World Health Organization (2023). Electronic Waste and Children's Health.
- [27] National Environment Management Authority (2020–2024). Annual Reports.

- [28] Baldé, C. P., Wang, F., Kuehr, R., Huisman, J., & Forti, V. (2022). *Global transboundary e-waste flows and circular economy: From waste to resource*. United Nations University (UNU) & International Telecommunication Union (ITU), Bonn/Geneva.
- [29] Sadeghi, S. M., Jesus, J., & Soares, H. M. V. M. (2020). A critical updated review of the hydrometallurgical routes for recycling zinc and manganese from spent zinc-based batteries. *Waste Management*, 113, 342-350.
- [30] Onyekwelu S.C.O. and Nwosah G.C. (1988): Engineering input in the manufacturing of laboratory research results to commercial plant specifications. Proceedings of the monthly Technical Seminar on the Chemical and Pharmaceutical sector, RMRDC, November 25th 1988.