Lithium Ion Battery Production in Nigeria: Issues and Challenges

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Abstract — **The worldwide lithium battery market is expected to grow by a factor of 5 to 10 in the next decade. In response to this projected vast increase in market demand, the federal government in some advanced countries like the US, has outlined a national blueprint to guide investments in the urgent development of a domestic lithium-battery manufacturing value chain. The benefits derivable from these efforts include equitable clean-energy manufacturing jobs, a clean-energy economy and the mitigation of climate change impacts. This paper examines the Nigeria's potentials for Lithium ion Battery development and the challenges stopping the country from tapping into these potentials and the benefits thereof. It focuses on current market factors that impact lithium ion battery development in Nigeria, evaluates market deterrents to widespread usage, and looked into possible scenarios on how the battery market in Nigeria could develop going forward. However, this growth will depend on strong supply chains, which rely on a secure and sustainable supply of raw minerals and metals most of which are in large supply in Nigeria but are grossly underutilized.**

Keywords — **Battery, Battery Production, Lithium ion Battery, Nigeria Potentials.**

I. Introduction

Energy storage systems (batteries) have become an essential part of resilient, renewable energy systems globally. The ability to gather and store energy in periods when demand is and make the energy available for use during periods of high demand from renewable technologies that are intermittent by nature, such as solar and wind, enables this technology to integrate into traditional energy infrastructure successfully and provide 24-hour service for electricity demand. Battery technology has evolved to meet this need, incorporating large and small-scale battery solutions that can provide storage capacity to technologies which range in size from multi-megawatt generation assets to small-scale solutions.

Many factors are driving this rapid evolution in battery technologies. First of all, countries all over the world are quickly drafting and ratifying a raft of new laws and guidance on the adoption of electric vehicle. This is a signal for a great revolution in the transport system [1]. In the bid to reduce the use of fossil fuel, Electric vehicle have proven to be a substitute for the internal combustion engine (ICE). The production of Lithium ion batteries (LIB) is of the solutions to reducing fossil fuel emissions. These batteries use several minerals which include lithium and cobalt (Li-Co), manganese, nickel, aluminum, graphite, rare earth elements (REE), iron, copper, as well as phosphate [2].

This growing demand for lithium ion batteries is pushing their prices to astronomical levels, and creates a huge opportunity for economic development of countries endowed with deposits of these minerals. In Nigeria, A number of states have Lithium ore deposits in large commercial quantities. This is the major raw mineral resource used in the production of lithium ion batteries for home appliances as well as batteries for electric vehicles. These states include Kogi, Nasarawa, Ekiti, Kwara, Cross River, Oyo, Plateau, and a few others [3]. Preliminary results have shown that the grades of lithium in lithium-producing mines across the world are comparable to the grades of Nigerian Lithium bearing ores [3].

The continued miniaturization of electronic devices and the need for high density, long cycle life batteries are another factor driving the rapid development of LIBS. Lithium which is derived from a Greek word meaning “stone” is a very soft, silvery-white metal that smokes and sizzles if water is poured upon it. Lithium is so light that a bar of it will float on water. Its melting point and heat capacity are the highest of any element. Hence, it is used as a coolant in some nuclear reactors and also in lubricating grease, industrial dryers, and air-conditioners, batteries, glass, medicines, and nuclear bombs [2].

Compared to lead acid batteries, Lithium ion batteries have a higher density, resiliency, and a longer life. The major advantage and core strength of a lithium ion battery is its low maintenance compared to that of a lead acid battery. Of the two batteries under similar operating conditions, lithium ion will retain a charge for longer durations than a similarly sized lead acid battery. This superior performance has resulted in lithium ion batteries becoming commonplace in many high-technology applications, including computers, cars, and smartphones.

Analysts say there is a potential shortfall in the global mining capacity required to extract the minerals needed to manufacture sufficient lithium ion batteries to meet projected EV demand as well as those from smart electronics devices [2]. Hence, it is a great time for investments in countries that have developed capacity in mining these raw materials. However, it seems that Nigeria's attention is yet to shift from oil.

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A. The Lithium Ion Battery Manufacturing Process

The current state-of-the-art battery manufacturing process includes the following three major parts:

- Electrode preparation,
- Cell assembly,
- Battery electrochemistry activation.

In the first step of the process, the conductive additive which also serves as the active material (AM), and binder are mixed together to form a uniform slurry with the solvent. To form the cathode, the binder polyvinylidene fluoride (PVDF) is dissolved in N-methyl pyrrolidone (NMP), and for the anode, the styrene-butadiene rubber (SBR) binder is dissolved in water with carboxymethyl cellulose (CMC). The slurry is then pumped into a slot die, coated on both sides of the current collector (Al foil for cathode and Cu foil for the anode), and delivered to drying equipment to evaporate the solvent [3].

After forming the electrodes, the next step is called calendaring. This process is used to adjust the physical properties (bonding, conductivity, density, porosity, etc.) of the electrodes. After all these processes, the finished electrodes are stamped and slitted to the required dimension to fit the cell design. Then excess water on the electrodes are removed by sending the electrodes to a vacuum oven. After the drying process, the moisture level of the electrodes is checked. This will ensure that the side reaction and corrosion in the cell are minimized [3]

The well prepared electrodes are sent to the dry room with dried separators for cell production. The electrodes and separator are winded or stacked layer by layer to form the internal structure of a cell. The aluminum is welded on the cathode current collector while the copper tabs are welded onto the anode current collector. The ultrasonic welding method is usually chosen by manufacturers. Some may choose the resistance welding method instead for their cell design. The cell stack is then transferred to the designed enclosure, which does not have a consistent standard currently. Each manufacturer has their preference depending on the purpose of the cells. The enclosure is filled with electrolyte before the final sealing and completes the cell production [4].

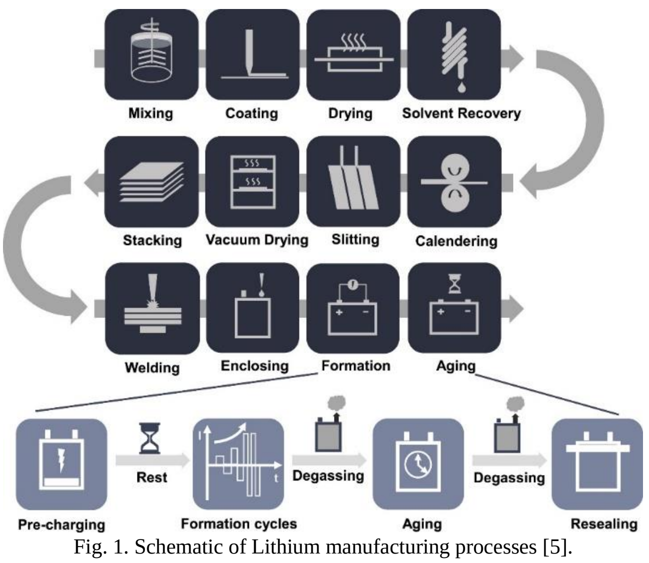

Fig. 1. Schematic of Lithium manufacturing processes [5].

There are electrochemistry activation steps that are usually applied to the finished cells to enable operation stability. This is done before moving the cells to the end product manufacturers A stable solid-electrolyte interface (SEI) layer can prevent the irreversible consumption of electrolyte and protect the anode from overpotential during fast charging, which can result in forming Li dendrites [6]. The formation and aging process starts from charging the cells to a relatively low voltage (e.g., 1.5V) to protect the copper current collector from corrosion. After this process a rest session for electrolyte wetting follows. The cells are charged/discharged under a low rate such as C/20, and then the rate will be gradually increased to ensure a stable SEI layer on the surface of the anode [6]. The gas generated from the formation process needs to be discharged for safety concerns. After or during formation cycles, the cells are stored on the aging shelves for complete electrolyte wetting and SEI stabilization.

B. Thermal Runaway

After producing the batteries, there is a need for a battery management system for practical battery applications.

Lithium-ion batteries have a narrow operating temperature range of between +15 and +45 °C. The functional safety, service life, and cycle stability of the battery cell - and also the functional safety of the battery and the entire electric car or electric tool system - depend to a large extent on the battery cell remaining in this range. Thermal runaway is a process that occurs if the temperature exceeds a critical level. Thermal runaway of the lithium-ion battery initiates an unstoppable chain reaction. During this process, the temperature rises rapidly within milliseconds leading to a sudden release of the energy stored in the battery. Temperatures of around 400 °C are thus created, the battery becomes gaseous, and a fire erupts that can hardly be extinguished by conventional means. The risk of thermal runaway begins at a temperature of 60 °C and becomes extremely critical at 100 °C. The particular temperature or the time the battery actually catches fire depends on the specific cause.

Several factors can lead to thermal runaway of a lithium-ion battery:

- Internal short circuit: Due to an accident or similar mechanical impact, e.g., if a tool falls down from a great height, the battery is deformed, material penetrates the battery cell and triggers an internal short circuit.
- External short circuit: if the battery cell is deformed by any means, this could lead to an external short circuit.
- Thermal runaway could also result from overcharging the battery beyond the maximum range of voltage stated in the data sheet of the battery. Whether the battery is damaged permanently or not will depend on the degree to which it was overcharged. A battery may be damaged permanently, and the service life of the battery will decrease.
- Excessive currents when charging or discharging the battery, e.g., when charging rapidly.

C. How Can the Risk Be Reduced?

To minimize the risk of thermal runaway, the mechanical and thermal stability of the battery must be guaranteed. This is ensured by appropriate monitoring mechanisms of the battery cells and the battery pack.

The battery management system ensures that the battery remains in its specified working range. This requires extremely precise measurement of the charge and discharge currents, cell voltage, and temperature. With regard to thermal runaway, also known as "venting with flame", the temperature is decisive.

II. The Nigeria Energy Profile

Systemic issues in Nigeria's energy delivery value chain, including on-grid and off-grid infrastructure, leaves more than 80 million Nigerians (~45% of the population) without access to electricity, with 66% of rural areas and nearly 15 percent of urban areas having no access to grid-connected electricity. Nigeria, with a population of about 200 million people, has the second-largest energy access deficit in the world, after India, with only 55% national electrification rate and only 39% access-rate in rural areas [8].

The current energy access deficit – outlined in Fig. 2 below – is complicated by the fact that Nigeria's energy demand is growing rapidly, with a projected annual increase of more than three percent from 2020–2025 [8].

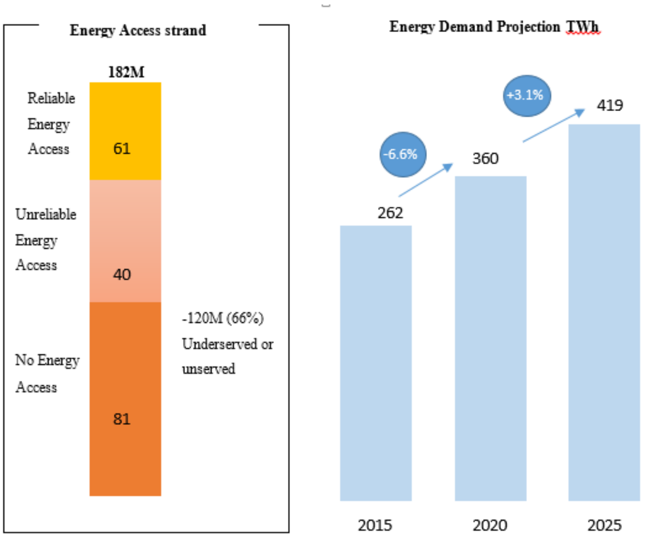

Fig. 2. Nigeria energy access gap [8].

The common method In Nigeria the most common ways people deal with the poor availability of renewable energy is to configure renewable generation sources with a diesel generator back-up supply. The diesel back-up generator provides a stable power supply at night, during inclement weather, or any time the primary, renewable power source is not able to satisfy the full load requirement. Diesel generators can provide stable electricity supply for a good amount of time, but the challenge with using them is they are noisy, expensive, environmentally damaging, and pose significant health hazards to those who experience prolonged exposure to diesel fumes.

However, Batteries are emerging as one of the most competitive alternatives to diesel generators when it comes to mitigating intermittency in mini-grid electricity supply.

III. The Nigeria's Battery Market and the Common Technology Options

The off-grid marketplace in Nigeria is relatively complex. It features small-scale batteries with relatively flexible operating standards, long operating life, rapid deployment, and reasonably cost-effective price point to be responsive to both the nascent state of the market and a challenging operating environment. As outlined in Table I below, the battery technologies prevalent in off-grid settings cover a wide range functionality and are in various stages of development.

TABLE I: Battery Technologies for Mini-Grid Deployment [8]

Battery Technology	Commercial Status	Cycle Life	Estimated Initial Cost (US$/kWh)
Lead-Acid	Available	1,650 at 50% depth of discharge, 1,050 at 80% depth of discharge	$300
Lithium-Ion	Available	1,900-3,000 at 80% depth of discharge	$700
Lithium-Sulfur	Mostly laboratory	(Data not available)	>$1,500 per kWh
Zinc-air	Available	~500	Competitive w/ Lead Acid
Lithium-Air	Laboratory	50-900	N/A
Vanadium Redox Batteries (flow)	Available	3,750+ at 80% DOD	$350-800
Zinc-bromine (flow)	Available	(Data not available)	(Data not available)
Sodium-sulfur	Mostly utility-scale	1,500-3,000	$600
Flywheel Energy Storage	Available for utilities and large mini-grids	100,000+	$1,333-3,000

The commercial availability of these battery technologies, their cycle life (the number of times they can be discharged and re-charged without battery performance degradation), and the estimated initial cost, have resulted in two battery technologies becoming the most prevalent in the Nigerian marketplace – Lead Acid and Lithium-Ion.

The most common battery used in the Nigerian off-grid activities is the Lead acid battery. These type of batteries are made of lead dioxide (cathode), metal lead (anode), and aqueous sulphuric acid (electrolyte). These include the flooded (in which electrodes are immersed in liquid electrolytes), gelled electrolyte, and absorbed glass matte batteries with brands such as Trojan, Decker, HBL, and Hoppecke. Despite advancements in battery technology, lead acid battery has continued to dominate the consumer market place with the advantage of being the first commercially available rechargeable battery. While lead acid batteries do suffer decreased performance when excessively discharged and when operating under extreme temperatures, they have remained competitive largely due to their dependability and low price-point compared to other battery technologies.[8]

On the other hand, Lithium ion batteries are newer and more technologically advanced than lead acid batteries. LIBs are increasingly gaining grounds in Nigeria's off-grid marketplace. However, due to their higher capital costs, they still continue to trail behind the lead acid batteries in the marketplace. Structurally, lithium ion batteries consist of a number of lithium ion cells together with electronics for battery management. They have a higher density, resiliency, and a longer life cycle than lead acid batteries.

A. Nigeria's Potential Lithium Ion Market Size

Lead acid will likely retain significant market share in Nigeria, but the market share of lithium ion batteries will continue to increase steadily. Lead acid batteries still enjoy ease of deployment and relative affordability, making them likely to remain dominant in the Nigeria battery market place for a much longer time. However, the market for lithium ion batteries could expand significantly in this timeframe, with a more than 60 percent increase in market value over five years in the Medium Scenario model, reaching more than US$5 million per year in both 2024 and 2025, as outlined in Fig. 3. This assessment yields the following year-over-year growth for the lithium ion battery market, with the market exceeding US$5 million per annum in both 2024 and 2025 in the medium scenario. This scenario assumes that lithium ion batteries will retain an approximately ten percent market share within the 2020–2025 timeframe [8].

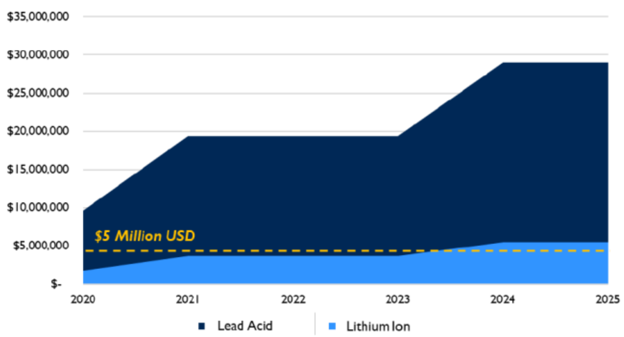

Fig. 3. Lithium Ion and Lead acid Annual Market (Medium Scenario) [8]

IV. The Threats and Challenges of Lithium Ion Development In Nigeria

There exists a few market dynamics that may influence how a battery manufacturer enters or their operations within the Nigerian market. These areas represent potential opportunities for battery vendors to influence and expand the market as well as outline possible challenges that the battery market may face.

A. Capital Cost

For mini-grid developers, the upfront capital cost of batteries is a key consideration in how they decide between multiple types of batteries. For Battery vendors, this is an important factor to consider when deciding their approach to marketing. Depending on the type of battery technology used and the overall battery volume, the capital cost may differ per kWh purchased.

According to mini-grid developers surveyed by PA-NPSP, lead acid batteries are the most economical for developers, with costs typically ranging from US$150 to US$300 per kWh [8]. The market is also mature, both in and outside of the Nigerian market. Their level of maturity makes lead acid batteries the technology of choice for large-scale, capital-intensive projects. The lead acid battery has some potential draw backs such as larger physical size and lower density cells. However, these drawbacks are balanced by the batteries low cost per kWh compared to the lithium ion batteries. The implication for their low density is that the developer needs to purchase and deploy a higher number of battery units to provide an equivalent amount of storage as compared to lithium ion batteries, driving up the overall capital cost, even if the per unit cost remains lower than lithium ion alternatives.

In comparison, lithium ion batteries are generally more expensive in Nigeria, with per kWh costs ranging from US$250 to US$500 per kWh. This high cost per Kwh hasn't deterred developers from increasingly deploying lithium ion batteries. They are banking on the potential lifecycle savings and increased performance and resiliency obtainable from lithium ion batteries when compared to lead acid batteries. For small-scale systems, the relatively high capital cost becomes less significant than the longer life cycle, the ability to operate at high temperatures, and deep discharge capability [9]

B. Environment and Technology Performance

Battery performance is often affected by the environment in which a battery is deployed. Nigeria is a challenging environment for batteries, with most off-grid systems deployed in remote locations, where community members are unfamiliar with battery operations and maintenance, and in extreme temperatures with high levels of dust. These factors can cause variances in performance compared to the manufacturer's performance specifications, or battery performance in a more favorable environment.

The higher power and higher energy density of lithium ion batteries make them more lightweight and thus they require fewer modules for their desired performance. This makes them easier to integrate into the battery module for larger off-grid systems.

Lithium ion batteries can be discharged between 1,900-3,000 times at 80% depth of discharge with minimal long term damage.[1] This resilience gives lithium ion batteries about six times the number of cycles compared to a lead acid, a characteristic that makes lithium ion generally a more flexible and resilient battery technology in the long-term. Disadvantages of this battery type include the tendency to degrade at high temperature and when stored at high voltage.

C. Financial Barriers and Regulatory Environments

There are a variety of regulatory and financial structures that support Nigeria's mini-grid and battery markets. It is important to consider these structures since they represent potential hurdles to market development as well as potential opportunities to capitalize on market incentives that may mitigate risk for mini-grid developers and battery vendors.

- **Global Standards:** Currently, there are no official standards for the quality assurance of batteries in Nigeria. However, there is a need to ensure consistency of quality of batteries by establishing independent and globally accepted standards, similar to that which exists for off-grid lighting applications.
- **Battery Waste and Recycling:** The Federal Ministry of Environment of Nigeria has formulated regulations for the disposal of battery waste, however, there is no established protocol for handling or recycling of batteries at the end of their useful life.

In Nigeria, there is still the absence of effective and detailed regulation on battery waste. There is also the absence of reputable, responsible, and safe recycling companies (e.g., Hinckley Recycling) to handle battery wastes, resulting in improper management of battery waste by the informal sector. The lithium ion batteries have various constituent-parts that could harm human health and the environment [8].

D. Product Warranties

The ability of the battery manufacturer to provide both product warranty and performance guarantee on its technologies is a critical factor in selecting a battery for use in off-grid applications. Most times, project developers are unable to access reliable, in-country post-sales support service – such as repair, replacement, refund, and compensation. There also exists an inconsistent policy on warranty. All these hurdles hinder the potential for large-scale deployment of batteries in Nigeria's off-grid market. They discourage developers from trying new and more technologically advanced products. The ability to supply a reliable product with accessible post-sale customer service is integral in ensuring long-term growth and a successful entry into Nigeria's off-grid market. Depending on the type of application of batteries and the business model for deployment, the energy access company and battery manufacturer must agree on the terms of warranties they will offer and how claims against those warranties will be managed [9].

V. The Way Forward

Projects Development Institute (PRODA) Enugu is one of the research institutes in Nigeria piloting the development of local capacity for the production of lithium ion battery in Nigeria. Some of the steps they have taken to achieve this goal include research and development, acquisition of production line machinery and training of staff. PRODA also intends to carry out pilot production using imported raw materials.

China still continues to play dominant roles in the lithium-ion battery development and supply chain to continued investment and strong local and domestic demand for its lithium-ion batteries. It is reported that China hosts 80 percent of global battery cell manufacturing capacity today. This capacity is expected to more than double, enough for more than 20 million electric vehicles in the next five years, according to the Bloomberg NEF report [10].

However, while investors are trying to beat each other in the search of lithium ion battery raw materials in countries such as USA, China, Zimbabwe, and the Democratic Republic of Congo, the case in Nigeria is largely the opposite. Even when there is an effort to explore these raw materials, not much attention is given to producing them at a scale for exportation purposes.

A report by the Carnegie Endowment International released in October 2021, found that consumption of critical raw material (CRM) is projected to increase by a factor of four for graphite, five for cobalt, and eighteen for lithium by 2030; and by a factor of thirteen for graphite, fourteen for cobalt, and nearly sixty for lithium by 2050 [8]. "The projected demand in CRMs creates opportunities for Africa to replace Asian supply chains," the report noted.

Although different battery manufacturing innovations have been proposed and developed in academia, very few can be adopted by the industry due to various reasons (e.g., cost, reliability, scalability, etc.). It is understandable that the risks of adopting new manufacturing technologies with low technology readiness levels may be high. Therefore, instead of adopting the new manufacturing technologies directly, more effective collaborations on the scale-up process could help both research and industrial ends.

Again, more research needs to be done to improve the safety and reliability of lithium ion batteries with respect to thermal runaway so that it can be adapted for use in various applications including the electric vehicles, currently in vogue in Europe and America, as well as Conventional IC engine and Solar installations.

It is advised that a lithium ion battery pilot plant be built and operated in Nigeria. This will involve installation, test run and hands on training of staff in the key areas of the battery development. This will eventually open the door for building a full blown factory for lithium ion production.

It is recommended that Nigeria pay proper heed to the mining of graphite, lithium and cobalt, manganese, aluminium, iron, rare earth elements etc., so as to benefit from them.

It is also recommended that research groups collaborate in the pursuit of this laudable venture so as to ensure that the production of lithium ion batteries in Nigeria becomes a reality soon.

VI. Conclusion

It is certain that LIBs will be widely used in electronics, EVs, and grid storage. Both academia and industries are pushing hard to further lower the cost and increase the energy density for LIBs.

There are many on-going research efforts geared towards developing local capacity for lithium ion battery production in Nigeria. This is largely due to the abundance of some of the CRM in some states in Nigeria as well as the government's drive towards import substitution. In the future these efforts will continue, and the hope is that Nigeria will become a leading LIB producer in Africa.

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