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Lithium-ion battery research and development: the Nigerian potential

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Lithium-ion batteries (LiBs) are growing in popularity as energy storage devices. Handheld, portable electronic devices use LiBs based on Lithium Cobalt Oxide (LiCoO2) which in spite of its attendant safety risks offers high energy density. Other types of LiBsbased on Lithium iron phosphate (LiFePO4), Lithium ion manganese oxide (LiMn2O4, Li2MnO3 or LMO) and Lithium nickel manganese cobalt oxide (LiNiMnCoO2 or NMC) have better safety issues with lower energy density.These batteries which are rechargeable are usedin cell phones, laptops and tablets, electric and hybrid cars (EV), grid storage, cordless power tools, medical equipment and other high-tech devices. Nigeria, with a population abovetwo hundredmillion is a big market for lithium-ion batteries. The mineral ore for the cathode of lithium ion batteries are available in Kogi, Nasarawa, Ekiti, Kwara, Cross River, Oyo, and Plateau States. These include amblygonite(Li,Na)AlPO4(F,OH), Lithium Sodium Aluminum Phosphate Fluoride Hydroxide and lepidolite (K(Li,Al)3(Al,Si,Rb)4O10(F,OH)2, Potassium lithium aluminum silicate hydroxide fluoride, spodumene: (LiAl(SiO3)2 Lithium Aluminum Silicate, petalite: (LiAl(Si2O5)2 aluminumhydroxy-[hydroxy(oxo)silyl]oxy- oxosilane;lithium),and graphite which is used as the anode material is available in Kaduna and Adamawa States. In view of these available resources, the Projects Development Institute (PRODA) Enugu, a Science and Engineering based Research Institute under the supervision of the Federal Ministry of Science and Technology has pioneered battery research and development with a particular focus on Lithium-ion batteries. It is expected in the long run that lithium-ion batteries would be produced locally for rechargeable lanterns in view of the country's energy deficit. This would spring up small and medium enterprises that would drive the economy by the beneficiation and refining of the raw materials content which are available in the country and thus creating wealth for our citizenry.
Keywords: Lithium-ion battery, Nigerian potential, energy, electronic devices

Introduction

Lithium, a soft, silvery-white alkali metal is the third element in the periodic table. It is the lightest of all metals. The earth's crust as a whole, contains about 20 parts per million of lithium, and the oceans contain 0.17 parts per million; the atmosphere has only minute amounts. [1]. Lithium has a lot of industrial uses. It is used in pharmaceuticals,ceramics, glass making and aluminum and magnesium alloys. The main potentialfor growthhowever is in the battery market, where lithium is utilized as electrode and electrolyte material in lithium non rechargeable batteries and in lithium-ion rechargeable batteries. The result of asurvey case study conducted by the United States Geological (USGS), showed that over the years 1996-2005 the amount of lithium used per year in the United States in four particular battery markets (camcorders, cameras, cell phones, and portable computers) grew threefold [2]. The consumption of lithium is growing worldwide. This growth is driven by the automotive industry as it continues to produce large numbers of hybrid electric vehicles and electric vehicles that use lithium batteries.In just 10 months in 2015, prices for the metals almost tripled to more than $20,000 a ton. This was caused by fears of a lithium shortage which was caused by a spike in the market for electric vehicles, which were suddenly competing with laptops and smartphones for lithium ion batteries. The demand for the metal will not abate anytime soon—on the contrary, electric car production is expected to increase more than thirtyfold by 2030 when annual global electric vehicles sales are forecast to hit 24.4 million [3].

World Lithium Deposits

Lithium is never found in its elemental, metallic form because it is highly reactive: lithium is highly flammable, and will even react spontaneously with water. (This high reactivity is why some lithium-ion batteries ignite or explode when exposed to high temperatures.) Instead, lithium is usually extracted from lithium minerals that can be found in igneous rocks (chiefly spodumene) and from lithium chloride salts that can be found in brine pools [5] .

The largest producer of lithium in the world is Chile, which extracts it from brine at the Atacama Salt Flat. Argentina also produces lithium from brine at the Hombre Muerto Salt Flat.

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Figure 1: Major lithium deposits by type (Sources, Deutsche Bank, USGS, Bloomberg New Energy Finance)

There is also an enormous lithium deposit in Bolivia at the Uyuni Salt Flat (the world's largest salt flat), but this resource remains untapped for now due to political and economic reasons. The largest producer of lithium from spodumene is Australia, which has a large deposit near Perth. Other major lithium producers include China, which produces it at salt lakes in Tibet and Qinghai, and the United States, which produces it from brine in Nevada [6]. Extracting lithium from brine is currently cheaper than mining it from spodumene, so there are many deposits of spodumene that are not currently being mined. Lithium is also present in seawater, but the concentration is too low to be economic.As of January 2010, the USGS estimated world total lithium reserves at 9.9×10^9 kg (economically extractable now) and identified lithium resources at 2.55×10^{10} kg (potentially economic). Most of the identified resources are in Bolivia and Chile (9×10^9 kg and 7.5×10^9 kg, respectively). World lithium production is currently on the order of 2×10^7 kg per year [4].

Figure 2: Spodumene (lithium aluminum silicate) is a mineral that is used as a commercial source of lithium. (Photograph courtesy of the U.S. Geological Survey.)

Natural Deposits Of Lithium In Nigeria

Nigeria has more than 44 different types of minerals discovered in 500 locations according to a report of the Ministry of Solid Mineral Development [7]. The countryis focusing its attention on 35 abundant industrial minerals because they have good international market prospects [8]. One of such minerals is lithium ore. The most common lithium ores in Nigeria are **spodumene**: $(LiAl(SiO_3)_2$ Lithium Aluminum Silicate, **amblygonite** $(Li,Na)AlPO_4(F,OH)$, Lithium Sodium Aluminum Phosphate Fluoride Hydroxideand **lepidolite**: $(K(Li,Al)_3(Al,Si,Rb)_4O_{10}(F,OH)_2$, Potassium lithium aluminum silicate hydroxide fluoride and **petalite**$(LiAl(Si_2O_5)_2$ aluminum; hydroxy- [hydroxy (oxo) silyl] oxy- oxosilane; lithium).

These ores are also exported from Nigeria to international buyers. There are lithium deposits in Kogi, Nasarawa, Ekiti, Kwara, Cross River, Oyo, Plateau, and a few other states in Nigeria [9]. At present there are no mining or processing facilities for lithium in the country. What is on ground are mining sites using direct human labour as shown in Figure 5 [9]. The high consumption of huge amount of lithium final products such as mobile phone battery and lithium ion solar batteries makes the country a huge market for lithium-ion batteries. It is expected that favorable regulations including subsidies and tax rebate would stimulate investmentin the local mining, beneficiation and utilization of Nigerian lithium ores, which would in turn drive research and development of made-in-Nigeria lithium-ion batteries for local consumption and probable export.

Figure. 3. Nigerian Lepidolite and amblygonite

Lithium Ion Battery

A lithium-ion battery or Li-ion battery (abbreviated as LIB) is a type of rechargeable battery. Lithium-ion batteries are commonly used for portable electronics and electric vehicles and are growing in popularity for military and aerospace applications [10]. It was developed by John Goodenough, RachidYazami and Akira Yoshino in the 1980s, [11] building on a concept proposed by M. Stanley Whittingham in the 1970s, [12] and it was commercialized by Sony and Asahi Kasei in 1991.When the cell charges and discharges, ions shuttle between cathode (positive electrode) and anode (negative electrode). On discharge, the anode undergoes oxidation, or loss of electrons, and the cathode sees a reduction, or a gain of electrons. Charge reverses the

movement. All materials in a battery possess a theoretical specific energy, and the key to high capacity and superior power delivery lies primarily in the *cathode*. For the last 10 years or so, the cathode has characterized the Li-ion battery. Common cathode materials are *Lithium Cobalt Oxide* (or Lithium Cobaltate), *Lithium Manganese Oxide* (also known as spinel or Lithium Manganate), *Lithium Iron Phosphate*, as well as *Lithium Nickel Manganese Cobalt* (or NMC) and *Lithium Nickel Cobalt Aluminum Oxide* (or NCA) [13].

Figure 4. Nigerian Kunzite

Figure 5: A lithium ore mining site in Nigeria, Source(https://www.nairaland.com/5083475/nigerian-supplier-lithium-ore)

Uses Of Lithium Ion Batteries

Consumer Electronics – Li-Ion batteries are most common in consumer electronics, with Laptop batteries being the largest segment. The more advanced Li-Ion Polymer batteries which can be formed to be very thin and flexible, are found in devices like the iPad, iPods and Smartphones. With the astronomical growth of this segment, battery production has also grown exponentially.

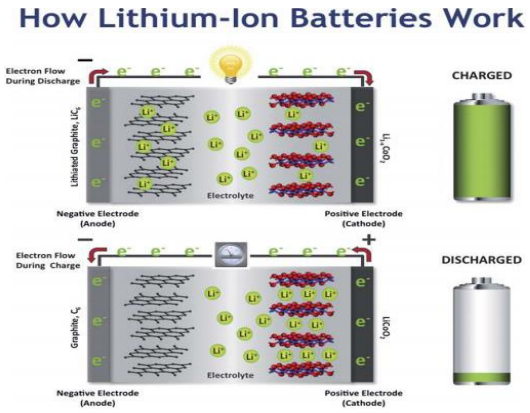

Figure 6: Working principle of lithium ion battery (Copyright 2011 ACS Publishers Ltd.)

Mass Grid Energy Storage – Following electric vehicles, the mass energy storage sector is growing as major utilities are installing Li-ion battery storage systems to harness excess power generated by the grid. These systems are many times larger than automotive batteries [14].

Home Energy Storage – Home energy storage is an important growth market and combined with continued advances in solar energy capture, has the potential to revolutionize how we power our homes.

Healthcare – In the US, the Government has set aside $22 billion for technology improvements to implement electronic medical records (EMR) which involves collecting data at the point of care or at the patient's bedside in hospitals. This requires mobile power in laptops for up to 18 hours or more, which no laptop battery can provide. Hospitals have used Li-ion external batteries which provide additional six hours of run time which is inadequate for EMR. Sealed Lead Acid (SLA) batteries mounted on mobile carts are also used but not preferred, due the inherent drawbacks of the SLA battery. Li-Ion batteries are growing in popularity as they are lighter and have a lower cost of ownership [14].

Electric Vehicles – The electric car has been the biggest catalyst for the growth of Li-ion battery manufacturing. There are two main categories in the automotive sectors; pure electric vehicles and "plug in" hybrids. Commercial vehicle fleets are also following suit led by both major Government initiatives as well as the corporate sector. Most electric vehicles and hybrids on the road today are passenger cars, however there are also versions of commercial vehicles and vans, utility trucks, buses, trains, motorcycles, scooters, and military vehicles. In addition to the car manufacturers with vehicles on the road already, almost all major manufacturers are developing electric vehicles. Major scooter and motorcycle manufacturers have launched electric scooters. The increasing cost of petrol coupled with the lower cost of

producing Li-ion batteries will spur growth in mobility sectors [14].

cellular transmission towers which have traditionally used lead acid batteries for emergency power storage. Weight, size and short cycle life of the lead acid battery is prompting

Table 1. The most common and economic lithium-bearing minerals

Mineral	Formular	Member	Li(%)
Spodumene	$LiAlSi_2O_6$	Pyroxene	3.7
Lepidolite	$K_2(Li)_{3-4}Al_{8-5}Si_{6-8}O_{20}(F,OH)_4$	Mica	1.4-3.6
Mica Group	$X_2Y_{4-6}Z_8O_20(OH,F)_4$		
	X = K, Na, Ca, Ba, Rb, Cs		
	Y = Al, Mg, Fe, Mn, Cr, Ti, Li		
	Z = Al, Si		
Petalite	$LiAlSi_4O_{10}$	Feldspathoid	1.6-2.3
Amblygonite	(Li,Na)Al(PO4)(F,OH)	Amblygonite	3.4-4.7
Triphylite-lithiophilite	$Li(Fe,Mn)PO_4$	Olivine	4.4

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Specifications	**Li-cobalt**	**Li-manganese**	**Li-phosphate**	**NMC** [1]
Voltage	3.60V	3.70V	3.30V	3.60/3.70V
Charge limit	4.20V	4.20V	3.60V	4.20V
Cycle life [2]	500	500–1,000	1,000–2,000	1,000–2,00
Operating temperature	Average	Average	Good	Good
Specific energy	150–190Wh/kg	100–135Wh/kg	90–120Wh/kg	140Wh/kg
Specific power	1C	10C, 40C pulse	35C continuous	10C
Safety	Average. Requires protection circuit and cell balancing of multi cell pack. Requirements for small formats with 1 or 2 cells can be relaxed		Very good, needs cell balancing and voltage protection	Good, needs cell balancing and voltage protection
Thermal runaway [3]	150°C (302°F)	250°C (482°F)	270°C (518°F)	210°C (410°F)
Cost	Raw material high	Material 30% less than cobalt	High	High
In use since	1994	2002	1999	2003
Researchers, manufacturers	Sony, Sanyo, FDK, Saft	NEC, Samsung, Hitachi	UT, QH, MIT A123, Valence	Sony, Sanyo, Nissan Motor
Notes	Very high specific energy, limited power; for cell phones, laptops	High power, average to high specific energy, power tools, medical, EVs	High power, average specific energy, higher self-discharge than other Li-ion	Very high specific energy, high power; tools, medical, EVs

Materials Handling – Forklift and lift truck manufacturers have introduced Li-ion battery powered lift trucks for use in warehouses.

Marine – Lead acid batteries have long been used in boats, yachts and ships. Li-ion batteries are making inroads here also.

Telecommunications – The rapid growth of mobile phone users worldwide has led to a massive surge in construction of telecommunication providers to switch to Li-ion batteries. This sector is still emerging and demand is expected to grow [14].

Market For Lithium Ion Batteries

Export of lithium ore is good business but refining to obtain pure lithium carbonate ready to be used is better although it requires enormous investment so also is the return on investment. World consumption of refined lithium was

212,719 metric tons in 2016. The leading refined Lithium carbonate consuming countries were China, the United States, and Germany. Demand for lithium worldwide is expected to grow largely because of increased consumption in China, which is being driven by growth in the phone batteries.

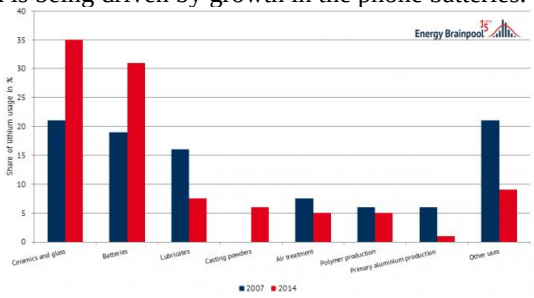

Figure 6: Share of Lithium consumption of different technological fields, Source: Energy Brainpool

Lithium has become a major component of the battery manufacturing industry. Lithium ion batteries are rechargeable, capable of a longer lifecycle, higher storage capacity and better efficiency than conventional batteries. The demand for these batteries is driven by the increasing adoption of portable electronic devices and the growing adoption of plug-in hybrid electric vehicles (PHEVs). The global Lithium ion Battery market size is projected to reach $53 billion by 2024, according to a new research report by Global Market Insights Inc. With over $23 billion in 2015, the market is set to grow at a 9% during the forecasted period of 2016 to 2024 [15].

Local Raw Materials For Lithium-Ion Batteries Available In Nigeria

The materials involved in lithium-ion batteries consist of carbon which is porous in nature, usually graphite, as the anode, and metal oxide for the cathode. In Nigeria, abundant deposits of graphite exist in Kaduna State, Northwest of Nigeria[16]. According to the portal of the Ministry of Mines and Steel development, two companies, Al-Masa'u Nigeria Ltd and Kaynuwa Earth Resources Ltd have exploratory licences for Kaduna and Adamawa State. In addition, Arif Synergy International Ltd has a Small Scale Mining Lease for Adamawa State [17]. Lithium ore have already been identified in some States particularly Nasarawa [9]. The need to beneficiate these minerals for suitability as LIB cathode and anode materials are obvious. The government needs the right policies and tax incentives to attract investment in this area. This would be a path towards import substitution and conservation of foreign exchange.

Figure 7: (Left). Cylindrical Panasonic 18650 lithium-ion battery cell before closing. (Right), An 18650 size lithium ion battery, with an alkaline AA for scale. 18650 are used for example in notebooks or Tesla Model S.

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The Projects Development Institute (PRODA) Enugu is a Science and Engineering based Research Institute under the supervision of the Federal Ministry of Science and Technology [FMST]. In addition to other mandates of the Institute, the Federal Ministry of Science and Technology directed her to commence research and development on batteries with particular focus on lithium-ion batteries. This research among other things is motivated by the availability of the raw materials for the cathode and anode materials, lithium ore and graphite in Nigeria. The Institute has started the initial research towards developing capacity to produce lithium-ion batteries for small electronic devices and

ultimately producing batteries for plug-in hybrid electric vehicles (PHEV).

In the first development phase, trainings are ongoing and procurement of some basic laboratory equipment for the production of pouch cell Lithium-ion battery typehas been made. Trainings are being scheduled for the research team members to produce pouch cell lithium-ion batteries for rechargeable lamps and cylindrical cells using the procured equipment. This is to make up for the energy deficit in the country and provide cheaper alternative for the general populace.

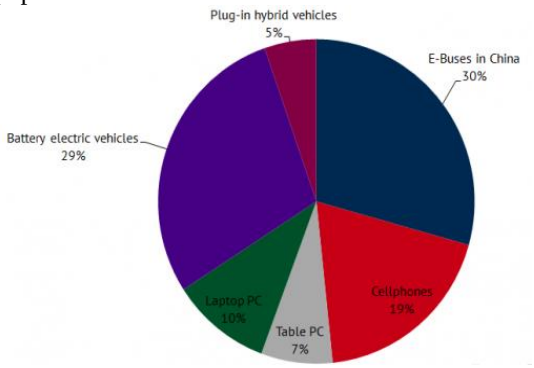

Figure 8: Share of different technologies in lithium-battery, Source: Energy Brainpool

Impact Of The Project To The Nation

This ambitious research and development project have beneficial impact to the Nigerian nation which includes:

- To contribute to the current technology on energy storage devices by the design and development of lithium-ion battery of different capacities. This will further the promotion of science, technology and innovative designs in the country.
- To reduce the over dependence on the importation of batteries for local use by the establishment of a pilot plant production of lithium batteries in PRODA Enugu in the long run. This would trigger for small and medium scale enterprise that will drive the economy.
- To reduce the cost of production of batteries by utilizing thin and flexible battery technology. This would kick start the beneficiation of some of the raw materials content which are available in the country and thus spring up many S.M.Es for creating wealth for our citizenry.

Conclusion

With the abundance of the local raw materials for the manufacturing of lithium – ion battery in Nigeriaespecially the cathode and anode materials, there is an ardent need for the government to continue to fund this research. Moreover, now that the research is making steady progress, it is expected that with steady and adequate funding from the government, Nigeria would not only start the local production of lithium-ion batteries soon, but would also spring up Small and Medium Enterprise that will drive the economy by the beneficiation and refining of the raw materials content for use by the manufacturing plants in the country and for export thus creating wealth for our citizenry.

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