LET THERE BE LIGHT:

HARNESSING NEXT-GENERATION BATTERIES FOR AFRICA'S ENERGY NEEDS

AUDA-NEPAD
AFRICAN UNION DEVELOPMENT AGENCY

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The African Union (AU) is a continental body consisting of all 55 countries on the African continent. It was established on 26th May 2001 in Addis Ababa, Ethiopia, and launched on 9th July 2002 in South Africa[1] with the aim of replacing the Organisation of African Unity (OAU). The most important decisions of the AU are made by the Assembly of the African Union, a semi-annual meeting of the Heads of State and Government of its member states. The AU's secretariat, the African Union Commission, is based in Addis Ababa, Ethiopia.

The AU was established following the 9th of September 1999 Sirte Declaration of the Heads of State and Governments of the Organisation of the African Unity (OAU). The AU is based on a common vision of a united and strong Africa and on the need to build a partnership between governments and all segments of civil society, in particular, women, youth and the private sector, in order to strengthen solidarity and cohesion amongst the peoples of Africa. As a continental organization, it focuses on the promotion of peace, security, and stability. The development work of the AU is guided by the AU Agenda 2063, which is a 50-year plan to harness Africa's comparative advantage to deliver on the vision of "The Africa We Want".

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[1] About the African Union https://au.int/en/overview

AU High-Level Panel on Emerging Technologies Report –Let there be Light:

Harnessing Next-Generation Batteries for Africa's Energy Needs

This Technology Report is the product of the African Union High Level Panel on Emerging Technologies (APET). It is part of a larger effort by the African Union Development Agency (AUDA-NEPAD) to promote knowledge and learning, share ideas, provide open access to its research, and contribute to development policy. The articles featured in the APET Technology Report is considered to have a bearing on the mission of AUDA-NEPAD, and its strategic objectives, as aligned to the AU Agenda 2063, which is a Pan African vision of an integrated, prosperous, and peaceful Africa, driven by its own citizens, representing a dynamic force in the international arena.

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Tributes

Prof Calestous Juma

"For a whole generation, and maybe for future generations of leaders, he was an exceptional teacher and thinker as well as one of the shining lights of Africa in the intellectual sphere." **– Dr Ibrahim Mayaki, AUDA-NEPAD**

"Those who had the pleasure of meeting him—or communicating with him online and off—will testify to his warmth, his love of learning, and his great generosity." **- H. E. Uhuru Kenyatta, President of the Republic of Kenya**

"Calestous was a tireless champion for economic and social development in Africa. His legacy will live on through the fruits of his many years of work as an impassioned scholar, fearless advocate and mentor to students and policymakers around the world."

"We have lost a brilliant mind who was dedicated to innovation, education and Africa's prosperity."
- H.E. Paul Kagame, President of the Republic of Rwanda

"Gifted with immense wit, charm, courage, humour and modesty—a rare combination, Professor Juma was a trusted advisor to Heads of State and Government throughout the world on critical issues affecting humankind today."
- The Common Market for Eastern and Southern Africa (COMESA)

Prof Diran Makinde

Many people in Africa and around the world will long remember Prof. Oladiran Martin Makinde as a champion for harnessing Science, Technology and Innovation for better livelihoods of the peoples of Africa; a firm believer that Science, Technology and Innovation can co-evolve with Regulations. But those of us who lived and worked with him nearly every day and will long ache with his passing, know Prof. Diran (as we popularly called him) by many other titles he held: Husband. Father. Brother. Grandfather. Director, mentor, advisor and many more.

He was the sunny, joyful person who lit every moment with his infectious smile whether you meet him in the corridors, staff kitchen, boardroom for meetings, but everywhere and always. He had an incredible ability to accommodate and work with people irrespective of their different viewpoints. He cherished life and life cherished him and everyone who met him, everyone who knew him will remember his invincible smile and contagious laugh.

A true gentleman with a great sense of life who lived up to the positive energy he chose to bring to those he interacted and interfaced with every single day. His wisdom and guidance were instrumental in the establishment of ABNE and the success that it continues to achieve to date are the outcomes of the firm building blocks he and others helped to put together 10 years

We have not yet come to terms with the passing away of Prof. Diran. We cannot know for certain as to why he left us this soon. But we remain comforted by the assurance that we will meet again one day. We pray for comfort, fortitude, and peace to all his loved ones.

Prof Oyewusi Ibidapo-Oye

In December 2016, the late Professor Oyewusi Ibidapo-Obe was appointed a member of the African Union High level Panel on Emerging Technologies (APET) by the then Chairperson of the African Union Commission (AUC), H.E. Dr Nkosazana Dlamini Zuma. This began our journey with this eminent expert who we fondly called Prof Oye.

His wit, ambience and welcoming spirit is a feature he brought to APET that would not be soon forgotten.

Prof Oye's characteristic of sacrificing his time and energy for the continent was quite authentic – he did that with charm and joy and always had something to contribute to discussions. He was ever ready to offer to the panel suggestions of continental experts that can contribute knowledge to Africa's development.

We look back at his loving tribute to the late Professor Calestous Juma, and the joy with which he spoke of continuing his legacy – which he adequately fulfilled. Today, we remember someone whose legacy has influenced many far and wide; the youth especially were his heartbeat.

Prof Oye was passionate about sustaining Africa's indigenous knowledge and we at AUDA-NEPAD pledge to carry on with his ideas on effectively harnessing our indigenous knowledge in addressing continental challenges.

Prof Oye! Your life was a blessing, your memory a treasure, you are loved beyond words and missed beyond measure. The day we heard of your death; it was like a dream. Death is appointed unto us all, but we just couldn't accept that it was your time. In the few days to your death, you were actively with us, so it was so hard to take that you would be with us no more.

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Acronyms

ABIC	African Battery Innovation Council
ASESMA	African School on Electronic Structure Methods and Applications
AfCFTA	African Continental Free Trade Area
AICC	African Innovation Capital Company
APET	African High-Level Panel on Innovation and Emerging Technologies
ARENA	International Renewable Energy Agency
ATTC	African Technology Transfer Centre
AUC	African Union Commission
CAGR	Compound Average Growth Rate
CHPC	Centre for High-Performance Computing
CSIR	Council for Scientific and Industrial Research
ERG	Eurasian Resources Group
ESG	Environmental, Social and Governance
EV	Electrically Powered Vehicles
FDI	Foreign Direct Investment
GHG	Greenhouse Gases
GHI	Global Horizontal Irradiance
ICE	Internal Combustion Engine
IoT	Internet of Things
kWh	Kilowatt-hours
LCO	Lithium Cobalt Oxide
LiBs	Lithium-Ion Batteries
Li-ion	Lithium Ion
LiPFs	Lithium Hexafluorophosphate
Li-S	Lithium-Sulphur
LME	London Metals Exchange
LMO	Lithium Manganese Oxide
LTO	Lithium-Titanate
NaFeCl2	Sodium Iron Dichloride Lithium
NCA	Nickel Cobalt Aluminium Oxide
NECSA	South African Nuclear Energy Corporation
NiFE	Nickel Iron

NMC	Nickel Manganese Cobalt Oxide
OECD	Organisation for Economic Co-operation and Development
OEMs	Original Equipment Manufacturers
PV	Photovoltaics
PWh	Petawatt Hours
RD&I	Research Development and Innovation
RFW	Regulatory Frameworks
SHS	Solar Home Systems
SIBs	Sodium-Ion Batteries
SKA	Square Kilometer Array
SSA	Sub-Saharan Africa
STEM	Science, Technology, Engineering, and Mathematics
TCFD	Task Force on Climate-related Financial Disclosure
UAVs	Unmanned Aerial Vehicles
UN's SDGs	United Nations 2030 Sustainable Development Goals

Executive Summary

Electric power is an essential component of modern human life that affords them healthcare, transportation, education, and communication systems. Electric power also enables humanity to provide means to produce potable water, food, and goods. Africa remains challenged with the fastest growing population in the world. Therefore, accelerated access to power that is affordable, sustainable, and high quality is key to Africa's prosperity and socio-economic development. However, electricity supply remains inaccessible, unreliable, and irregularly distributed across the continent, more especially in the sub-Saharan Africa region.

In recent years, electricity derived from renewable resources such as solar and wind has become more affordable than electricity derived from fossil-based fuels. This timeous development is expected to play an essential role in the realisation of accelerated affordable electricity access to Africans. However, modern society requires an uninterrupted, on-demand and consistent electricity supply of exact voltage (220V) and frequency (typically 50Hz). The electricity generated using renewable resources such as wind and solar is typically not aligned with the demand for electricity by Africa's society. Africa needs cost-effective energy buffers that can be harnessed to mitigate the discrepancy between electricity demand and supply. Such buffers are known as energy storage systems. These energy storage systems can improve the supply of electricity through robust storage capacities across the continent.

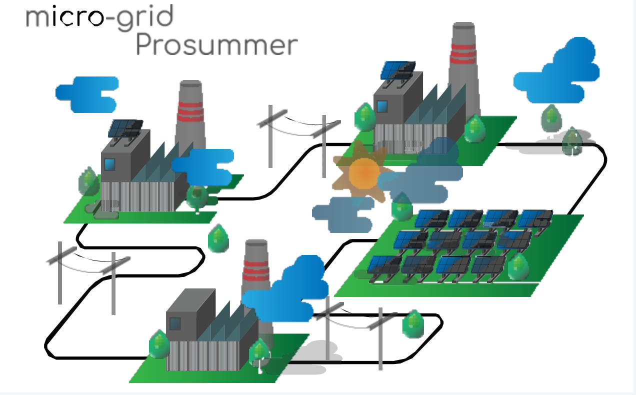
Notably, major advances have been realised in the development and production of Energy Storage Systems, particularly those systems containing Li-ion batteries. Consequently, major car manufacturers worldwide are starting to see the inevitable and gear up to replace the internal combustion drive train with inherently more efficient battery-powered electric motors. The battery industry is expected to develop into a staggering multitrillion-dollar market by 2040. With accurate planning, Africa has the potential to become a major beneficiary from this technology because of her endowment with the minerals suitable for next-generation batteries. This can significantly make Africa competitive with other global players in the battery industry.

This APET's next generation batteries report focuses on the strategic framework that African Union Member States can enact towards energy storage through next generation batteries. It further articulates the two key objectives that Member States can focus on to achieve these objectives and produce measurable impacts and specific implementation frameworks.

To accomplish this, African Union Member States are encouraged to build cross-cutting research and development for universities and research institutions that heavily collaborates with the public-private sector. It can rely on Africa's ability to generate new ideas and knowledge and translate them into valuable technologies and services. In this way, Member States can build knowledge-driven economies for the direct socio-economic benefit of Africans and all humanity. This can ensure that Member States guarantee the creation of a desired future for their citizens.

Most importantly, this APET report articulates a continental model for a programme that was both illustrative and demonstrated the preferred implementation scenario specifically adopted and adapted for the African context. The value proposition relies heavily on the key competitive advantages of the African continent. It is known that African countries are endowed with the minerals required for next generation battery technologies. Because of this advantage, African countries are encouraged to leverage these minerals and improve their beneficiation up to next generation battery required standards to realise more value and benefit. It was also shown that the greatest investments in the value chain should be dedicated to the processing and beneficiation value chain of minerals. This can also incorporate the manufacturing of cells for batteries and packaging of batteries, as this part of the value remains lucrative. It has been reported that simply selling unprocessed minerals does not bring value to Africans as a benefit from these materials.

Thus, properly beneficiating these materials will enable Africa to best benefit and improve her socio-economic development[1]. Overall, the suggested programme directly addresses two of the priority areas for SDG7 and Agenda 2063 Goal 2 and 7 implementations. These include scaling up capacity building and strengthening for the African citizenry and can be achieved through proper education and training programmes that aim at equipping Africans with the right skills to properly benefit from the next generation battery technology. This can also be achieved through renewed and cross-sectoral approaches across all stakeholders in Africa and international partners. Furthermore, African Union Member States ought to develop human and institutional capacities that focus primarily on skills in support of universal energy access and energy sector transformation. Member States are encouraged to enhance innovation systems at national, regional, continental levels. This can include research, development, deployment and diffusion in the design and operation of the whole energy system.



Summarised below are the recommendations that APET has identified for African Union Member States to best benefit from the next generation battery technologies. This is to assist African countries to successfully combat poverty within their citizenry:

1. Africa's decision-makers and policymakers are encouraged to capitalise on the worlds desire to produce next generation batteries such as Li-ion batteries (LiBs). Efforts by African Union Member States can focus on local mineral beneficiation, and local battery assembly. Member States are encouraged to make investments towards local factories for refining and beneficiation of local natural resources. This suggestion will not only benefit Africans from the significant added value of materials but also stimulate job creation and local supply chain. In turn, this will significantly create countless opportunities for local socio-economic growth.

2. African Union Member States are encouraged to formulate regulatory frameworks that will help monitor and protect Africa's countries from foreign exploitation of mineral resources critical to produce NGB. Essentially, these resources can be exploited to the benefit of Africa first. Furthermore, these regulatory frameworks can also be responsible for awarding mining rights that ensure local material beneficiation and prohibit raw materials to be exported without substantial local refinement. These regulatory frameworks will also ensure that the local refinery is allocated to a local battery assembly plant.

3. Member States are encouraged to adopt a model where governments bid to host the different research and development, innovation, and manufacturing hubs across the continent based on their available material and expertise. In this way, there can be a continental drive towards establishing a business case for a full LiBs value chain in Africa. In addition, investments are encouraged by all stakeholders towards research and development, intellectual property patents, human resources development, facilities and equipment, and supply chain contracts in Africa. This can also include efforts towards the employment of Africa's workforce (scientists, engineers, and technologies with doctoral degrees) to improve research and development and enable technological advancement efficiencies.

[1] UN Policy Briefs in Support of the First SDG7 Review at the UN High-Level Political Forum

1

Introduction

1.1 Setting the context: Africa's energy challenges

As reported by the World Economic Forum, "Africa's population is projected to double to about 2 billion by 2050. More so, by the year 2100, Africa's population could easily have doubled again.[3] If that happens, at least four billion of the world's 11 billion people will be African.

This dramatic increase in population presents numerous challenges to local economies, food supply, energy demand, health service delivery, education systems, and infrastructure maintenance in African countries. To timeously and successfully address these challenges and effectively meet the United Nation's 2030 Sustainable Development Goals (SGDs) as well as the African Union's Agenda 2063, Africa must prioritise and implement some continental policies related to critical technologies.

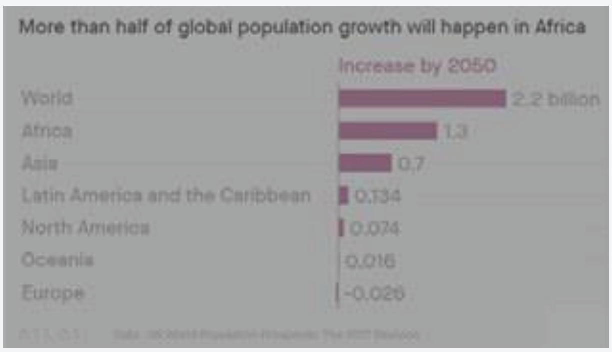


Figure 1: Projected global population growth by 2050

The Agenda 2063, which summarises Africa's development aspirations over a 50-year period, is pioneering for a 50% increase access towards electricity and 50% increase of electricity generation and distribution. The agenda also aspires for 70% of Africans having access to electricity by 2023 as well as 30% improvements in energy efficiency. Additionally, affordable clean energy is among the United Nation's Sustainable Development Goals (SDGs) that focuses on universal electrification. To this end, Africa is working towards achieving SDG 7 and Agenda 2063 Goal 7, within the context of Africa. This can be achieved by creating synergies between Power Africa, Sustainable Energy for All, and climate finance to achieve universal energy access before 2030.[4,5]

Achieving universal clean energy for Africa requires considerations on the impacts of climate change by incorporating greenhouse- gas-emissions mitigation strategies according to the Paris Agreement addressing climate change. The Climate Bonds Initiative, an international investor-focused not-for-profit organisation, is working towards mobilising a US$100 trillion bond market for climate change solutions.[6] This initiative's mission focuses on driving down the cost of capital for large-

[3] https://www.weforum.org/agenda/2019/06/9-7-billion-on-earth-by-2050-but-growth-rate-slowing-says-new-un-population-report/
[4] IRENA and IEA-ETSAP (Energy Technology Systems Analysis Program), 2015a. Solar Heating and Cooling for Residential Applications: Technology Brief, Abu Dhabi: IRENA.
[5] IRENA (2015), Africa 2030: Roadmap for a Renewable Energy Future. IRENA, Abu Dhabi. www.irena.org/remap
[6] https://www.climatebonds.net/2020/09/climate-bonds-initiative-and-fsd-africa-launch-africa-green-bonds-toolkit-practical-guide

scale climate, and infrastructure projects and to support governments seeking to improve the energy situation in their countries. Increased capital markets investment that has been put in place to meet climate goals Africa amounted to US$898 million in 2019. Furthermore, it was reported that Africa's market was dominated by the US$567 million project loan to Redstone Solar Plant. However, even when accounting for this, the composition investments altered considerably in 2019 with the remainder composed of issuance from corporate institutions and Nigeria's second green sovereign.

1.2 Patterns of Africa's access to electrification across the continent

According to the African Development Bank[7], "Over 640 million Africans have no access to energy, corresponding to an electricity access rate for African countries at just over 40 percent, the lowest in the world. Per capita consumption of energy in sub-Saharan Africa (excluding South Africa) is 180 kWh, compared to 13,000 kWh per capita in the United States and 6,500 kWh in Europe".

Africa's access to electricity varies from region to region across the continent. For instance, North Africa is almost entirely (up to 99%) electrified. Whereas within sub-Saharan Africa (SSA), excluding South Africa, electrification rates in most countries remain below 30%, South Africa is predominantly electrified by up to 86%. Notably, the lack of access to electricity in SSA is predominant in rural areas, accounting for 63% of SSA's population.[8] The majority of the rural population is off-grid and sparsely distributed.[9] Fortunately, since 2014 the number of people without access to power in SSA has declined. This is because the electrification efforts with SSA have surpassed population growth. However, there is still more work ahead for African countries to address the electrification challenges and disparities observed across the continent. To this end, APET is suggesting an increasing role of decentralised renewable energy solutions that have been gaining momentum across the continent recently.

The lack of access to electricity is not the only component of SSA's electrification challenge. Even among the people who do have access to electricity, there are still wide disparities in annual per capita consumption between the three regions. For instance, there is an average of 225 kilowatt-hours (kWh) power available in SSA, and with rural areas having access to as little as 100 kWh. Comparatively, there is an average of 1,500 kWh in North Africa, and 4,200 kWh in South Africa. Furthermore, even the places where the grid connection already exists, homes and industries often must make do with an erratic power supply.

[7] Light Up and Power Africa – A New Deal on Energy for Africa https://www.afdb.org/en/the-high-5/light-up-and-power-africa-%E2%80%93-a-new-deal-on-energy-for-africa

[8] https://www.worldbank.org/en/region/afr/overview

[9] Tracking the SDG7: The Energy Progress Report: https://trackingsdg7.esmap.org/data/files/download-documents/2019-Tracking%20SDG7-Full%20Report.pdf

These erratic power supplies are characterised by long outages, averaging to 7 outages per month due to severe under-capacities within SSA countries.[10] This scenario has a profound negative impact on industrial productivity and overall quality of life for SSA rural citizens. Therefore, making power available to all Africans by 2030, in line with the UN's SDGs, is a major challenge for Africa. [11,12]

1.3 Existing proposed solutions in addressing Africa's energy challenges

In its report, the African Union High-Level Panel on Emerging Technologies (APET) has recommended that African Union Member States harness microgrid technology for their socio-economic transformation of the continent.[13] APET further suggested that policymakers and decision-makers in governments and the private sector adapt and contextualise microgrids implementation for Africa's realities. This should take into account factors such as site selection, the expected number of connections per site, and both the demand and willingness to pay. Furthermore, it remains crucial to consider additional factors such as the expected return per connection and the development of skills and capacities that addresses the under-served communities. Most particularly, this capacity strengthening should address the role of the "informal sector" in supporting microgrid implementation. The above- mentioned elements could mitigate against cases reported in some countries where microgrid installations have suffered from improper operation and maintenance. This will, therefore, help communities that can barely realise the intended benefits of microgrids.

Additionally, African countries could address the electrification challenge through solar power, to immediately address the additional generation capacity that is required to achieve the universal electrification of the continent. Fortunately, Africa has the highest solar resource based on global horizontal irradiance (GHI). The International Renewable Energy Agency (ARENA) determined a continental photovoltaic (PV) power generation potential of up to 660 Petawatt hours, where1 Petawatt hour (PWh) equals 1,000,000 GWh per year.[14] The same study reported a power generation potential of 460 PWh from wind energy. This study excluded "remote areas" that were not close to the existing national grids. Thus, these figures are only directly relevant to underserved demand that is already connected to the existing grid supply. However, these figures demonstrated the vast electrification potential for Africa through harnessing solar resources. The photovoltaic (PV) generation potential is significantly higher if the "remote areas" are included through the distributed generation model. This is imperative to accomplish universal electrification for Africa.

The World Bank 5-tier metric can be used to measure the level of access to energy based on eight factors. These factors are capacity, availability, reliability, quality, affordability, legality, convenience, and health and safety. This is a useful framework that Africa can use to understand electrification within the continent.[15] There is a call that Africa adopts the Tier 3-level electrification when harnessing solar energy that includes general lighting, air circulation, radio, television, and low-energy appliances such as for general food processing and washing. These are generally considered the threshold for enabling economic transformation and corresponds to an electricity per capita consumption of 160 kWh per year.[16,17]

[10] Cole, M, Elliott, R, Occhiali, G & Strobl, E 2018, 'Power outages and firm performance in Sub-Saharan Africa', Journal of Development Economics, vol. 134, pp. 150-159. https://doi.org/10.1016/j.jdeveco.2018.05.003

[11] https://www.iea.org/reports/sdg7-data-and-projections/access-to-electricity

[12] https://www.iea.org/reports/africa-energy-outlook-2019

[13] https://www.nepad.org/blog/let-there-be-light-harnessing-microgrid-energy-africa#_ftn4

[14] Sebastian, Hermann, Asami Miketa, Nicolas Fichaux (2014), Estimating the Renewable Energy Potential in Africa, IRENA-KTH working paper, International Renewable Energy Agency, Abu Dhabi.

[15] World Bank, https://www.seforall.org/sites/default/files/GTF-2105-Full-Report.pdf

[16] Re-thinking Access to Energy Business Models Ways to Walk the Water-Energy-Food Nexus Talk in Sub-Saharan Africa, RES4Africa Foundation, Rome, Italy (2019): https://[16] sun-connect-news.org/fileadmin/DATEIEN/Dateien/New/RES4Africa-RE-thinking-Access-to-Energy-Business-Models.pdf

[17] https://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC?locations=ZF

1.4 Opportunities for the power generation industry of renewable energy

In Africa, the power generation industry is dominated by costly small-scale power systems that are running on fossil fuels. Furthermore, the African Development Bank claims that fossil fuels are currently the most expensive means of generating electricity. Fossil fuels' cost ranges between US$0.20 and US$0.30 per kWh. This is much higher than the cost of conventional generation. In contrast, the Levelised Cost of Electricity (LCOE) from renewable sources as reported by Bloomberg (see Figure 3) recently showed that both electricity from photovoltaic and wind are significantly lower than the cost of electricity derived from fossil fuel.

Renewable energy will assist economies to transition the highest greenhouse gas (GHG) towards low carbon economies and to strategically reduce GHG is to switch from fossil fuels to renewable energy. Currently, Africa's renewable energy is only contributing a very small share of the total energy generation and usage. The combined renewable energy constitutes about 13% of the primary energy supply across the world. Thus, renewable energy will urgently reduce carbon emissions. Furthermore, renewable energy will bring electricity in African areas that are not currently connected to the central grid. It can also improve the unreliable grid and act as back-up systems wherever required.

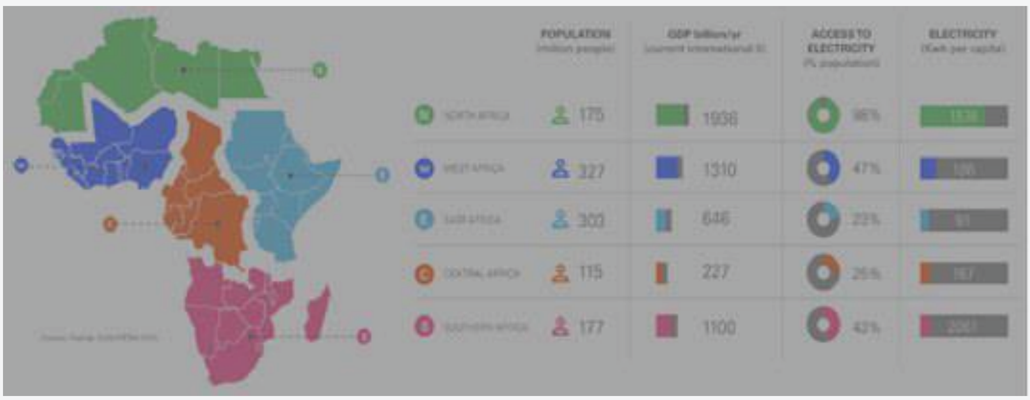


Figure 2: Africa's regional comparison of population, GDP per year, access to electricity and electricity per capita

Additionally, renewable energy can also enable economic development for developing African countries. Figure 4 shows that numerous African countries are geographically well-placed. Thus, providing them with the opportunity to exploit the energy potential, as most of these sub-Saharan African countries are in low latitudes with high sunlight. Thus, renewable energy helps address the increasing concerns about future energy prices and energy security. This is against a background of a rapid global increase in demand for energy and driven primarily by rising living standards in developing and emerging countries. Furthermore, renewable energy offers economic opportunities because renewable energy technologies are already competitive at market prices. Thus, decentralised electricity generation can potentially mobilise small-scale private investment for African economies. Consequently, investments in renewable energy are also offering considerable scope for generating employment opportunities, a key public policy concern in numerous African countries. This is because there is substantial employment potential associated with project development, construction, and installation for all renewable energy technologies.

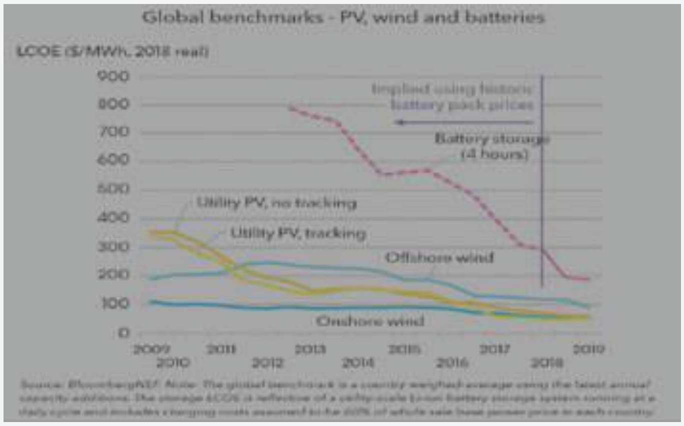


Figure 3: The global benchmarks of photovoltaic and wind batteries LCOE

Based on the solar radiation data, the potential to extract solar electricity in Africa is among the best in the world and presents a major opportunity as prices continue to fall. The total theoretical potentials on the African continent are estimated at around 470 Petawatt hours (PWh), 660 PWh, and 460 PWh for concentrating solar power (CSP), PV, and wind, respectively.[18] According to Figure 3, the utility PV, offshore wind and onshore wind energy generation prices have been significantly decreasing since 2009. Thus, this is projected to fall even further soon, most particularly when the battery storage capacity increases.

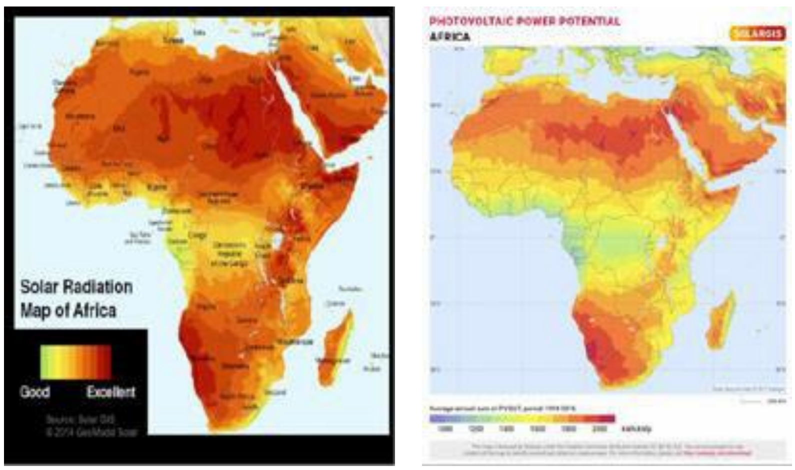


Figure 4: The photovoltaic power potential in Africa

To meet the looming electricity demands, more of Africa's energy will have to be derived from renewable energy sources such as solar, wind, and hydropower. Thus, Africa's large rural population presents opportunities for decentralised micro-grid installations supplied by renewable energy. This is supported by one of the key messages of the SDG7 achievement policy document which reads: "To deliver universal energy access by 2030, decentralised options are the least-cost option for 60% of people currently lacking access". Thus, Africa can achieve enhanced power supply for its citizens.

[18] S. Hermann, A. Miketa, N. Fichaux (2014), Estimating the Renewable Energy Potential in Africa, IRENA-KTH working paper, International Renewable Energy Agency,

1.4.1 Why solar energy is currently failing in addressing Africa's energy needs

With an unelectrified population of 650 million across the continent, the required distributed generation capacity is 104 TWh/ year, entailing of a battery storage capacity of roughly 700 GWh.[19] However, it must be noted that this is a small fraction of the solar PV resource potential of Africa. Therefore, this immediately begs the question of why many people in Africa are there still without electricity. The main reason for such disparity is the cost needed to store the electricity generated from solar sources. In particular, the main reason for such a cost and uneven distribution are solar energy storage technologies. Notably, the cost of solar panels has decreased considerably to a point where they are now within reach for numerous African inhabitants. Therefore, the main impediment to large-scale adoption of solar photovoltaics is the cost of energy storage. While there are other energy storage solutions such as flywheels, compressed air, thermal, pumped hydro, and supercapacitors, batteries remain the most flexible technology.

Traditionally, lead-acid batteries have been employed with solar photovoltaics and they remain popularly used as energy storage units for numerous Africans because of their low cost. Evidently, energy storage technology is the single most important factor and deciding the success or failure of SDG7 in Africa. Therefore, this has major continental implications on government policies that govern and regulate solar energy generation and storage frameworks. Thus, the question that African governments need to answer is how they can generate electricity of 104 TWh/year that is needed to power Africa through solar and wind energy translate into actual storage capacity. This scaling-up of storage facilities will contribute tremendously to the immediate industrialisation programmes needed to increase the capacity of up to a factor of between 20% and 25% in Africa as shown in Figure 1.[20] However, as it is, the photovoltaic generation remains an under-utilised potential.[21] Incredibly, evidence has shown that this apparent paradox between the solar resource potential and its actualisation arises primarily from government policy. This is observed even though there are apparent grand opportunities with their adoption for electrification purposes in Africa.

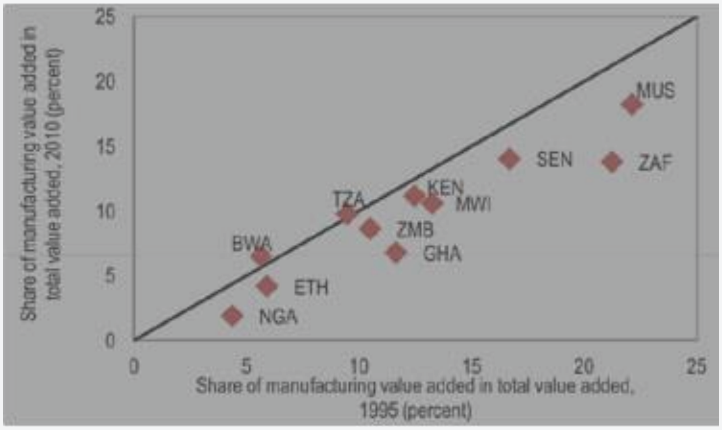


Figure 5: De-industrialisation in sub-Saharan Africa[22]

[19] Renewables (2013), Global Status Report: https://www.ren21.net/wp-content/uploads/2019/05/GSR2013_Full-Report_English.pdf
[20] P. Trotter, Energy planning in Africa: Challenges and opportunities for insourcing capabilities, Smith School of Enterprise and the Environment University of Oxford, United Kingdom, Long-term Energy Scenario (LTES) Forum, Berlin, April 12th, 2019: https://www.irena.org/-/media/Files/IRENA/Agency/Events/2019/Apr/LTES-2019/Philipp-Trotter-
--University-of-Oxford.pdf?la=en&hash=E5D20154DE9C03D63DEA775270B3CC1638720FEF.
[21] Jäger-Waldau, A., PV Status Report 2019, EUR 29938 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-12608-9, doi:10.2760/326629, JRC118058.
[22] International Monetary Fund: World Economic and Financial Surveys, Regional Economic Outlook, Sub-Saharan Africa (2015)

Other nations around the world are already aware and capitalising on the benefits of PV generation. Consequently, large-scale alliances and collaborations are being formulated for strategic positioning and competing for control of this technology. As the whole world is moving towards strategically positioning themselves to take advantage of these opportunities, Africa must follow suit. However, the question that African countries must answer is how they are going to position themselves at national, regional, and continental levels. Africa must also capitalise on the strategic advantages she has over other countries of the world, such as her talent of youth and endowment with natural resources needed for this kind of technology development, manufacturing, and implementation. Africa cannot afford to wait and see what transpires of this technology without active and deliberate participation.

APET believes that Africa is at a critical technological turning point. This presents a rare chance for Africa that should not be let slip by and join the ever-growing list of missed opportunities for Africa. Currently, there is a global revolution in electrochemical energy storage that is going to leave the traditional models of human mobility and energy access turned on their heads. The critical consideration is where this technological turning point will leave African countries. The solution is that, while it remains difficult to predict for certain at this stage, it remains apparent that Africans cannot afford the "wait and see" attitude. Instead, Africa must act with urgency by seizing any opportunities presented at her disposal. In addition, Africa must deliberately create other opportunities so her citizens can take control of their technological destiny in this rapidly churning global revolution.

1.5 Batteries at the centre of the challenge, opportunity and solution

While the costs of electricity derived from renewable resources have fallen below the cost of electricity from fossil-based resources, renewable resources do not necessarily supply the correct quality of electrical power. A successful modern industry requires an uninterrupted, on-demand, consistent electricity supply of exact voltage (220V) and frequency (typically 50Hz). Therefore, the electricity generated using renewable resources such as wind and solar is typically not aligned with the demand generated by society. Thus, Africa needs cost-effective energy buffers that can be applied to mitigate the discrepancy between electricity demand and supply. Such buffers are known as Energy Storage Systems.

Recently, major advances have been realised towards the development and production of Energy Storage Systems, most particularly systems containing Li-ion batteries. In addition, major car manufacturers worldwide are starting to see the inevitable and gear up to replace the internal combustion drive train with inherently more efficient battery-powered electric motors. Furthermore, in 2018, the World Bank Group committed an initial US$1 billion towards a programme to accelerate investments in battery storage systems in emerging countries.[23] These kinds of investments are intended to increase the effectiveness of wind and solar power, improve existing grid reliability and quality, and reduce carbon emissions.

1.6 Conclusion

There is a need for African governments to stimulate and ensure socio-economic advances in the production of Energy Storage Systems, by investing in next generation batteries such as Li-ion batteries. Notably, major car manufacturers worldwide are inevitably replacing the internal combustion drive train with inherently more efficient battery-powered electric motors. Therefore, there is a need for Member States investment towards a programme that will accelerate battery storage systems in their countries. These kinds of investments can effectively increase the capacity for wind and solar power. Thus, improve the existing grid reliability and quality, and reduce carbon emissions. This can be executed so to address the looming electricity demands through renewable energy sources such as solar, wind, and hydropower. Consequently, this is support Africa's decentralised micro-grid installations supplied by the renewable energy and accomplish SDG7 policy frameworks that are aimed at delivering universal energy access by 2030 to the 60% of African people currently lacking access. Thus, Africa can achieve enhanced power supply for its citizens.

[23] https://www.worldbank.org/en/news/feature/2018/09/26/powering-new-markets-for-battery-storage

2

Critical Analysis of Next-Generation Batteries

2.1 Introduction to Batteries

Electrical power plays a fundamental role in our daily modern life. Today, many of the 3rd Industrial Revolution devices for computing and communications such as portable computers, tablets and mobile phones rely heavily on power from energy storage devices such as batteries. Although we cannot store electricity, we can store electrical energy in the chemicals found inside a battery and later convert that energy into electricity when needed.

A battery is formed when two or more cells are connected. An individual energy cell is a complicated system of chemistries and components, packaged in an effective way to facilitate practical energy storage applications. All cells comprise three essential components known as the anode and cathode terminals (typically metals), and an electrolyte medium (Figure 6). The electrolyte medium separates these terminals while allowing the flow of electrical charge between them. When discharging electricity through the connected external circuit, ions from the anode transport current through the electrolyte in the cell, while the electrons flow in the external circuit. This process is what generates an electric current to power the devices that the batteries are connected to.

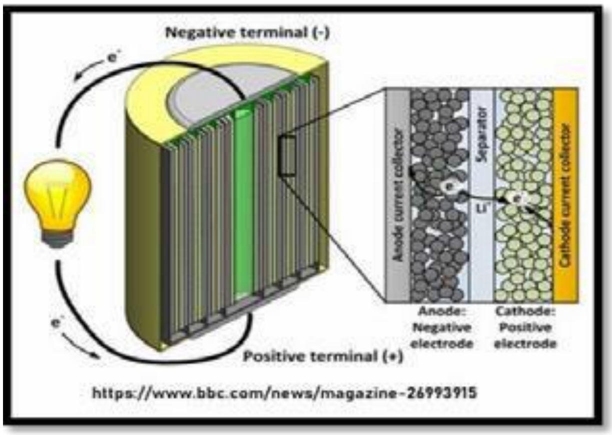


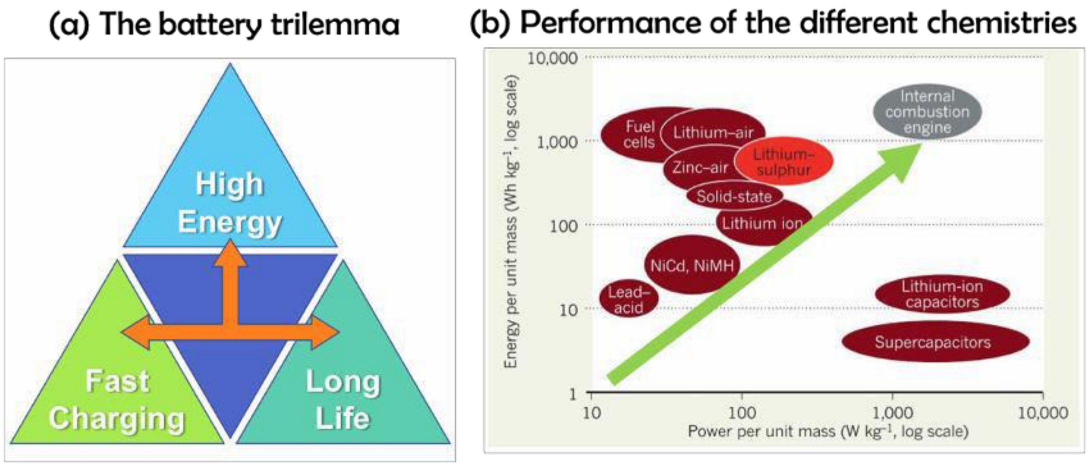
Figure 6: Li-ion battery showing anode (negative terminal) and cathode (positive terminal) electrodes, separator, and electrolytes

Leaps of significant technological advances in energy storage have been made since the Italian physicist Alessandro Volta created the first modern-day battery in 1800, with numerous chemistries and methodologies employed since then. The rechargeable lithium-ion battery is today the most widely applied battery since its first commercial release for portable electronics by Sony and Asahi Kasei Corporation in 1991. Lithium is the lightest of all known metals and it has the greatest electrochemical potential, thus offering one of the best energies to weight ratios.[24] Thus, it is no surprise then that lithium-ion batteries have become the most highly invested battery technology for most modern rechargeable applications. This includes the latest global drive towards the electrification of vehicles for a cleaner environment. Advances in battery technology have primarily been made in the chemistries, physicochemical, and mechanical characteristics of cathodes and anodes. However, there has been a much stronger focus on the electrolyte recently. Consequently, these advances are yielding higher energy and power densities, reduced physical weight and size, a longer cycle life, improved safety, and significant cost reduction.

[24] P. Peljo, H.H. Girault, Electrochemical potential window of battery electrolytes: the HOMO–LUMO misconception, Energy and Environmental Science 11 (2018)

2.2 Characteristics of Current and Next-Generation Batteries

In addition to being affordable and safe, the ideal battery should be able to store the largest amount of energy for the smallest mass and volume (energy density). The battery should also be able to deliver and/or accept the highest amount of energy in the shortest possible time (power density). An ideal battery should be able to withstand the largest number of charge and/or discharge cycles (long cycle life). These three requirements are a challenge to mutually optimise in the same battery, leading to what has been called the "battery trilemma," as shown in Figure 7 (a). The performance of the selected battery technologies is compared to the internal combustion engine as shown in Figure 7 (b). In Figure 7 (b), the green arrow showed the preferred path in the development of battery technologies as it offers an "ideal" balance between energy and power densities. Thus, all battery technologies lie above the green arrow, indicating comparatively low power densities. In contrast, the supercapacitors exhibit very high-power densities, but poor energy densities. However, all the battery chemistries above "lithium ion" in Figure 7 (b) are yet to be commercially demonstrated. But even to commercialised, deviate significantly from the green arrow. Therefore, this showed that major advances are required to bring battery technologies closer to the performance of the internal combustion engine.



Source: IDTechEx Research – Redox Flow Batteries For Stationary Storage

Source: IDTechEx Research – Advanced Li-ion & Beyond Li-ion Batteries 2018-2028

Figure 7: (a) Performance considerations in battery technology lead to a "battery trilemma", and; (b) The dream of a battery technology that can compete with the internal combustion engine in both energy and power densities.

2.2.1 Summary of the current battery technologies

The different lithium-ion battery technologies are classified into "chemistries," loosely based on the chemical composition of the cathode. The five main chemical compositions of the current technologies include lithium cobalt oxide (LCO), lithium nickel cobalt aluminium oxide (NCA), lithium nickel manganese cobalt oxide (NMC), lithium manganese oxide (LMO), and lithium-iron- phosphate (LFP). All these chemical compositions employ a graphite (carbon) anode. But the sixth chemistry was also defined as a lithium-titanate (LTO). In this case, the graphite in the anode of LMO or NCA is replaced with lithium titanate. Of these six, LCO is the most mature chemical composition and chemistry of choice for consumer electronics. However, this is not the focus of this report. The characteristics of the remaining five main battery chemical compositions can be qualitatively compared on multi-criteria charts as shown in Figure 8. In addition, these charts reveal significant variation among the different chemistries on the six criteria under consideration. Evidently, NMC exhibits the most balanced profile of these charts. Therefore, this feature along with a comparatively clear path towards further advances makes this battery chemical composition an attractive choice for large-scale production.

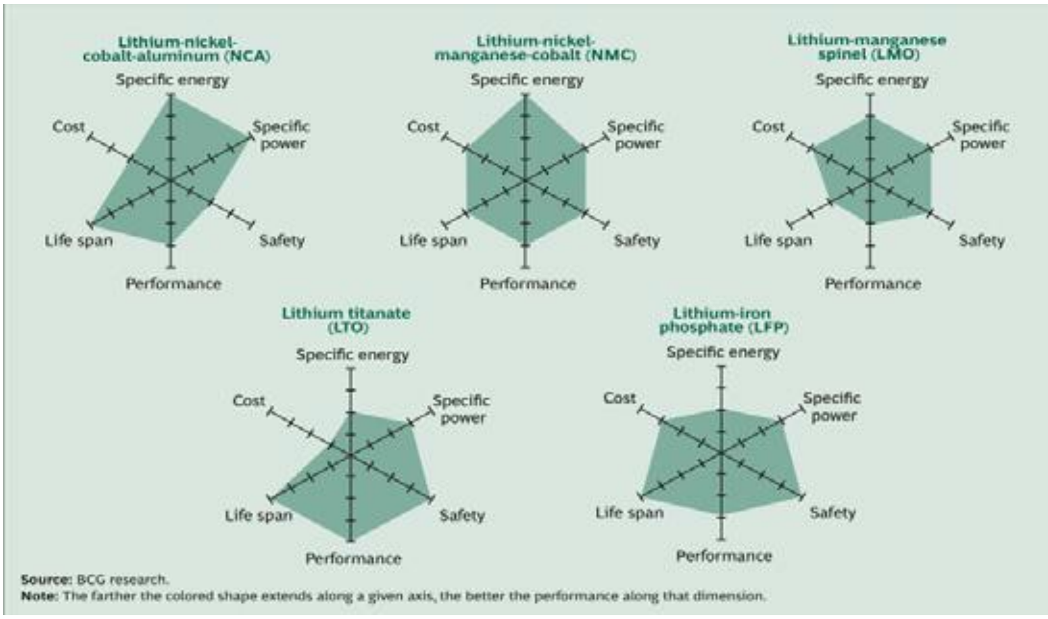


Figure 8: A qualitative comparison of the five main battery chemistries on six criteria. The "Performance" axis refers to how the battery performs under both hot and cold weather conditions. NMC offers a more balanced profile on all six criteria, which partly explains why this chemistry currently commands the most interest in research, development, and large-scale production.

Lithium-ion battery technologies are also classified into "generations," even though this is an unambiguous delineation under this classification. Table 1 showed the classification that was partially adopted in this report. Notably, the "generations" have been defined based on the specific battery chemical composition. For specific chemistry, the generations reveal more clearly a strategy for performance advancement. For example, for NMC in Figure 8, showed a two-prong strategy of increasing energy density by increasing nickel content and reducing costs by reducing cobalt content. On the other hand, the industry-wide generations of Table 1 only exhibit broader strategies. For instance, Table 1 showed that until Generation 3, advances were mainly in the cathode. But since then, advances were taking place in both electrodes and the electrolytes. According to Table 1, the next-generation (highlighted) batteries will be from two chemical compositions. The first chemical composition consists of high-energy NMC (HE-NMC) that contains a high lithium content NMC. The second chemical composition is the high-voltage spinel (HVS). The HVS is an improved LMO characterised by a partial replacement of the manganese with nickel. Both chemistries were complemented with anodes of increasing silicon content for higher capacities.

Table 1: Generations of Lithium Battery Technologies.[26]

Generation	Chemistry
5	Lithium/Oxygen (Lithium-air)
4	All-solid-state with Lithium metal anode Conversion materials (Lithium-sulphur)
3b*	Cathode: HE-NMC, HVS Anode: Silicon/carbon
3a	Cathode: NMC 622 to NMC811 Anode: Carbon + Silicon (5-10%)
2b	Cathode: NMC523 to NMC622 Anode: 100% carbon
2a	Cathode: NMC111 Anode: 100% carbon
1	Cathode: LFP, NCA Anode: 100% carbon

*Generation 3b has been identified as the "next-generation"

The different generations of battery technology lead to different addressable applications and these have been classified into three overlapping phases, according to Figure 9 (b). the next-generation batteries are targeting Phase II of applications, most particularly the electric vehicles and energy storage systems (ESS) such as for mini-grids. Thus, the pivotal role of the next-generation batteries to ESS is the centerpiece of this report. As advanced NMC chemistry, followed by HVS, is envisaged to initially dominate Phase II applications. These will be primarily driven by automotive applications as shown in Figure 9 (a). Therefore, the proposed immediate strategy for industrialisation is focused on this Phase II application corresponding chemistry. Nonetheless, this view is by no means universally accepted. For instance, NCA has been suggested as the most suitable for solar home systems (SHS) because of their high energy density beating LFP on price.[27] However, there is a perception that the overall cost profile of NCA relative to NMC (Figure 9) makes it unfavourable for large-scale ESS in the African context.

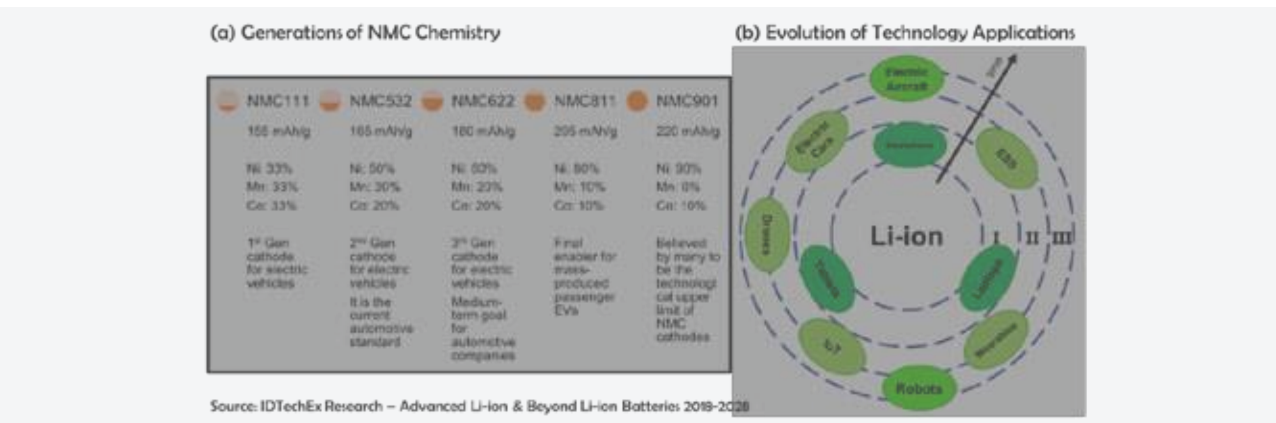


Figure 9: (a) Advances in NMC chemistry according to generations, and; (b) Applications for lithium-ion batteries divided into three phases with more advanced chemistries demanded, for applications in the outer regions.

[26] T. Placke, Progress and Challenges: Generation 3b, European Battery Cell R & I Workshop, Brussels (2018)
[27] S. Deuten, J.J.G. Vilchez, C. Thiel, Analysis and testing of electric car incentive scenarios in the Netherlands and Norway, Technological Forecasting & Social Change 151 (2020) 119847

2.3 Possible Technology Roadmap

To conclude this chapter, attempts of a technology forecast was made. Thus, the current situation where numerous of the battery chemical compositions are under investigation, it makes it incredibly difficult to confidently predict the battery chemical compositions that will potentially dominate the market in the future. Accordingly, the following discussion about the possible future evolution of battery technology ought to be understood in the context of this caveat. Furthermore, the primary drivers for transition to new battery technologies are different for various applications. For instance, power and energy densities are primary considerations in electromobility. However, the cost of production and affordability may override these other characteristics in large-scale stationary storage applications. This report is mainly focused on the latter applications. Thus, this latter technology cost and affordability for Africa will be elaborated upon throughout this report. Table 2 is a projected technology trajectory to a period just beyond 2030 by the International Energy Agency (IEA). Unsurprisingly, there are some slight differences between Tables 1 and 2 that are reflecting the inherent uncertainties in these projections. Nonetheless, the broad perspective is the same.

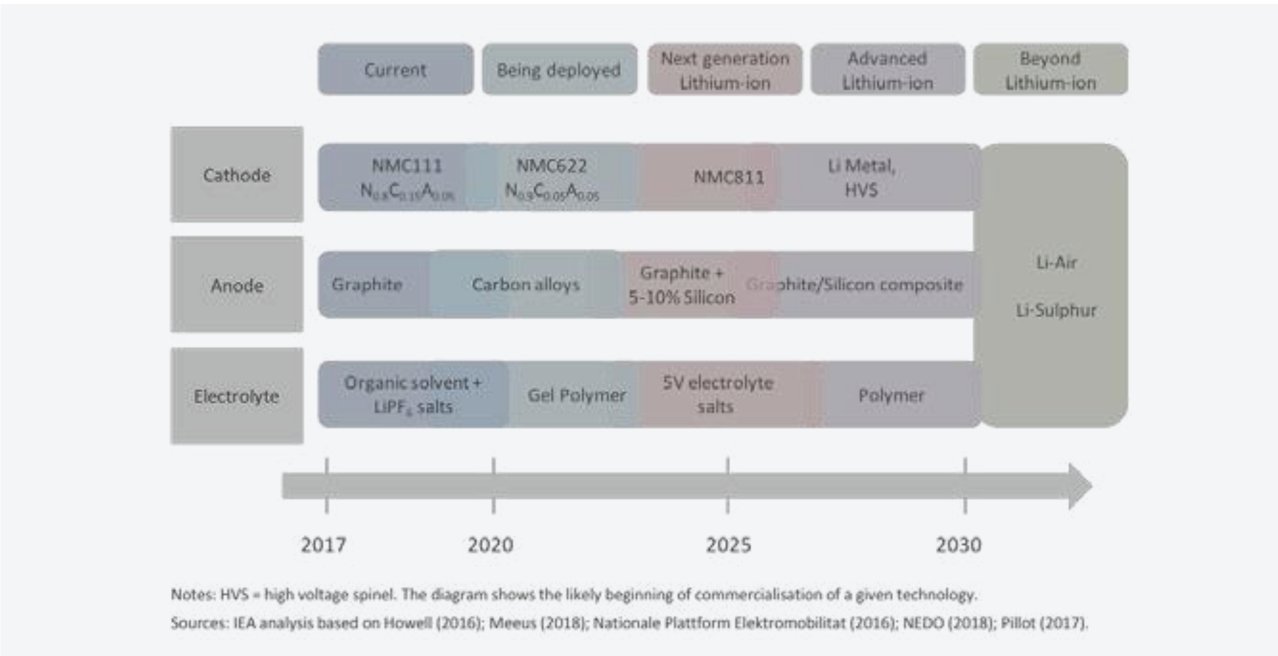


Table 2: Expected commercialisation timeline for battery technology up to just past 2030.

What is currently available in the market since 2017 are the cathodes comprising of NMC111, graphite as anode and electrolytes which consist of organic solvent and LiPF6 salts. However, since 2020, an anode that consists of carbon alloys, cathode consisting of NMC622, and electrolyte that is of a gel polymer are being developed. The next generation Li-ion batteries projected to emerge around 2025 will consist of cathodes known as NMC811, anodes made from graphite and silicon (5-10%), and 5V electrolyte salts. The advanced Li-ion consists of Li metal HVS cathodes, graphite and silicone composites as anodes and polymeric electrolytes (Table 2). Beyond the Li-ion batteries consists of Li-air and Li-sulphur as cathode, anode, and electrolytes beyond 2030.

2.3.1 Advanced Lithium-ion Batteries

These batteries aim to achieve high energy densities through a combination of high-voltage cathodes (about 5 eV) and high-capacity anodes such as graphite/silicon composites (about 1500 mAh/g compared to 400 mAh/g for graphite). However, the high voltages impose new stringent demands on the electrochemical stability of the electrolytes. To address this and other challenges, solid electrolytes are under development. For example, inorganic solid electrolytes, particularly oxides, appear to be the most promising since organic solid electrolytes. Currently, the organic solid electrolytes do not meet the conductivity threshold and have to be operated at high temperatures ranging between 50°C and 80°C.[28] Fortunately, there appears to be significant progress towards advanced lithium-ion batteries with numerous companies. Recently, announcements of prototypes have been made by Sion Power Corporation. This company introduced their Licerion battery with a Li metal anode and a Ni-rich cathode providing an energy density of 500 Wh/kg.

2.3.2 Beyond Lithium-ion Batteries

There are conversion chemistries involved in Li-ion batteries, but the lithium is the charge carrier. Furthermore, the preceding chemistries rely on intercalation chemistry. This means that they rely on reversible insertion and de-insertion of lithium ions at the battery electrodes. However, there is a fundamental limit of between 350 Wh/kg and 400 Wh/kg in the amount of lithium ions that can be accommodated inside the crystal structure of an electrode. As advanced lithium-ion batteries are already expected to reach this limit, chemistries that overcome this limit are imperative. Interestingly, the lithium conversion chemistries offer the most promising solution to such limitations. Among these are lithium-sulphur and lithium-air, with the former closer to commercialisation. For example, Oxis Energy is planning to commercialise lithium-sulphur batteries. These kinds of batteries are targeting the transportation industry, primarily aviation, buses, and trucks.[29] Hence, the lithium-sulphur batteries offer a very high theoretical specific capacity of 1675 mAh/g, the energy density of 2600 Wh/kg, and high energy efficiency of 80%.[30] However, the severe capacity fading is caused by the shuttle effect of the polysulfide. Therefore, this needs to be addressed for large-scale commercialisation of lithium-sulphur batteries.[31]

2.3.3 Beyond Lithium Batteries

The chemistries belonging to these kinds of batteries are neither in Table 1 nor 2. This is because these elements of interest represent a complete departure from lithium as the core of the technology by adopting other elements. For example, they incorporate sodium, magnesium, aluminium, and zinc elements. As these chemistries are fundamentally analogous to lithium technology, they are roughly expected to follow with some leap-frogging analogous trajectories. For example, the sodium-ion, advanced sodium-ion, and beyond sodium-ion chemistries. Notably, the increasing interest towards these elements is their natural abundance leading to their affordability and favourable environmental profiles leading to their sustainability. Thus, there is significant ongoing research in ion and conversion chemistries for sodium,[32] magnesium,[33] aluminium,[34] and zinc.[35] However, at this point of the research, it is impossible to project their commercialisation timeline.

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[28] J. Schnell, N. Vaishali, L.W. Horowitz, F. Paulot, P. Ginoux, M. Zhao, D.E. Horton, Air quality impacts from the electrification of light-duty passenger vehicles in the United States. Atmospheric Environment 208 (2019) 95-102

[29] https://oxisenergy.com/

[30] A. Eftekhari, The rise of lithium–selenium batteries, Sustainable Energy Fuels 1 (2017) 14-29: https://doi.org/10.1039/C6SE00094K

[31] H. Wei, Y. Liu, X. Zhai, F. Wang, X. Ren, F. Tao, T. Li, G. Wang, F. Ren, Application of Carbon Nanotube-Based Materials as Interlayers in High-Performance Lithium-Sulfur Batteries: A Review, Frontier Energy Research (2020): https://doi.org/10.3389/fenrg.2020.585795

[32] V.L. Martins, H.R. Neves, I.E. Monje, M.M. Leite, P.F.M. De Oliveira, R.M. Antoniassi, S. Chauque, W.G. Morais, E.C. Melo, T.T. Obana, B.L. Souza, R.M. Torresi, An overview on the development of electrochemical capacitors and batteries: Part II, An Acad Bras Cienc 2 (2020) 92: e20200800 DOI 10.1590/0001-3765202020200800

[33] Z. Zhao-Karger, M. Fichtner, Beyond intercalation chemistry for rechargeable Mg batteries: A Short Review and Perspective, Frontiers in Chemistry, 6 (2018) 656: doi: 10.3389/fchem.2018.00656

[34] T. Leisegang, F. Meutzner, M. Zschornak, W. Münchgesang, R. Schmid, T. Nestler, R.A. Eremin, A.A. Kabanov, V.A. Blatov, D.C. Meyer, The aluminium ion battery: A sustainable and seminal concept? Frontiers in Chemistry (2019): https://doi.org/10.3389/fchem.2019.00268

[35] W. Zhang, X. Zhai, Y. Zhang, H. Wei, J. Ma, J. Wang, L. Liang, Y. Liu, G. Wang, F. Ren, S. Wei, Application of manganese-based materials in aqueous rechargeable zinc-ion batteries, Frontiers in Energy Research, (2020): https://doi.org/10.3389/fenrg.2020.00195

The redox flow batteries (RFBs) are a different battery format because they primarily rely on the reduction-oxidation (redox) reaction between two salt solutions that are stored in separate tanks. In this case, during the redox operation, each solution is pumped through one of the electrode compartments of the cell where the solutions are situated. These salts can interact through a permeable membrane that allows for the redox process to occur. Because of the low energy densities, this battery configuration is intrinsically suited to large-scale (at least tens of KWh to the MGWh scale), and long-term storage which can be more than 6 hours. However, these are enabled by the large tanks installed for higher capacity. Thus, RFBs appear to be an attractive proposition for Africa's electrification through mini-grids and micro-grids. Nonetheless, the capital cost of the vanadium flow battery, which is the most developed of these technologies, remains too high for deep market penetration. But since Africa does not possess a strategic advantage in this battery technology, this report does not pursue it further.

Notably, supercapacitors are not traditionally defined as batteries. This is because supercapacitors store their energy electrostatically, instead of electrochemically, as traditional batteries do. That is why, as energy storage devices, supercapacitors can either compete with or complement batteries. Supercapacitors are characterised by their high-power density and very low energy density as shown in figure 7 (b). Unfortunately, their low energy density coupled with self-discharge remains a major drawback that limits supercapacitors applications. Their only niche application is only electric buses. Supercapacitors can be employed in tandem with batteries for applications demanding both high energy density (batteries) and high-power density (supercapacitors). Consequently, supercapacitors will not be discussed any further in this report.

2.4 Conclusion

An ideal battery ought to be cheap, safe, and be able to store the largest amount of energy for the smallest mass as well as energy density. Innovators ought to ascertain that the battery can deliver and/or accept the highest amount of energy in the shortest power density. In this way, the ideal battery can hold up the enormously long-life cycles. Therefore, African innovators can ensure that the batteries are mutually optimised with energy and power densities. Thus, all battery technologies must exhibit high-power densities. Hence, such batteries can enhance the continental drive towards emerging technologies, more especially artificial intelligence, digital technologies, and the electrification of mechanisation for a cleaner environment. Notably, advances in battery technology have primarily been in the chemistries, most particularly, physicochemical, and mechanical characteristics of cathodes and anodes. Therefore, African innovators ought to focus on electrolyte chemistry to improve efficiencies. Thus, Africa's innovators can yield higher energy and power densities, reduced physical weight and size, a longer cycle life, improved safety, and significant cost reduction.

3

Relevance of Next-Generation Batteries to Africa's Development

3.1 The context of next generation batteries in Africa's needs

While the rest of the developed world is navigating towards Industry 4.0 with technologies such as autonomous vehicles, artificial intelligence, internet of things, drones, robotics and wearable devices, numerous parts of Africa have not yet successfully implemented Industry 2.0. Thus, it remains clear that African countries need to invest in an energy supply that is reliable, accessible, and affordable before implementing the latest technologies. Therefore, in identifying applications for next generation batteries for Africa, the focus should first be on addressing the dire need for stable and continuously available energy supply. Thus, failure to address this energy crisis immediately, will most likely be disastrous for Africa's future. This challenge will hinder the technological advancement of Africa's inhabitants. Hence, for now, to address this energy challenge, investment and innovation efforts must focus towards the best and latest battery technologies for Africa's huge energy storage needs. Thus, addressing the future applications of the next generation batteries for Africa can enable the advent of the new Industry 4.0 technologies. This is because industry 4.0 technologies are highly reliant on reliable, accessible, and affordable energy supply for successful applications and implementations.

3.2 Current applications of NGB in Africa

Numerous successful projects have been completed in Africa, where batteries have complemented large-scale solar installations. One such example is a combined solar plant and battery system situated in the Zambian Province of Chisamba. This system is stationed at the Agricultural Knowledge and Training Centre based in the Chibombo District. This plant is run by the German and Zambian Ministry of Agriculture. The plant consists of 260 solar modules with a total capacity of 86 kWh. This plant supplies a 90,000 m^2 grain-field farm with 450 kWh needed for renewable energy meant for irrigation purposes up to 12 hours per day. It was reported by Tobias Kriete (BayWa r.e. Africa Regional Manager for Solar Projects)[36] that the combined PV plant and battery system were designed to ensure a stable supply of electricity. This was specifically addressing energy security and productivity.

In some parts of Africa such as South Africa, next generation batteries are being employed in more advanced technologies such as drones for agricultural and aerial photography, unmanned aerial vehicles (UAV) for military and logistics, and robotics for security and education. It is also utilised on the Internet of Things (IoT) applications such as remote sensing and traffic monitoring. For example, the Lightstone, a South African analytics company, revealed that since the inception of electrically

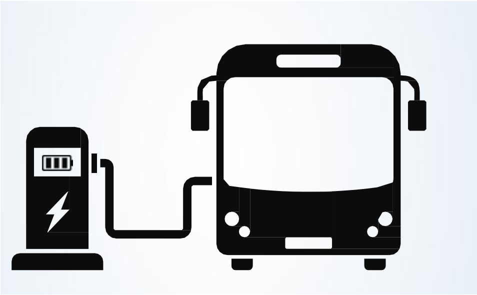
36 https://www.baywa-re.fr/en/company/news/details/national-energy-globe-award-for-solar-project-in-zambia/

powered vehicles (EV) in South Africa, a total of 375 have been sold. Incredibly, the sales of electric vehicles (EV) are estimated to account for 55% of all new vehicle sales by 2040. Thus, this clearly demonstrates the potential that the next generation batteries possess in Africa. This is because next generation batteries will observe the greatest future demand coming from EVs.

3.2.1 Case studies of next generation batteries

In this sub-section, relevant case studies of next generation battery applications are being presented. One case study is successful, and the other case study was unsuccessful.

3.2.1.1 Case Study: Electric bus powered by Lithium ion batteries[37]



Market: Commercial
Solution: Fully Electric Bus
Product: Lithium-ion intelligent battery module assembled into a system of 92kWh at 332V.
Application: Working with a leading global bus builder, Valence has become a key supplier of electric buses in Europe. The main offering in this range of vehicles is a 10-meter bus that can carry up to 37 seated passengers and has a maximum range of 150 kilometers. The electric buses are powered through lithium-ion batteries with wireless charging and full remote monitoring.
Result: This vehicle is such a success that it is being used across the United Kingdom and Europe for city transportation, university transport, airport and ride shuttles, and tourism. Currently, there are over 60 buses that are in service. Furthermore, this vehicle is well-positioned to be part of the largest fully electric bus fleet in Europe.

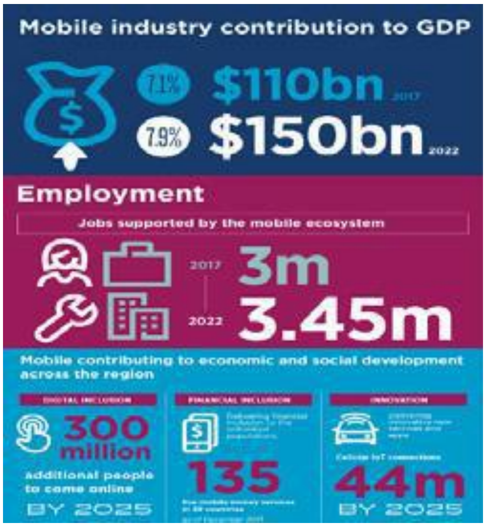
3.2.1.2 Case Study: Galaxy Note 7 recall[38]

Market: Commercial
Solution: Lithium-ion battery for mobile cellular phone
Product: Mobile Cellular phone Galaxy Note 7
Application: Fires emanating from the battery caused bodily harm to several people as well as property damage reports that were filed. Samsung's probe found that the overheating and burning of the phones was caused by faults within the batteries. According to the findings, the problems emanated from insufficient insulation material within the batteries. The design did not provide an adequate room that could safely accommodate the batteries' electrodes.
Result: The primary recall occurred on September 15th, 2016, with 1 million cellular phones being recalled. There were 66 reports of battery failures between August 16th and September 15th, 2016. Eventually, all cellular phones were deactivated to avoid further liability issues with the cellular phones that had not been sent back during the recall.

3.3 The relevance of Next Generation Batteries in Africa

The lithium-ion battery has transformed the way we live and work. This is because their ability to store substantial energy in small footprints has resulted in the mass distribution of portable electronic devices across the continent. This includes mobile phones and portable computers throughout Africa. In many parts of Africa, the number of people with mobile phones far outnumber those with access to electricity. Notwithstanding, many must walk a great distance to get a clear telecommunications signal and/or recharge their device's batteries.

[37] http://lithiumwerks.com/wp-content/uploads/2016/02/Case-Study-Motive-Electric-Bus-Optare.pdf
[38] https://en.wikipedia.org/wiki/Samsung_Galaxy_Note_7



With a penetration of 44% in 2017, mobile phones have transformed the lives of hundreds of millions of African. In most cases, these mobile phones are the first and only way to connect for most Africans with the outside world. Of course, mobile phones (and tablets) rely on battery storage, with the dominant technology being lithium-ion batteries. Interestingly, mobile phone technology has made it possible for poor countries to leapfrog outdated and expensive landline telephonic installations. For instance, in 2017, according to gmsa.com, mobile technologies and services generated 7,1% of the GDP across sub-Saharan Africa. This was a contribution amounting to US$110 billion and supporting over 3 million jobs in the mobile sector ecosystem.

Mobile-money services is an innovative technology that has enabled Africans people to send money directly from their mobile devices to purchase services and products. Mobile-money services have significantly transformed the way money is transferred across the continent. For example, the Mobile Economy Sub Saharan Africa (2018) reported that in 2017, the total value and number of mobile money transactions grew by 14,4% and 17,9% to reach $19,9 billion and $1,2 billion, respectively.[39] Across the region, it was observed that mobile money continues to play a significant role in offering financial services to people with limited access to conventional financial institutions. Therefore, renewable energy presents the greatest opportunity for Africa to leapfrog the dire need for access to clean energy that is accessible, reliable, and affordable. This access will enable more Africans to have access to mobile phone and digital technologies that will address their socio-economic challenges. Therefore, the next generation batteries are significantly complementing the renewable energy sources. This will allow for a continuous supply of electricity even when the renewable source is inactive, such as when the sun is not shining on solar panels.

3.4 Harnessing the power of NGB

> "Ending poverty and ensuring sustainability are the defining challenges of our time. Energy is central to both of them.
>
> World Bank Group President
> Jim Yong Kim

It has been found that there is a direct correlation between economic growth and a reliable electricity supply. Therefore, if Africa is to fulfil its promise of uplifting its people through poverty alleviation, it needs power and clean renewable power. In addition, the former World Bank President Dr Jim Yong Kim stated that battery storage can help African countries leapfrog to the next generation of power generation technology and expand energy access. Thus, for the developing African countries, next generation batteries are a game-changer.

The reality is that energy storage is going to unlock huge opportunities for more renewable energy investment in Africa. This will be at both utility and distribution levels. Consequently, this will completely disrupt the traditional African power sector model. The expectation is that up to 42% of people in Africa will be serviced through off-grid or mini-grid solutions by 2050. In addition, the rural areas with limited infrastructure and power supply, the off-grid battery energy storage solutions will fill the gap of energy shortages. This will empower numerous rural people and businesses currently with limited access to power supply.

In a major announcement at the One Planet Summit in September 2018, the World Bank Group committed US$1 billion for a new global programme. This new global programme will accelerate investments in battery storage for energy systems in developing and middle-income countries, such as African countries. In addition, the World Bank Group is expecting to mobilise another US$4 billion in concessional climate financing and public and private investments. Thus, the battery storage programme is envisaged to develop middle-income countries.

[39] State of the Industry Report on Mobile Money (2018): https://www.gsma.com/r/wp-content/uploads/2019/05/GSMA-State-of-the-Industry-Report-on-Mobile-Money-2018-

This will significantly ramp up their utilisation of renewables, most particularly wind and solar power. Consequently, this will improve energy security, increase grid stability, and expand access to electricity for African countries. For far too long, Africa has been referred to as the "dark continent" because of lagging behind in technological transformation and reliable power generation. Therefore, the energy transformation through next generation batteries is the tipping point for Africa's future. Potentially, this transformation will provide new opportunities for unprecedented growth. For instance, it will enable businesses to get started and grow, generate jobs for Africa's youth, and even create new markets across the continent. Additionally, children from most African countries currently without electricity can be able to study after dark. On the other hand, healthcare facilities such as hospitals and clinics can store life-saving vaccines, even when having unreliable power supplies. Thus, African countries can grow more competitive economies and improve the overall quality of life for all Africa's citizens.

3.5 Desirable criteria for microgrids

For the Li-ion battery technology to effectively develop and be competitive for grid-connected use in Europe, the specific battery- bank costs must be under €200/kWh with a lifetime above 2500 cycles.[40] Thus, it is more likely that Li-ion batteries will become more competitive for distributed power before they are adopted for centralised applications. Amongst the LIBs chemistries, the LFP is the chemistry that is more likely to dominate the grid storage space. This will occur primarily because of their longer cycle life, low cost, and eco-friendly material.[41] As manufacturing costs fall through learning, the floor price will ultimately be dictated by the essential materials such that of NMC, which is not expected to fall below $100/kWh.[42]

3.6 Conclusion

Currently, Africa is navigating its way towards Industry 4.0 with technologies such as autonomous vehicles, artificial intelligence, internet of things, drones, robotics, and wearable devices. However, Africa is yet to successfully implemented Industry 2.0. Thus, African countries need to urgently invest towards energy supply that can be reliable, accessible, and affordable so to effectively implement these intended emerging technologies. Therefore, Africa is encouraged to focus on addressing the dire need for stable and continuously available energy supply. Successful implementation of reliable energy supply in the form of the next generation batteries will power advanced technologies such as drones for agricultural and aerial photography, unmanned aerial vehicles (UAV) for military and logistics, Internet of Things (IoT), artificial intelligence, blockchain technologies, electric vehicles, and robotics for security and education. Thus, this clearly demonstrates the potential next generation batteries that will observe the greatest future demand in Africa.

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[40] H.C. Hesse, M. Schimpe, D. Kucevic, A. Jossen, Lithium-Ion Battery Storage for the Grid—A Review of Stationary Battery Storage System Design Tailored for Applications in Modern Power Grids, Energies 10 (2017) 2107: https://doi.org/10.3390/en10122107

[41] G. Zubi, R. Dufo-López, M. Carvalho, G. Pasaoglu, The lithium-ion battery: State of the art and future perspectives, Renewable and Sustainable Energy Reviews, 89 (2018) 292-308: DOI: 10.1016/j.rser.2018.03.002.

[42] MIT Energy Initiative. 2019. Insights into Future Mobility. Cambridge, MA: MIT Energy Initiative. http://energy.mit.edu/insightsintofuturemobility

4

Risks and Benefits of the Next Generation Battery Technology

The sub-Saharan Africa power sector is significantly underdeveloped in terms of installed capacity, energy access, and/or overall consumption. Since access to clean, affordable, adequate quality electricity is an essential component in any modern economy, any electricity shortage correlates directly with missed opportunities for GDP growth and poverty alleviation. Thus, the socio-economic promise to Africa, in general, is vested in the ability of Africa's governments and investors towards a drastic acceleration in the electricity production capacity.

If national wealth creation and prosperity for Africans is the desired benefit, African governments need to formulate regulatory frameworks (RFW) around the localisation of state-of-the-art battery production. This RFWs will enable the deployment of large numbers of micro-grids to meet the electricity generation capacity growth. Furthermore, Africa needs to formulate well-coordinated research, development, and innovation (RD&I) strategic plan. This RD&I strategic plan will sustain an African human resource pool that can meaningfully contribute to the sustainable development of next generation batteries. Currently, the greatest risk that the African continent needs to urgently address is the absence of a clear commitment towards the RFW and RD&I strategic plan.

The risks and benefits of both approaches are explained in this sub-section

4.1 Risks and benefits pertaining to local mineral beneficiation towards the production of state-of-the-art batteries

The sheer size of the international NGB market is primarily driven by the worldwide desire to convert the transportation industry from the conventional internal combustion engine (ICE) to an electromotive engine. While it has been known for several years that electrically-driven transportation is far more energy-efficient than transport made possibly with the ICE, there are two other reasons that have caused this conversion to gain momentum. The first reason is that it has been projected that the cost-effectiveness and economic feasibility of NGB will enable the mass production of EV and power electric vehicles. Furthermore, the perceived risk emanating from the human-induced climate change has caused governments' considerations around the world towards targeting partial or complete ban of internal combustion engines. Overshadowed by the EV battery market potential, but still very prominent on its own, is the potential of batteries, often referred to as "the holy grail" of renewable energy systems. Therefore, the next generation battery industry is expected to develop into a staggering multi-trillion dollar market by 2040. With accurate and strategic planning, Africa has the potential to become a major beneficiary and be competitive against technologically savvy and industrialised countries across the world.

A "low risk-high benefit scenario" can be built around the beneficiation of these African resources that are linked to the predicted surge for battery-grade material. These materials include manganese, cobalt, nickel, lithium, graphite, flour, copper, and aluminium. Furthermore, apart from the revenues created from the production of battery-grade materials, local manufacturing of state-of-the-art batteries will allow Africa's continued export from its existing car assembly industry. Effectively, this will improve the position of Africa's manufacturing and expand job opportunities for socio-economic development of Africans going forward. The financial risks associated with the establishment of an RFW are minimal. This is because the capital investment can be made by the private sector. The aim of establishing the RFW is primarily to protect the interests of Africans in the next generation value chain, prevent the export of raw and unrefined materials, and facilitate the local refinement of materials to battery-grade materials in exchange for export rights. Furthermore, since the main financial risk will be borne by the private sector, there are numerous inherently cost-effective battery chemistries on the verge of commercial production. However, it remains risky to lock onto the battery's chemistry, even though it is currently regarded as the state-of-the-art. Notably, changing battery assembly plant from a graphite anode/NMC811 cathode into a Li-anode /sulphur cathode is not just about adjusting the assembly line, but has major implications to the raw material processing systems leading to expensive alterations. Thus, the current state-of-the-art battery is expected to have a higher content of elements that is strategic to Africa. The NGB is chasing inherently cheaper materials made from Zn/air, LiS, Li-air, and with enhanced thermal storage properties. These materials are widely available minerals, and this presents an opportunity for African countries and private to increase profitability.

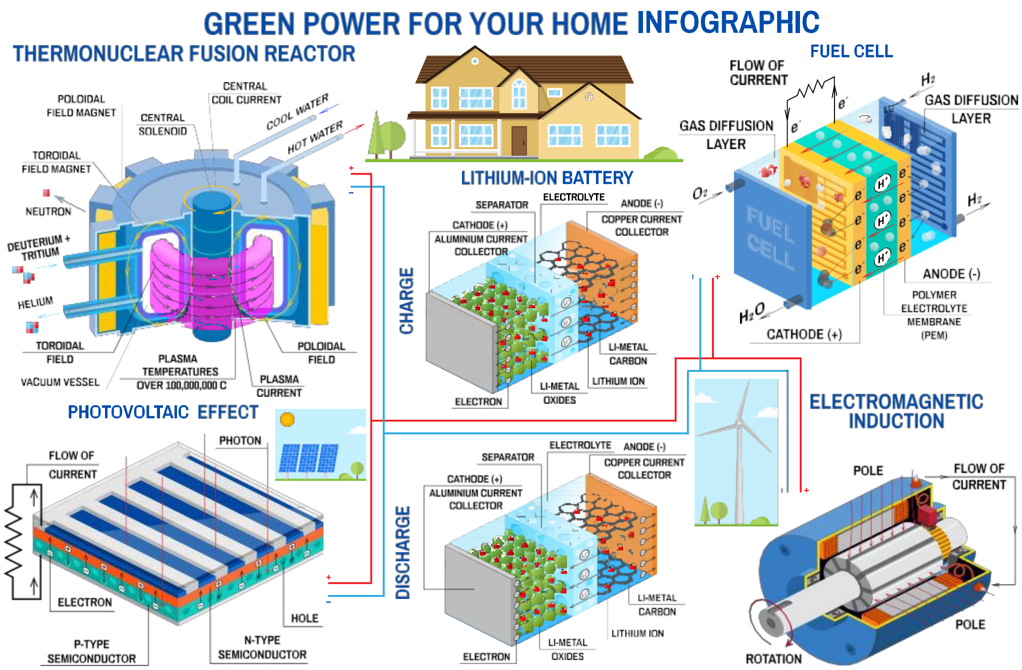
4.2 Risks and benefits pertaining to a coordinated RD&I plan

The financial burden associated with the development of a coordinated research development and innovation (RD&I) plan is substantial. This is because the investment in human resource and battery technology may only show financial benefits in the long run. In addition, the unique intellectual property outputs generated by the human resources that form part of the RD&I plan are competing with well-established and significantly better-funded research consortia worldwide. However, without an RD&I plan, the sustainability of the African battery industry will be compromised. Nevertheless, the financial risks of these initiatives are certainly controlled if the RD&I is focused on African based battery material refinement, battery assembly and development within Africa, and effective and well-distributed deployment of an energy storage system. However, African countries must avoid a case where they risk developing the technology within the continent, only to completely abandon the minerals through which Africa has a strategic advantage. Therefore, it is essential that African Union Member States take charge of technology development and ensure that it matches Africa's strategic advantages.

4.3 Conclusion

Presently, the sub-Saharan Africa power sector is significantly underdeveloped with respect to installed capacity, energy access, and overall consumption. However, African Union Member States ought to improve access to clean, affordable, and adequate quality electricity as an essential component of Africa's economy. Notably, any electricity shortage correlates directly with missed opportunities for GDP growth and poverty alleviation. Thus, the socio-economic promise to Africa, in general, is vested in the ability of Africa's governments and investors towards a drastic acceleration in the electricity production capacity. It also assists Member States to create wealth and prosperity for their citizenry.

African governments need to formulate regulatory frameworks (RFW) around the localisation of state-of-the-art battery production. This RFWs will enable the deployment of large numbers of micro-grids to meet the electricity generation capacity growth. Furthermore, Africa needs to formulate well-coordinated research, development, and innovation (RD&I) strategic plan. This RD&I strategic plan will sustain an African human resource pool that can meaningfully contribute to the sustainable development of next generation batteries. Therefore, there is a need for a clear and urgent commitment to RFW and RD&I strategic plans. Fortunately, the NGB market will grow as the innovation is primarily driven by the worldwide desire to convert the transportation industry from the conventional internal combustion engine (ICE) to an electromotive engine. This is because of the projected promise of their NGB's cost-effectiveness, reliability, and economic feasibility. Hence, with accurate and strategic planning, Africa has the potential to become a major beneficiary and be competitive against technologically savvy and industrialised countries across the world with respect to NGBs.


GREEN POWER FOR YOUR HOME INFOGRAPHIC
THERMONUCLEAR FUSION REACTOR
POLOIDAL FIELD MAGNET
CENTRAL SOLENOID
CENTRAL COIL CURRENT
COOL WATER
HOT WATER
TOROIDAL FIELD MAGNET
NEUTRON
DEUTERIUM + TRITIUM
HELIUM
TOROIDAL FIELD
VACUUM VESSEL
PLASMA TEMPERATURES OVER 100,000,000 C
PLASMA CURRENT
POLOIDAL FIELD
LITHIUM-ION BATTERY
CHARGE
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LI-METAL CARBON
LITHIUM ION
LI-METAL OXIDES
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ANODE (-)
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PHOTON
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ELECTRON
HOLE
P-TYPE SEMICONDUCTOR
N-TYPE SEMICONDUCTOR
ELECTROMAGNETIC INDUCTION
POLE
FLOW OF CURRENT
ROTATION

5

Ethical Considerations

5.1 Ethical considerations the environmental, social, and governance in LiBs industry

The Environmental, Social, and Governance (ESG) paradigm is bringing about profound changes to the way private and private institutions conduct business as environmental, social, and governance issues increasingly rise in priority. Additionally, the African LIBs industry comes into being in a global context with high expectations of sustainability and business ethics to the point where ESG has become a competitive advantage.[43,44] Therefore, the industry is encouraged to aspire towards a vision of the highest ethical motivation. That is, developing a business model embedded in stakeholder dialogue, participation, and collaborative sustainability management.[45] The main aim of this model is promoting responsible business practices in order to preserve Africa's collective heritage in nature, culture, and the care and protection of vulnerable groups in society such as women, children, the elderly, ethnic minorities, and the poor. Therefore, without the structural baggage of existing organisations, the African LIBs industry has a clear opportunity to leapfrog in ESG performance. This can be accomplished through appropriate design with respect to structural and policy frameworks from the outset.

Regarding the lithium-ion batteries (LIBs) technology, the fundamental question that Africa's innovators need to answer is what is an "ethical battery." Unfortunately, the discussion of LIBs ethics is complex, and two aspects must be clarified at the outset for tractability. The first aspect, as correctly noted recently by the London Metals Exchange,[46] is that the perimeter and parameters of ethical considerations continue to evolve with growing knowledge and societal expectations. Accordingly, this discussion is only a snapshot in time of rapidly dynamic factors that will shape and define our understanding of what constitutes an "ethical battery." Therefore, this suggests that the LIBs industry needs to stay alert to these developments and constantly reassess itself to proactively address the issues as they arise. The second aspect is that LiBs is an enabling technology. Therefore, as the LIBs' widen its applications and enabling various technologies, there must be an assessment of ethical implications in a wide range of sectors. Thus, it remains essential to clearly delineate the remit of this report with respect to the ethics of LIBs. In this regard, the scope of ethical considerations for this report in the LIBs value chain consists of mineral extraction, processing and refining, precursor and battery manufacturing, distribution, second life, and recycling and disposal. These considerations are made along with the associated research, development, and innovation activities, as shown in Figure 10. This necessary delineation excludes many important ethical issues in the various applications of LIBs. For example, the use of weaponised devices powered by LiBs. Within this value chain, some issues are general and cut across multiple operations. These are discussed first. On the other hand, those issues that relate to specific operations are addressed under their respective sections.

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[43] M. Taliento, C. Favino, A. Netti, Impact of Environmental, Social, and Governance Information on Economic Performance: Evidence of a Corporate 'Sustainability Advantage' from Europe, Sustainability 11 (2019) 1738; https://doi.org/10.3390/su11061738.

[44] Favino, Christian, Taliento, Marco, Netti, Antonio, Impact of Environmental, Social, and Governance Information on Economic Performance: Evidence of a Corporate 'Sustaina- bility Advantage' from Europe, Sustainability 11 (2019): DOI: 10.3390/su11061738. -

[45] I. Oncioiu, D.-M. Popescu, A. Elena Aviana, A. Serban, F. Rotaru, M. Petrescu, A. Marin-Pantelescu, The Role of Environmental, Social, and Governance Disclosure in Financial Transparency, Sustainability 12 (2020) 6757-6773; doi:10.3390/su12176757.

[46] https://www.lme.com/-/media/Files/New-initiatives/Responsible-Sourcing/

The Environmental, Social, and Corporate Governance (ESG) paradigm, in its general form, applies to all components of the LIBs value chain. The "environmental" aspect is primarily concerned with sustainable resource management and the protection of the environment from harmful industrial emissions. The focus of the "social" aspect is concerned with the people; employee working conditions as well as community/stakeholder relations. This essentially means the corporate social responsibility (CSR). Lastly, the "governance" aspect addresses the transparency of all processes and the avoidance of conflict of interest, as well as inclusivity and diversity. It also caters for the equitable compensation of employees and directors. All these aspects must be entrenched into the design of the industry, not only to fulfil societal expectations but for the good of a responsible business. This is primarily because there is compelling evidence of positive correlations between the financial performance of corporations and their performance in environmental and social issues.[47] In addition, there have been reports of recent evidence presented directly from the African context supporting this correlation.[48]

On the investment considerations, better performance has been reported for institutional investors that apply ESG metrics in the selection of investment portfolios using the Equator Principle.[49] This investment approach in turn exerts more pressure on corporations for ESG performance.[50] Accordingly, it is expected that businesses demonstrating greater transparency through ESG reporting will attract better investment funding in the future.[51] This is consistent with the green bonds performing at a premium over ordinary bonds.[52] Already, a clear statement of the momentum towards transparent ESG reporting in the broader LIBs sector emerges from the recent December 2018 launch of the Task Force on Climate-related Financial Disclosure (TCFD) under the Electric Utility Preparer Forum coordinated by the World Business Council for Sustainable Development.[53] In this regard, LIBs will help mitigate climate change. This will happen if they are primarily employed to facilitate renewable energy penetration, rather than storing energy from fossil fuels.

Equality, diversity, and inclusivity are currently under the spotlight in the management circles. Rather than leaving these to chance, there is a thrust towards achieving them by the deliberate design of organisations.[54,55] Many organisations are establishing equality, diversity, and inclusivity working groups to directly address these management issues. Some of the specific issues that they are focusing on include equal opportunity and addressing inequality. For example, institutions are addressing the gender pay gap, sexual harassment at the workplace, work-life balance, and actively seeking to reduce the vulnerability of disadvantaged social groups. Therefore, the African LIBs industry must not create new economic inequalities nor exacerbate existing ones by becoming a premium product only affordable to the rich. Consequently, government subsidies might be needed to facilitate the affordability of LiBs technology.

[47] E. Albertini, Does Environmental Management Improve Financial Performance? A Meta-Analytical Review, Organization & Environment 26 (2013) 431-457: DOI: 10.1177/1086026613510301.

[48] A. Aboud, A. Diab, The impact of social, environmental, and corporate governance disclosures on firm value: Evidence from Egypt, Journal of Accounting in Emerging Econo- mies, 8 (2018) 442-458: https://doi.org/10.1108/JAEE-08-2017-0079.

[49] E. Nizam, A. Ng, G. Dewandaru, R. Nagayev, M. Nkoba, The Impact of Social and Environmental Sustainability on Financial Performance: A Global Analysis of the Banking Sector, Journal of Multinational Financial Management 49 (2019): DOI: 10.1016/j.mulfin.2019.01.002.

[50] A. Dyck, K.V. Lins, L. Roth, H.F. Wagner, Do institutional investors drive corporate social responsibility? International evidence, Journal of Financial Economics, 131 (2019) 693-714: https://doi.org/10.1016/j.jfineco.2018.08.013.

[51] A. Hamrouni, R. Boussaada, N. Toumi, Corporate social responsibility disclosure and debt financing, Journal of Applied Accounting Research 20 (2019): DOI: 10.1108/JAAR- 01-2018-0020.

[52] R. Johnson, The link between environmental, social, and corporate governance disclosure and the cost of capital in South Africa, Journal of Economic and Financial Sciences 13 (2020), 543: https://doi.org/10.4102/jef.v13i1.543.

[53] https://www.wbcsd.org/Programs/Redefining-Value/External-Disclosure/TCFD/Resources/Disclosure-in-a-time-of-transition-Climate-related-financial-disclosure-and-the-opportunity-for-the-electric-utilities-sector

[54] https://www.gov.uk/government/publications/the-business-case-for-equality-and-diversity-a-survey-of-the-academic-literature, https://www.forbes.com/sites/tomaspremuzic/2019/06/20/how-to-design-a-diversity-intervention-that-actually-works/

[55] M. Derven, Diversity and inclusion by design: Best practices from six global companies, Industrial and Commercial Training 46 (2014): DOI: 10.1108/ICT-09-2013-0063.

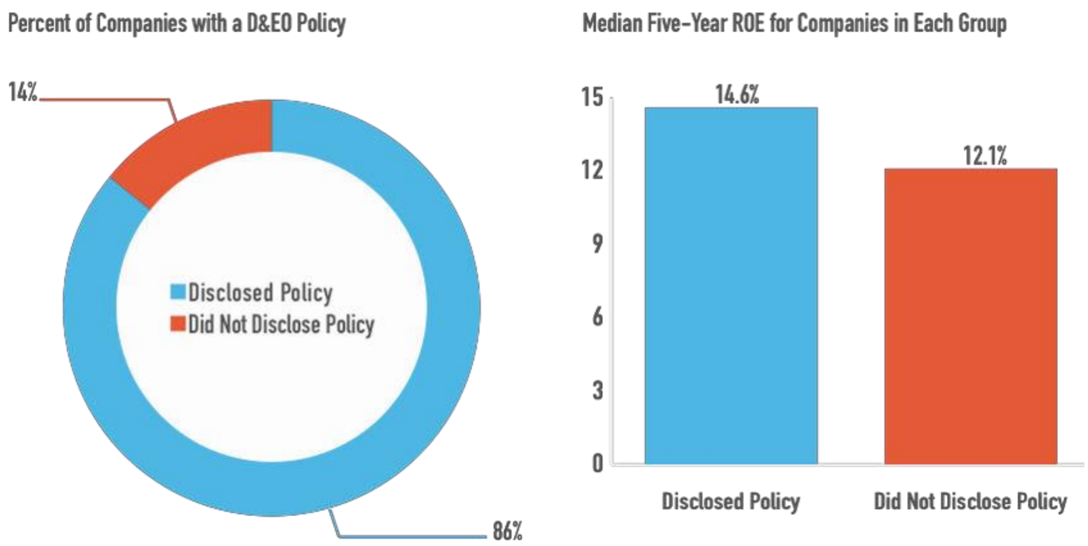


Figure 10: A study of 890 companies shows a 2.5% higher return-on-equity (ROE) for companies that disclosed their diversity and equal opportunity (D&EO) policies.[56]

Another issue currently under intense scrutiny is that of gender diversity in corporate boards. Research has shown a strong positive correlation between corporate transparency when measured by ESG disclosures and the feminisation of corporate boards. However, this effect is only observed once the number of women members reach a critical mass.[57,58] Hence, this indicates the need for a judicious design of corporate boards. In addition, the impacts of gender on corporate ESG performance are even more striking when one considers that if an institution's CEO has a daughter, that institution can perform about 9% better than a median institution.[59] Accordingly, all corporate entities formed directly from the implementation of this report's programme are encouraged to carefully design their corporate boards for optimal gender diversity.

It is essential that the African LIBs industry strives for independent ESG reporting. Unfortunately, as it is a rapidly developing field, there is currently an explosive proliferation of independent frameworks for measuring and reporting the ESG performance of an organisation. In fact, it is estimated that over 150 rating systems exist, and they cover over 10,000 sustainability performance metrics.[60] However, standardisation will eventually take place, with efforts in that direction already underway. In the meantime, possible choices for the African LIBs industry could include the Global Reporting Initiative (GRI), Dow Jones Sustainability Index (DJSI), and Bloomberg ESG Score. As this is a rapidly evolving area, the final decision ought to be left until the time of implementation.

[56] https://justcapital.com/reports/the-win-win-of-just-jobs/

[57] M. Taliento, C. Favino, A. Netti, Impact of Environmental, Social, and Governance Information on Economic Performance: Evidence of a Corporate 'Sustainability Advantage' from Europe, Sustainability 11 (2019) 1738; doi:10.3390/su11061738.

[58] N. Mohamed, N.K. Allam, Recent advances in the design of cathode materials for Li-ion batteries, RSC Advances 10 (2020) 21662-21685: https://doi.org/10.1039/D0RA03314F.

[59] M. Philippot, G. Alvarez, E. Ayerbe, J. Van Mierlo, M. Messagie, Eco-efficiency of a lithium-ion battery for electric vehicles: influence of manufacturing country and commodity prices on GHG emissions and costs, Batteries 5 (2019) 23: https://doi.org/10.3390/batteries5010023.

[60] https://www.ft.com/content/1244dc6e-8bec-11e9-a1c1-51bf8f989972

5.2 Mineral Extraction and Pre-processing

The African LIBs industry will be a customer of the various battery minerals that are mined across Africa. Consequently, mineral supply chains are under increasing pressure from the responsible sourcing movement demanding certification for the provenance of minerals. The issues in view include "conflict minerals." "Conflict minerals" are the minerals extracted from conflict zones where the revenue may be used to perpetuate the conflict, forced labour, worst forms of child labour, human rights violations, money laundering, corruption, and bribery. In addition, a more cumbersome problem is artisanal mining that, on one hand, has a big economic value to poor communities, while on the other, it is subject to unsafe and abusive working conditions. It will often result in the collapse of mine shafts and consequently deaths that are difficult to monitor.[61]

As evidence of some of the momentum towards responsible sourcing, the London Metals Exchange (LME) published a position paper in October 2018[62] setting out a proposed pathway for its listed brands. These brands are supposed to carry out certified audits against the Organisation for Economic Co-operation and Development (OECD) due diligence guidance for responsible supply chains of minerals from conflict-affected and high-risk areas and/or equivalent standard. The LME will have the power to delist brands that do not comply with the new requirements. Notably, the LME position paper singled out cobalt, a crucial battery mineral, as the mineral demanding the most urgent attention. This greater focus on cobalt is in part because of the Amnesty International Report published in 2016. This report documented hazardous working conditions for both adults and children in cobalt artisanal mines in the Democratic Republic of Congo.[63]

It is therefore encouraged that the African LIBs industry, as a customer of the mineral supply chains, aims for industry best practice for responsible sourcing. In that regard, the LME position paper (and future developments from it) could serve as a benchmark for responsible sourcing for the African LIBs industry. In particular, the LME position paper requires environmental (ISO 14001) and occupational health and safety (ISO 45001) certification for the metal suppliers to its listed brands. Apart from the LME position paper, other recent initiatives also exist. Most notably, is the International Responsible Business Conduct Agreement for the Metals Sector.[64] These positions for the best practice frameworks must be consulted during the development of the African LIBs industry.

There is currently significant battery mineral prospecting and feasibility work across Africa. This suggests the prospect of emerging and large mining operations coming onstream soon. Such as the LME, the African LIBs industry should demand community engagement from its suppliers involved in these greenfield projects. thus, it is essential to obtain a social license to operate in cases where projects impact indigenous communities. This can be accomplished through recognition of local land rights, cultures (e.g., preservation of sacred natural sites), and traditions as well as the institutions that support them.[65] Another important consideration in these greenfield projects is the preservation of biodiversity and protection of certain rare species.

5.3 Battery Manufacturing

There are two main ESG considerations for manufacturing in Africa. These considerations are the high energy intensity of battery manufacturing and product design for a circular economy. Therefore, several factors can influence the overall energy intensity of the battery manufacturing process including the cell chemistry, production volume, nature of processing steps such as the use of nanomaterials which are known to increase energy demand, and process optimisation. This means that there is high variability in battery manufacturing energy intensity. The impact of a given energy intensity on green-house gases (GHG)

[61] https://edition.cnn.com/2019/02/18/africa/zimbabwe-mine-disaster-intl/index.html
[62] https://www.lme.com/-/media/Files/New-initiatives/Responsible-Sourcing/
[63] https://www.amnesty.org/en/documents/afr62/3183/2016/en/
[64] https://www.imvoconvenanten.nl/metallurgisch?sc_lang=en
[65] A Vision for a Sustainable Battery Value Chain in 2030: Unlocking the Full Potential to Power Sustainable Development and Climate Change Mitigation: http://www3.wefo- rum.org/docs/WEF_A_Vision_for_a_Sustainable_Battery_Value_Chain_in_2030_Report.pdf

emissions is also highly variable predicated upon the carbon intensity of the electricity mix employed to power the plant. Furthermore, the averages that have been reported for the industry are 328 kWh cumulative energy density and 110 kg CO2 equivalent to produce 1 kWh of battery storage.[66]

In addition to optimising the manufacturing process, the overall eco-efficiency of battery manufacturing can be increased considerably by optimising the renewable content of the plant's supply electricity mix. With an optimal electricity mix, GHG emissions as low as 39.5 kg CO2eq/kWh have been reported.[67] Most importantly, the achievable eco-efficiency may be a vital factor in deciding the location of the battery manufacturing plant. Ideally, the plant should generate at least a substantial part of its renewable energy demand.

The battery manufacturing process should aim to design both the cells and packs for product circularity to ultimately support transitions to circular economies. A circular economy is defined as a regenerative system in which resource input and waste, emission, and energy leakage are minimised. This is accomplished by slowing, closing, and narrowing material and energy loops.[68] The processes of loop narrowing (increasing resource efficiency), slowing (extending product service life), and closing (closing the loop between post-use and production) is meant to optimise resource flows through closed-loop supply chains, as shown in Figure 11.

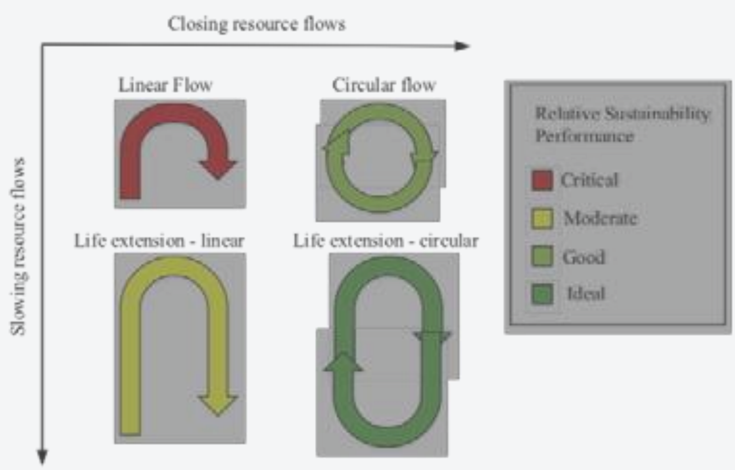


Figure 11: Circular economy: The transition from the traditional linear flow to the longest closed-loop possible for a given product.[69]

In practice, the transitions in Figure 11 are achieved through product repair and maintenance, reuse and redistribution, refurbishment and remanufacturing, recycling, and cascading and repurposing.[70] Most of these operations are already considered standard practice for the LIBs industry. Therefore, the African LIBs industry can leapfrog in circular product design and

[66] J.F. Peters, M. Baumann, B. Zimmermann, J. Braun, M. Weil, The environmental impact of Li-Ion batteries and the role of key parameters – A review, Renewable and Sustaina- ble Energy Reviews 67 (2017) 491-506.
[67] https://www.iea.org/reports/global-energy-co2-status-report-2019/emissions.
[68] O. Velázquez-Martínez, J. Valio, A. Santasalo-Aarnio, M. Reuter, R. Serna-Guerrero, A Critical Review of Lithium-Ion Battery Recycling Processes from a Circular Economy Perspective, Batteries 5 (2019) 68: https://doi.org/10.3390/batteries5040068.
[69] I. Esparragoza, J. Mesa-Cogollo, A case study approach to introduce circular economy in sustainable design education, International Conference on Engineering and Product Design Education, September 2019, Department of Design, Manufacture Aad Engineering Management, University of Strathclyde, United Kingdom: DOI: 10.35199/epde2019.3.
[70] X. Zeng, M. Li, D. Abd ElHady, W. Alshitari, A.S. AlBogami, J. Lu, K. Amine, Commercialization of lithium battery technologies for electric vehicles: A Review, Advanced Energy Materials 9 (2019): https://doi.org/10.1002/aenm.201900161.

should strive for certification. Furthermore, while circularity indicators are still an active area of research,[71] the certification scheme offered by the Cradle-to-Cradle Product Innovation Institute might currently be a viable pragmatic choice.[72] Thus, a key aspect is that the whole LIBs industry needs to be viewed as an entire ecosystem producing economic, ecologic, and social value. This can be done so that the manufacturing sector cannot be optimised in isolation from both the upstream and downstream operations.

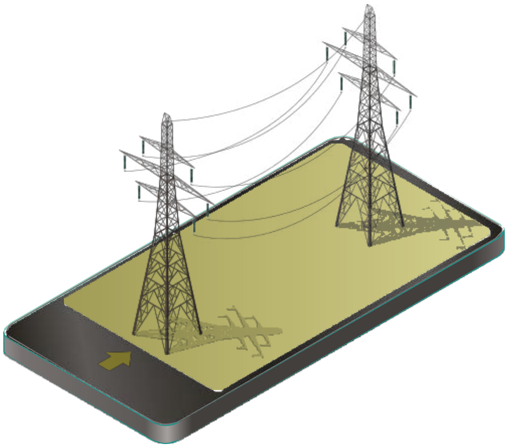
5.4 Distribution, Second Life, Recycling, and Disposal

There is an ethical difficulty that arises with the warranty for a product that undergoes refurbishing, repurposing, and second life. This is especially so for LIBs because of their complex safety issues. For instance, the questions for consideration include the one who must take responsibility if a battery in a second life application explodes with damaging consequences. However, the answer depends on the business model adopted by the industry. The key lies in a clear framework that delineates legal responsibility among the various players of the value chain.

What is most important is that LIBs must be safe at every stage of the value chain, optimise resource utilisation efficiency, minimise harm to the environment, and be transformative to the socio-economic fabric of Africa through empowering vulnerable groups. Furthermore, the various operations of the LIBs value chain must develop local infrastructure and talent and pay attention to vulnerable groups. The African LIBs industry must strive to deliver an economic level of electrification to the impoverished African communities. It must also be capable of supporting small-scale to medium-scale entrepreneurship. Finally, hope is not only for these communities to be electrically independent. However, it is for them to eventually become prosumers of the electricity industry and be able to earn revenue from their own power generation activities.

5.5 Conclusion

While developing NGBs, there is a need to develop a robust ESG paradigm that will guide its impact across the continent. Successfully developing an ESG for the African continent will greatly improve Africa's LiBs industry for better sustainability and business ethics. Therefore, the LiBs industry is encouraged to aspire towards a vision of the highest ethical motivation. This means that the African continent can develop a business model embedded in stakeholder dialogue, participation, and collaborative heritage. Therefore, the African LIBs industry has a distinct prospect to catapult its ESG performance. This can be accomplished through appropriate design with respect to structural and policy frameworks from the outset.



[71] F. Saidani, F.X. Hutter, R-G. Scurtu, W. Braunwarth, J.N. Burghartz, Lithium-ion battery models: a comparative study and a model-based powerline communication, Advances in Radio Science 15 (2017) 83–91: https://doi.org/10.5194/ars-15-83-2017.

[72] M. Chouchane, A. Rucci, T. Lombardo, A.C. Ngandjong, A.A. Franco, Lithium ion battery electrodes predicted from manufacturing simulations: Assessing the impact of the carbon-binder spatial location on the electrochemical performance, Journal of Power Sources 444 (2019) 227285: https://doi.org/10.1016/j.jpowsour.2019.227285.

6

Strategy, Research, Development and Innovation

6.1 The Strategic Perspective

There are two high-level expressions of the urgent aspiration for human development and sustainability that have a direct bearing on Africa's strategy on next-generation battery technology. The first aspiration is the UN's SDG 7 that defines three targets by 2030. The first target is to ensure access to affordable, reliable, sustainable, and modern energy for all. The second target is to substantially increase the share of renewable energy in the global energy mix. The third target is to double the global rate of improvement in energy efficiency. Furthermore, the second aspiration is the AU's Agenda 2063 with specific reference to five goals. Goal 1 offers Africans a high standard of living, quality of life, and well-being for all. The second goal is ensuring well- educated citizens and skills revolution underpinned by science, technology, and innovation. The third goal is offering Africans to have healthy and well-nourished citizens. The fourth goal talks to transformed African economies and job creation. The seventh goal is that Africa must be environmentally sustainable and have climate-resilient economies. Although the specific targets are different, there is a congruency between SDG 7 and the selected goals of Agenda 2063. Since SDG 7 has a closer timeframe, it offers a more meaningful reference for assessing progress towards achieving these aspirations.

A recent review of SDG 7, according to the Policy Briefs in Support of the First SDG 7 Review at the UN High-Level Political Forum (2018), concluded that while North Africa is on track to achieve universal electrification by 2030, the sub-Saharan African region will fall short.[73] In particular, the report stated that by 2030, there will be 590 million people with no access to electricity and 900 million with no access to clean cooking in sub-Saharan Africa. However, this is somewhat surprising considering the concerted international response to SDG 7 with over 60 foreign initiatives being launched to support electrification in Africa.[74] However, examining the biggest of these initiatives, Power Africa,[75] a US Government-led initiative, gives at least some clues for this lack of success. The programme's target of increasing installed generation capacity by 30 GW by 2030 does not consider plant retirements. During the retirement time, the power generation falls far short of the generation requirements to electrify the 650 million of unelectrified people. Additionally, the programme's accounting of electrification rates includes mere access to an electric lantern which, in fact, is not even tier 1-level electrification. Overall, the absence of an overarching continental strategy is one of the main obstacles to electrification.[76]

These failures demand a return to the fundamentals to examine the nature of the problem methodically and rigorously. This includes investigating why Africa remains unelectrified and analysing the underlying causes of such anomalies. Unless these causes are explicitly identified and addressed head-on, any efforts towards electrification of Africa will continue to fall short. While there is a general acknowledgement that the problem is complex and multifaceted, it also remains apparent that the LiBs for NGB technology solutions are not affordable. However, Africa must answer the question that, why are these solutions not affordable to Africans when the continent is endowed with the minerals suitable for such technologies. To answer this gap, the two reasons to explain this phenomenon are intertwined. For instance, the first technology problem is that Africa does not have

[73] https://www.un.org/development/desa/en/news/sustainable/new-publication-calls-for-urgent-action-on-energy-to-achieve-global-goals.html
[74] http://bruegel.org/2017/09/the-role-of-international-institutions-in-fostering-sub-saharan-africas-electrification/
[75] https://www.usaid.gov/powerafrica
[76] http://bruegel.org/2017/09/the-role-of-international-institutions-in-fostering-sub-saharan-africas-electrification/

control of the price point. This is because Africa does not own these technologies at this point. Secondly, the technologies can be over-engineered or under-engineered for Africa's requirements. However, either way, they become too costly for Africans and unsustainable. Furthermore, the other challenge is poverty. It has been reported that 437 million people in sub-Saharan Africa live in extreme poverty, characterised by living by less than US$1.90/day. In addition, it has been projected that 9 in 10 people will live in extreme poverty in sub-Saharan Africa by 2030.[77] Therefore, Africa needs to strategically think about equitable and deep wealth creation in Africa, as opposed to cosmetic wealth only.

Currently, there is a global revolution underway in electrochemical energy storage to support energy transitions towards circular economies and zero-emission societies. The global energy storage market is projected to grow 13-fold to 158 GWh by 2024.[78] At the centre of this revolution are rechargeable batteries (and supercapacitors to a more limited extent), in particular, lithium-ion technology. Notably, this revolution has a direct bearing on the aspirations summarised above because of the prospect of reconfiguring the economics of electrification through increased use of renewable energy sources (primarily wind and solar) both in national grids and mini-grids (including stand-alone facilities), and the latter for off-grid communities. This revolution needs to be strategically harnessed to deliver on the energy storage and electrification aspirations for Africa. Yet a serious technological problem is already apparent in this revolution; the battery technology is currently directed by the technical requirements for electromobility. While there is some overlap, these requirements still differ in some important respects from those for large- scale off-grid electrification of Africa. Therefore, this is a significant strategic issue that Africa needs to come to grips with. Its importance has recently been highlighted by the World Bank Group.

It has been acknowledged by experts that increased utilisation of wind and solar power with robust storage can help decarbonise power systems, expand energy access, improve grid reliability, and increase energy system resilience. However, it has been further reported that the requirements of developing countries' grids are not yet fully considered in the current energy storage market. This is despite that these African countries may have the largest potential for battery deployment. Currently, the battery market is driven by the electric vehicle industry. Most mainstream technologies cannot provide long-duration storage or withstand harsh climatic conditions, and low operation as well as maintenance capacity.[79] In particular, the performance of most lithium- ion battery technologies degrades rapidly at temperatures above 25°C and this necessitates for robust cooling mechanisms suitable for hot climates. To address this technological challenge, the World Bank Group is responding through the Energy Storage Partnership Program (ESP) initiative. This is a US$1B initiative that is meant to stimulate and support battery storage solutions that meet the technical requirements for large-scale energy storage. Thus, African governments must be able to device more methods through which they can be able to address this technological problem since it threatens the prospect of large-scale electrification of Africa through a robust energy revolution.

In this report, some steps are outlined that may be used by African countries to address the electrification problem of Africa. This can be coupled with strategies of deep wealth creation and technology mastery. It is being proposed that an immediate industrialisation programme that directly harnesses the current energy storage revolution should be put in place. This programme can be implemented in a five-year timeframe. Notably, this strategy entails adopting current state-of-the-art lithium-ion battery technologies for local manufacturing capitalising on Africa's key competitive advantage, which is the battery minerals. Because of the nature of the technology, this programme is optimal for the emerging electric vehicle market. But it will also support off-grid electrification in the meantime. The immediate industrialisation is underpinned by a broad research, development, and innovation programme that aims to establish a full lithium-ion battery value chain in Africa and eventually steer battery technology towards the long-term goal of bespoke solutions most suited to Africa's electrification. The main research priorities are defined for the first 10 years. Furthermore, comprehensive, coherent, and responsive policies for wealth creation and technology mastery are a critical ingredient of the entire programme. These are discussed in detail in the next chapter. The impetus for this programme is the realisation that the electrification problem in fact presents an unprecedented technological opportunity for Africa.

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77 https://blogs.worldbank.org/opendata/number-extremely-poor-people-continues-rise-sub-saharan-africa
78 https://renewablesnow.com/news/global-energy-storage-market-to-hit-158-gwh-in-2024-650563/
79 http://www.worldbank.org/en/news/press-release/2019/05/28/new-international-partnership-established-to-increase-the-use-of-energy-storage-in-developing-countries

To understand this opportunity, there is a need to look at the lithium-ion battery value chain continent-wide as it stands today. Figure 12 is a simple schematic showing significant gaps, represented by the red colour, in the value chain. Notably, the only part that Africa controls is the mining and initial processing. Demonstrably, this is only a tiny fraction of the total value of the LiBs value chain. Furthermore, there is also some existing distribution infrastructure for handling the imported product. However, this too falls short of what is required to support the energy storage revolution. The question that African governments must answer is who controls and benefits from the red segments in Figure 12. Addressing this question will provide technical strategies and frameworks through which African governments will be able to formulate policies that will provide opportunities for the African people. While recycling and disposal are largely still under development, with only about 9% of the lithium-ion battery being recycled, the most lucrative part of the value chain in Figure 12 (highlighted in oval) is owned and controlled outside Africa.

Incredibly, the battery market is currently dominated by three Asian players that include Japan (Panasonic), South Korea (Samsung SDI, LG Chem, SKI), and China (BYD, CATL). Collectively, they are estimated to control about 80% of the battery storage market. There are currently significant activities in Europe and North America to build gigafactories for battery manufacturing. Notably, governments around the world are taking swift and decisive steps to stimulate and support domestic battery manufacturing capacity. The greatest question that needs immediate answers is that what are African governments, researchers, and innovators doing about these loopholes so to increase their share in the battery energy storage market.

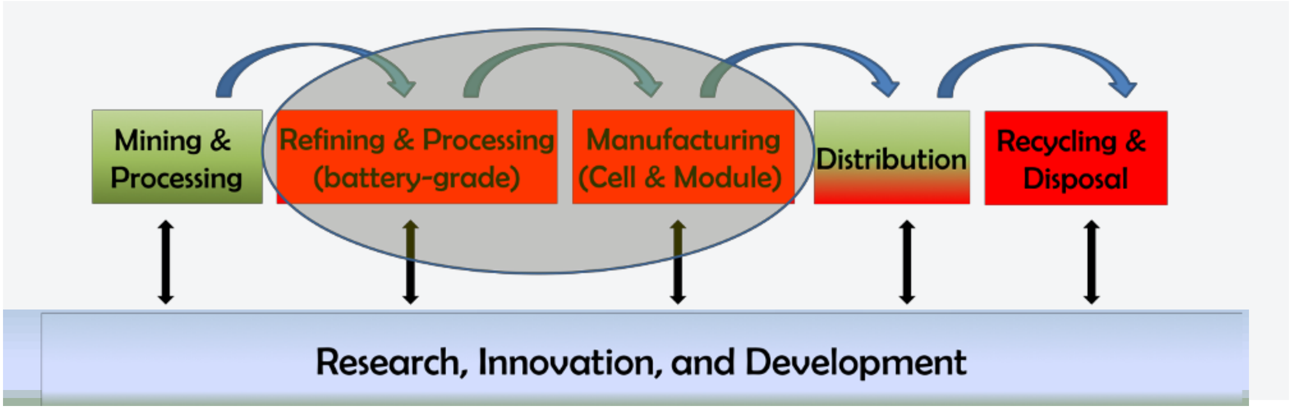

Figure 12: Simplified schematic of the lithium-ion battery technology value chain. Green boxes are sectors of the value chain where substantial infrastructure already exists while none exists for the red boxes. The yellow oval highlights sectors that need to be created for the immediate industrialisation component of our proposed programme. Manufacturing includes battery-management-system and packs technology.

The gaps in Figure 12 clearly demonstrate that Africa subsidises high standards of living for other nations through the double whammy. Firstly, this is facilitated by giving away Africa's minerals only to create a few jobs for Africans. The benefiting countries can further industrialise their own nations at the expense of the African people and wealth. Subsequently, the minimal income that Africa gains from selling minerals to these countries is used to buy back her own minerals in product-form at exorbitant prices. Unfortunately, this discrepancy clearly results in the net transfer of wealth creation opportunities from Africa to other nations. Notably, Africa cannot prosper while it continues to haemorrhage wealth to the rest of the world with no clear strategic roadmap towards reducing this anomaly and eventually stopping it. In general, nations that have managed to pull themselves out of poverty in a sustainable way have done so through mastering at least some area of modern technology. Thus, Africa desperately needs to master at least one area or some areas of speciality of modern technology. The question is: where is the biggest opportunity for such an ambitious endeavour in 21st century Africa?

The panel is arguing that as a continent, Africa has formidable competitive advantages in lithium-ion battery technology. Endowed with all the key minerals required in lithium-ion battery manufacturing, Africa can and should establish a full and viable lithium- ion value chain. This will result in a shorter and substantially more lucrative value chain with numerous fundamental benefits to the African economies. Table 3 showed the levels of production and reserves of 'The Big Five' battery minerals for NMC chemistry, as well as the LCO, LMO and NCA.

Table 3: The 'Big Five' lithium-ion battery minerals: African production (2018) and known reserves. Data for nickel is for 2017. For each mineral, data is given only for the top-ranked producer or holder of the largest known reserves.

Minerals	Production (Metric	Known Reserves (Metric Tonnes)	Country (Production, Reserves)	World Ranking (Production, Reserves)
Lithiuma	1,600	70,000	Zimbabwe, *	5, *
Cobaltb	90,000	3,400,000	Democratic Republic of Congo	1, 1
Manganeseb	5,300,000	200,000,000	South Africa	1, 1
Nickelc	48,000	3,700,000	South Africa	11, 6
Graphitea	9,000	17,000,000	Madagascar, Tanzania, Mozambique	9, 4

[a]Statista: https://www.statista.com/. *Quantifying lithium deposits is difficult because it occurs in both rock ores and brines, that latter is difficult to quantify. [b]Investing News: https://investingnews.com/. [c]World Mining Data: https://www.world-mining-data

The next tier of minerals for lithium-ion batteries includes aluminium and copper. These are primarily employed as current collectors for the cathode and anode, respectively. Incredibly, there is a large supply of these minerals in Africa. For example, there are 45 million metric tonnes of bauxite produced in Guinea[80] and 755,000 metric tonnes of copper in Zambia in 2017.[81] Even when LFP chemistry is considered, Africa still boasts an abundant resource in the two key additional minerals, iron and phosphate. For example, South Africa produces 80 million metric tonnes of iron ore, making it the 7th largest producer in the world.[82] On the other hand, Morocco and Western Sahara are ranked 3rd in the world at 33 million metric tonnes of phosphate production and holding 70% of the world's reserves.[83]

To capitalise on this mineral resource base, a key strategic imperative for success is establishing the entire value chain for battery technology underpinned by the giga-scale model of production. Although we cannot ascertain the data for Africa, the Australian case is as illuminating as it is compelling. For example, Figure 13 exhibited the stunning reality that by only focusing on mining and processing lithium ore into concentrate, only a minuscule 0.53% of the value chain was accrued to Australia in 2017. However, Figure 13 also revealed that the real value comes from electrochemical production, battery cell production, and battery pack/ systems assembly. This clearly demonstrates that a similar could be observed in the case of Africa and African countries missing on such wealth creation opportunities within the value chain.

[80] https://en.wikipedia.org/wiki/List_of_countries_by_bauxite_production
[81] https://investingnews.com/
[82] https://www.worldatlas.com
[83] https://investingnews.com

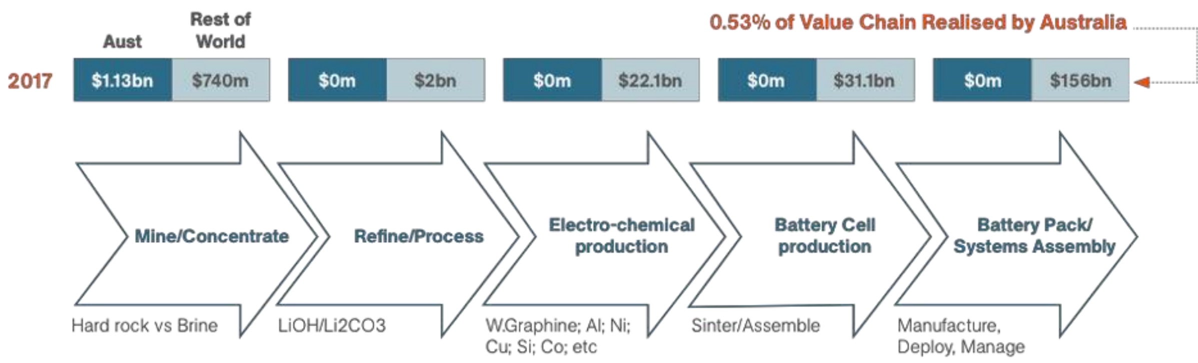

Figure 13: Lithium value chain in lithium-ion battery technology [Source: Future Smart Strategies, 2018].[84]

In response to this realisation, Australia is moving swiftly towards establishing a full lithium-ion battery value chain by building manufacturing plants under licensed technologies. For example, the Townsville Gigafactory (15 GWh) Project and Renaissance One in Darwin have been established by Australia. Furthermore, there are efforts in enhancing the corresponding research base. For example, the Lithium Australia, and the Future Battery Industries Cooperative Research Centre are focusing on such efforts. Furthermore, this is closely complemented with a "Lithium Valley" strategy in Western Australia that includes the planned Kemerton Lithium Hydroxide Plant. Notably, Australia is a resource-rich continent as is Africa. Therefore, it offers realistic and instructive insights on the trajectory Africa might follow. Hence, Africa needs to declare lithium-ion battery manufacturing a strategic industry and adopt a radical agenda of industrialisation, research, development, and innovation coupled with a strong enabling policy framework. In the remainder of this chapter, the proposed bold strategy for industrialisation, research, development, and innovation is discussed. The policy framework is the subject of the next chapter.

6.2 Immediate Industrialisation

In developing the strategy for immediate industrialisation, it seems most logical to first target the high-value segments of the value chain. Indeed, this is the approach widely adopted in recent projects around the world. As shown in Figure 13, the most value is in the battery packing and systems assembly link of the value chain, followed by battery cell production. Thus, APET suggests an initial manufacturing programme that includes cell production and packing/systems assembly. In this regard, the trajectory that seems to have worked elsewhere is:

- Build and operate a pilot plant: Typically, a few can be created with a capacity of 100 MWh/year in size. This usually requires choosing a chemistry and then manufacturing under license with a technology partner. The cost of such a plant can be up to US$200 million. The timeline from feasibility study to plant commissioning is about 18 months. Notably, the purpose of the pilot plant is to develop local skills and build the associated industrial ecosystem and infrastructure. Typically, the plant is operated for at least a year. Overall, the pilot plant is a critical stage of technology demonstration and the firming up of the business case for large-scale commercial manufacturing.

- Full-scale plant: To benefit from economies of scale, a capacity of 10 GWh/year is recommended. While it is difficult to get accurate numbers for the capital budgets for battery manufacturing plants, it is estimated the cost about US$2B with a timeline of approximately three years from feasibility study to plant commissioning. The cost estimate is based on US$200M/ GWh[85] according to data from the Joint Research Centre Science for Policy Report (2017).[86]

[84] The Lithium-Ion Battery Value Chain, New Economy Opportunities for Australia, Commonwealth of Australia 2018
[85] McKinsey Report: https://www.mckinsey.com/industries/oil-and-gas/our-insights/recharging-economies-the-ev-battery-manufacturing-outlook-for-europe.
[86] EU Competitiveness in Advanced Li-ion Batteries for E-Mobility and Stationary Storage Applications – Opportunities and Actions (2017).

- In tandem with the two preceding steps, the groundwork for the associated industrial ecosystem and infrastructure is laid out. The ecosystem includes elements of both backward and forward integration to fully close the gaps identified in Figure 13. Salient among these are lithium refineries, electrolyte and separator manufacturing plants, and other battery-grade inputs for backward integration. In addition, the distribution facilities, recycling/repurposing, and disposal plants support the forward integration. Notably, significant support infrastructure may be required and any critical infrastructure such as power, road, rail, port, and airport facilities should be provided by the governments.

The implementation of the immediate industrialisation programme involves governments, established companies, and start-ups ecosystems. Typically, ambitious start-ups build consortia with established companies that have expertise in various aspects of the value chain. This should be supported by governments through support infrastructure, grants, and other policy frameworks as discussed in Chapter 7. Examples by which this model is being implemented include Northvolt of Sweden, the Imperium (iM3) consortium for the Townsville Gigafactory Project, and Saft in France. In the case of Saft, the programme is implemented through a consortium with Solvay (from Belgium with expertise in polymer and electrolyte solutions), Manz (from Germany, with an expertise in cell and module assembly equipment), and Siemens (from Germany, with expertise in manufacturing automation solutions). Saft is set to launch the mass production of 3rd generation liquid electrolyte lithium-ion batteries in 2020, followed by Generation 3B in 2022, and then 4th generation (solid-state) batteries in 2024.[87] Finally, assuming a 2020 start of this programme in Africa, the immediate industrialisation programme could be complete by 2025.

6.3 Research, Innovation, and Development (RI&D)

The scope of the proposed research programme spans the entire battery technology value chain from the atomistic modelling of materials to the recycling and disposal of batteries. Consequently, multi-sector collaborations are necessary to support the full research programme. This demands a tightly woven network of co-creating actors capable of delivering a compact and strategic research and development agenda. Through this agenda, basic and applied research can be intimately integrated together for seamless translation into innovative products. As discussed in Chapter 10, a pragmatic paradigm for the best use of the collective resources in this scenario appears to be the Triple Helix institutional form. This organisational form has demonstrated its capacity to accelerate the development of economically viable innovations through the efficient flow of knowledge and action within the innovation ecosystem. However, because of the great diversity of actors coming together for this continental project, it is critical to appropriately calibrate the institutional form to the different circumstances of the actors as organisational and governance structures will vary in each situation.

Precise funding requirements for the RI&D program cannot be readily estimated without detailed knowledge of its components. Data from other countries and regions can only be indicative as circumstances can vary widely from one place to another. For instance, the European Union through the European Battery Association is set to directly invest €200 million in battery research and innovation. On the hand, the British Government through the ISCF Faraday Battery Challenge invested £246 million for their RI&D programme.

6.3.1 Research Priorities

The research priorities are determined by the demands of establishing a viable full value chain for next-generation batteries. Thus, the components of the research strategy inherently span the entire value chain, as shown in Figures 12 and 13. However, since the closing of the gaps in the value chain is a phased programme, the research priorities need to be developed in tandem and closely coordinated with the industrialisation programme. Furthermore, in identifying and implementing the priorities, deep collaboration among the three main actors known as governments, industry, and research institutions, is required. This can be carried most particularly by establishing suitable consortia between industry and research institutions. This process can be

[87] Reuters Business News, September 12, 2018: https://www.reuters.com/article/uk-autos-batteries-saft-

substantially facilitated by African governments. Ideally, the industry should lead the identification of research priorities as this enhances the opportunities for commercial use of the research programme. Since both the industrialisation and research programmes entail cross-sectoral and multidisciplinary components, a successful implementation calls for a coherent overall strategy under a new and strong institutional framework as will be discussed in chapter 10.

As a flexible guide, APET suggests the following criteria for determining the research priorities:

- Maximal support for the immediate industrialisation programme: The phasing must be appropriately synchronised with the timeline of the industrialisation programme. This can also facilitate the training of the next-generation engineers and scientists for the nascent industry;
- Energy storage focused: As there is no battery technology that can satisfy all the requirements of all the different applications, it is expected that in future, there will be technology differentiation with distinct specialisations for particular applications. Therefore, the long-term strategy is to develop a bespoke plug and forget mini/micro-grid and stand-alone energy storage solutions optimised for the African context. Thus, Africa can exclude any significant expenditure in specialised technologies for other application spaces such as electric vehicles;
- Effective low-cost solutions: Affordability of the final product is a key success factor for the electrification of Africa, and this should be prioritised;
- Maximise Africa's strategic advantages in this industry; and
- Cost-efficiency: Some programmes require minimal upgrades to existing infrastructure (see Chapter 10) and therefore present low-hanging fruit that should be targeted.

In what follows, this report will only give preliminary examples of aspects that may be considered for the research, development, and innovation programmes. Notably, the panel is deliberately refraining from prescribing any specific research areas as more detailed research and evidence as well as deep collaboration among all the main actors are required first, all of which are beyond the scope of this report.

6.3.1.1 Mining and Processing

Mining and some processing are already taking place across Africa. The research could be directed towards the overall efficiency of resource extraction, recovery, and disposal. However, heavy investment in this area does not seem imperative.

6.3.1.2 Refining and Processing of Battery-grade Materials

The extreme purity of more than 99.8% is demanded in materials for battery applications. Consequently, advanced processing technologies are required to meet stringent requirements. Based on research by the panel and experts, none of the main battery minerals is currently being processed to battery-grade quality in Africa. This is a key research area that needs an adequate priority to build manufacturing capacity in this segment of the value chain.

6.3.1.3 Manufacturing of Materials, Battery Cells and Modules

To unlock the full potential of the industry, this part of the value chain must be given the highest priority. Currently, this is the most intellectual property heavy part of the industry, and therefore a technology partner is mandatory for initial entry. Unsurprisingly, it is also the most lucrative segment of the value chain and our proposed entry point for the immediate industrialisation programme. Thus, the foundation for the eventual success of the entire programme must be laid here. Therefore, the main research priorities fall into two broad categories:

- Advanced battery materials research: This is a full-strength programme spanning from materials discovery, synthesis, characterisation, and fabrication. Ideally, only one or two chemical compositions for battery materials would be selected to focus limited resources on a manageable scale; and

- Advanced battery cell research: This covers cell manufacturing, module, and pack assembly together with the battery management systems and other controls. The state-of-the-art cell manufacturing is a painstakingly delicate engineering operation characterised by very slow learning rates. Significant cost reductions can be realised by better manufacturing technologies. Africa could even leapfrog to factory-of-the-future technologies since it does not yet have any technology lock- in barriers to overcome. The proposed pilot plant could be used as a testbed for some of those technologies.

The entire programme needs to be supported by multi-scale modelling from an atomic scale to the module level. This research programme together with the immediate industrialisation programme constitutes most of the high-value jobs in this industry.

6.3.1.4 Product Distribution

Mapping out existing distribution channels and performing projections of future requirements is necessary. Furthermore, developing rigorous models for efficient product distribution and waste collection systems for the entire industry is also vital.

6.3.1.5 Second Life, Recycling, and Disposal

It is essential to develop solutions with a recyclability and sustainability profile to promote eventual transitions to circular economies. This may be carried out with an emphasis on an adapted form of the 3R strategy consisting of "reuse", "remanufacturing", and "recycle".[88] In this case, research is required to establish appropriate recycling and disposal technologies essential for used LIBs. Furthermore, the recycle and disposal stream will include batteries that are not manufactured in Africa meant for electric vehicles and other applications. Thus, extending the service life of a battery significantly enhances its sustainability profile. After the normal use of about 10 years, an EV battery retains about 80% of the nominal capacity. Therefore, it can be viable for less energy- demanding applications such as residential buildings.[89] Additionally, to be fit for this secondary application, the battery pack has to be tested, refurbished, and repurposed. It is known that the use of a retired EV battery in a different application is called its second life and may extend its overall service life quite considerably, as shown in Figure 13. For example, with an 18-year total battery life, the second-life use may be up to 8 years. Thus, this clearly reduces the overall raw materials intensity of the industry.[90]

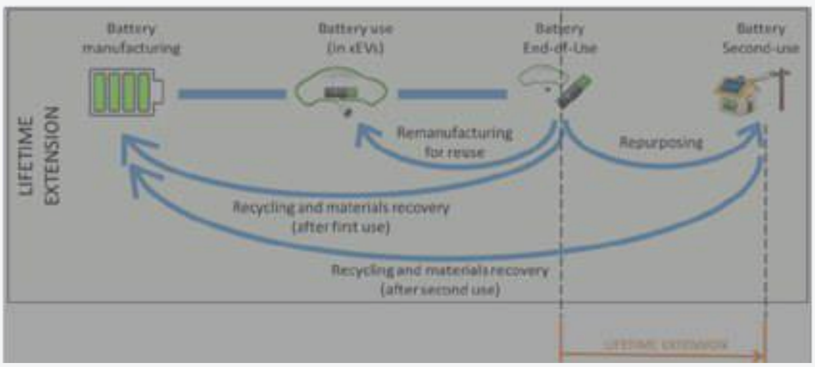

Figure 14: Extending battery life through second-life applications before recycling; thus, creating a circular economy for battery technology.[91]

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[88] M. Kurdve, M. Zackrisson, M.I. Johansson,B. Ebin, U. Harlin, Considerations when modelling EV battery circularity systems, Batteries 5 (2019) 40: https://doi.org/10.3390/ batteries5020040.
[89] S. Arens, S. Schlüters, B. Hanke, K. von Maydell, C. Agert, Sustainable Residential Energy Supply: A Literature Review-Based Morphological Analysis, Energies 13 (2020) 432: http://dx.doi.org/10.3390/en13020432.
[90] L.C. Casals, B.A. Garcia, M.M.G. Benitez, A cost analysis of electric vehicle batteries second life businesses, Conference Paper, July 2014, DOI: 10.13140/2.1.2046.8485: https://www.researchgate.net/publication/266322044.
[91] S. Bobba, F. Mathieux, G.A. Blengini, How will second-use of batteries affect stocks and flows in the EU? A model for traction Li-ion batteries, Resources, Conservation and Recycling, 145 (2019) 279-291: https://doi.org/10.1016/j.resconrec.2019.02.022.

In order to determine the phasing of research priorities for second life, recycling, and disposal, reliable estimates of used battery streams are required. Considering the rapid growth in EVs and shorter service life for this application, the expectation is that used EV batteries will initially constitute the largest stream. The World Economic Forum estimated that the global cumulative second-life storage capacity at almost one TWh will be accomplished by 2030 (Figure 15). Therefore, this clearly demonstrates the significance of this part of the value chain to the industry. Unfortunately, accurate estimates specific to Africa are currently difficult to find, indicating a need for further research. Nonetheless, a rough estimate for this report can be obtained by doubling the estimated 145,000 EVs by 2025 in South Africa alone.[92] By interpolation in Figure 15, about 3 GWh of second-life storage is then estimated by 2025 for the continent. Assuming a use-life of 10 years, the infrastructure for second-life use with a processing capacity of about 120,000 tpa based on a 400 kg battery pack per vehicle can be achieved. Recycling should be ready by 2030 while collection facilities must be phased in earlier to begin the gradually acculuate materials.

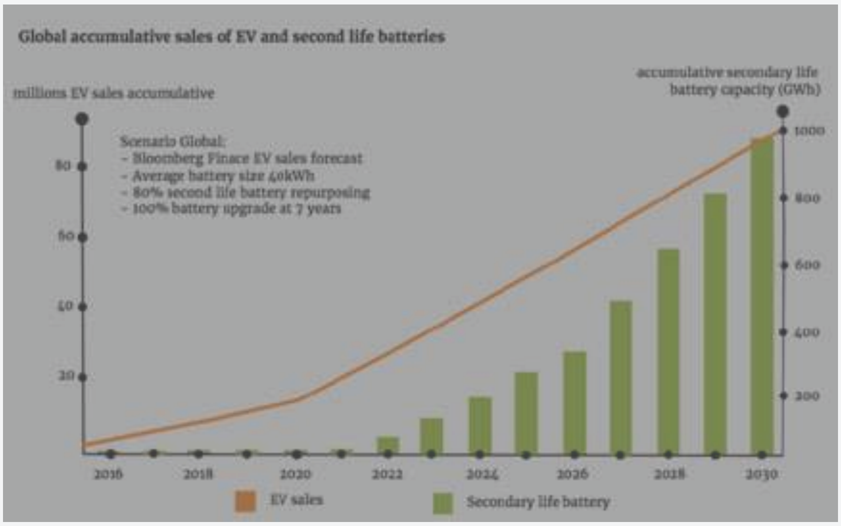


Figure 15: The projected cumulative capacity of second-life batteries as flexible storage for renewable energies.[93]

Lithium-ion battery recycling is significantly different from conventional batteries. A wide range of recycling technologies can be considered, as shown in Figure 15. However, it is crucial to note that these recycling technologies are still in their infancy with considerable research and development yet to be carried out. For instance, the US Department of Energy only recently established its Lithium Battery R&D Recycling Centre led by Argonne National Laboratory.[94] LIBs recycle rates are at about 3%[95] and this is extremely low. Furthermore, most commercial technologies only recycle cathodes so to recover cobalt and nickel and considering the lithium recovery uneconomical.[96] However, hydrometallurgical routes offer a more promising path towards lithium recovery.[97] Accordingly, a substantial part of the research effort should be focused on determining the most appropriate technology for the African context and developing the technology up to a commercial scale. The same is also true for final disposal technologies.

[92] https://www.businesslive.co.za/bd/life/motoring/2019-01-31-get-ready-for-the-brave-new-electric-car-world/
[93] https://www.weforum.org/agenda/2017/11/battery-batteries-electric-cars-carbon-sustainable-power-energy/
[94] Recycling Today, February 18, 2019: https://www.anl.gov/article/recell-center-could-save-costly-nickel-and-cobalt-transform-battery-recycling-worldwide
[95] A. Beaudet, F. Larouche, K. Amouzega, P. Bouchard, K. Zaghib, Key Challenges and Opportunities for Recycling Electric Vehicle Battery Materials: Review, Sustainability 12 (2020) 5837: doi:10.3390/su12145837.
[96] https://www.iisd.org/sites/default/files/publications/sustainability-second-life-cobalt-lithium-recycling.pdf.
[97] X. Zheng, Z. Zhu, X. Lin, Y. Zhang, Y. He, H. Cao, Z. Sun, Research Green Industrial Processes—Review A Mini-Review on Metal Recycling from Spent Lithium Ion Batteries, Engineering 4 (2018) 361-370: https://doi.org/10.1016/j.eng.2018.05.018.

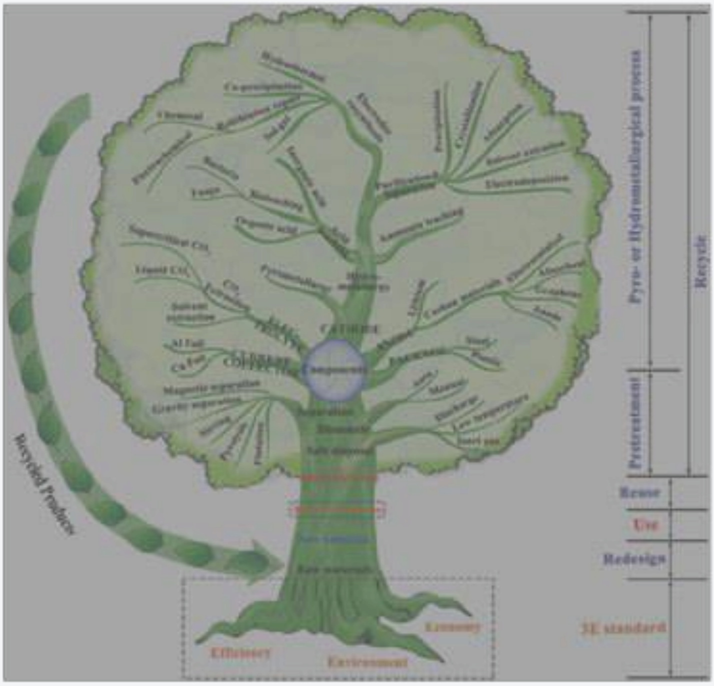


Figure 16: Examples of battery recycling technologies.[98]

6.3.1.6 Policy Framework

There are complex policy issues, technical standards, safety, and environmental regulations that need to be worked out throughout the value chain. While some of these could be adapted from other jurisdictions, original development will almost certainly be required in areas where bespoke innovative solutions are implemented such as in battery recycling. Another important area of policy research is intellectual property (IP) protection offer certainty and predictability to innovators. Africa is currently poorly ranking on many of the key metrics in this area as reported by the World Intellectual Property Organisation Global Index on Innovation[99] and the US International IP Index.[100]

6.3.1.7 Commercial Environment

African governments are encouraged to address the need to understand both the local and global operating environment and continually innovate and update business models for the industry. This includes developing strategies to improve both the overall Logistics Performance Index[101] and WEF Global Competitiveness Index of the continent. These are respected indices in the business world that determine the global flow of FDI.[102] Therefore, there is a need for Africa to affect some research focusing on developing specific strategies for achieving better performance on the indices.

[98] X. Zhang, L. Li, E. Fan, Q. Xue, Y. Bian, F. Wua, R. Chen, Towards sustainable and systematic recycling of spent rechargeable batteries, Chemical Society Reviews 47 (2018) 7239-7302: https://doi.org/10.1039/C8CS00297E.
[99] https://www.wipo.int/publications/en/
[100] https://www.uschamber.com/press-release/us-chamber-releases-2019-international-ip-index
[101] https://lpi.worldbank.org/
[102] https://www.weforum.org/reports/the-global-competitveness-report-2018

6.4 Geographic Distribution of the Programme

If this programme is implemented on a continental scale as is envisaged in this report, APET suggests the creation of manufacturing hubs with co-located innovation clusters. For instance, this means that a bauxite refinery to produce battery-grade aluminium is located near a bauxite mine. This can be done along with other downstream industries such as the manufacture of rolled aluminium foil for cathode current collectors, and production of aluminium alloy cans and cases for battery packaging. This manufacturing hub can be supported by an appropriate research and innovation cluster consisting of research institutions and entrepreneurs. This can allow deep collaboration and a strong knowledge triangle for accelerated innovation and commercialisation. The innovation cluster can benefit from an efficient sharing of infrastructure, facilities, knowledge, skills, and expertise offered by the physical proximity. An important consideration is building on existing strengths. For instance, the assumption is that research institutions, more especially universities, already exist. However, these research institutions may need some additional resourcing and capacity-strengthening to host the new programme. In some cases, these research institutions may already possess specialised facilities for a particular segment of the value chain. Thus, that can be exploited in the location of innovation clusters. For example, the University of the Western Cape in South Africa already has a very small lithium-ion battery pilot plant. This might make this university a good candidate to host a component of the programme. Furthermore, it is envisaged that once the details of the full programme have been worked out, AU Member States can submit technical bids to host the various components of the programme.

6.5 Conclusion

Based on the urgent aspiration for human development and sustainability, Africa's strategy on next-generation battery technology must ensure access to affordable and reliable energy for all Africans. Africa ought to substantially increase its share of renewable energy in the global energy framework. This will offer Africans a high standard of living, quality of life, and well-being for all according to the SDGs. If the NGBs programme is implemented on a continental scale, there is a need to create manufacturing hubs with co-located innovation clusters. This can be structured such that there are other downstream industries such as the manufacture of rolled aluminium foil for cathode current collectors, and production of aluminium alloy cans and cases for battery packaging. Furthermore, the manufacturing hub can be supported by an appropriate research and innovation cluster consisting of research institutions and entrepreneurs. Consequently, the deep collaboration and a strong knowledge triangle for accelerated innovation and commercialisation could benefit innovation clusters for an efficient sharing of infrastructure, facilities, knowledge, skills, and expertise offered by the physical proximity.

7

Policy and Regulatory Framework

The overall intent of the policy framework is to stimulate and support a viable value chain for lithium-ion battery technology across the continent. This requires policy stability, predictability, and regulatory transparency to achieve social, technological, and environmental sustainability while enhancing the ease of doing business and de-risking long-term capital investment. The ideal case is the implementation of the policy framework on the continental scale and in any case, at least the regional scale should be targeted since individual national economies may not offer large enough markets. Existing regional and continental institutions that may facilitate policy development such as the African Centre for Technology Studies need to be identified and consulted. Some aspects of the envisaged policy package are outlined in the following discussion.

7.1 Minerals Policy

The objective of these policies is to develop and secure battery grade feedstock for the immediate industrialisation programme. The policy should discourage the export of battery minerals in ore form; instead, comprehensive incentives should be offered for advanced beneficiation. The level of beneficiation should gradually increase so that by 2030, there exists enough local capacity to produce battery-grade feedstock from all the minerals mined on the continent. For example, the requirement for lithium exportation may initially simply involve processing to a 6% concentrate (lithium carbonate) before gradually ramping it up to battery quality by 2030. This needs to be complemented with a preferential pricing regime for the local battery manufacturers. A minerals policy underpinned by a strong drive towards local beneficiation is already implicitly present in the African Mining Vision.[103]

7.2 Market Policy

The battery industry is extremely competitive with rapid reconfigurations of the market landscape. For example, the market share of the South Korean giants such as LG Chem, Samsung SDI, and SKI dropped from 30% in 2014 to a mere 11% by 2018. At the same time, significant growth was reported by the Japanese companies such as Panasonic, primarily through a partnership with Tesla, and Chinese companies such as BYD and CATL, largely underpinned by the domestic market competitors [Korean Economic Research Institute]. Recently, LG Chem is reportedly suing Volkswagen to enforce an exclusive supplier status after the latter entered into a supply deal with SKI.[104] Not only is the competition coming from the traditional battery manufacturers, but also from car manufacturers backwards integrating to future-proof supply chains.[105]

Most importantly, for the proposed African lithium-ion battery industry to take off and thrive in this hostile environment, it is imperative to introduce a package of policies to secure viable domestic markets for the proposed battery production capacity. Notably, governments and state utilities will be large consumers of energy storage products. Therefore, it is necessary to implement policies for government departments and their associated entities directing the procurement of energy storage products to support the continental battery strategy.[106]

[103] https://au.int/sites/default/files/documents/30984-doc-africa_mining_vision_english.pdf
[104] http://www.koreaherald.com/view.php?ud=20190512000157
[105] https://www.koreatimes.co.kr/www/tech/2019/04/133_265987.html
[106] https://www.theafricareport.com/21865/africa-must-assume-its-place-in-the-global-battery-race/

7.3 Investment Policy

A successful innovation programme mandates the creation of a robust venture capital ecosystem. It is, therefore, necessary to establish a venture capital investment vehicle under the direct supervision of the AU Commission. Its scope can focus primarily on all emerging technologies within the ambit of the AUDA-NEPAD programme. For ease of reference, APET is designating this investment vehicle as to the African Innovation Capital Company (AICC) throughout this report. Principally, the primary objective of the AICC is to supplement private equity in the emerging technologies space to support the full life cycle of innovation. Crucially, the AICC will provide risk capital in the early stages of innovation for seed investments, start-up support and financing, and early growth support frameworks. Thus, hand-holding nascent innovations across the "valley of death." A co-investment model in which AICC co-invests a 30% equity with reputable private venture capital entities. To support the full life cycle of innovation in terms of seed, start-up, early growth, expansion, and maturity, there are two types of primary investment funds being proposed:

- "Risk" funds: This is public risk capital directly funded from the AU Commission budget and dedicated to the early stages of innovation; and
- "Safe" funds: The African diaspora is the primary source of these funds targeted at the late stages of innovation including early growth, expansion, and maturity stages. There is a significant opportunity to harness substantial investment funds from the African diaspora if a suitable transparent investment instrument is established, such as diaspora bonds.

Overall, a continent-wide favourable financial environment needs to be created to encourage all innovation actors in emerging technologies to participate. A concessionary environment for borrowers is required with comprehensive credit platforms such as loan guarantees and soft loans.

7.4 Procurement and Taxation Policy

It is essential to provide substantial incentives for the acquisition of land, equipment, and machinery intended for the entire battery value chain. This should include tax exemption packages and other subsidies for innovators and Africa's companies.

7.5 Second Life, Recycling, and Disposal Policy

As a rule of thumb, electric vehicle batteries retain about 80% of their original capacity when they are retired.[107] The useful life of these battery packs can be extended by repurposing them for secondary use, typically in stationary applications, as shown in figure 17. The motivation for LiBs recycling is the protection of human health and the environment as well as the recovery of valuable metals for the battery industry. Most significantly, it needs to be recognised that LiBs contain materials that are toxic and considered heavy metals such as cobalt[108] and flammable such as organic electrolytes. These materials are reactive in the event of a catastrophic failure such as lithium hexafluorophosphate ($LiPF_6$) as they can react with other battery components to produce toxic hydrofluoric acid (HF) acid.[109] On the other hand, raw materials make up about 60% of the total battery cost, of which 40% is cathode materials. Therefore, recycling these materials makes economic sense and reduces the energy intensity of battery production by between 40% and 50%.[110]

An end-of-life LiBs management system that couples to the second-life system need to be developed. There are many possible configurations for the relationship between the recycling and second-life systems. The exact configuration implemented depends on the business model adopted. This in turn depends on the regulatory framework. Generally, two business models are possible depending on the legal obligations imposed on the original equipment manufacturers (OEMs), i.e., the battery or EV manufacturers.[111]

[107] https://www.greencape.co.za/assets/Uploads/ELECTRIC-VEHICLES-MARKET-INTELLIGENCE-REPORT-WEB.pdf.
[108] L. Leyssens, B. Vinck, C. Straeten, F. Wuyts, L. Maes, Cobalt toxicity in humans. A review of the potential sources and systemic health effects, Toxicology, 387 (2017): DOI: 10.1016/j.tox.2017.05.015.
[109] F. Larsson, P. Andersson, P. Blomqvist, Toxic fluoride gas emissions from lithium-ion battery fires, Scientific Reports 7 (2017) 10018: https://doi.org/10.1038/s41598-017-09784-z.
[110] https://greet.es.anl.gov/publication-lib-lca
[111] M. Kurdve, M. Zackrisson, M.I. Johansson, B. Ebin, U. Harlin, Considerations when modelling EV battery circularity systems, Batteries 5 (2019) 40; doi:10.3390/batter- ies5020040.

Under a policy of extended producer responsibility, the OEMs are required to meet a specified recycle rate for their batteries. In this case, the Power Battery Recycling Company in Figure 17 is controlled by the OEM.

While this policy framework may be simpler to enforce and could encourage OEMs to design batteries for recyclability, it imposes a significant commercial burden on the OEM because of the large capital investment to build battery recycling plants. In contrast, an open market policy for the recycling and second-life business allows independent actors to participate purely on the profit performance of the sector. This model is currently prevalent for used lead-acid batteries in Africa and the main challenge is the proliferation of backyard operations placing an enormous burden on licensing and inspection as well-documented by The Lead Recycling Africa Project.[112] There are also additional problems unique to LiBs under this model. While lead-acid batteries consist of only one chemistry, LIBs come in many different chemistries requiring different recycling technologies. The streams from different chemistries are more likely to be mixed in the free market environment, demanding extensive product labelling to ensure safe handling and processing. Additionally, the disassembly of LIB packs is far more complicated than that of lead-acid batteries and, if not fully discharged, catastrophic explosions can occur.

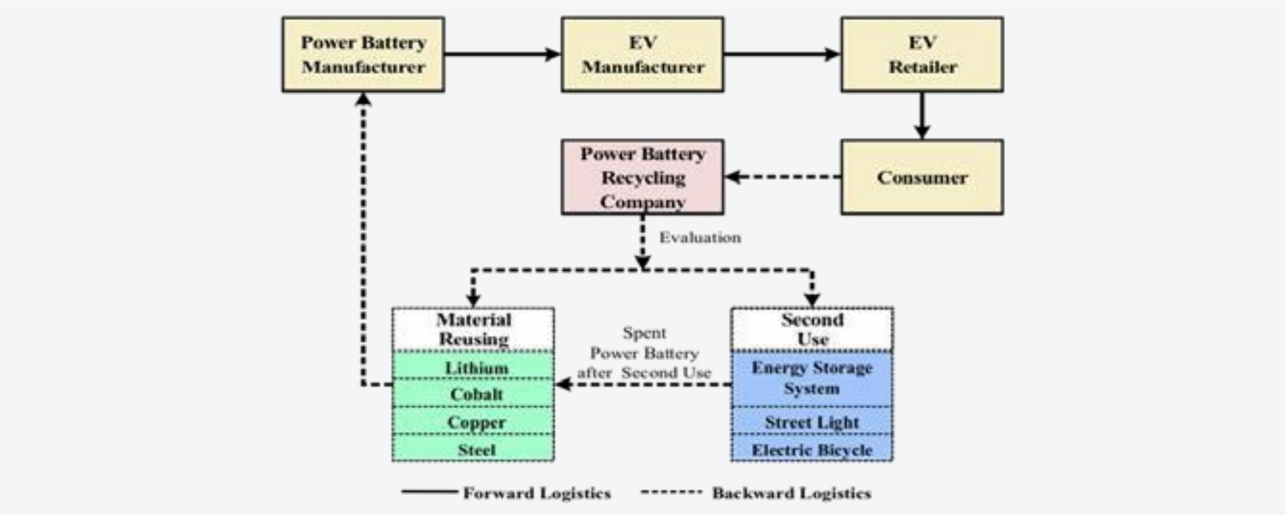


Figure 17: A possible coupling between recycling and second-life operations where the recycling operation performs the state-of-health testing of used electric vehicle (EV) battery packs.115

While further research is needed to determine the most appropriate policy environment, some general considerations may be stated here. For example, the material stock and flows need to be quantified to develop policies that guide the safe second-use of used battery packs from electric vehicles considering the heterogeneity of these packs.[113] That means appropriate technical standards will need to be developed regulating the collection, transportation, and testing of the used batteries before they can be repurposed for second-life applications. In particular, the regulatory framework needs to address the increased risk that the second-life user is exposed to since the state of health of a used battery is strongly dependent on its usage history. Thus, a regulatory framework that provides classification and handling of end-of-life LiBs is required. Notably, a wide range of LiBs recycling technologies exists as shown in figure 17.[114] Consequently, the most appropriate technology can be determined once the characteristics of the LiBs are known, i.e. chemistries and quantities.

[113] E. Martinez-Laserna, I. Gandiaga, E. Sarasketa-Zabala, J. Badeda, D.L. Stroe, M. Swierczynski, A Goikoetxea, Battery second life: Hype, hope or reality? A critical review of the state of the art, Renewable and Sustainable Energy Reviews 93 (2018): DOI: 10.1016/j.rser.2018.04.035.-

[114] M. Chen, X. Ma, B. Chen, R. Arsenault, P. Karlson, N. Simon, Y. Wang, Recycling end-of-life electric vehicle lithium-ion batteries, Joule 3 (2019) 1–25: https://doi.org/10.1016/j.joule.2019.09.014.

[115] E. Mossali, N. Picone, L. Gentilini, O. Rodrìguez, J.M. Pérez, M. Colledani, Lithium-ion batteries towards circular economy: A literature review of opportunities and issues of recycling treatments, Journal of Environmental Management 264 (2020) 110500: https://doi.org/10.1016/j.jenvman.2020.110500.

Policy incentives need to be deployed to attract private players into the LiBs recycling business so that a robust waste LIBs collection and recycling infrastructure can be established. In particular, it should be noted that the LIBs second life and recycling business is sensitive to the price of new batteries. Therefore, it is possible for this price to fall below the profitability margin for this recycling business in future. Such a case may necessitate further government incentives to support the continued removal of hazardous LiBs waste from the environment. Since a more effective strategy in LiBs recycling requires the separation of the LiBs waste streams according to chemistry, labelling regulations should be developed so that the LIB chemistry can be readily identified from the product casing. Thus, public education programmes to support recycling will be required for the public to understand the risks and benefits of LiBs recycling. Finally, in the absence of recycling infrastructure, it may be possible to temporarily dispose of small amounts of fully discharged used LiBs in landfills that are sealed to prevent groundwater contamination from metal leachate.

7.6 Conclusion

African governments are encouraged to create policy and legal frameworks that can stimulate and support a viable value chain for lithium-ion battery technology across the continent. This will require policy stability, predictability, and regulatory transparency so to achieve social, technological, and environmental sustainability. In turn, these policy and regulatory frameworks could enhance doing business and de-risk long-term capital investment for the private sector. These policies can be implemented at national, regional, and continental levels to ensure the appropriate investments are put forward by the private sector. There is a need to invest in LiBs recycling business so that a robust waste LiBs collection and recycling infrastructure can be established. Notably, the LiBs second life and recycling business is sensitive to the price of new batteries; thus, impacting profitability margin of the recycling business in future. However, incentivising and strengthening the capacity of the recycling business will ensure a continued removal of hazardous LiBs waste from the environment.

8

Youth, Skills, and Capacity Development

8.1 Human resource development and technology education

The energy storage technology will continue to play a significant role in the promotion of greener environment, industry stimulation through reliable energy supply, and poverty alleviation through job creation. Therefore, to benefit from this huge opportunity, Africa needs to invest heavily in human resource development and technology education relating to next generation batteries. To ensure business continuity at the projected rate of expansion, the focus really lies in substantial human resource development.

Currently, the bulk of the advanced battery technologies are developed in the northern hemisphere. There are large investments that have been put into research and development of next generation batteries such as solid-state and nanotechnologies. Thus, it is not surprising that almost all the intellectual resources are also located up north. For example, Japan and South Korea dominate the pioneering of new technologies, while China dominates the mass production and deployment. The United States of America and Germany have also contributed to improved battery technologies, manufacturing, and testing processes. However, the largest human resource pool lies in Asia, resulting in many start-up manufacturers in Europe and the United States of America headhunting in Asia. A case in point is Sweden's Northolt employing former Sony and BASF executive Yasuo Anno as its Chief Development Officer. Therefore, with a robust human resource development programme and technology education in Africa can significantly improve skills for the youth in Africa and improve prospects of job creation and youth employment. Thus, Africa needs to put in place enabling policies that will support such efforts and improve the prospects of the next generation battery technology lifespan in the African continent.

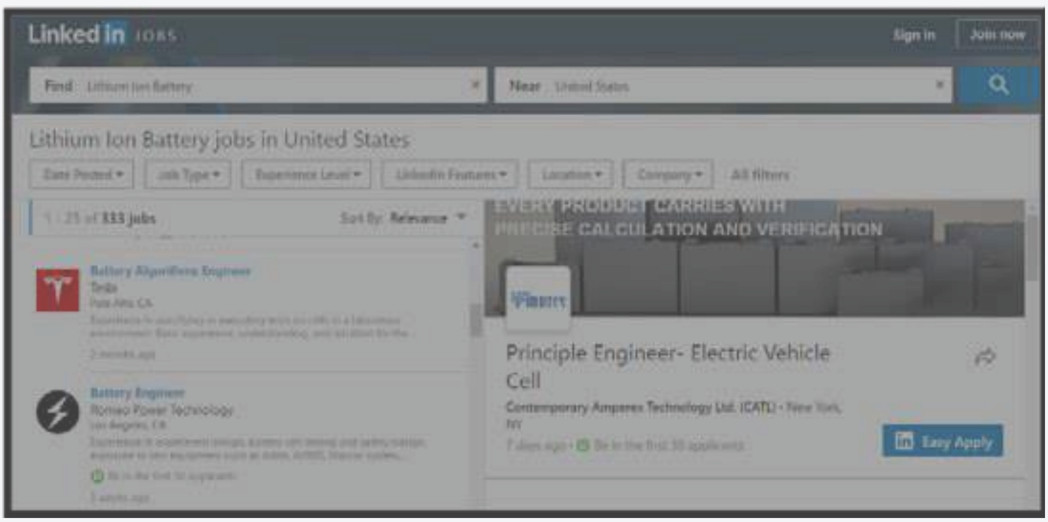


Figure 18: Linked in jobs showing lithium-ion batteries jobs in the United States

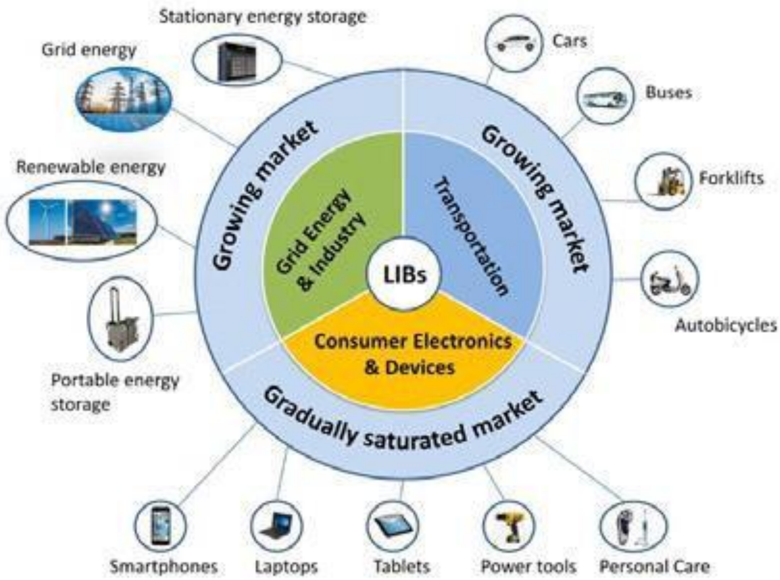
8.2 Investment in research for next generation battery technologies

Numerous northern hemisphere universities, national laboratories, and other higher learning institutions have established a curriculum to educate learners on battery technologies, as well as to pioneer new technologies and methodologies. For example, in South Africa, several government-led initiatives and institutions have been formed to address next generation batteries and human resource development. A leading institution in South Africa is the Energy Storage Innovation Laboratory at the University of the Western Cape, headed by Prof Ben Bladergroen. The Energy Storage Innovation Laboratory was launched in 2015 and focuses on electrochemical energy storage systems including the development of Li-ion, NaFeCl2 and NiFe batteries. This laboratory was created as a platform to commercialise emerging technologies in partnership with local businesses. Other South African initiatives involving batteries include Council for Scientific and Industrial Research (CSIR) with an Energy Materials unit, Uyilo with a Battery Testing Laboratory, South African Nuclear Energy Corporation (NECSA) focusing on LiFP6 development, the University of Limpopo as a precursor manufacturer, and Nelson Mandela Metropolitan University focusing on the certification of cells, amongst others.

While the initiatives to invest in battery technology education and related industries is commendable, it is far from sufficient. A challenge facing many African countries is access to funding to establish a noteworthy centre for next generation battery technology excellence. It is thus more reasonable to suggest that next generation battery technology hubs be established in designated regions and/or countries that have greater access to the critical battery raw materials. For instance, a speciality technology hub should be established in South Africa due to the abundance of manganese and fluorspar. This can incredibly combine expert resources so that a joint and concentrated effort is applied to further the knowledge base and current developments. Another speciality technology hub could be established in West Africa, perhaps Ghana or Guinea, due to the abundance of Bauxite (aluminium) and graphite. And another hub can be opened in the Democratic Republic of Congo due to the world's dependencies on its reserves of cobalt. Local beneficiation efforts can fund these technology hubs so that improvements can be made in raw material processing and beneficiation to increase the value of the exported material. Human resources can be developed to understand battery manufacturing processes. Research can be done to discover the possible next best thing for batteries.

8.3 Conclusion

If African countries only possess the raw material supplies for batteries, Africa will continue to be an extractive economy. However, minimal beneficiation of these materials will result in flat or negative GDP growth rates and large dependency on technical and financial assistance from other countries. To change this landscape, a focus must be placed on increased technology education through a pang of hunger for advancement in society. Right from basic and secondary education levels, Science, Technology, Engineering, and Mathematics (STEM) subjects must be promulgated, along with a clear strategy the on technologies that Africa should focus on for its future. Therefore, a robust human resource development programme and technology education in Africa can significantly improve skills for the youth in Africa and improve prospects of job creation and youth employment. This can be enabled by deliberate enabling policies that will support such efforts and improve the prospects of the next generation battery technology lifespan in the African continent.



Source: Ding, Y., Cano, Z.P., Yu, A. et al. Automotive Li-Ion Batteries: Current Status and Future Perspectives. Electrochem. Energ. Rev. 2, 1–28 (2019). https://doi.org/10.1007/s41918-018-0022-z

9

Readiness of Africa for Implementation of Next-Generation Battery Technologies

Africa has a tremendous backlog when it comes to research and innovation in many areas and energy storage is no exception. Therefore, without a coordinated approach, it is unlikely that a mainstream NGB will be developed and commercialised in Africa. This will not be because of a lack of potential, but because of the fierce competition worldwide. This competition is fuelled by the promise of generating US$300 billion in revenue by 2024. Thus, Africa's readiness to partake in the NGB implementation is mainly based on its strategic resource advantage. In this report, several key aspects of Africa's readiness to implement NGB technologies with particular focus on the institutional framework, infrastructure, and human capital are discussed. The report also identified the existing strengths in Africa, while pointing out areas of concern and suggesting possible approaches for overcoming the potential challenges. The assumption is that the availability of the market is based on the extremely low levels of electrification, as this electrification challenge has already been alluded to in this report.

9.1 Institutional Framework

The entire programme brings together a large diversity of actors from the Member States' governments, industries, universities, and research institutions. Notably, APET favours an institutional form of framework, which is mission-driven and can efficiently coordinate all the various heterogeneous components and actors to lead them towards a successfully shared vision. As the next section will discuss, APET suggests a Triple Helix, with the appropriate contextualisation, as a suitable reference model for the development of the institutional framework.[116]

9.1.1 The Model

To manage and implement the entire programme set out in this report, APET proposes that the first step is to create a fully-fledged institution. However, it is critical that the board of directors of this organisation are drawn from the key decisions makers of the Member States' governments, industries, universities, and research institutions. For purposes of further referencing throughout this report, this new institution was designated as the African Battery Innovation Council (ABIC). The ABIC will have a clear mandate to discharge all the functions prescribed or implied by this report, creating, and administering, a suitable institutional infrastructure to fulfil the vision and objectives of this report. Accordingly, the AU Commission shall ensure that the ABIC is duly and expeditiously constituted and commissioned as well as adequately resourced and empowered to perform its functions. The full new institutional infrastructure, of which ABIC is the highest level, is envisioned within the well-established framework of the Triple Helix for innovation systems, as shown in Figure 19. The Triple Helix is an institutional form that results from bringing together academia, industry, and state actors to form a trilateral interface of a deeply collaborating network of equal partners.[117]

[116] Y. Cai, What contextual factors shape 'innovation in innovation'? Integration of insights from the Triple Helix and the institutional logics perspective, Social Science Informa- tion (2015) 1–28: DOI: 10.1177/0539018415583527.
[117] https://doi.org/10.4324/9781315620183

There is considerable evidence of success for this institutional form in driving large-scale innovation systems. Examples are from developed economies such as Japan, Europe, and North America.[118] This model has also been observed in developing countries such as China and Pakistan as the best testimony to this success. Furthermore, there are studies that demonstrated the successful implementation of such a model in the specific case of lithium-ion battery technology in the case of the Joint Centre for Energy Storage Research in the United States of America.[119]

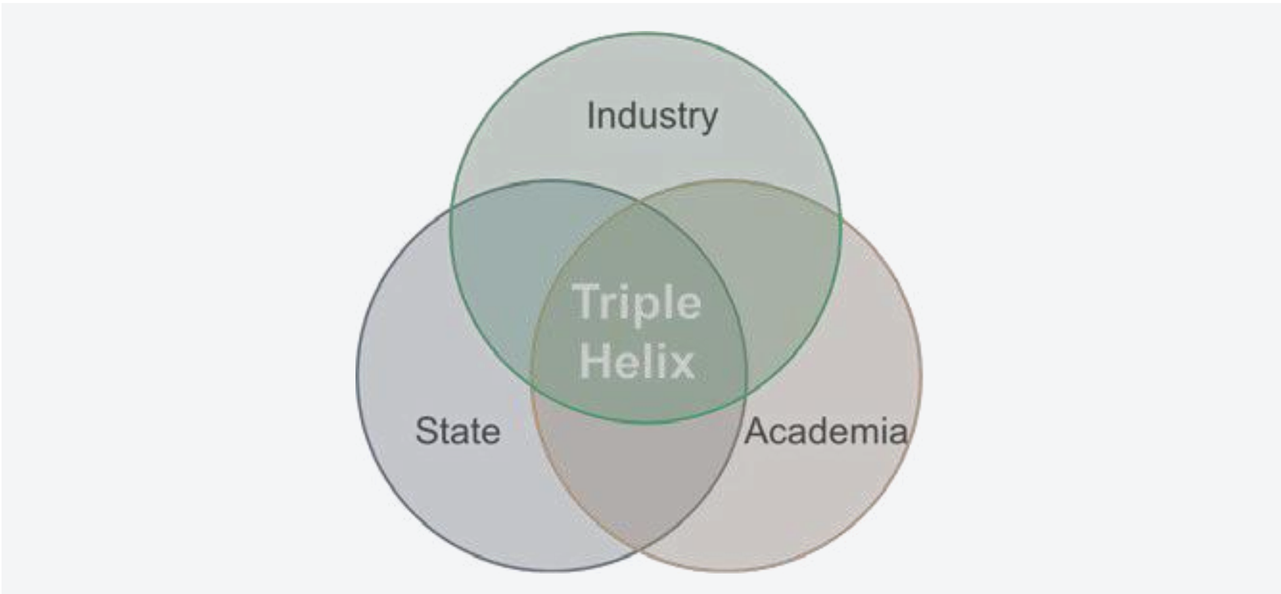


Figure 19: The 'Triple Helix', the cross-cutting hybrid space consisting of deeply collaborative actors from state, industry, and academic institutions to co-create innovative products and services. It has been demonstrated to be the nexus of successful innovation systems and it integrates both the supply and demand sides of innovation.

Within the Triple Helix are embedded innovation spaces such as a model similar to the Materials Innovation Factory at the University of Liverpool.[120] In this particular case, leading academics, researchers, start-ups and global corporations, alongside bespoke robots and digitally-enabled capabilities, are all located under one roof.[121] Crucially, these innovation spaces must contain an in-built capability to act as a technology transfer ecosystem that facilitates product development, commercialisation, and technology adoption. For this APET suggests the establishment of an African Technology Transfer Centre (ATTC) under the ABIC as an institution that directly supports innovators and entrepreneurs. This centre will also provide intellectual property market infrastructure to manage the entire patenting process that involves application filing, licensing, and transfers, and encouraging declaring patents on an international basis. The ATTC can also facilitate the establishment and standardisation of relevant technical processes and products. To achieve this, there are many suitable models that may be adapted for the creation of this entity. Examples include the Robert C. Byrd National Technology Transfer Centre (USA), China International Technology Transfer Centre, and European Technology Transfer Offices Circle. Furthermore, it is necessary for the ATTC to build synergistic alliances with existing innovation initiatives such as the Africa Innovation Summit. Also, worth highlighting in this Triple Helix institutional framework is the proposed African Innovation Capital Company (AICC) as discussed under

[118] https://doi.org/10.5367/ihe.2013.0165
[119] M.A. Shapiro, The Triple Helix within the lithium-ion battery research network: a case study of JCESR, Translational Materials Research (2018) 5 044001: DOI: https://doi. org/10.1088/2053-1613/aae860.
[120] https://www.liverpool.ac.uk/materials-innovation-factory/
[121] https://www.unilever.com/news/news-and-features/Feature-article/2018/fast-tracking-discovery-at-the-materials-innovation-factory.html
[122] https://doi.org/10.1007/978-3-319-91301-8, https://doi.org/10.1007/978-3-030-11735-1

"Investment Policy" in Chapter 8. This is a critical institution designed to overcome the well-known financial barriers for investment in the African energy sector.[122] Apart from the Triple Helix structure, a second key consideration in the organisation of the research, development, and innovation is to minimise or circumvent the enormous barriers arising from building physical infrastructure and research facilities. In this regard, the ABIC will, after determining the research priorities against the entire value chain, undertake a detailed infrastructure survey across the continent. The purpose of this survey is to determine where research facilities and skills already exist or can be upgraded with minimal resources and, among other strategic considerations, match these with the research priorities. Strategic considerations could include the advisability of co-locating a research priority with a strategic area for a specific element of the value chain. Consequently, the research, development, and innovation programme of the ABIC is expected to be distributed across the continent, as discussed in Chapter 7. By taking advantage of existing facilities and competencies, the ABIC can launch its research programme quicker and with significantly lower upfront costs. Similar models already exist elsewhere such as the Faraday Institution (United Kingdom) and the Joint Centre for Energy Storage Research (United States of America). The infrastructure of manufacturing hubs and innovation clusters can be networked through the ABIC to ensure efficient knowledge dissemination and continued creation of opportunities for collaboration.[123]

9.1.2 The Justification

While it is possible and encouraged for individual countries and regions to implement the proposed institutional and policy framework, the real optimal value of this programme can only be realised through a continent-wide strategy. There are several reasons to advocate for this approach. Firstly, the bedrock of the proposed programme is Africa's clear strategic advantage in abundant battery mineral resources. However, no single AU Member State has all the main minerals required for state-of-the-art lithium-ion battery technology. Thus, the full competitive advantage can only be achieved by a judicious consolidation of the complementary advantages of the different countries. Secondly, lithium-ion battery manufacturing is not scale-neutral business and therefore a "critical mass" needs to be achieved. Undoubtedly, the winning formula is the giga-scale model now widely implemented across the globe.

Notably, Africa's manufacturers, as part of the fast-moving global market, will have to compete with these global giga-scale producers. This is nearly impossible without deriving the true value of the technology that lies in economies of scale. Attempts to manufacture at the wrong scale could completely wipe out our fundamental competitive advantage in the face of intense global competition. As an industry benchmark, a production capacity of 10 GWh/year is considered the lower limit for achieving the scale effects required for cost-competitive production [Boston Consulting Group]. This is consistent with the findings of a recent report by McKinsey that plants larger than 8 GWh/year are twice as productive per dollar than smaller plants.[124] For the specific case of NCA chemistry, a recent model gave somewhat similar results, as shown in Figure 20.

[123] K. Palage, R. Lundmark, P. Söderholm, The innovation effects of renewable energy policies and their interaction: the case of solar photovoltaics, Environmental Economics and Policy Studies, 21 (2019) 217-254: DOI: 10.1007/s10018-018-0228-7.

[124] https://www.mckinsey.com/industries/oil-and-gas/our-insights/recharging-economies-the-ev-battery-manufacturing-outlook-for-europe.

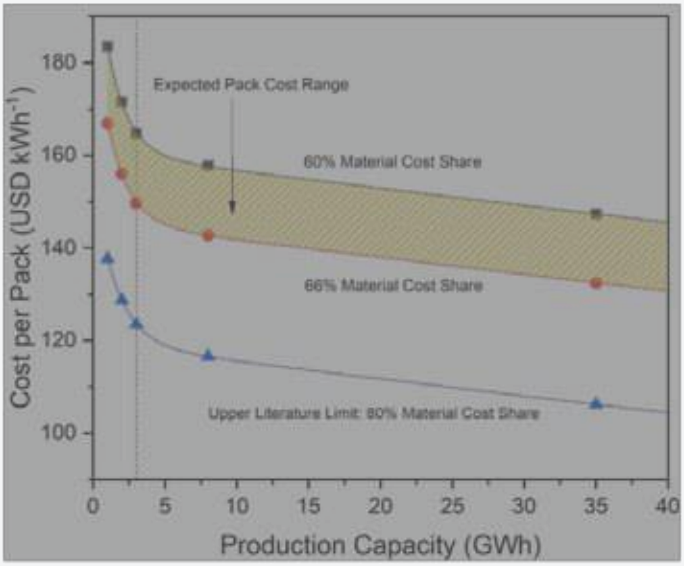


Figure 20: Cost per battery pack for batteries based on NCA/Gr cell chemistry as a function of factory production capacity, with curves representing 60%, 66%, and 88% share, respectively, material cost. The dotted line indicates 3 GWh, the point at which process-based economy of scale effects reach their maximum.[125,126]

A continent-wide strategy could offer a path towards the most efficient utilisation of Africa's lean budgets through aggregation, cohesiveness, and synergy instead of a multiplicity of disparate underfunded programmes. Additionally, a single institution with overarching strategic oversight of the entire programme can provide the rationalisation in terms of avoiding fragmentation and duplication of efforts. This can also afford a strategic agility imperative for technology readiness in a rapidly evolving global environment. Furthermore, the early phases of the proposed industrialisation programme rely heavily on foreign direct investment (FDI), primarily owing to the inescapable necessity for technology partners. Notably, these are large investments that can only be recouped over long periods of time and security of investment needs to be guaranteed.

The reality is that AU Member States continue to fall in and out of turmoil. Consequently, Africa performs poorly on most of the standard metrics of attractiveness to FDI as summarised in the global FDI Attractiveness Index. In such a situation, an economic programme with the backing of the AU's apparatus that can secure its critical economic infrastructure against instability thereby safeguarding and guaranteeing the security of investment can be attractive to FDI. The continent-wide strategy will give further impetus to the current movement towards the establishment of the African Continental Free Trade Area (AfCFTA) that is expected to enter its operational phase. Furthermore, the "Tentative Framework for Action" of the African Mining Vision emphasises that Africa will only achieve its ultimate goal of industrialisation and development by acting collectively. There is also a need for recognising the importance of human resource development and research and development aimed at developing local capacity to support its industrialisation drive.[127]

[125] M. Wentker, M. Greenwood, J. Leker, A bottom-up approach to lithium-ion battery cost modelling with a focus on cathode active materials, Energies 12 (2019) 504: https:// doi.org/10.3390/en12030504.

[126] https://seekingalpha.com/article/4352962-why-tesla-should-be-aware-of-new-holy-grail-in-lithium-batteries.

[127] https://au.int/sites/default/files/documents/30984-doc-africa_mining_vision_english.pdf.

If a continent-wide strategy at the AU level proves unfeasible, an alternative strategy could be to form an African Battery Group consisting of all AU Member States that have definite competitive advantages in the lithium-ion battery space. This formation can then implement the proposed programme with appropriate templating of our proposed institutional framework. In any case, APET anticipates that there will be considerable research and public brainstorming to generate practical and creative ideas on how this institutional framework can be successfully concretised.

9.2 Infrastructure: Immediate Industrialisation

Currently, there is no lithium-ion battery plant in Africa. The laboratory-scale facility at the University of the Western Cape is the closest there is to a lithium-ion battery plant in Africa. Part of the infrastructure required for immediate industrialisation is a pilot plant (say 300 MWh capacity) based on state-of-the-art manufacturing technologies. This can be used for research and training while at the same time producing a commercial product. The decision about the pilot plant ought to be made in consultation with industry partners. As a result, one of the earliest priorities of the ABIC is to establish an industry partnership to build an industry- led consortium that will drive the investment in the pilot plant. Therefore, APET suggest that ABIC should invest about 30% into the pilot plant. The primary interest of ABIC in the pilot plant is to run a research programme on battery manufacturing technologies to develop realistic platforms for factory-of-the-future approaches that will be required for large-scale local production. Advanced manufacturing techniques can significantly drive down production costs enabling the African industry to withstand aggressive global competition.

9.2.1 Raw materials advantage

As already discussed in Chapter 7, the single most important measure of Africa's readiness for seizing control of the lithium-ion battery value chain is its possession of the five main battery minerals. These minerals are lithium, cobalt, nickel, manganese, and graphite. As described, the battery quality production status of these minerals in Africa includes commercial production such as cobalt, copper, and manganese. It also involves a pilot or laboratory scale such as lithium and current projects in nickel and graphite.

Commercial production includes Eurasian Resources Group (ERG) and South Africa's Manganese Metal Company. ERG's subsidiary, Chambishi Metals Plc, operates a refinery producing both battery-ready cobalt (6,800 tpa) and copper (55,000 tpa) in Zambia. On the other hand, Manganese Metal Company is the world's only non-China producer (30,000 tpa) of battery-grade electrolytic manganese metal. However, 95% of the manganese is exported.[128] However, there is only one reported pilot/laboratory-scale plant producing battery-grade material. In 2018, the Prospect Mineral Resources commissioned a small lithium carbonate pilot plant (1200 kg/year) to produce battery-grade (99.9% purity) material at the Acardia Lithium Project in Zimbabwe.[129] Nonetheless, it is encouraging to note that some mineral beneficiation initiatives targeting the lithium-ion battery value chain are already happening. For example, the Thakadu Battery Materials in South Africa is building a nickel refinery to produce 25,000 tpa high- purity battery-ready nickel sulphate from a crude stream supplied by Sibanye-Stillwater (formerly known as Lonmin.[130]

Furthermore, there are several recent projects underway for graphite. Examples include Kibaran Resources' Epanko Graphite Project to produce 60,000 tpa battery-ready graphite in Tanzania,[131] Mahenge Liandu Graphite Project owned by Armadale Capital (Tanzania), and Battery Minerals' Montepuez Graphite Project in Mozambique.[132] There is also active battery mineral exploration through much of Africa. For instance, African Battery Minerals has active exploration programmes in the Democratic Republic of Congo, Cameroon, and Cote D'Ivoire.[133] The Montero Mining and Exploration is actively prospecting for lithium in Namibia.[134]

[128] https://www.mmc.co.za/
[129] https://www.mining-technology.com/projects/arcadia-lithium-project-harare/
[130] http://thakadugroup.com/in-the-press/
[131] https://www.kibaranresources.com/projects/epanko-graphite-project-knl-100/
[132] https://www.batteryminerals.com
[133] https://www.abmplc.com
[134] https://monteromining.com/projects/exploration-and-development-focus/

Furthermore, as expected, the current focus of the production of battery-grade materials in Africa is the global market and, in many cases, long-term off-take agreements are already in place. While such agreements may initially limit the ability of producers to supply the African market, it is exciting that this infrastructure already exists and could be upgraded rapidly to meet local demand.

9.2.2 Manufacturing technology advantage

The non-existence of a lithium-ion battery plant in Africa presents an opportunity to leapfrog in manufacturing technology. The proposed pilot plant should be used as a testbed for factory-of-the-future concepts to develop home-grown advanced manufacturing technologies required to take full control of the entire battery value chain.

9.2.3 Logistics advantage

There is a significant cost involved in shipping raw materials from Africa to China, processing and converting them into batteries that are shipped back to Africa. The logistics constitute at least 10% of the landed cost of the batteries. This cost represents a distinct competitive advantage for lithium-ion production on the African continent. The initial battery production in Africa is targeted at domestic consumption. Notably, this is the main market strategy initially adopted by the Chinese industry.

9.3 Infrastructure: Research, Development, and Innovation

9.3.1 Large-scale facilities for materials research

Materials discovery is at the core of next-generation battery technologies. Therefore, large-scale facilities for materials characterisation, namely synchrotron light sources and research nuclear reactors (as neutron sources), are critical to a successful materials discovery programme. However, these are currently not available in Africa. There is a strong movement called The African Light Source[135] promoting the establishment of a continental synchrotron facility. These efforts need to be supported at the highest level of the AU.

Currently, there are eight African countries with research nuclear reactors. These countries include South Africa, the Democratic Republic of Congo, Egypt, Algeria, Morocco, Nigeria, Ghana, and Libya. Among these, only NECSA in South Africa has some limited instrumentation to support some of the characterisation process required. As a result, the bulk of the advanced materials characterisation (synchrotron and neutrons) will initially have to be carried out at international facilities. For example, these can be carried out in ILL (France), ISIS (UK), and OPAL (Australia). However, a survey is required to determine the availability and distribution of mid-scale national facilities within universities and research centres that provide X-Ray Diffraction, Electron Microscopy (High-Resolution Scanning Electron Microscopy and Transmission Electron Microscopy), Nuclei Magnetic Resonance, and Mass Spectrometry. Most of these instruments are available in universities and research institutions in South Africa, Botswana, and several other countries. Sufficient small-scale facilities (individual research groups) that provide optical methods, electrochemistry, and more are expected to be available. These should be identified and strengthened where necessary.

9.3.2 High-performance computing infrastructure

Computational methods based on quantum mechanics have become an indispensable part of the advanced materials discovery toolkit. Interestingly, there is a growing infrastructure in high-performance computing (HPC), from the Centre for High-Performance Computing (CHPC) launched in 2007 in Cape Town. There are ongoing rollouts in Namibia, Ghana, Zambia, Kenya, Mozambique, and Madagascar. While much of the expansion in HPC infrastructure across Africa is driven by the big data demands of the Square Kilometre Array (SKA). Furthermore, there is usually reasonable capacity available for material

[135] http://www.africanlightsource.org

science research to piggyback on. While the total computing load will be distributed across the different national HPC sites, it can be estimated that a dedicated combined capacity of at least 300 teraflops. The 300 teraflops will be required to support both the standard and advanced high-throughput and machine-learning methods that are required. However, an assessment is required to ascertain the availability of this capacity from available resources. Alongside this HPC infrastructure, there is also a growing African skills base in computational materials science spearheaded by the African School on Electronic Structure Methods and Applications (ASESMA) that has been running since 2008. This programme, set to continue at least through next year, has trained hundreds of African students and academics in computational materials science, a valuable resource for this project. This project should facilitate the extension of the ASESMA programme beyond 2020.

9.4 Human Capital

The World Bank (2014) reported that the decade long development of the sub-Saharan African science, technology, engineering, and mathematics (STEM) research quality remained quite low at about 32% below the world average.[136] This trend was characterised by only 29% of the total research output of the region. In comparison, STEM research output was found to be 68% in Malaysia and Vietnam, over the same time as Africa. Notably, this report made three key observations and recommendations relevant to our proposed programme, as follows:

- The research quality and quantity are adversely affected by the fragmentation of efforts reflected in extremely low (2%) levels of intra-Africa collaborations. Therefore, it becomes essential to substantially expand and deepen intra-Africa collaborations. This can be carried out through scaling up existing regional research and research-based educational programmes. These include programmes such as the African Institute of Mathematical Sciences, African Centres of Excellence, Regional Initiative for Science Education, Pan-African University, Nelson Mandela Institutes for Science and Technology, and Rhodes University FORUM. The continent-wide strategy advocated in this report may offer the best platform to take advantage of these existing institutions to stimulate and support intra-Africa collaboration;
- There are limited knowledge transfer and collaborations between universities involved in STEM research and the private sector in Africa. Therefore, the proposed industry-driven research programme that occurs at the nexus of the Triple Helix inherently weaves together all relevant stakeholders to undertake focused research with well-defined and direct technological usefulness; and
- Even though the research quality from diaspora returnees is exceptionally high, it makes up only about 3% of the total research output. The report concluded that this empirical finding corroborated the widespread belief that the large and well-trained scientific African diaspora in Europe, North America and elsewhere should be further tapped to raise the quantity and quality of SSA research. APET believes that stronger links with the scientific African diaspora can be forged. This cannot only be through their intellectual involvement in the African research enterprise but also (and even more so) by being financially invested in Africa's research. This investment can be achieved through frameworks such as the diaspora bonds being proposed in this report. Additionally, since evidence has demonstrated a clear research competence for the diaspora returnees, it is important to identify and fully exploit this valuable resource for Africa's proposed programme, benefit, and capacity strengthening.

Other initiatives should also be considered for the human capital development required to support the entire lithium-ion battery technology. For example, international expertise should be sought to train and develop Africa's talent. This may be achieved through cooperation with world-class universities and institutions to establish branch facilities for research and training in the battery technology innovation hubs across Africa. The promotion of discovery and innovation leading to deep technology outcomes can also be achieved through incentives such as grand challenge prizes. Examples in Europe include the €10M EIC Horizon Prize for Innovative Batteries for e-Vehicles administered by the European Innovation Council.

[136] https://openknowledge.worldbank.org/bitstream/handle/10986/23142/9781464807008.pdf?sequence=1.

Notably, creating and developing an innovation ecosystem requires periodically bringing all the key stakeholders together so to articulate an inspirational narrative and a clear sense of mission. This may take the form of annual conferences and expositions as platforms for technical communication, showcasing breakthroughs, and for developing and strengthening multi-sector collaborations. Furthermore, there are existing training programmes across Africa that may need strengthening and expansion. Examples include the African Energy Leadership Centre at the University of the Witwatersrand in South Africa.[137]

9.5 Conclusion

Africa ought to improve her research and innovation in numerous areas such as energy storage through a coordinated approach. This can significantly mainstream NGB development and commercialisation in Africa. This will make Africa more competitive, increase potential worldwide, and urgently generate revenue. Notably, Africa's readiness to partake in the NGB implementation is principally established on its strategic resource advantage. Africa's readiness to implement NGB technologies should focus on institutional frameworks, infrastructure development, and robust human capital. Furthermore, Africa ought to identify her existing strengths, while mapping out areas of concern that need an urgent address. In so doing, Africa could formulate strategic approaches to overcoming potential challenges. Notably, creating and developing an innovation ecosystem requires periodically bringing all the key stakeholders together so to articulate an inspirational narrative and a clear sense of mission.

10

Recommendations

10.1 Mineral resources and regulatory frameworks recommendations for Member States

The recommendations that APET is providing to African Union Member States to best exploit next generation batteries for improved power storage capacity are summarised as follows:

- African Leaders are encouraged to alter their mindset around the value of resources. Notably, it can be acknowledged that much quicker monetary gains can be made from direct mineral resources sales. However, the much better value of these mineral resources can be unlocked when a significant portion of the value chain is retained within the borders of the continent. Therefore, Member States are encouraged to make investments towards local factories for refining and beneficiation of local natural resources. This beneficiation of local minerals can lead to the production of useful precursors for battery-grade feedstock materials. Following this suggestion will not only benefit Africans from the significant added value of materials in terms of the return value but also stimulate job creation. It will also stimulate the local supply chain and that will create countless opportunities for local economic growth.
- A Regulatory Framework to monitor these activities in Africa must be developed, implemented, and enforced. This will protect the foreign exploitation of African resources. This is specifically towards those mineral resources that are critical to producing NGB including currently commercially available Li-ion batteries. African resources should be exploited to the benefit of Africa first.

  These Regulatory Frameworks include conditions regarding:
- — Awarding mining rights: No mining exploitation rights should be granted to any investor without a clear plan for local material beneficiation. New mining agreements should include clauses that prohibit raw materials be exported without substantial local refinement.
  — If the local refinery, precursor or battery component production is operated by a foreign investor, a predetermined portion of the product including salts of Li, Co, Mn, Ni, as well as NMC precursors, graphite, lithium–titanium oxide TiO2, LPF6, LFP, and copper foil needs to be allocated to a local battery assembly plant.
- There is a need for the development of a database around exploitation activities across the African continent. This database can indicate the type of material, quantities, and the level of refinement according to what Member States have agreed upon with mining companies. Consequently, this database will facilitate effective coordination and allocation of local resources for local battery production.
- Member States are encouraged to prioritize elemental infrastructure for facilities that refine and produce feedstock for NGB. This infrastructure includes ports, roads, and railway infrastructure, water, and electricity supply.
- As part of the plan to produce a state of the art Li-ion battery assembly facilities including a battery component supply chain based on African resources, these facilities need to be incentivized by the creation of special economic zones. A predetermined portion of locally produced NGBs must be incorporated into a substantial number of microgrids that will address the benefits as described in another APET report entitled; Micro-Grid; Empowering communities and enabling transformation in Africa.

[137] https://www.wbs.ac.za/academic-programmes/masters-of-management/mm-in-the-field-of-energy-leadership/.

- In support of the initiative supported by the Regulatory Frameworks, necessary skill needs to be developed and harnessed within the continent. It is suggested that leading institutions in Africa can be supported to offer training and courses specifically aimed to support the immediate and long-term battery production needs for the continent.

10.2 Improving skills, manufacturing, and research hubs across the continent

These are the recommendations for governments on how to host different hubs in the

- Member States are encouraged to adopt a model where governments bid to host the different research and development, innovation, and manufacturing hubs across the continent based on their available material and expertise.
- There is a need to establish a business case for a full LIBs value chain in Africa.
- The largest manufacturers of rechargeable lithium ion batteries are all based in the northern hemisphere with no large-scale commercial production facilities in the southern hemisphere, specifically in sub-Saharan Africa. This is except for several experimental laboratories in Africa. Therefore, these leading manufacturers are encouraged to invest billions of dollars into their research and development, intellectual property patents, human resources development, facilities and equipment, and supply chain contracts in Africa.
- These large manufacturing companies are encouraged to escalate their efforts towards employing into their Africa's workforce numerous scientists, engineers, and technologies with doctoral degrees in their respective fields. This will improve research and development and build can Africa's human resource training. Effectively, this investment can enable technological advancement and improve overall efficiencies.

10.3 Summary of the structural and requisite institutional elements for realistic next generation battery technological timeline

The next generation battery programme of action set out in this report is as follows:

- The first agenda is to create an institution that will drive all aspects of the battery revolution in Africa. For reference purposes in this report, we refer to this institution as the African Battery Innovation Council (ABIC). The ABIC should be adequately resourced and empowered through appropriate policy instruments to formulate and implement the continental battery strategy.
- This report has identified the two main components of the strategy, namely:
    - Immediate Industrialisation: The Immediate Industrialisation programme consists of a substantial package of continent-wide policies that can be used to attract investment into the lithium-ion battery space. Additionally, an ABIC-supported pilot plant (about 1 GW capacity) must be built and commissioned so to drive research and training while producing commercial batteries at the same time is proposed.
    - Research, Development, and Innovation: The research, development, and innovation component are a comprehensive programme, managed by the ABIC. This programme is meant to develop critical competencies across the entire lithium- ion battery technology value chain. Furthermore, to minimise upfront costs of the programme launch, the ABIC will as much as possible avoid building new physical infrastructure and research facilities. This can be achieved by capitalising on any existing resources across the continent. The overall objective of this programme is to eventually develop home- grown battery technologies that best match the demands of our own application environments.

In both main components of this strategy, the ABIC will, in consultation with national governments and other policy think tanks, formulate, and implement appropriate policy portfolios. This can be carried out to achieve an efficient and synergistic continental integration of the entire lithium-ion battery technology value chain. Thus, this report outlines some of the relevant policies to address different aspects of the value chain such as minerals, procurement, market, recycling and reuse, and investment. Additionally, the ABIC will develop other institutional infrastructure such as creating new organisations to implement the various aspects of the entire programme. For instance, this report has identified the need to establish an African Technology Transfer Centre (ATTC) as well as an African Innovation Capital Company (AICC).

The primary function of the ATTC is to bring together industry, start-ups, universities, and research institutions to build technology transfer ecosystems that facilitate product development, commercialisation, and technology adoption. On the other hand, the AICC is a venture capital investment vehicle under the direct supervision of the AU Commission. This vehicle will enable the AU to channel various investment funds so to develop and support a viable venture capital ecosystem for emerging technologies. None of these organisations is created in perpetuity. Instead, these institutions have a finite mandate of typically renewable 5 years based on specific outcomes and the overall objectives of the entire ABIC programme.

Apart from many positive externalities, the key benefits of the proposed programme include accelerating the adoption of a scalable clean energy future that will improve the health and economy of the continent. To accomplish this, the programme will support the advancement of next-generation solar energy and battery materials and devices. It will also support the integration of next generation batteries with systems and the microgrid. The programme will also create ideas for research, development, and innovation. It will also educate and create training programmes for innovative approaches and ecosystems for the African people. This will enable the generation of innovations and facilitate their pathways into the market. Consequently, this enables Africa to compete at a world stage as a significant and respectable peer among world-class leaders of the energy revolution. This will also address the technological challenges Africa is facing and ultimately improve Africa's economic outlook. Africa must deliver this mammoth programme; whose scale and pace are unprecedented on this continent because Africa must light up!

10.4 Conclusion

Under the current landscape of advanced battery technologies with advanced manufacturers, Africa does not have to reinvent the wheel. Furthermore, Africa can certainly not afford at this juncture to make similar mega-scale investments to discover the next breakthrough in battery technology. Rather, efforts in Africa should be directed towards piggybacking on the latest available commercialized battery technology through strategic partnerships with leading players. Simultaneously, African governments are encouraged to invest available funds in regional technology hubs to develop local human resources. These technology hubs can also direct efforts towards improving the quality of processing of the critical raw materials extracted from African soil, as well as experiments to improve the overall quality and lifespan of the main components in batteries. In this way, Africa can meet the continent's dire need for energy storage, while also contributing to next generation batteries by keeping abreast of the latest technology.

11

Bibliography

A. Ahmadian, M. Sedghi, A. Elkamel, M. Fowler, M. Aliakbar Golkar, Plug-in electric vehicle batteries degradation modelling for smart grid studies: Review, assessment, and conceptual framework, Renewable and Sustainable Energy Reviews 81 (2018) 2609- 2624: DOI: 10.1016/j.rser.2017.06.067.

A. Conde, J.J.T.C. Wright, U. Ibusuki, Battery global value chain and its technological challenges for electric vehicle mobility, RAI Revista de Administração e Inovação 14 (2017) 333-338: https://doi.org/10.1016/j.rai.2017.07.001.
A. Mourant, Next generation batteries will power up the energy storage industry, Renewable Energy Focus 17 (2016) 41-43, ISSN 1755-0084, https://doi.org/10.1016/j.ref.2015.11.004.

A.K. Worku, D.W. Ayele, N.G. Habtu, Recent advances and future perspectives in engineering of bifunctional electrocatalysts for rechargeable zinc-air batteries, Materials Today Advances 9 (2021) 100116.

Accelerating SDG 7 Achievement, Policy Briefs in Support of the First SDG 7 Review at the UN High-Level Political Forum 2018, Developed by United Nations Economic Commission for Africa (UNECA) in collaboration with The African Development Bank, ENERGIA, UNCTAD, UNESCWA, RCREEE, SACREEE, ECREEE, EACREEE, FIA Foundation, IRENA, UNIDO and IEA: https://

Africa: Switching on Smart Power for COVID-19 Recovery and Renewal, 10th July 2020: https://www.bakermckenzie.com/en/ insight/publications/2020/07/africa-smart-power-covid19-recovery.

APET Report: Micro-Grids Empowering Communities and Enabling Transformation in Africa.
B. Ackers, Ethical considerations of corporate social responsibility -A South African perspective, South African Journal of Business Management 46(2015) 11-21.

Benchmarking of Technology, Trends and Technology Developments Department of Trade and Industry (2004): https://www. westerncape.gov.za/text/2004/11/technologydevelopmenttrends.pdf.

Climate Finance Update: Major Emerging Market Green Bond Fund Launched (May 2017): https://sdg.iisd.org/news/climate- finance-update-major-emerging-market-green-bond-fund-launched/

CSIR Shareholder's Compact, Cycle commencing 1 April 2020: https://www.csir.co.za/sites/default/files/Documents/Shareholder%20Compact_2020_21_%283%29.pdf.

D.B. Agusdinata, W. Liu, H. Eakin, H. Romero, Socio-environmental impacts of lithium mineral extraction: towards a research agenda, Environmental Research Letters 13 (2018) 123001: https://doi.org/10.1088/1748-9326/aae9b1

E. Mossali, N. Picone, L. Gentilini, O. Rodrìguez, J.M. Pérez, M. Colledani, Lithium-ion batteries towards circular economy: A literature review of opportunities and issues of recycling treatments, Journal of Environmental Management 264 (2020) 110500, ISSN 0301-4797: https://doi.org/10.1016/j.jenvman.2020.110500.

E.A. Olivetti, G. Ceder, G.G. Gaustad, X. Fu, Lithium-Ion Battery Supply Chain Considerations: Analysis of Potential Bottlenecks in Critical Metals Joule 1 (2017) 229-243: https://doi.org/10.1016/j.joule.2017.08.019.

Energy Storage Partnership (ESP) targets developing countries expansion, Green Building Africa – Net carbon zero building cities, May 30, 2019: https://www.greenbuildingafrica.co.za/energy-storage-partnership-esp-targets-developing-countries-expansion/.

European Commission - Horizon 2020 - Work Programme 2018-2020 Cross-cutting activities. Call: Building a Low-Carbon, Climate Resilient Future: Next-Generation Batteries H2020-LC-BAT-2019-2020. European Commission Decision C (2020) 6320 of 17 September 2020: https://ec.europa.eu/research/participants/data/ref/h2020/wp/2018-2020/main/h2020-wp1820-cc-activities_en.pdf.

F. Moreno-Brieva, R. Marín, Technology generation and international collaboration in the Global Value Chain of Lithium Batteries, Resources, Conservation and Recycling 146 (2019) 232-243, ISSN 0921-3449, https://doi.org/10.1016/j.resconrec.2019.03.026.
F. Moreno-Brieva, R. Marín, Technology generation and international collaboration in the Global Value Chain of Lithium

F. Pan, Q. Wang, Redox Species of Redox Flow Batteries: A Review, Molecules, 20 (2015) 20499–20517: doi: 10.3390/ molecules201119711.

F. Wu, J. Maier, Y. Yu, Guidelines and trends for next-generation rechargeable lithium and lithium-ion batteries, Chemical Society Review 49 (2020) 1569-1614: https://doi.org/10.1039/C7CS00863E.

G. Hao, Q. Lai, H. Zhang, Nanostructured Mn-based oxides as high-performance cathodes for next generation Li-ion batteries, Journal of Energy Chemistry (2020) ISSN 2095-4956, https://doi.org/10.1016/j.jechem.2020.11.035.

G. Reid, J. Julve, Second Life-Batteries as Flexible Storage for Renewables Energies, Kurzstudie Im Auftrag Des Bundesverbandes Erneuerbare Energie E.V. Und Der Hannover Messe (2016): https://www.bee-ev.de/fileadmin/Publikationen/Studien/201604_ Second_Life-Batterien_als_flexible_Speicher.pdf.

G. Zubi, R.S. Adhikari, N.E. Sanchez, W. Acuna-Bravo, Lithium-ion battery-packs for solar home systems: Layout, cost and implementation perspectives, Journal of Energy Storage 32 (2020) 101985:

G.A. Mill, The financial performance of a socially responsible investment over time and a possible link with corporate social responsibility, Journal of Business Ethics 63 (2006) 131-148.

H Jalilian, J Weiss, De-industrialisation in sub-Saharan Africa: myth or crisis? Journal of African Economies, Volume 9, Issue 1, March 2000, Pages 24–43, https://doi.org/10.1093/jae/9.1.24

H. Pang, G. Zhang, X. Xiao, H. Xue, Brief Overview of Next-Generation Batteries. In: One-dimensional Transition Metal Oxides and Their Analogues for Batteries. Springer Briefs in Materials, Springer, Singapore. (2020) https://doi.org/10.1007/978-981-15- 5066-9_3.

Hopes of a West Australian 'Lithium Valley' threatened, 18 July, 2018, International Mining: https://im-mining.com/2018/07/18/hopes-west-australian-lithium-valley-threatened/.

https://au.int/sites/default/files/newsevents/workingdocuments/33178-wd-stisa-english_-_final.pdf.
I. Kinash, U. Andrusiv, O. Golovnia, I. Popadynets, Aspects of the formation and development of innovation infrastructure in Ukraine, Management Science Letters 9 (2019) 2403–2414: doi: 10.5267/j.msl.2019.7.015.

IEA, IRENA, UNSD, WB, WHO (2019), Tracking SDG 7: The Energy Progress Report 2019, Washington DC.
Industrial Policy Action Plan (2018/19 – 2020/21, Economic sectors, employment, and infrastructure, Department of Trade and Industry, Republic of South Africa: https://www.gov.za/sites/default/files/gcis_document/201805/industrial-policy-action-plan.pdf.

Investment in renewable energy generates jobs. Supply of skilled workforce needs to catch up, Research brief, Renewable Energy (ILO, 2011): https://www.ilo.org/wcmsp5/groups/public/---ed_emp/---

J. Drábek, S. Lorincová, J. Javorčíková, Investing in Human Capital as a Key Factor for the Development of Enterprises, Issues of Human Resource Management (2017): DOI: 10.5772/67741: https://www.intechopen.com/books/issues-of-human-resource- management/investing-in-human-capital-as-a-key-factor-for-the-development-of-enterprises.

J. Schiffera, R. Ortegab, A. Astolfic, J¨org Raischa, T. Sezie, Conditions for Stability of Droop–Controlled Inverter–Based Microgrids, Automatica, 50 (2014) 2457-2469. ISSN: 0005-1098: https://doi.org/10.1016/j.automatica.2014.08.009.

J.-P. Yaacou, H. Noura, O. Salman, A. Chehab, Security analysis of drones' systems: Attacks, limitations, and recommendations, Internet of Things (2020): doi: 10.1016/j.iot.2020.100218.

K. Baes, M. Kolk, F. Carlot, A. Merhaba, Y. Ito, Future of batteries, Winner takes all? Arthur D. Little Luxembourg S.A. 2018: https:// www.adlittle.com/sites/default/files/viewpoints/adl_future_of_batteries-min.pdf.

K. Ehsanul, K. Pawan, K. Sandeep, A. Adedeji, K. Ki-Hyun, Solar energy: Potential and future prospects, Renewable and Sustainable Energy Reviews 82 (2018) 894-900: http://dx.doi.org/10.1016/j.rser.2017.09.094

L.I. Farfan-Cabrera, M. Tapia-Gaspar, J. Pérez-González, Tribology of Polymer Matrix Composites Within the Automotive Industry, Reference Module in Materials Science and Materials Engineering (2021): DOI: https://doi.org/10.1016/B978-0-12-819724- 0.00029-X.

M. Barry, P. Fitzgerald, South Africa: The Sustainable Development Challenge, Third World Quarterly, vol. 15, no. 2, 1994, pp. 227–242. JSTOR, www.jstor.org/stable/3993144. Accessed 13 Dec. 2020.

M. Killera, M. Farrokhseresht, N.G. Paterakis, Implementation of large-scale Li-ion battery energy storage systems within the EMEA region, Applied Energy 260 (2020) 114166.

M. Motyka, A. Slaugther, S. Sanborn, K. Sharma, D.V. Shah, Supercharged: Challenges and opportunities in global battery storage markets, Deloitte Center for Energy Solutions, 2018: https://www2.deloitte.com/content/dam/Deloitte/bg/Documents/energy- resources/gx-er-challenges-opportunities-global-

M.A. Hannan, AliQ. Al-Shetwi, R.A. Begum, S.E. Young, M.M. Hoque, Pin Jern Ker, M. Mansur, Khaled Alzaareer, Review The value of thermal management control strategies for battery energy storage in grid decarbonization: Issues and recommendations, Journal of Cleaner Production 276 (2020) 124223: https://doi.org/10.1016/j.jclepro.2020.124223.

M.A. Shapiro, Next-generation battery research and development: Non-politicized science at the Joint Center for Energy Storage Research, Energy Policy 145 (2020) 111771, ISSN 0301-4215, https://doi.org/10.1016/j.enpol.2020.111771.

M.M. Elkadragy, M. Alici, A. Alsersy, A. Opal, J. Nathwani, J. Knebel, M. Hiller, Off-grid and decentralized hybrid renewable electricity systems data analysis platform (OSDAP): A building block of a comprehensive techno-economic approach based on contrastive case studies in Sub-Saharan Africa and Canada, Journal of Energy Storage (2020) 101965 In Press: https://doi.org/10.1016/j. est.2020.101965.

N. Okonjo-Iweala, Africa can play a leading role in the fight against climate change, Combatting Climate Change, An urgent call for comprehensive global and local action, Foresight Africa: https://www.brookings.edu/wp-content/uploads/2020/01/ ForesightAfrica2020_Chapter4_20200110.pdf.

N.S. Pillay, A.C. Brent, J.K. Musango, Affordability of battery electric vehicles based on disposable income and the impact on provincial residential electricity requirements in South Africa, Energy 171 (2019) 1077-1087.

New International Partnership Established to Increase the Use of Energy Storage in Developing Countries, May 28, 2019: https:// www.worldbank.org/en/news/press-release/2019/05/28/new-international-partnership-established-to-increase-the-use-of-energy-storage-in-developing-countries.

P.P. Ganzera, C. Chais, P.M. Olea, Product, process, marketing, and organizational innovation in industries of the flat knitting sector, RAI Revista de Administração e Inovação, 14 (2017) 321-332: https://doi.org/10.1016/j.rai.2017.07.002.

R. Abbas, K. Michael, M.G. Michael, The regulatory considerations, and ethical dilemmas of location-based services (LBS): A literature review, Information Technology and People, (2014) 2-20: https://doi.org/10.1108/ITP-12-2012-0156: ISSN: 0959-3845.

R. Grabowski. Deindustrialization in Africa, International Journal of African Development 3 (2015) 51-67, Southern

R. Konidenaa, V. Bhandari, A. Mburu, Best practices from International experiences for Eastern Africa countries regarding ancillary services markets, The Electricity Journal 33 (2020) 106800: https://doi.org/10.1016/j.tej.2020.106800.

S. Batchelora, E. Brown, J. Learya, N. Scotta, A. Alsop, M. Leach, Solar electric cooking in Africa: Where will the transition happen first? Energy Research & Social Science 40 (2018) 257-272: https://doi.org/10.1016/j.erss.2018.01.019.

S. Bräuer, F. Plenter, B. Klör, M. Monhof, D. Beverungen, J. Becker, Transactions for trading used electric vehicle batteries: theoretical underpinning and information systems design principles, Business Research 13 (2020) 311–342. https://doi.org/10.1007/s40685-019-0091-9.

S. Nanda, A. Bhargav, A. Manthiram, Anode-free, Lean-Electrolyte Lithium-Sulfur Batteries Enabled by Tellurium-Stabilized Lithium Deposition, Joule, 2020; DOI: 10.1016/j.joule.2020.03.020.

Scale-up of Solar and Wind Puts Existing Coal, Gas at Risk, April 28, 2020, Bloomberg NEF (BNEF): https://about.bnef.com/blog/scale-up-of-solar-and-wind-puts-existing-coal-gas-at-risk/.

Science, Technology, and Innovation Strategy for Africa 2024: https://au.int/sites/default/files/documents/38756-doc-stisa_science_tech_innovation_strategy.pdf

Shaping Europe's digital future, 10 September 2020, Europe invests in research on the batteries of the future: https://ec.europa. eu/digital-single-market/en/news/europe-invests-research-batteries-future.

Technologies for producing battery raw materials: https://www.outotec.com/products-and-services/commodities/battery-metals/technologies-for-producing-battery-raw-materials/.

Technology and Innovation for the Future of Production: Accelerating Value Creation, March 2017, in collaboration with A.T. Kearney: http://www3.weforum.org/docs/WEF_White_Paper_Technology_Innovation_Future_of_Production_2017.pdf.

The road ahead for lithium-ion batteries, February 26th, 2019, Africa's Power Journal: https://www.esi-africa.com/industry-sectors/future-energy/the-road-ahead-for-lithium-ion-batteries/.

The Sustainable Development Goals Report, 2019, United Nations: https://brasilnaagenda2030.files.wordpress.com/2019/09/the-sustainable-development-goals-report-2019.pdf.

The World Bank Treasury, What are green bonds? Public-Private Infrastructure Advisory Facility (PPIAF), Enabling Infrastructure Investment, 2015 International Bank for Reconstruction and Development/The World Bank, Washington D.C., United States of America

UN Policy Briefs in Support of the First SDG7 Review at the UN High-Level Political Forum

UNEP (2017), Atlas of Africa Energy Resources, United Nations Environment Programme, PO Box 30552, Nairobi 00100, Kenya. Varvara Sharova, Paul Wolff, Benedikt Konersmann, Ferdinand Ferstl, Robert Stanek and Markus Hackmann, Evaluation of Lithium-Ion Battery Cell Value Chain, (2020) Working Paper Forschungsförderung, No. 168, Hans-Böckler-Stiftung, Düsseldorf: https://www.econstor.eu/bitstream/10419/217243/1/hbs-fofoe-wp-168-2020.pdf.

Venture capital, The Innovation Policy Platform: http://www.innovationpolicyplatform.org/www.innovationpolicyplatform.org/ content/venture-capital/index.html.

W. Park, D. Lippoldt, Technology Transfer and the Economic Implications of the Strengthening of Intellectual Property Rights in Developing Countries, (2008)

X.-Q. Zhang, C.-Z. Zhao, J.-Q. Huang, Q. Zhang, Recent Advances in Energy Chemical Engineering of Next-Generation Lithium Batteries, Engineering 4 (2018) 831-847, ISSN 2095-8099, https://doi.org/10.1016/j.eng.2018.10.008.

Y. Huang, J. Duan, X. Zheng, J. Wen, Y. Dai, Z. Wang, W. Luo, Y. Huang, Lithium Metal-Based Composite: An Emerging Material for Next-Generation Batteries, Matter 3 (2020) 1009-1030, ISSN 2590-2385,

Z. Chen, W. Zhang, Z. Yang, A review on cathode materials for advanced lithium-ion batteries: microstructure designs and performance regulations, Nanotechnology 31 (2019): DOI: https://doi.org/10.1088/1361-6528/ab4447.

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