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POWER AFRICA
NIGERIA POWER SECTOR PROGRAM
BATTERY STORAGE REPORT

March 2021

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ACRONYMS

Acronym	Definition
CAPEX	Capital Expenditure
EPC	Engineering Procurement Company
GW	Gigawatt
MW	Megawatt
OEM	Original Equipment Manufacturer
PA-NPSP	Power Africa - Nigeria Power Sector Program
SHS	Solar Home System
USD	United States Dollar

1 EXECUTIVE SUMMARY

This document was developed to support off-grid solar companies in Nigeria by analyzing the off-grid battery market, assessing its potential for growth, and outlining potential business models to enable market growth. This Report focuses on current market factors that impact battery storage deployment in Nigeria, evaluates market deterrents to widespread usage, and evaluates flexible and integrated business models for the market expansion and financing of batteries.

The purpose of this Report is to explore the potential for batteries to facilitate the use of renewable, solar generation options to replace diesel generation in Nigeria's off-grid storage marketplace. Increasing renewable energy use – and specifically mini-grid development – requires strengthening off-grid developers' access to technology solutions which mitigate renewable energy intermittency and allow renewable energy generation to be transitioned to cleaner, more resilient energy back-up mechanisms. The USAID Power Africa Nigeria Power Sector Program (PA-NPSP) developed a market survey that was circulated amongst prominent Nigerian mini-grid developers and collected, analyzed, and incorporated their feedback into this Report. This survey was used to develop inputs used to review the current state of lead acid and lithium ion battery use cases – the most prevalent batteries in the Nigerian off-grid market.

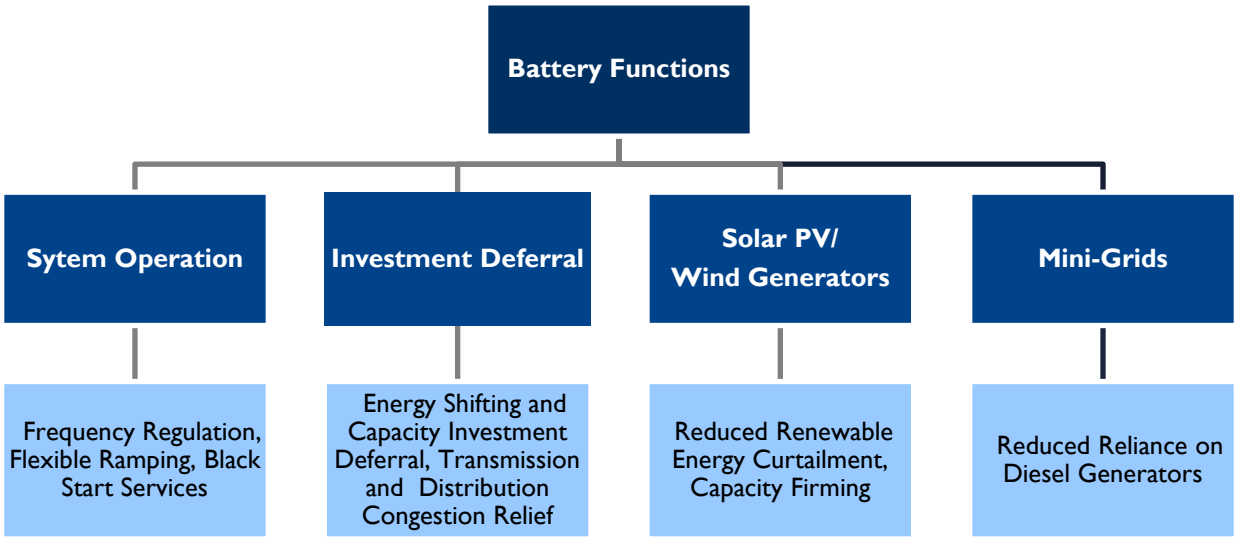
Further, PA-NPSP modeled multiple scenarios for how the battery market could develop between 2020 and 2025. The analysis concluded that the estimated battery market for off-grid uses could be valued at between US$80 million and US$300 million within the next five years. PA-NPSP has outlined the strengths and weaknesses of potential mini-grid developer-to-battery provider business models, including how these models solve for current market impediments and key challenges to deployment.

2 INTRODUCTION

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

The large, "utility scale" batteries can provide a range of services based on the type, and size, of the generation asset, as outlined in Figure 1 below:

Figure 1: Common Battery Services within a Utility Scale System[1]



The smaller scale solar solutions, such as mini-grids under 1MW in size, incorporate batteries primarily to reduce reliance on diesel generators and to provide back-up services in the event the mini-grid does not receive full exposure to solar radiation. These battery applications are most prevalent in the Nigerian off-grid context.

2.1 NIGERIA'S OFF-GRID SECTOR

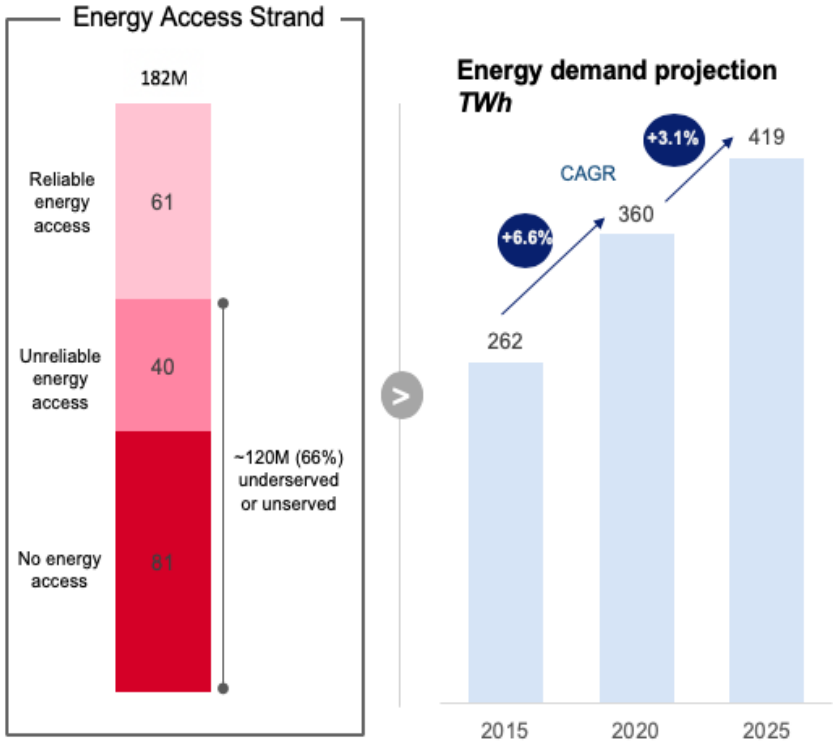
Systemic issues in Nigeria's energy delivery value chain, including on-grid and off-grid infrastructure, leaves more than 80 million Nigerians (~45 percent of the population) without access to electricity, with 66 percent of rural areas and nearly 15 percent of urban areas having no access to grid-connected electricity. Nigeria, with a population of about 200 million people, has the second-largest energy access deficit in the world, after India, with only 55 percent national electrification rate and only 39 percent access-rate in rural areas.[2]

The current energy access deficit – outlined in Figure 2 below – is complicated by the fact that Nigeria's energy demand is growing rapidly, with a projected annual increase of more than three percent from 2020-2025. The acute lack of reliable and affordable grid-based electricity, coupled with progressively

[1] International Renewable Energy Agency
[2] World Bank, Rural Electrification Agency

expanding demand for electricity services, has produced a secondary market for energy supply services. Currently, an estimated 42GW of small diesel generating sets are operated daily by households and businesses to meet their power needs. While diesel generators remain a dominant market force for small-to-medium scale consumers, solar technologies are beginning to take market share. Mini-grids and solar home systems (SHS) are now competing with diesel gensets to provide off-grid electricity. As solar and other renewable technologies continue to scale up, one design element will remain consistent: the need to mitigate the inherently intermittent energy supply of renewable generation sources.[3] The most

Figure 2: Nigeria's Energy Access Gap



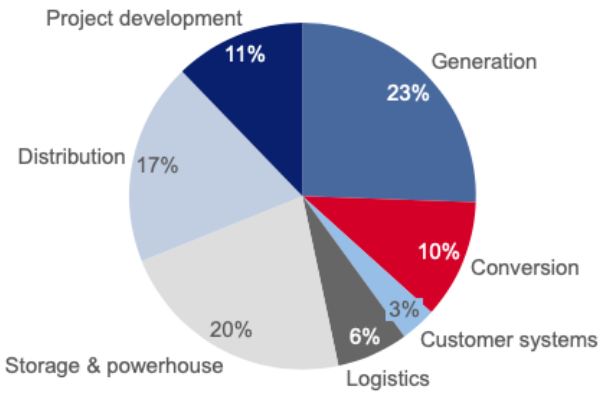
common method for mitigating renewable energy intermittency is to configure renewable generation assets with a diesel generator back-up supply. The diesel back-up generator provides a stable power supply at night, during inclement weather, or any time the primary, renewable power source is not able to satisfy the full load requirement. Diesel generators are capable of providing stable electricity supply, but they are loud, expensive, environmentally damaging, and pose significant health hazards to those who experience prolonged exposure to diesel fumes. As mini-grid and other off-grid applications expand their market share compared to diesel gensets, the need for cleaner, more efficient alternatives will expand in lockstep.

The purpose of this report is to explore the potential for integrating batteries into off-grid renewable energy solutions as an alternative to diesel generation backups and provide guidance to potential battery vendors looking to enter – or better navigate – the Nigerian marketplace. Batteries are emerging as one of the most competitive alternatives to diesel generators when it comes to mitigating intermittency in mini-grid electricity supply. Compared to alternatives, batteries are quiet, rechargeable, do not produce exhaust, and are becoming more price competitive with diesel generator backups for renewable energy solutions such as solar. However, as outlined in the Figure below, the significance of battery capital cost in off-grid applications – with upwards of 20 percent of the cost of a solar mini-grid site needed for battery

[3] Figure: PA-NPSP Research

storage – emphasizes the need for understanding the fundamental elements of Nigeria's battery marketplace, how best to navigate that marketplace, and the potential market size for battery providers.[4]

Figure 3: Mini-Grid Investment Breakdown



2.2 SURVEYING THE MARKETPLACE

To achieve the goal of providing a general guide to battery vendors looking to expand into the Nigerian market, PA-NPSP performed a survey of leading mini-grid developers operating in Nigeria. This survey covered aspects of battery deployment for off-grid applications including financing structures and costs, preferred battery technologies, and captured common experiences amongst developers as to the overall battery market strengths and weaknesses. The results of this survey constitute the basis of current market realities and analysis in this Report. The companies surveyed for this report include:

- A4&T
- ACOB Lighting
- Havenhill Synergy
- ICE Commercial Power
- PowerGen
- Rubitec Solar

[4] Figure: PA-NPSP Research

3 DEFINING AND NAVIGATING THE BATTERY MARKET

Multiple battery technologies are available in Nigeria. These energy storage technologies have unique properties that determine how and where they may be most technically suitable for off-grid applications. This section of the Report outlines core attributes of Nigeria's battery market landscape for renewable solar technology in the off-grid context.

3.1 COMMON TECHNOLOGY OPTIONS IN NIGERIA'S BATTERY MARKET

The Nigerian off-grid marketplace requires small-scale batteries with relatively flexible operating standards, long operating life, rapid deployment, and reasonably cost-effective price point to be responsive to both the nascent state of the market and a challenging operating environment. As outlined in Table 1 below, the battery technologies prevalent in off-grid settings cover a wide range functionality and are in various stages of development. [5]

Table 1: Battery Technologies for Mini-Grid Deployment

Battery Technology	Commercial Status	Cycle Life	Estimated Initial Cost (US$/kWh)[6]
Lead-Acid	Available	1,650 at 50% depth of discharge, 1,050 at 80% depth of discharge	$300
Lithium-Ion	Available	1,900-3,000 at 80% depth of discharge	$700
Lithium-Sulfur	Mostly laboratory	(Data not available)	>$1,500 per kWh
Zinc-air	Available	~500	Competitive w/ Lead Acid
Lithium-Air	Laboratory	50-900	N/A
Vanadium Redox Batteries (flow)	Available	3,750+ at 80% DOD	$350-800
Zinc-bromine (flow)	Available	(Data not available)	(Data not available)
Sodium-sulfur	Mostly utility-scale	1,500-3,000	$600
Flywheel Energy Storage	Available for utilities and large mini-grids	100,000+	$1,333-3,000

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

[5] Table: United States Agency for International Development

[6] Estimated from a global perspective using 2018 data, prices may vary from what mini-grid developers experience in the Nigerian market during the period the PA-NPSP survey was taken

Lead acid batteries are currently the most common type of battery used in the Nigerian off-grid context. Lead acid batteries consist of lead dioxide (cathode), metal lead (anode), and aqueous sulphuric acid (electrolyte). These include the flooded (in which electrodes are immersed in liquid electrolytes), gelled electrolyte, and absorbed glass matte batteries with brands such as Trojan, Decker, HBL, and Hoppecke. Lead acid was the first rechargeable battery in common commercial use and continues to be widely used despite advancements in battery technology. While lead acid batteries do suffer decreased performance when excessively discharged and when operating under extreme temperatures, they have remained competitive largely due to their dependability and low price-point compared to other battery technologies.

Lithium ion batteries are more technologically advanced than lead acid batteries and are increasingly common in Nigeria's off-grid marketplace. However, they have not overtaken lead acid's market share, largely due to a higher capital cost. Structurally, lithium ion batteries consist of a number of lithium ion cells together with electronics for battery management. They have a higher density, resiliency, and a longer life cycle than lead acid batteries. The core strength of a lithium ion battery is that it is low maintenance compared to a lead acid battery. Of the two batteries, lithium ion will retain a charge for longer durations than a similarly sized lead acid battery under the same operating conditions. This superior performance has resulted in lithium ion batteries becoming commonplace in many high-technology applications, including computers, cars, and smartphones. However, lithium ion batteries are traditionally more expensive than lead acid batteries, leading to their relatively slow uptake in emerging markets and off-grid contexts.

While there are other battery options available on the market, lead acid and lithium ion batteries likely provide the most flexibility for off-grid solutions in the Nigerian context. The strengths and weaknesses of both lead acid and lithium ion battery options are explored below in greater detail.

3.2 Entering Nigeria's Battery Market

For battery vendors looking to more effectively navigate this landscape, there are a handful of market aspects that may influence how a vendor enters or operates within the Nigerian market. These areas represent potential opportunities for battery vendors to influence and expand the market as well as outline possible challenges that the battery market may face.

This section of the Report outlines five main areas of the Nigerian battery market landscape and, where applicable, compares and contrasts the differences between the two most common batteries in the Nigerian off-grid market: (1) lead acid batteries and (2) lithium ion batteries.

- Capital Cost
- Technology Performance
- Regulatory and Fiscal Incentives
- Product Warranties
- New Technologies

3.2.1 Capital Cost

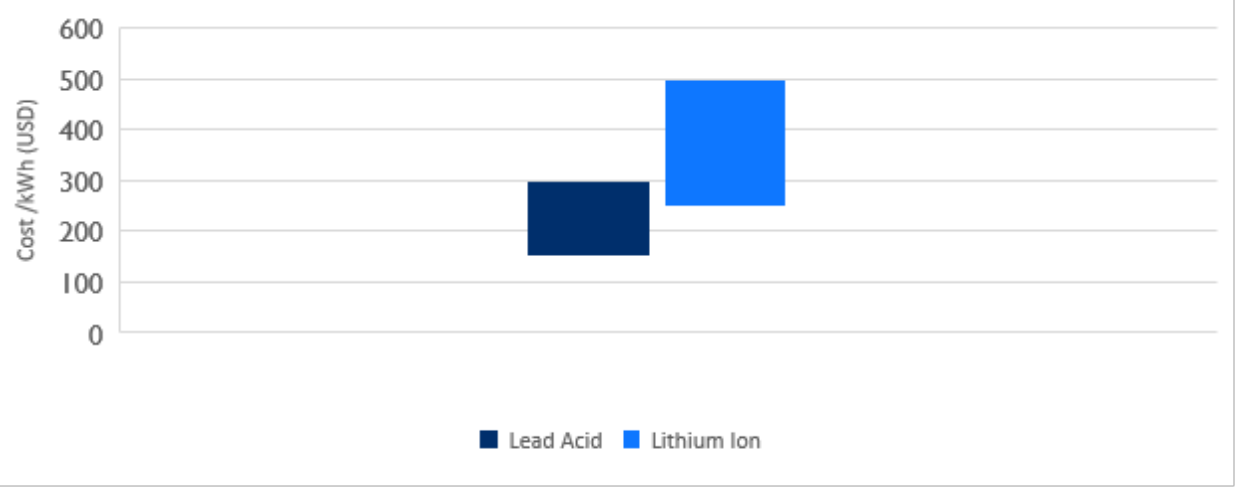
The upfront capital cost of batteries is a key consideration for mini-grid developers, in how they decide between multiple types of batteries, and for battery vendors, in how they approach marketing. In many cases, costs differ per total kWh purchased depending on overall battery volume and the type of battery technology used. This section reviews the capital cost of the two battery technologies and relies on information obtained from Nigerian mini-grid developers by PA-NPSP's market survey.

- **Lead Acid:** According to mini-grid developers surveyed by PA-NPSP, lead acid batteries are the most economical for developers, with costs typically ranging from US$150 to US$300 per kWh, as outlined in Figure 4 below. The lower cost is largely due to the fact that the technology is highly

mature, both in and outside of the Nigerian market. Their level of maturity makes lead acid batteries the technology of choice for large-scale, capital-intensive projects. The comparatively low cost per kWh for lead acid batteries is balanced against potential drawbacks such as the comparatively larger physical footprint of the units themselves and the fact that they are lower density than their lithium ion-based peers. Their low density means that the developer must procure and deploy a higher number of battery units to provide an equivalent amount of storage as compared to lithium ion batteries, driving up the overall capital cost, even if the per unit cost remains lower than lithium ion alternatives.

- **Lithium Ion:** In comparison, lithium ion batteries are generally more expensive in Nigeria, with per kWh costs ranging from US$250 to US$500 per kWh. Despite the higher capital cost, project developers are increasingly deploying lithium ion to take advantage of potential lifecycle savings and increased performance and resiliency compared to lead acid batteries. For small-scale systems, the relatively high capital cost becomes less significant than the longer life cycle, the ability to operate at high temperatures, and deep discharge capability. [7]

Figure 4: Range of Battery Capital Costs

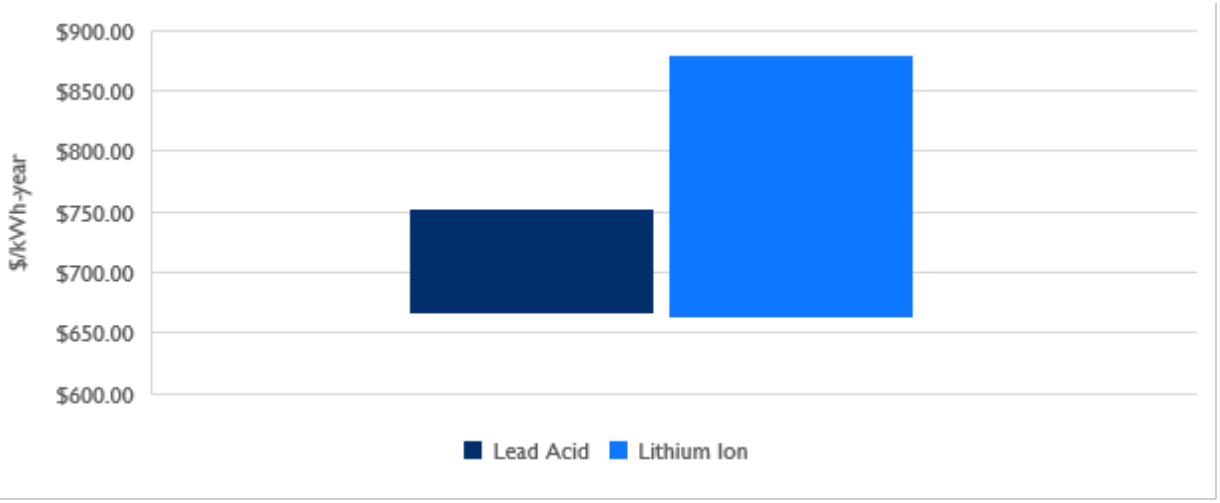


While lithium ion batteries typically have a higher initial capital cost, they have become more competitive when viewed in terms of their levelized cost of energy – a longer-term metric for defining potential costs associated with different energy generation and storage technologies[8]. As Figure 4 outlines, the levelized cost of energy of solar and lead acid battery storage, in some cases, can be less expensive than the levelized cost for lithium ion batteries. As battery technology continues to improve, this cost will likely continue to become more competitive compared to diesel backup generators and other alternative storage systems for mini-grids. Evolving awareness and safe, environmentally friendly disposal methods for used batteries is yet another enabler for increased deployment of battery storage solutions.

[7] Figure: PA-NPSP Industry Survey

[8] Levelized cost of energy "Measures lifetime costs divided by energy production and calculates present value of the total cost of building and operating a [energy technology] over an assumed lifetime. It also allows the comparison of different technologies (e.g., wind, solar, natural gas) of unequal life spans, project size, different capital cost, risk, return, and capacities; U.S. Department of Energy

Figure 5: Levelized Cost of Energy for Residential Solar and Storage ($/kWh-year)[9]



3.2.2 TECHNOLOGY PERFORMANCE

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

- **Lead Acid:** Generally, lead acid batteries have a lower energy density and a lower level of resilience than lithium ion options. Lead acid batteries can be cycled approximately 1,650 at a 50% depth of discharge (or 1,050 times at 80% depth of discharge) before seeing substantial performance degradation.[10] From a performance perspective, this makes lead acid a near peer to lithium ion in the short term, but in a multi-year use in the Nigerian off-grid environment, lead acid battery performance may fall off more quickly than other alternatives. Similarly, lead acid life cycle is relatively short under normal operating conditions, and high temperatures and/or deep discharge cycles (environmental factors commonly occurring in Nigeria) may further reduce the operating life and battery performance.

  Further, lead acid batteries tend to be physically heavy, therefore requiring different housing than lithium ion batteries, and can be less durable than lithium-based systems when deep cycled. A full discharge causes strain and each discharge/charge cycle can permanently deprive the battery of a small amount of capacity. For example, if lead acid batteries are over-discharged or forced to remain in the discharged state for prolonged periods, a hardened lead sulphate can coat the battery's electrodes. This coating can affect the ability of the battery to recharge while also reducing the efficiency and life of the batteries. Finally, the lead acid battery's lower density creates voltage discrepancies between multiple battery modules that can lead to state-of-charge deviations when connecting between them.

- **Lithium Ion:** Comparatively, lithium ion batteries have high power and energy density, making them more resilient than lead acid counterparts. This higher power/energy density also means that they are more lightweight and require fewer modules for desired performance making them easier to integrate into the battery module for larger off-grid systems.

[9] Lazard
[10] United States Agency for International Development

Lithium ion batteries can be discharged between 1,900-3,000 times at 80% depth of discharge with minimal long term damage.[11] This resilience gives lithium ion batteries about six times the number of cycles compared to a lead acid, a characteristic that makes lithium ion generally a more flexible and resilient battery technology in the long-term. Disadvantages of this battery type include the tendency to degrade at high temperature and when stored at high voltage. Both are challenges that can be overcome by structural designs in battery housing and the strategic placement of the battery system on-site as well as using a battery management system.

3.2.3 REGULATORY AND FINANCIAL BARRIERS

There are a variety of regulatory and financial structures that support Nigeria's mini-grid and battery markets. These are important as they represent potential hurdles to market development, but also potential opportunities to capitalize on market incentives that may mitigate risk for mini-grid developers and battery vendors.

- **Import Regulation and Incentives:** Presently, the government of Nigeria charges inconsistent import duties and value added tax on the importation of lead acid and lithium ion batteries into the country. Energy access companies argue that duty-free importation of solar components together with batteries will incentivize the scaling of energy access businesses in Nigeria.
- **Global Standards:** Currently, there are no official standards for the quality assurance of batteries in Nigeria. However, there is a need to ensure consistency of quality of batteries by establishing independent and globally accepted standards, similar to that which exists for off-grid lighting applications.
- **Battery Waste and Recycling:** The Federal Ministry of Environment of Nigeria has formulated regulations for the disposal of battery waste, however, there is no established protocol for handling or recycling of batteries at the end of their useful life. The Renewable Energy Association of Nigeria, in cooperation with the Heinrich Böll Foundation, developed a policy guidance paper in 2020 to define policy avenues though which the Federal government could incentivize used lead acid battery recycling operations to both increase battery availability and mitigate risks associated with improper disposal and/or recycling operations of battery waste.[12] The absence of effective and detailed regulation on battery waste, as well as reputable, responsible, and safe recycling companies (e.g., Hinckley Recycling) results in improper management of battery waste by the informal sector. Despite the absence of heavy metals in lithium ion batteries, there are various constituent-parts with potentially negative effects on human health and the environment. And having very little recycling value, lithium ion batteries are quite unattractive for local and global recycling markets. As a result, they are more likely to be disposed of in an uncontrolled manner.[13]

3.2.4 PRODUCT WARRANTIES

The ability of the battery manufacturer to provide both product warranty and performance guarantee on its technologies is a critical factor in selecting a battery for use in off-grid applications. The inability of project developers to access reliable, in-country post-sales support service – such as repair, replacement, refund and compensation – and a sometimes-inconsistent warranty environment further hinders the potential for large-scale deployment of batteries in Nigeria's off-grid market because it disincentivizes developers from trying new, more technologically advanced products. The ability to supply a reliable product with accessible post-sale customer service is integral in ensuring long-term growth and a successful entry into Nigeria's off-grid market.

[11] United States Agency for International Development
[12] Renewable Energy Associate of Nigeria
[13] Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). "End-of-Life Management of Batteries in the Off-grid Solar Sector," 2017

Depending on the type of application of batteries and the business model for deployment, the energy access company and battery manufacturer must agree on the terms of warranties they will offer and how claims against those warranties will be managed. For battery storage services, typically there are two primary types of warranties:[14]

- **A product warranty:** This guarantees against product defects, typically provided by the original equipment manufacturer (OEM) for specific components or the vendor for the good as a whole.
- **A performance warranty:** This guarantees that the product will achieve certain performance milestones tied to the operation of the battery unit.

3.2.5 NEW TECHNOLOGIES

The integration of battery banks with a battery management system enables real-time control and monitoring of many functions vital to the correct and safe operation of the battery. This includes monitoring of temperatures, voltages and currents, maintenance scheduling, battery performance optimization, failure prediction and/or prevention, as well as battery data collection and analysis. The solar photovoltaic cell voltage measurement and control is the most important function of the battery management system, however the management of environmental stresses, such as temperature monitoring, can contribute positively to a battery's lifetime as well.

Currently in Nigeria most suppliers only deliver the core technology (i.e. battery packs) but the battery management system integration must be completed individually, and can lead to problems in battery, inverter, and battery management system interaction.[15] For example, improper design, integration and/or installation may lead to voltage excursions due to overcharge, over-discharge, or high-power pulses. This can lead to a significantly reduced battery life and safety issues.

[14] Norton Rose Fulbright

[15] Shell Foundation and Grantham Institute, Imperial College. "Energy storage trends for off-grid services in emerging markets: Insights from social enterprises," 2018

4 THE BATTERY MARKET FOR OFF-GRID SYSTEMS

Nigeria's battery market landscape is characterized by its relative immaturity compared to the status of batteries globally. Utility-scale batteries are nonexistent, with large-scale renewable energy development still in fledgling phases of maturity. For small-scale mini-grid operations – the focus of this Report – the landscape is slightly more promising, with off-grid developers both recognizing the importance of batteries to make off-grid renewable energy installations economically and practically viable. This section will cover:

- Programs supporting Nigerian off-grid
- Battery Market Scenario Development
- Nigeria's Battery Market Size
- Nigeria's Potential Lithium Ion Market

4.1 PROGRAMS SUPPORTING NIGERIAN OFF-GRID

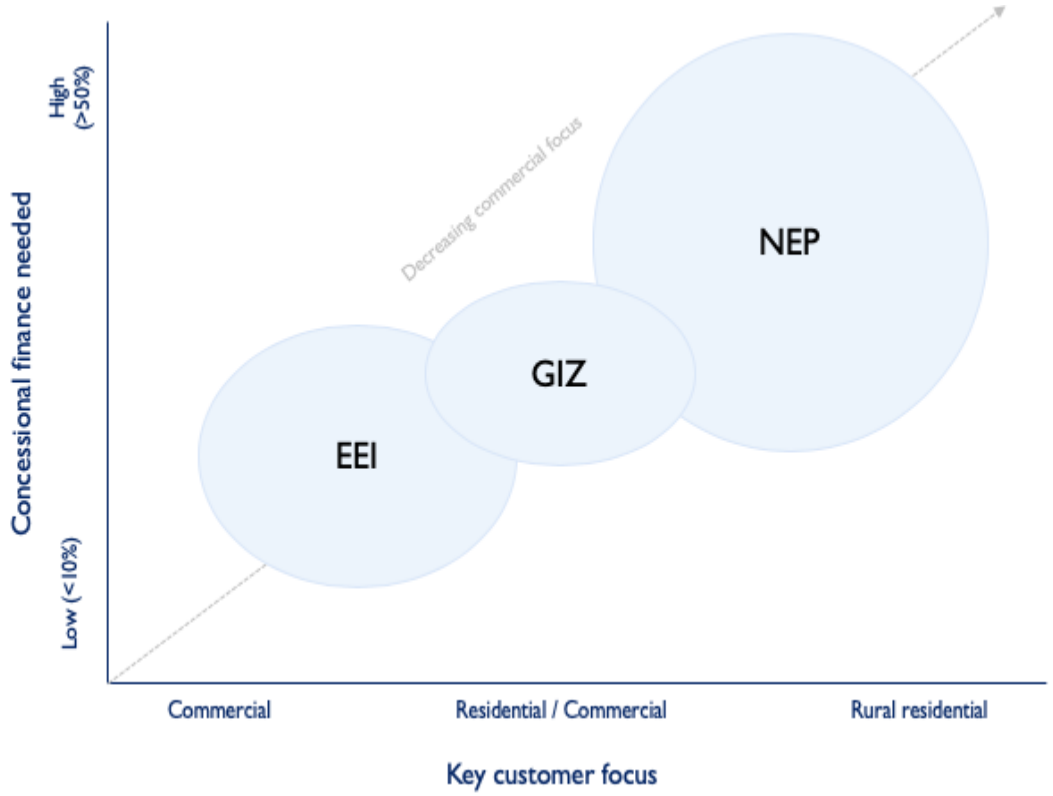
The number of local and international programs supporting Nigeria's off-grid market has increased significantly in recent years. This includes government-led efforts targeted at identifying the potential scale of Nigeria's mini-grid marketplace, as well as those programs focused on supporting and accelerating mini-grid developer maturity and expansion by deploying financing programs specifically tied to the mini-grid market. Chief among the Nigerian government's efforts to estimate the potential size of Nigeria's mini-grid market are the Rural Electrification Agency's geospatial assessment of off-grid potential and the federal government's Rural Electrification Strategy and Implementation Plan.

- **Rural Electrification Agency Geospatial Assessment:** Estimates 17,702 individual settlements are best-served by mini-grids.
- **Rural Electrification Strategy and Implementation Plan:** Part of this plan sets a goal of developing 10,000 individual mini-grid communities by 2023.

The targets and limits outlined in these guiding assessments – one detailing a 10,000 mini-grid goal, the other outlining a potential market need across more than 17,000 individual mini-grid communities – are supported by a variety of government, donor, and multilateral financial institution programs that are targeting Nigeria's mini-grid and off-grid marketplace for expansion. Both the World Bank and African Development Bank have launched the US$350 million and US$200 million Nigeria Electrification Project respectively – to catalyze growth across Nigeria's power sector. Within this program, the World Bank has allocated US$150 million in subsidies for mini-grids alone, with US$70 million allocated towards a minimum subsidy tender and US$80 million for a performance based grant that provides US$350 per connection for mini-grid developers.

Additionally, GIZ's Mini-Grid Acceleration Scheme, Interconnected Mini-Grid Acceleration Scheme, and REA's Energizing Economies Initiative all seek to accelerate the uptake of mini-grid technology in Nigeria. As emphasized in Figure 6, these programs, coupled with REA's strategic plan to push for 10,000 mini-grids with an estimated addressable market of more than 17,000 mini-grid communities, demonstrate the comprehensive coverage of donor-funded programs designed to catalyze growth in the Nigerian mini-grid market and are indicative of the rapidly expanding need for battery units.

Figure 6: Nigeria Off-Grid Donor Program Activity



4.2 BATTERY MARKET SCENARIO DEVELOPMENT

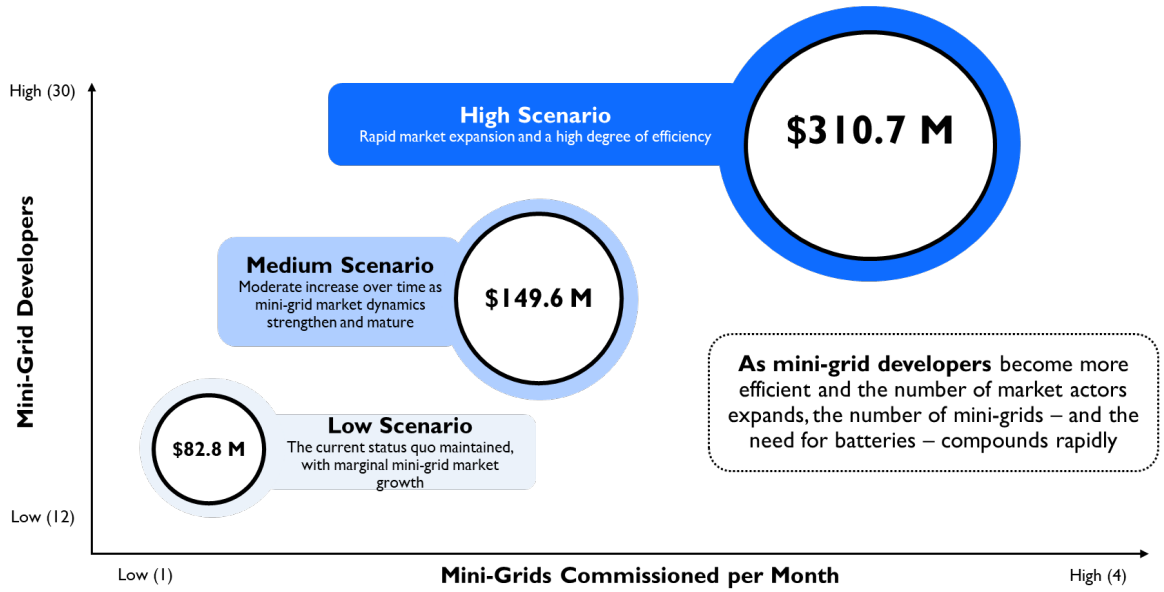
Mini-grids, solar distributed energy systems up to 1MW in size, represent a growing market for batteries in Nigeria. Due to the highly intermittent nature of solar energy, the constrained economics of mini-grid developers, and the need for flexible, and affordable, storage solutions, battery integration with mini-grid technology makes a natural pairing. Further, the mini-grid marketplace in Nigeria is poised to mitigate the challenge of solar intermittency by providing more stable, consistent, and resilient energy supplies for the typical mini-grid model, even in the difficult climates and locations where these mini-grids are often deployed.

To assess the potential size of the battery market, PA-NPSP has developed a series of market assessments based on mini-grid market assumptions, including the likelihood that the number of market actors will expand from 2020-2025, and the likelihood that most mini-grids developed (approximately 60%) will be 50-100kW in size. The sub-1 MW size is largely due to Nigerian Electricity Regulatory Commission requirements that mandate a regulatory permit for mini-grids between 100kW and 1MW in size. PA-NPSP estimates also assume mini-grid developers will both become more efficient over time and have increasing access to capital. This analysis resulted in three market scenarios (Figure 7) from 2020-2025[16] with the following assumptions outlined below:

[16] This analysis does not take into account battery replacement rates

Figure 7: Mini-Grid-Driven Battery Market Scenarios

Scenario	Number of Mini-Grid Developers Active	Number of Mini-Grids Constructed Per Month
Low Expansion: *The current status quo maintained, with marginal mini-grid market growth*	12	1-3
Medium Expansion: *Moderate increase over time as mini-grid market dynamics strengthen and mature*	20	1-3
High Expansion: *Rapid market expansion and a high degree of efficiency*	30	1-4

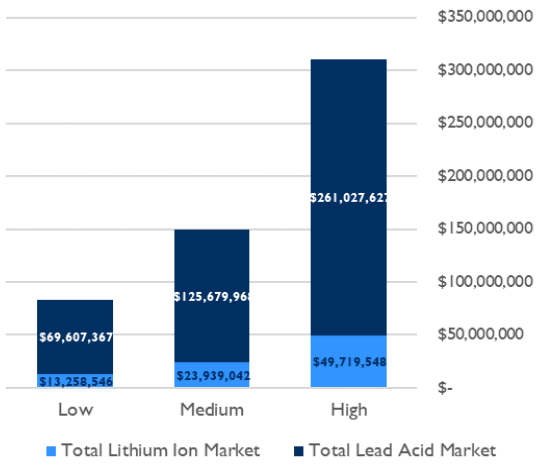


4.3 Nigeria's Off-Grid Battery Market Size

Modeling low, medium, and high scenarios outlined in Section 4.2 produced an estimate of Nigeria's battery market solely in the context of off-grid deployment. As outlined in Figure 8, this estimate ranges from US$82 million to more than US$310 million over the five years from 2020-2025.

Across all three scenarios, it is important to recognize the interconnected relationship between the increasing number of active mini-grid developers in the Nigerian off-grid market and the ability to expand the Nigerian battery market for off-grid implementation. In fact, the number of active mini-grid companies is a substantial driver of potential growth in Nigeria's battery market with a compounding effect as a result of each additional active developer - each building new mini-grids - across a 5 year period. It is interesting to note that

Figure 8: Lead Acid and Lithium-Ion Market Size by Scenario

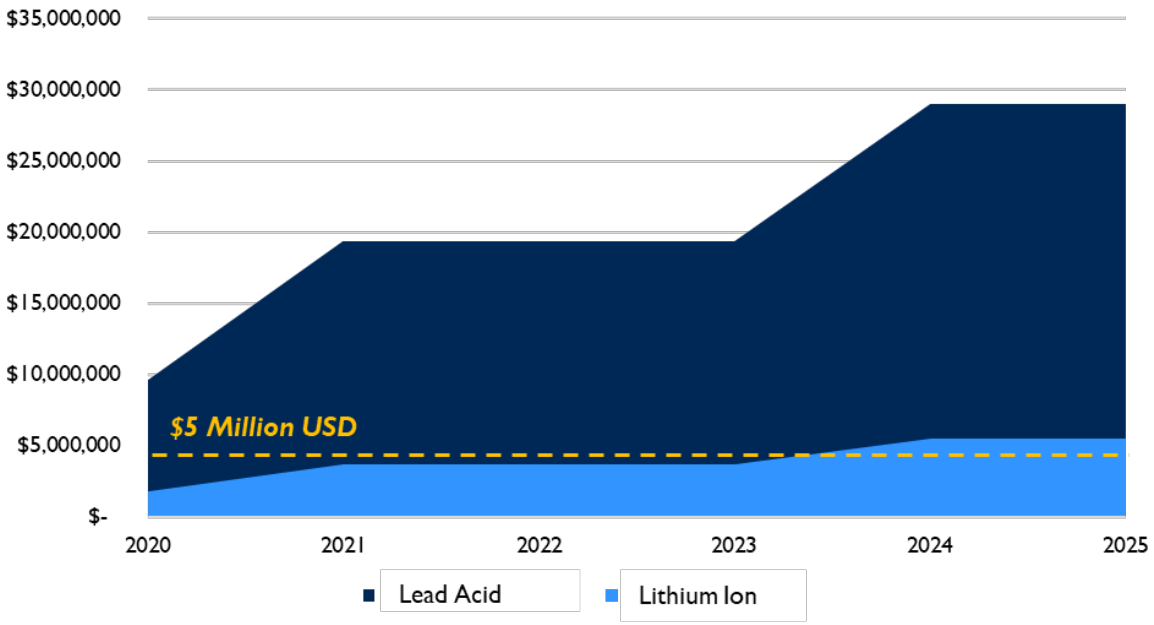


this compounding effect actually exceeds the anticipated market growth rate of a scenario where existing companies only become more efficient.

4.4 NIGERIA'S POTENTIAL LITHIUM ION MARKET SIZE

Lead acid will likely retain significant market share in Nigeria, but the market share of lithium ion batteries will continue to increase steadily. Lead acid batteries are anticipated to remain a dominant battery option within this timeframe due to their relative affordability and ease of deployment. However, the market for lithium ion batteries could expand significantly in this timeframe, with a more than 60 percent increase in market value over five years in the Medium Scenario model, reaching more than US$5 million per year in both 2024 and 2025, as outlined in Figure 9. This assessment yields the following year-over-year growth for the lithium ion battery market, with the market exceeding US$5 million per annum in both 2024 and 2025 in the medium scenario. This scenario assumes that lithium ion batteries will retain an approximately ten percent market share within the 2020-2025 timeframe.

Figure 9: Lead Acid and Lithium Ion Annual Market (Medium Scenario)



5 DEVELOPING NEW BUSINESS MODELS FOR BATTERY USE IN MINI-GRID SYSTEMS

To take advantage of the substantial potential for battery market growth with respect to Nigeria's mini-grid marketplace, mini-grid developers and battery providers may benefit from developing new, innovative ways to manage existing challenges to market expansion and supporting battery service, including maintenance and distribution services. A variety of challenges associated with integrating battery units into mini-grid system design remain. These challenges include:

- **Ensuring Local Availability**: The local availability of batteries is a challenge for mini-grid developers operating in Nigeria. There are no local battery manufacturers and systems procured from abroad have varying levels of quality and cost. Further, developers have experienced challenges importing systems into Nigeria, with customs codes often inconsistently applied to renewable and off-grid technologies.
- **Securing Well-Matched, Flexible Financing:** It can be challenging for mini-grid developers to access Naira-denominated financing to mitigate challenges associated with extreme exchange rate fluctuations, both due to the limited pool of local financing and inflexible term sheets. For international financing, a mismatch between collected revenues from mini-grid operations (in Naira) and the lender currency (e.g., U.S. Dollars) exposes international lenders to this same exchange rate volatility.
- **Completing a Load Profile**: Developing load profiles for mini-grid systems, including accounting for battery integration, can be challenging in Nigeria's off-grid environment. Communities where mini-grid systems are most appropriate are often challenging to reach, leading to high time and labor costs to perform load profiles across geographically dispersed communities.
- **Lack of Local Capacity**: Mini-grid developers are often challenged by the degree of local technical capacity to install, operate, and maintain renewable energy systems. This capacity has been developed in recent years, with the advent of training materials and programs developed through Nigeria's Rural Electrification Agency and the Renewable Energy Association of Nigeria. However, the growing integration of battery units into mini-grid systems has increased the breadth and complexity of knowledge demanded of trained staff.

In order to successfully navigate Nigeria's battery landscape, mini-grid developers and battery vendors may have to adapt the frameworks they use to do business. A PA-NPSP survey of prominent mini-grid developers operating in Nigeria indicates that the current market preference is for (1) the outright purchase of batteries through direct sales and (2) leasing of batteries. The business models explored below represent a list of potential business models for facilitating purchases by mini-grid developers from battery vendors, in turn providing more flexibility for both parties and spurring the rate of integrating battery units into the Nigerian off-grid market.

This list includes:

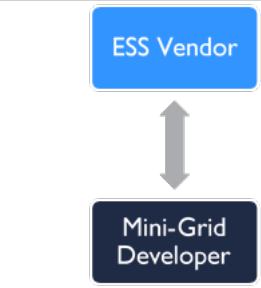
- Direct Sales
- Original Equipment Manufacturer (OEM) Tie Ups
- Engineering, Procurement, and Construction (EPC) Tie Ups
- Storage as a Service
- Lease and Lease to Own
- Vendor Finance

The primary actors in each of these models are similar as indicated by the diagrams beside each model. It should be noted that both actors, mini-grid developers and battery vendors, must consider the importance of insurance and warranties when assessing which business model may be appropriate for a company's business goals and market position.

5.1 Direct Sales

The direct sales model is the most straightforward business model for distributing batteries, in Nigeria or elsewhere. In this model, a single buyer directly purchases a battery from a single seller. Typically, the battery is paid for up front, while the buyer may have back-end financing.

Figure 10: Direct Sale Model



- ***Strengths:*** The strength of the Direct Sales model lies in its simplicity. Individual businesses sell directly to individual buyers. The ability of the seller to succeed is directly tied to their own business acumen and distribution capacity.
- ***Weaknesses:*** This approach may not scale as rapidly as other business models. Individual customers and mini-grid developers must be identified, marketed to, sold to, and then those relationships must be maintained on a highly individualized basis. This model also necessitates individual companies/consumers having sufficient capital – or sufficient financial savvy to qualify for a loan – to purchase a unit up front.

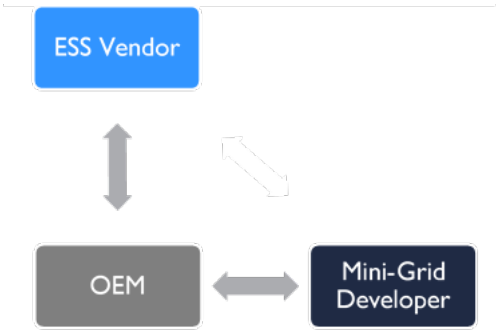
Table 2: Direct Sales Model Attributes

Battery Market Challenges	Direct Sales Business Model Addresses
Lack of local availability	X
Securing flexible financing	X
Completing load profiles	X
Lack of local capacity	X

5.2 Original Equipment Manufacturers Tie Up Model

The Original Equipment Manufacturers (OEM) Tie Up model is the first of two business models that require fostering partnerships with other entities. In this context, OEMs are those companies that manufacture the mini-grid technology that is implemented in the Nigerian market. This is most likely to include solar panel and electronic equipment manufacturers that produce the housing, appliances and wiring that comprise mini-grid technology. This relationship can be based on multiple factors including consolidation of supply, increasing the scale of distribution, the variety of financing options available to consumers, or other benefits along the energy storage value chain.

Figure 11: OEM Tie Up Model



- ***Strengths:*** Potential synergies may be realized if energy storage vendors are able to vertically align supply, distribution, or other business components with one of their primary OEMs. Further, energy storage vendors could reduce costs by arranging bulk and/or packaged deals with OEMs for certain components. Savings could be justified by the promise of distribution/supply synergies with the OEM that allow for the vendor to reach a higher number of mini-grid developer

customers or cross-sell their products with services or products provided by the OEM in similar business areas or geographic areas where the OEM may have a stronger presence than the vendor, or vice versa.

- ***Weaknesses:*** Weaknesses include the potentially high degree of complexity compared to other models. Arranging an OEM tie up likely requires a comparatively high degree of business acumen and may not be the most appropriate option for vendors new to the market or who do not have a strong history with an individual OEM.

Table 3: OEM Tie Up Attributes

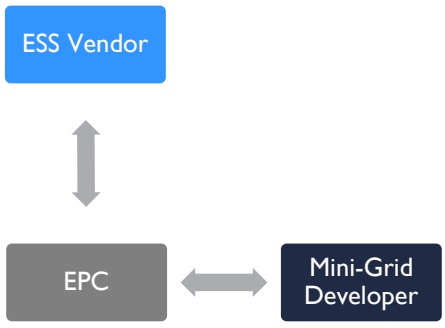
Battery Market Challenges	OEM Tie Ups Business Model Addresses
Lack of local availability	✔
Securing flexible financing	X
Completing load profiles	X
Lack of local capacity	✔

5.3 Engineering, Procurement, and Construction Tie Ups

Engineering, Procurement, and Construction (EPC) tie ups are typically intended to be turnkey agreements, where a battery vendor/owner contracts with an EPC firm to design, build, and commission a storage system or mini-grid. For the battery vendors, partnering with an EPC is a strategy to harness the distribution potential of the EPCs business relationships, project pipeline, and potential for co-delivery of services. In this respect, the EPC tie up functions similarly to the OEM tie-up, differing only in how the EPC partner engages potential consumers and the type of synergies that are achieved between the EPC and the battery vendor. While OEM partnerships are "upstream," EPC tie ups are "downstream," and may have greater potential to interface with mini-grid developers.

- ***Strengths:*** While OEM tie-ups are attractive for vendors seeking to trim supply costs and leverage distribution synergies, EPC tie-ups primarily offer synergies that are grounded in their ability to leverage their project portfolio and relationships. EPCs are well-positioned to be able to identify existing projects where energy storage services may be beneficial. This type of tie-up may give battery vendors access to markets that, particularly in the Nigerian context, are under-developed. Further, EPCs generally have longstanding relationships with many large-scale institutions and off-takers in their operational geography, enabling them to potentially act as a gateway to large institutional battery purchasers.

Figure 12: EPC Tie Up Model



- ***Weaknesses:*** The weaknesses of EPC tie-ups reflect those of OEM tie-ups: there may be a high degree of complexity when negotiating and establishing relationships with EPC firms compared to other potential battery business models.

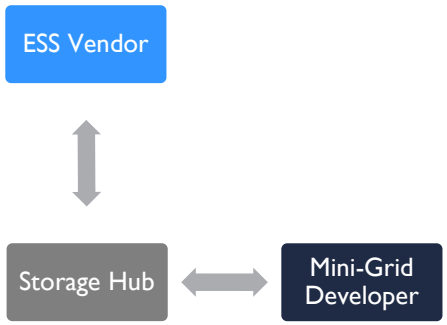
Table 4: EPC Tie Up Attributes

Battery Market Challenges	EPC Tie Ups Business Model Addresses
Lack of local availability	X
Securing flexible financing	X
Completing load profiles	✔
Lack of local capacity	✔

5.4 STORAGE AS SERVICE

Storage as a service is a business model primed for rapid development in emerging off-grid markets such as Nigeria. This model treats small-scale battery storage as a traditional "service," paid for on a rental or subscription basis. Typically, energy storage units would be maintained and charged at a central location and operated on a "hub and spokes" design. Individual customers and/or individual mini-grid operators would procure the service of a maintained and fully charged storage unit from this location, paying a set rental fee or using a set subscription rate depending on how the model is arranged. When the storage unit has depleted its charge, the customer returns it to the central distribution hub for re-charge and any necessary servicing.

Figure 13: Storage as Service Model



- ***Strengths:*** The Storage as a Service model may be a strong fit for companies and customers that are looking for a highly flexible method for procuring storage services. Battery vendors could set up storage as a service hub with relatively low levels of capital expenditure and without the need to spend time and effort developing strong, geographically dispersed distribution channels that the direct to consumer sales model would require. This is due to the relative simplicity of storage units and the relative ease and minimal oversight that would be required to remotely operate and maintain automated payment services and/or charging of storage units. This makes it a highly efficient model for deploying flexibly-priced storage services in a range of customer environments. Battery as a Service may be a better fit for lithium ion batteries, as they are generally more resilient and can handle more individual cycles than lead acid batteries.
- ***Weaknesses:*** Storage as service hubs may require partnership with a "host" company or business to host the storage as a service hub or receptacle. This may also be a strength of the model, depending on the type and number of synergies that can be derived from the partnership, the rent due on the hosting of the storage as a service hub, and the level of effort required of a storage company to identify and complete the partnership process.

Table 5: Storage as a Service Attributes

Battery Market Challenges	Storage as a Service Business Model Addresses
Lack of local availability	✔
Securing flexible financing	X
Completing load profiles	✔
Lack of local capacity	X

5.5 LEASE AND LEASE-TO-OWN

A lease business model can be implemented in two different ways. The first emphasizes short term leasing of a battery unit. Lease payments are made to the battery vendor at set intervals and the unit is returned after the lease period has expired. This differs from the "rent" charged for storage as a service as the customer would be responsible for re-charging the unit during the lease and typically will lease the battery over a longer time frame, making it a strong fit for mini-grid developers that are looking to develop more flexible financing arrangements than outright purchase, but need a battery more consistently than the storage as a service model may allow.

The second option is lease-to-own. Up-front, lease-to-own functions much the same as a traditional lease. The primary difference is that the end result of the lease-to-own model is the customer's ownership of the storage unit. This model may appeal to a different customer set who have ownership in mind but require some flexibility in payment. Overall, both options are slightly less flexible than the storage as a service option for both customers and vendors, but leasing allows for longer-term access to the battery unit. Specific lease terms will have to be negotiated, including to what degree the vendor, or the lessee, is responsible for operations and maintenance of the battery unit.

Figure 14: Lease and Lease to Own Model

- ***Strengths:*** Leasing provides a familiar business model to many mini-grid electricity consumers. It may appeal to more advanced energy consumers in that they are able to reliably charge storage units in their home or workplace. Leasing also provides more flexibility for the sophisticated energy consumer who needs sustained access to an energy storage device for longer periods of time including, potentially, the aspiration of ownership.
- ***Weaknesses:*** Compared to the highly flexible storage as a service option, leasing does not have the same flexibility for those that cannot reliably charge their device. This is unlikely to be an issue in the mini-grid context but is a consideration if recurring low levels of solar radiation are anticipated. This model also relies heavily on customer consistency in making their lease payments but is more flexible than the direct-to-consumer (outright purchase) model which may require customers to pay the entire amount up-front or pay installments on a loan that has an interest rate.

Table 6: Lease/Lease to Own Attributes

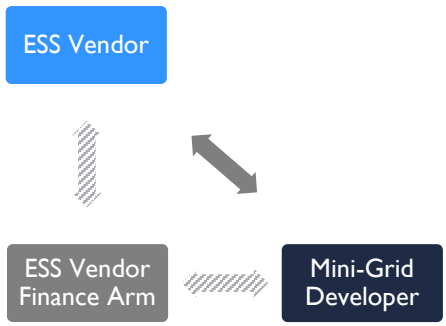
Battery Market Challenges	Lease/Lease-to-Own Business Model Addresses
Lack of local availability	X
Securing flexible financing	✔
Completing load profiles	X
Lack of local capacity	X

5.6 VENDOR FINANCE

In this model, a battery vendor offers financing to potential customers and mini-grid developers in the form of a loan. This loan is then used to pay the purchase price of the battery vendor's product, and the customer begins to repay the balance of the loan, including interest, to the battery vendor's financing arm.

- ***Strengths:*** This model is attractive for vendors targeting customers in the middle of the socioeconomic scale and mini-grid developers who may need flexible financing arrangements but may be comfortable servicing debt, as opposed to lease terms or the necessity for outright purchase. Target customers are most likely interested in owning a battery but require or may be interested in loan-based financing. This implies that customers attracted by the vendor finance model are most likely those that are in the middle tier of size and operational footprint.

Figure 15: Vendor Finance Model



- ***Weaknesses:*** Vendor financing adds additional financial complexity for battery vendors. In addition to establishing a vendor financing capacity within their organization, they have to have the long-term vision and capacity to manage vendor finance outlays over the loan tenor.

Table 7: Vendor Finance Attributes

Battery Market Challenges	Vendor Finance Model Business Model Addresses
Lack of local availability	X
Securing flexible financing	✔
Completing load profiles	X
Lack of local capacity	X

6 CONCLUSION

Battery storage is an essential part of successfully scaling the mini-grid market in Nigeria. Batteries may provide the necessary flexibility to mitigate many of the challenges associated with renewable, solar technology, including the intermittency of power supply and the sometimes-challenging economics that mini-grid developers face in delivering off-grid solutions with a stable rate of return. PA-NPSP's survey of mini-grid developers supports this conclusion, with many developers viewing the integration of storage solutions into the Nigerian mini-grid market as a necessity in order for the market to continue growth.

This high degree of importance necessitates action by mini-grid developers to encourage battery technology development in Nigeria, but more importantly, this demands an increased level of action from battery vendors themselves. Battery technology options in Nigeria are available, but they are limited in quantity and source. These constraints pose risks to the ability of Nigeria's off-grid mini-grid marketplace to successfully scale, even as the batteries become more cost-effective, more technologically advanced, and as more Nigerian mini-grid developers integrate storage into their systems design.

PA-NPSP has drawn a handful of targeted recommendations for battery vendors looking to position for success in the Nigerian battery market. These strategic recommendations include:

1. **Expand Target Customer Base for Batteries:** Beyond the application of battery technologies in mini-grids, the commercial and industrial market segment constitute a significant growth opportunity. Key factors, such as the recently announced increase in electricity tariff and volatility in fuel prices, could drive market growth going forward. Deploying hybrid power systems together with battery storage presents opportunities for providing stable and reliable power supply to both households and commercial and industrial customers.
2. **Strengthen Warranty Arrangements:** Improving the quality and length of warranties on batteries would be crucial in increasing the bankability of batteries in off-grid applications; this includes developing appropriate codes, standards, and regulations for efficient installation, use and management of batteries across the product life cycle. Energy access companies can collaborate with battery manufacturers to provide integrated power solutions with 'fully-wrapped' warranties. Markets and regulations in Nigeria also need to ensure revenue certainty for off-grid investments.
3. **Diversify Available Business Models:** Battery vendors and mini-grid developers that begin to diversify the business models they use to approach battery procurement may be able to gain traction in the marketplace. New business models may provide more flexible financing options for mini-grid developers, allowing them to purchase units more consistently or deploy units in a wider range of situations.