In collaboration with the
Global Battery Alliance, the
Energy Storage Partnership
and the Faraday Institution

Closing the Loop on Energy Access in Africa

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Cover: Getty images

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Foreword

The Global Battery Alliance's 2030 vision is to provide 600 million people with access to electricity via battery deployment.

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Access to clean, reliable electricity is one of the greatest challenges to sustainable development in Africa. Energy storage, particularly batteries, will be critical in supporting Africa's progress to full energy access by 2030, enabling off-grid and on-grid electrification. This increasing demand for batteries also brings increasing challenges, however, due to the growing stream of decommissioned batteries. Historic pollution cases from substandard lead-acid recycling facilities on the continent, and a lack of lithium-ion recycling infrastructure – the two most used technologies for energy access applications – highlight the gap countries face in implementing a sustainable battery supply chain.

This report aims to advance the Global Battery Alliance (GBA) 2030 vision to provide 600 million people with access to electricity via battery deployment. The World Economic Forum, in collaboration with the GBA, the Energy Storage Partnership and the Faraday Institution, supported by the African Circular Economy Alliance, seeks to support energy access outcomes through the sustainable scale-up of batteries in sub-Saharan Africa and mobilize actions to reduce the gap between those with and without electricity by 70%.[1]

Market opportunities for batteries in energy access applications are analysed and recommendations are provided for public and private stakeholders on how to support a sustainable scale-up of battery deployment in Africa and the battery supply chain, through recycling and high-quality repurposing initiatives. The report aims to bring a holistic approach to the attention of financial institution and donors, in terms of financing energy access infrastructure and supporting investments on battery deployment and clean infrastructure, high-standard recycling facilities and battery remanufacturing.

Extensive consultation with stakeholders during the project highlights the need for improved collaboration across African countries and between policy-makers and industry to advance the objectives of improved energy access and battery end-of-life management. This report supports local stakeholders and lays the foundation for a network of champions that endorse and support the implementation of the report's recommendations.

Supported through Danish development cooperation, the Ministry of Foreign Affairs of Denmark is proud to support this important and timely work to further our understanding of how to supply access to energy in a sustainable way that includes local stakeholders and provide the necessary technical expertise for accelerated climate action.

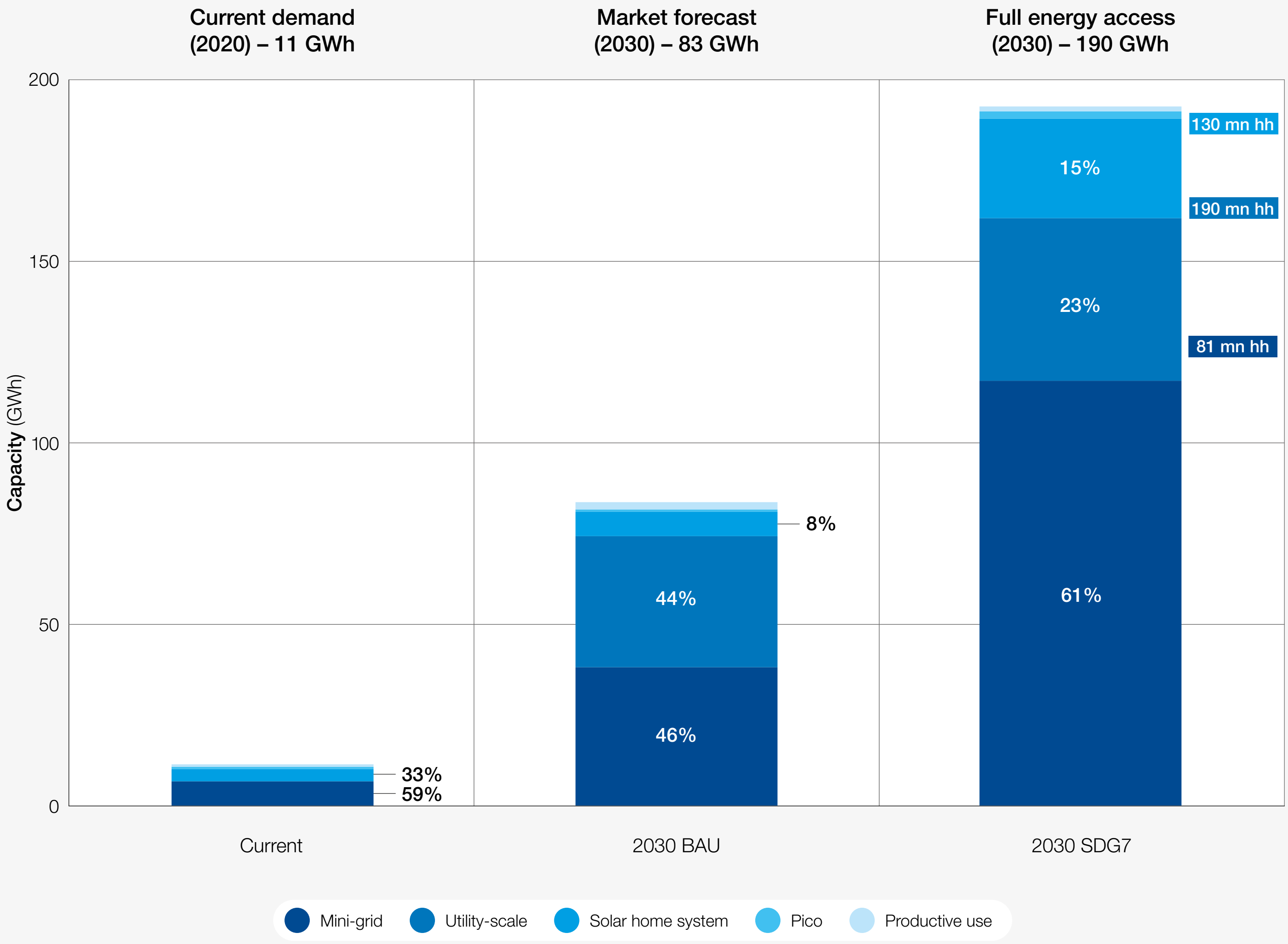
Executive summary

Batteries have the potential to unlock economic development and significant improvements in health, education and productivity in Africa.

Batteries are critical to supporting sub-Saharan Africa's energy access goals.[2] Access to clean and reliable electricity is one of the greatest challenges to sustainable development in Africa, with nearly 550 million people lacking access to electricity and an additional 150 million facing an unreliable connection.[3] Batteries play a role in both an off-grid and weak-grid context, by enabling the use of decentralized energy technologies, such as solar home systems (SHS), and improving the reliability of the grid. Through their impact on energy access, batteries unlock significant improvements in health, education and productivity.

Improvements in energy access over the next decade could drive an estimated sevenfold increase in stationary battery capacity in the region, to 83 GWh.[4] Stationary battery capacity in Africa could grow by 22% annually to 2030, due to demand from energy access applications – mini-grids alone could represent 40% of the 2030 market (section 1). Battery capacity could be twice as large under a full energy access scenario, however, reflecting the need to continue improving affordability of batteries and energy access business models.

FIGURE 1 **Projected development of stationary storage capacity[5] in sub-Saharan Africa[6]**



Meeting the growing battery demand at a lower economic, environmental and human cost will require high-quality recycling and repurposing, currently non-existent across most African countries. Environmentally sound reuse, repurposing or recycling (elements of a more circular value chain) will be essential to mitigate these costs (section 2).[7] High-quality repurposing can also reduce the cost of achieving universal energy access goals, lowering battery prices by an estimated 30% (section 4).

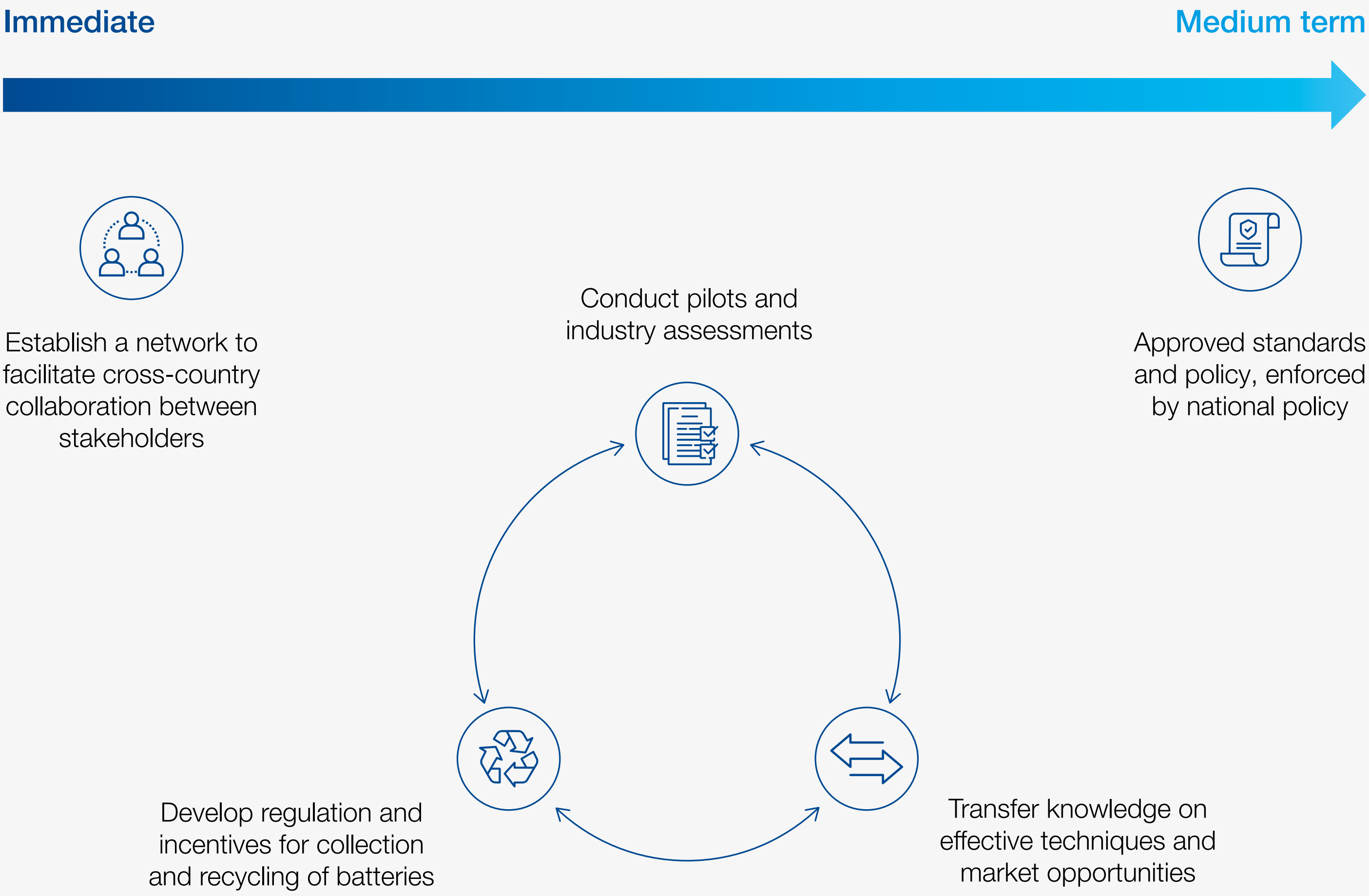
High-quality recycling and repurposing also create additional benefits, through employment and upskilling opportunities.[8] By advancing renewable powered electrification, repurposed batteries both accelerate variable renewable energy uptake and advance the indirect benefits associated with clean and reliable energy (such as improved health and education outcomes). Through the development of local recycling and repurposing supply chains, countries can also benefit from quality employment opportunities, with sales of 1,000 SHSs associated with approximately 40 new jobs in the value chain.[9]

This report sits at the nexus of energy access, as set out in the Sustainable Development Goals (SDGs), and battery end-of-life (EOL) management, providing analysis and recommendations on how to support a sustainable and rapid increase in energy access by improving battery repurposing and recycling markets in African countries. Specifically, the report analyses opportunities and challenges for:

- Lead-acid battery recycling (sections 3.3 and 5)
- Lithium-ion battery recycling (sections 3.4 and 5)
- Lithium-ion battery repurposing (sections 3.2 and 4)

The report also discusses the continued efforts required to scale up energy access markets (see Box 1), if national energy access goals are to be met.

FIGURE 2 **Overarching recommendations (section 6)**



A first step will be to increase partnerships between stakeholders across African countries and internationally.

Recommendations include creating a coalition of stakeholders to coordinate on market transformation activities, including pilots, regulation, standards and enforcement. Figure 2 highlights commonalities in recommendations for each market. A first step will be to increase partnerships between stakeholders across African countries and internationally. Given the fragmented or immature nature of each market, these coalitions will be essential to: inform the development of regulation and standards by policy-makers; ensure the creation of sustainable business models and market incentives that align with policy ambitions; and increase awareness of the most effective policies and industry techniques. In all markets, strong government leadership will be a major success factor. The exact activities and stakeholders recommended for these coalitions will differ by market, as set out below.

Lead-acid battery recycling recommendations:

- Adopt and apply ambitious standards for the management of used lead-acid batteries (ULABs)
- Conduct assessments of domestic lead-acid battery recycling industries
- Dispose of ULABs only with recyclers committed to ambitious standards
- Source recycled lead only from recyclers committed to ambitious standards
- Support awareness-raising, know-how transfer and collaborative learning

Lithium-ion battery recycling recommendations:

- Initiate and roll out lithium-ion battery collection in pilot settings
- Combine existing take-back systems with incentive models
- Set up circular battery centres to develop and implement EOL management solutions

Lithium-ion battery repurposing recommendations:

- Set up a network of public-private circular battery centres to conduct trials on the performance of repurposed batteries across energy access applications
- Set an international, industry-approved quality assurance framework for repurposed batteries, potentially linking to the Global Battery Alliance (GBA)'s Battery Passport
- Disseminate lessons learned across countries, as well as between policy-makers and industry on a global scale
- Facilitate global linkages among EOL battery providers, remanufacturers and consumers
- Set out targets and white papers on opportunities for repurposing, including viable local business models and market segments suited to repurposed batteries
- Improve data sharing on EOL battery health, supported by the GBA's Battery Passport
- Global collaboration on designing first-life batteries to minimize repurposing costs

Next steps

Stakeholder consultation throughout the report has informed the development of recommendations that bring together recycling, repurposing and energy access markets.

1

The outlook for battery demand in Africa

Batteries are expected to make up a significant part of the future energy market in Africa due to declining costs and flexibility.

Batteries support improved energy access by increasing the reliability of the grid and supporting solutions for off-grid consumers. Electricity access in the region has improved markedly in the past 20 years, from 25% to 47% of the population.[10] The off-grid solar (OGS) and mini-grids markets have played vital roles in this expansion – sales of off-grid solar products have increased by 10% year-on-year in recent years, while more than 2,000 mini-grids are in operation.[11] For both off-grid and weak-grid populations, batteries play a role in improving access and reliability of energy provision and lowering associated costs.[12] Figure 3 summarizes the multiple services batteries provide.

FIGURE 3 **Services provided by batteries to support energy access**[13]

Users lacking access to reliable energy in SSA…

Individuals

- 550 million (50%) lack grid connection
- 160 million (14%) grid-connected people have access less than 12 hours/day

Businesses

- 13% cite access to electricity as biggest obstacle

benefit from storage in a range of technology applications…

Pico-systems
< 10W

Solar home systems
5-350W

Productive use
70-300W

Mini-grids
300-100kW

Utility-scale

where it often delivers multiple flexibility services

Off-grid services
– (VRE) self-consumption optimization

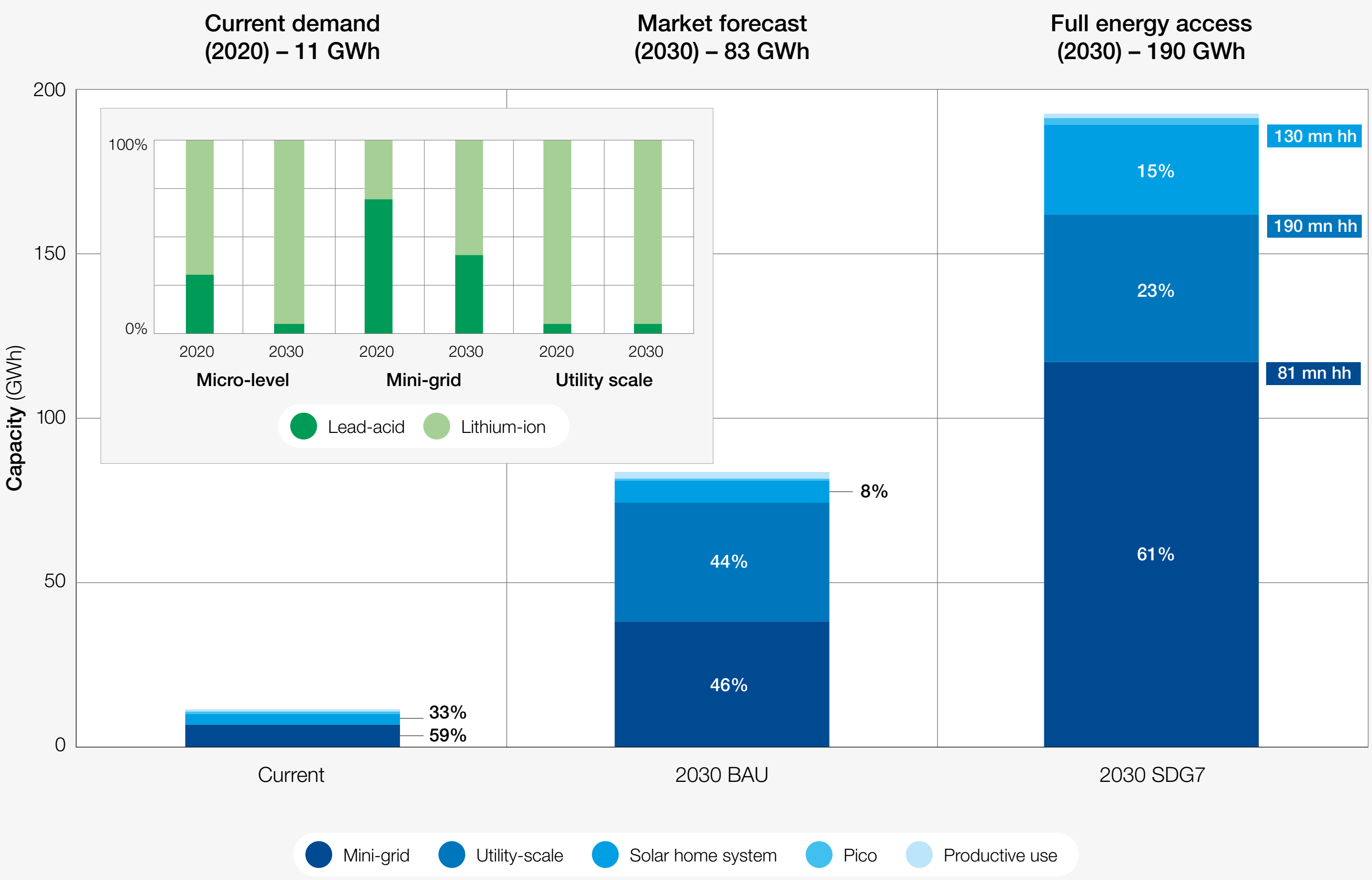
Behind-the-meter services
– Uninterruptible power supply
– Backup power
– (VRE) self-consumption optimization
– Time-of-use optimization

Grid and mini-grid services
– Frequency and voltage control
– VRE ramp control
– (VRE) generation time shift
– Firm capacity
– Grid congestion relief (T&D deferral)
– Balancing seasonal variability

Batteries are particularly attractive in Africa's stationary storage markets due to their modularity and increasing cost-competitiveness. Though pumped hydropower is the most widespread energy storage technology across sub-Saharan Africa today, batteries are expected to take a significant share of the future market due to declining costs and flexibility – including the range of storage services they provide and their ability to be tailored to consumer needs.[14] Significant cost declines – 90% since 2010 – have already contributed to growing sales of SHS, where batteries account for approximately two-thirds of total systems costs.[15] Further cost declines, 50% forecast by 2030 relative to 2017, could help replicate this trend in larger applications.[16]

Market projections forecast a sevenfold increase in the battery market to 2030, to 83 GWh, with even larger growth in battery demand in the full energy access scenario, where 190 GWh is required.[17] As shown in Figure 4, mini-grids and utility-scale storage represent the vast majority of storage capacity, but smaller energy access solutions will still be critical for a large number of households. Despite the progress towards universal energy access that demand forecasts reflect, the battery market would have to be more than twice as large to meet the storage needs under a full energy access scenario, highlighting the remaining energy access gap in 2030.

FIGURE 4 | Projected development of storage capacity[18]



BOX 1

Recommendations to support the growth of the battery market in energy access applications

To increase the adoption of batteries in energy access applications will require a range of measures to reduce costs, improve access to finance and increase the market value that batteries can access. In particular, efforts should focus on:

- **Support to the off-grid solar and mini-grid markets** through consumer subsidies, results-based financing for OGS companies and clear policy roadmaps for off-grid electrification. Government and international donor organizations need to continue efforts to address: the low affordability of energy access solutions, particularly mini-grids; the costly or limited access to consumer and commercial finance; and uncertain business models (particularly for mini-grids).
- **Designing electricity market regulation and grid policies to recognize and renumerate the value of battery storage.** For instance, providing clear technical guidelines for the safe interconnection of batteries to national distribution and transmission infrastructure; and ensuring batteries are renumerated for the multiple flexibility services they can provide[19] to help advance the investment case for behind-the-meter, mini-grid and grid storage.[20, 21]
- **Reducing batteries' purchase and maintenance costs**, for instance by: procurement of batteries through industry trade associations; demonstration projects to reduce costs of capital; and development or enforcement of warranties applicable to energy access contexts.[22]
- **Increasing consumer financing to purchase batteries**. Studies demonstrate that batteries can offer substantial savings compared to alternatives, such as fossil-fuel backup generators, in a range of energy access applications.[23] However, concessional finance is required to help consumers overcome the higher upfront costs of batteries and consumers' borrowing constraints.
- **In the longer run, directing research and development (R&D) towards battery chemistries that could be better suited to the local operating conditions** and have lower upfront costs – such as zinc-air, sodium-ion and redox flow.[24]

> **Off-grid solar is the fastest and cheapest solution for many of the 600 million people in Africa living without clean energy access. The industry plays an important role (re)building sustainable economies and communities, and in boosting resilience for some of the world's poorest people. Circular products and business models not only enhance environmental sustainability, but also represent an opportunity to add value for consumers and support local value chains and jobs.**
>
> Koen Peters, Executive Director, GOGLA

Lithium-ion batteries are increasingly the battery chemistry of choice in smaller energy storage applications and are expected to become ubiquitous across larger systems by 2030. Pico solar products and smaller SHSs have seen a shift from lead-acid to lithium-ion batteries, with their lower weight and longer lifespans particularly beneficial in the context of the pay-as-you-go (PAYGo) business model for OGS.[25,26] Industry experts expect a similar shift to occur across larger applications in the next 5–10 years, as lithium-ion battery costs continue to decline.[27]

Lead-acid batteries continue to face residual demand in larger applications, due to strong value chains and clearer expectations on performance in harsh conditions.[28] The lower upfront costs of lead-acid batteries particularly affect OGS market players' decisions when products with high overall capital costs, such as mini-grids, are considered.[29]

The potential role of other technologies remains small leading up to 2030, with chemistries such as sodium-ion and zinc-air at early stages of commercialization and with limited supply chains across Africa.

BOX 2 Lithium-ion batteries outperform lead-acid on most metrics, but are more expensive

The two most common battery chemistries in energy access applications are lead-acid and lithium-ion.[30] Of the many lithium-ion sub-chemistries, lithium iron phosphate (LFP) batteries are the most prevalent within energy access applications. Their lower cost and relatively higher cycle life are particularly advantageous in cost-sensitive markets, while their lower power and energy density are relatively unimportant for stationary storage applications.[31]

Lithium-ion batteries outperform lead-acid on many metrics, including:

- Cycle life – on average, thousands of cycles for lithium-ion, hundreds for lead-acid
- Depth of discharge, otherwise considered the useable energy capacity within the battery – around 80% for lithium-ion, 60% for lead-acid
- Energy density – between 100 Wh/kg and 250 Wh/kg for lithium-ion, less than 30 Wh/kg for lead-acid[32]

Demand for lead-acid batteries persists in some energy access applications, however, because of lower upfront costs.[33] In addition, lithium-ion batteries represent a safety hazard as they are combustible, meaning handling and storing them requires specific training.

Lead-acid batteries are relatively easy to recycle (section 3.3) and high material value can be extracted, meaning they are not candidates for second-life use. In contrast, lithium-ion battery recycling is costly and technically difficult (section 3.4), meaning second-life use is more economically attractive.

2 The circular battery value chain opportunity

A circular battery value chain will be critical to ensure the sustainable scale-up of Africa's battery market.

2.1 Challenges to battery market scale-up

While Africa's growing battery market reflects progress towards universal energy access, there remain critical challenges to market scale-up.

Challenges that hinder more widespread adoption of batteries for energy storage include:

- Prohibitively high upfront and maintenance costs of batteries in energy access markets, with energy access companies paying around $410/kWh relative to $140/kWh paid by electric vehicle (EV) manufacturers[34]
- Consumers' financial constraints, which prevent adoption of batteries even when they provide longer-term financial savings[35]
- The limited value of batteries under current electricity market regulation, which often fails to provide compensation for the ancillary services batteries provide, weakening battery investment cases[36]

At the same time, the expanding battery value chain also creates challenges across the continent, from:

- An increase in hazardous waste, which can lead to increased environmental pollution and dire impacts on human health if EOL management is not in place (see section 3 for more detail)
- An increase in raw material demand, driven by international demand for lithium-ion EV batteries, which can increase the social, environmental and integrity risks of the extractive sector

2.2 The benefits of a circular battery value chain

In a circular battery value chain, maximizing battery first life is a priority for all African countries. Among the top-selling non-quality-verified solar products, Lighting Global found that almost 50% failed its battery storage durability test.[37] The first step in minimizing battery waste will be to improve the average performance of first-life batteries entering energy access markets through the enforcement of industry standards.

In a circular battery value chain, batteries reaching EOL are repurposed, reused or recycled. For the purpose of the report, the circular battery value chain is defined as follows:

- Reuse implies remanufacturing or repairing a battery to be used for the same application for which it was originally designed (e.g. an SHS battery is reused in an SHS application).
- Repurposing implies remanufacturing a battery for a different application from the one for which it was originally designed, ensuring it is certified to be of high quality before it re-enters the market (e.g. an EV battery is repurposed in a mini-grid application).
- Recycling means that the raw materials within a battery are recovered and made available for future industrial use.

In the short term, the markets for repurposing and recycling may compete for EOL battery volumes. In the longer term, the markets are complementary: repurposed batteries will eventually require recycling.

A circular battery value chain will be critical to ensure the sustainable scale-up of Africa's battery market. Increased circularity can help to:

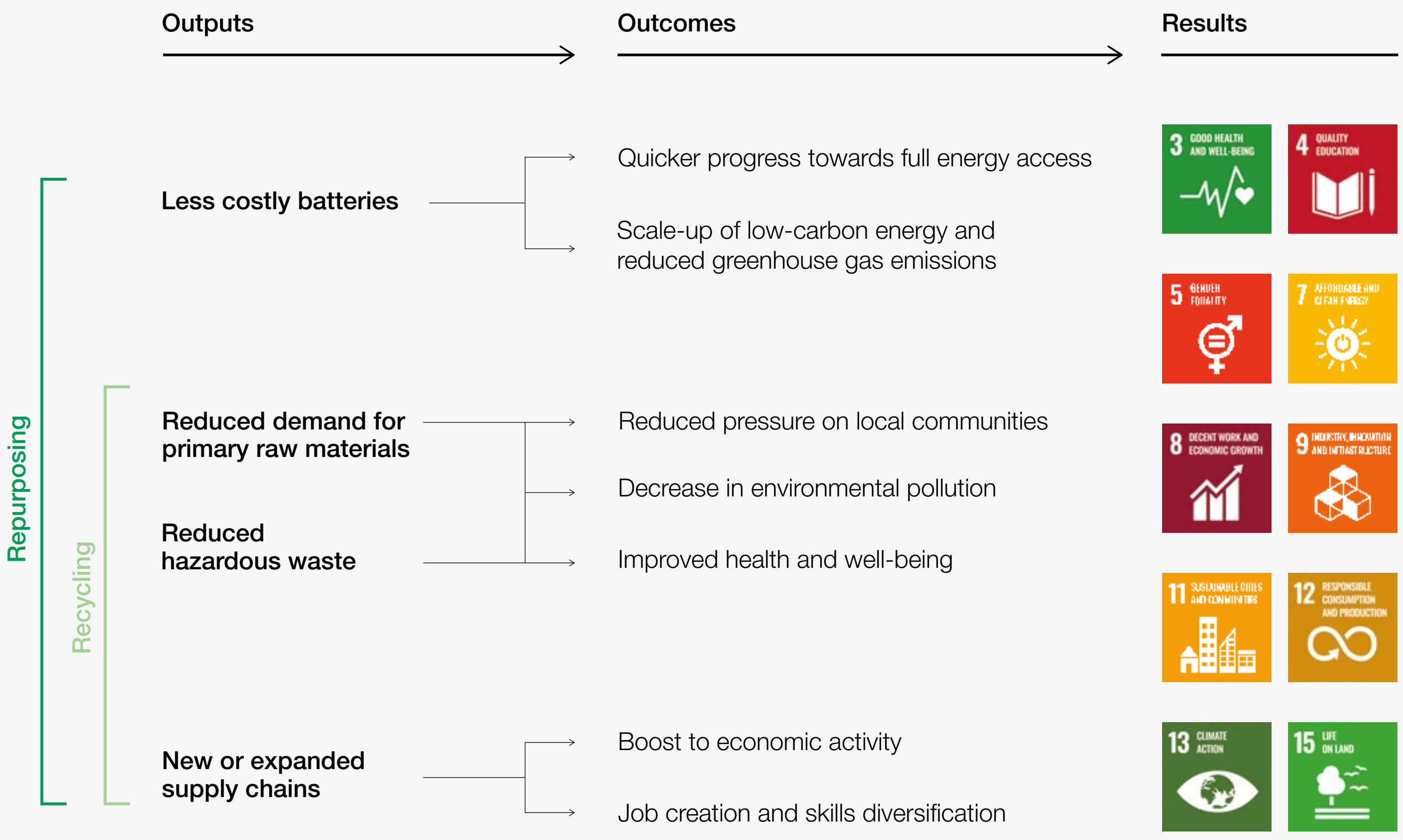
- Ensure sustainable demand for raw materials, reducing the social and environmental pressures associated with the extractive sector
- Reduce hazardous waste accumulation and uncontrolled disposal of waste, safeguarding the health and environment of local populations that are at risk under the status quo[38,39]
- Potentially lower the costs of energy storage through repurposed batteries, thereby accelerating progress towards Goal 7 and unlocking the multiple health, education and productivity benefits associated with clean, reliable energy[40]

> **Batteries are crucial for achieving the energy transition and broadening access to clean energy around the world, particularly for off-grid communities in less-developed countries. As this report shows, in Africa the battery market is forecast to grow sevenfold by 2030. It is crucial to ensure the vast opportunities that batteries present do not come at the expense of the world's most vulnerable communities. We must set and obtain ambitious goals for battery recycling, as access to information on first-life battery usage and end-of-life metrics could reduce costs of repurposed batteries by around 20%. Facilitating the sustainable scale-up of the battery value chain has been the focus of the Eurasian Resources Group's work, together with our partners and other stakeholders in the Global Battery Alliance.**
>
> Benedikt Sobotka, Chief Executive Officer of Eurasian Resources Group and Co-Chair of the Global Battery Alliance

The circular value chain can also help to deliver numerous co-benefits for the local populations in African countries, in line with achievement of the UN's 2030 Sustainable Development Goals, as shown in Figure 5.

However, ethical considerations associated with the repurposing and reuse of batteries must be carefully considered before markets are scaled up.

FIGURE 5 **Recycling and repurposing could support progress towards numerous SDGs**[41]



2.3 Ethical considerations must be at the forefront of the circular battery vision

Ethical considerations must be at the forefront of the circular battery vision

Despite the benefits to be gained from reuse and repurposing, they also pose new challenges that need to be mitigated:

- Health and safety risks from the remanufacturing process
- Negative impacts on environment and health due to poor EOL management
- Increase in hazardous waste through imports of low-quality repurposed batteries

Imports of repurposed batteries (section 3.2) must meet stringent safety and quality requirements. African countries have the opportunity to import batteries repurposed abroad, but to ensure such imports provide the benefits highlighted will require:

- Safe transportation: battery shipments must occur only once the batteries pass a functionality test, and can be considered a fully functional product (Box 4)
- Consumer quality or cost improvements: batteries must provide at least the same quality as batteries currently used in energy access markets at a lower cost or deliver higher quality at price parity
- Safe EOL management: repurposed battery suppliers/distributors must be liable under extended producer responsibility (EPR) regulations or the equivalent EOL requirements of the importing country

3

The status of battery end-of-life management in Africa

EOL management and recycling of batteries in Africa is still a major logistical and environmental challenge.

3.1 Overview of the battery value chain

African countries provide raw materials critical to the global battery supply chain. Africa is home to many mineral deposits relevant for battery production. Most notably, Katanga in the Democratic Republic of the Congo (DRC) hosts the world's largest cobalt deposits and supplies more than two-thirds of the world's cobalt production.[42] Cobalt is used in lithium-ion batteries with particularly high energy densities**.** Along with cobalt, various other battery raw materials are mined in Africa.

TABLE 1 **World market shares of major African mining countries for battery raw materials**

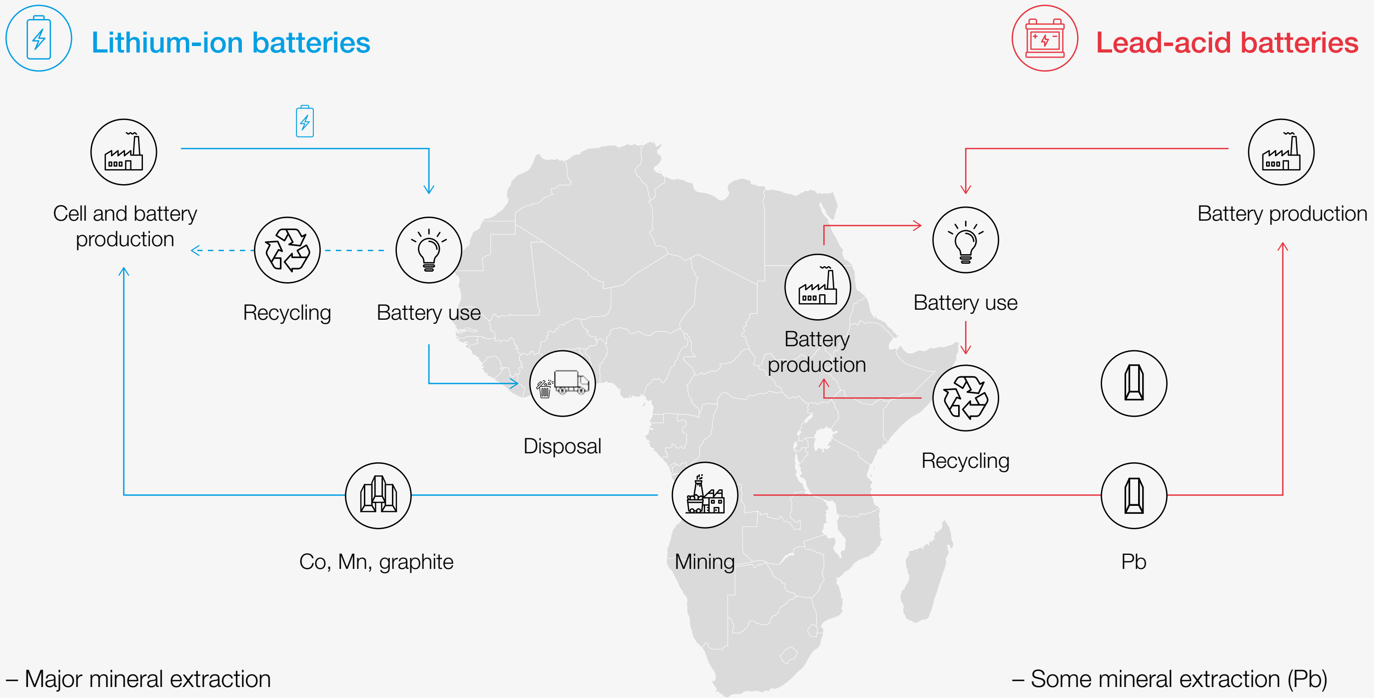
	Country share of world primary production (%)					
	Lead	Cobalt	Lithium	Nickel	Manganese	Graphite
DRC		65				
Gabon					8.2	
Ghana					8.6	
Madagascar		1.6		1.5		4.2
Mozambique						9.3
Namibia			0.5		0.04	0.3
Nigeria	0.4					
South Africa	0.7	0.6		1.9	28.2	
Zambia		0.9				
Zimbabwe		0.2	1.7	0.8		0.2

Source: USGS 2020a

Cobalt mining in the DRC is associated with considerable socioeconomic challenges. Artisanal cobalt mining in the DCR provides an important livelihood for a large number of people. However, it is often linked to insufficient health and safety measures, the use of child labour and untransparent business practices.[43] A number of initiatives, including the Cobalt Action Partnership of the Global Battery Alliance and the Fund for the Prevention of Child Labour in Mining Communities – a Global Battery Alliance Collaboration – have been established within the DRC Copperbelt region to address those challenges.

Only a small proportion of lead-acid battery manufacturing occurs locally, with most mined raw materials exported. Minerals and metals for battery production are almost exclusively exported to non-African destinations. There are some local lead-acid battery producers in countries such as South Africa, Nigeria, Ethiopia and Kenya. They either source raw materials from their own battery recycling plants or import battery components for assembly.

FIGURE 6 **Battery supply chain in Africa, 2020**



- Major mineral extraction (Co, Mn, graphite)
- Exclusively foreign production
- No established collection and recycling; uncontrolled disposal
- Exports for recycling still in infancy
- No local repurposing supply chain

- Some mineral extraction (Pb)
- Mostly foreign production but some local producers
- Established collection and recycling (formal and informal)

Imports of used batteries are common, mostly in the context of second-hand product imports. Nigeria, Tanzania, Guinea and Ghana are major importers of second-hand vehicles, including their used lead-acid batteries (ULABs). Other second-hand imports (e.g. used electronic equipment) also cause an influx of used batteries with limited remaining lifetimes.

EOL management and recycling of batteries in Africa is still a major logistical and environmental challenge. While lead-acid batteries are commonly collected and recycled, these practices are often associated with severe pollution. At the same time, take-back and recycling systems for lithium-ion batteries are still in their infancy. These aspects are analysed in more detail in sections 3.3, 3.4 and 5 of this report.

3.2 Lithium-ion battery repurposing

The repurposing of lithium-ion batteries locally, or the importation of repurposed batteries, is at an early stage of commercial development. Figure 7 summarizes pilots of repurposed lithium-ion batteries on the continent. Lead-acid batteries are not repurposed because of the limited storage capacity at EOL and the large financial incentives from recycling (section 3.3).

Companies are beginning to repurpose batteries from local electronic waste, driven by the cost of alternative EOL management options. The high cost of recycling implies that incentives to collect lithium-ion batteries are few, and where lithium-ion batteries are collected there are strong financial incentives to repurpose rather than recycle (section 3.3). Companies in Kenya, Nigeria and Rwanda (Box 3) are trialling the remanufacture of EOL batteries from OGS and consumer electronic applications.[44] To date, projects are benefiting from partial grant-funding while looking to scale into commercial opportunities in the near term.

BOX 3

Management of lithium-ion batteries in Rwanda

Government of Rwanda started to address e-waste and battery waste issues more than 10 years ago and passed regulations requiring producers and importers to finance and organize environmentally sound collection and recycling. While implementation began on a voluntary basis, the government has announced mandatory enforcement starting in 2021.

At the same time, the roll-out of off-grid solar power is tied to EOL management requirements: to receive funding from the Development Bank of Rwanda and large donor agencies, solar companies must provide “disposal agreements” proving that applicants have established solutions for e-waste management.

To kickstart environmentally sound e-waste management, the government also set up an e-waste dismantling facility, operated by the private company Enviroserve Rwanda and used by solar off-grid companies to manage obsolete equipment. Enviroserve has accumulated 11 metric tonnes of lithium-ion batteries. Non-reusable batteries are currently stockpiled, as plans to export them for recycling were too costly to be sustainable. Enviroserve is exploring battery repurposing as one solution to waste battery accumulation, with tests suggesting that more than 50% of battery cells are suitable for repurposing.

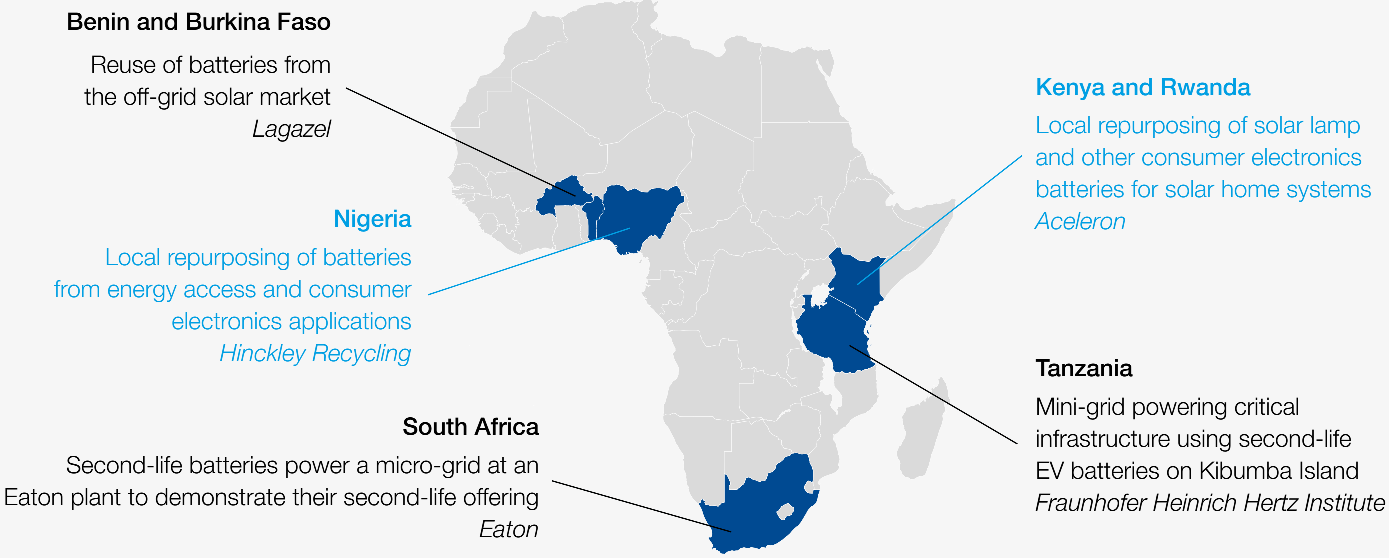
EOL volumes, mostly from the energy access market, are currently too low for repurposing to meet the battery demand that would arise from meeting the government’s 2024 off-grid electrification targets. Rwanda’s emerging EV market could, however, provide a new source of supply for repurposing initiatives, and would be particularly suited to mini-grid and grid-repurposed batteries.[45] The potential for e-mobility is recognized by international players such as Volkswagen (assembling EVs in Rwanda since 2019) and Siemens (planning to set up 15 charging stations in Kigali). Local firms – Ampersand and Safi – also have plans to scale up their electric motorbike and vehicle operations in the market.

> “ The high cost of recycling implies that incentives to collect lithium-ion batteries are few, and where lithium-ion batteries are collected there are strong financial incentives to repurpose rather than recycle.

Companies are also selling imported repurposed batteries in African countries, after collection, remanufacturing and testing for functionality in foreign markets. One company interviewed sells imported repurposed batteries for use in local mini-grids, where applications are focused on providing backup power to commercial and industrial consumers.[46] As Box 4 sets out, these batteries are tested to ensure their safety and performance before importation. Other pilots using imported repurposed batteries are fully grant-funded but further away from reaching commercial scale. This includes the Kibumba Island mini-grid (Tanzania)[47] and Lagazel’s pilot (Benin and Burkina Faso).[48]

FIGURE 7

Battery supply chain in Africa, 2020

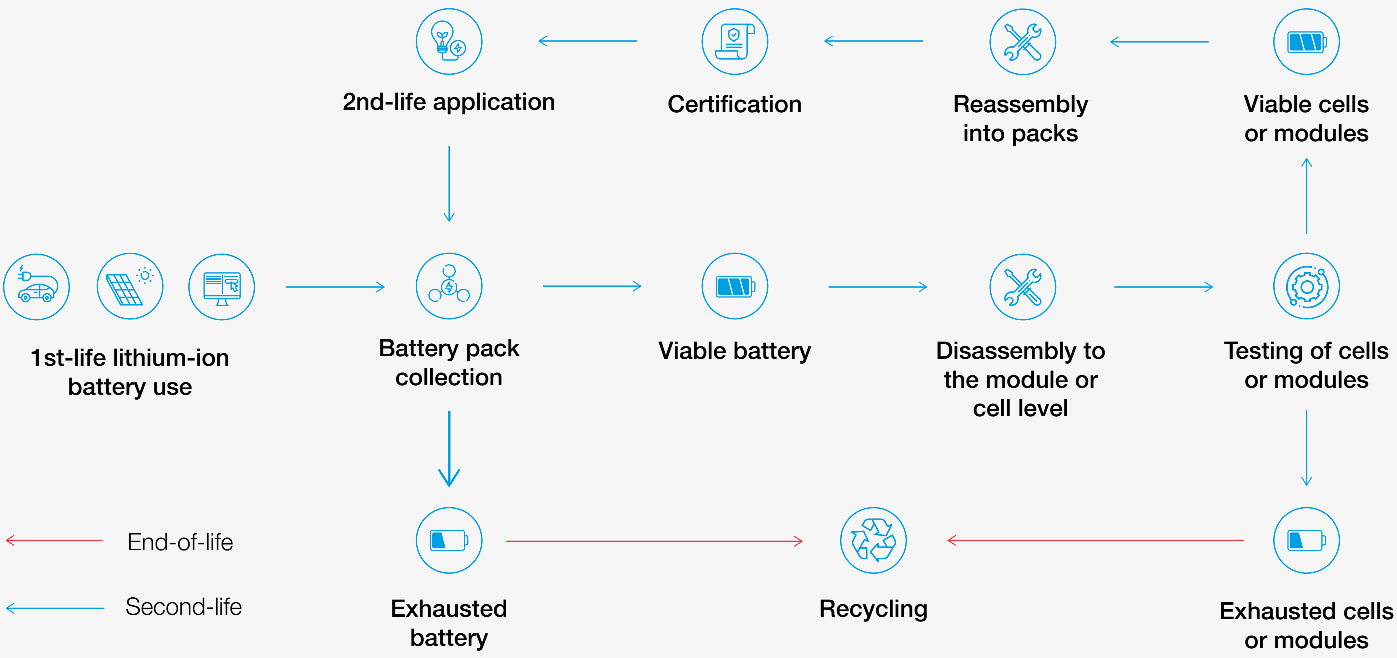


The repurposing industry is also nascent but growing in OECD countries, driven by the proliferation of EV batteries and demand for lower-cost stationary storage. The global value chain is centred on EV batteries, which are remanufactured by original equipment manufacturers (OEM) or sold on to a remanufacturing company.

Applications of second-life batteries globally are highly varied and do not demonstrate that one application or user is particularly suitable for repurposed batteries. Applications have been chosen in an ad hoc way. One interviewed company repurposes EV batteries for forklifts and golf carts because the limited scale of its operations prevents it from supplying larger systems.[49] EV manufacturers that operate charging stations have, in a similarly expedient manner, found repurposed EV batteries to be an ideal way to reduce their business costs.

FIGURE 8

Overview of the battery repurposing value chain



BOX 4

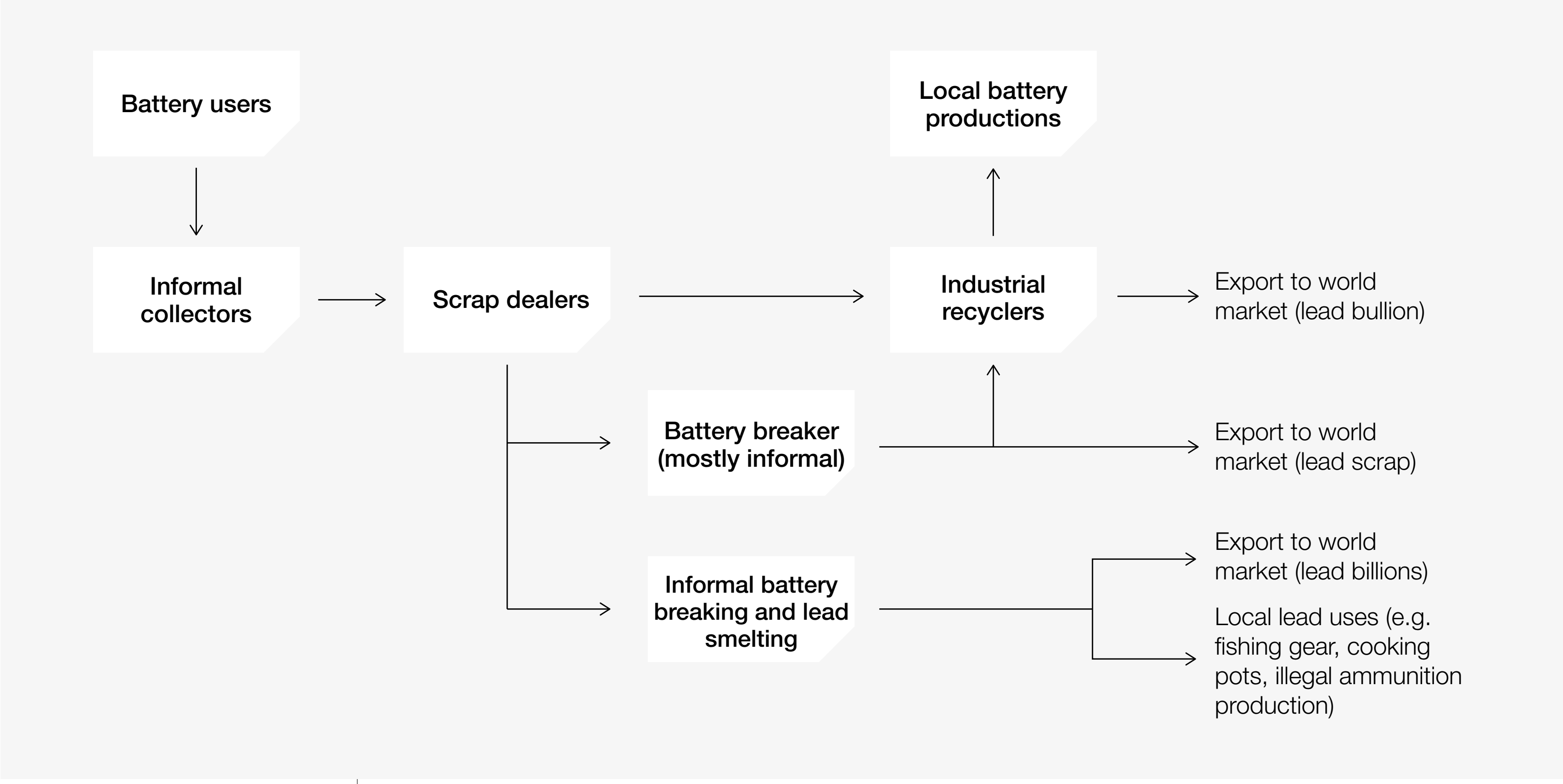
An overview of the battery repurposing value chain

Batteries that reach EOL outside of African countries will need to be fully remanufactured up to module level, and tested for functionality before importation into African countries.[50] The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal (the Basel Convention) establishes strict controls over transboundary movements of hazardous and non-hazardous waste by applying the "prior informed consent" procedure – shipments made without consent between parties are illegal.[51] The Basel Ban Amendment, which entered into force in December 2019, goes further by prohibiting all exports of hazardous waste from Organisation for Economic Co-operation and Development (OECD) countries, regardless of prior informed consent.[52] Given this regulation, all batteries reaching EOL outside Africa must be remanufactured and classified as a functional product before shipment, implying that remanufacturing up to module level occurs outside Africa.

3.3 Lead-acid battery recycling

Recovery of lead results in widespread collection and recycling. Lead-acid batteries contain between 60% and 65% lead, which has a high material value, ranging from $1,600/t to $2,500/t on the world market,[53] encouraging battery collection, trade and recycling in almost all parts of Africa, with involvement by formal and informal sectors. Figure 9 characterizes the key players in Africa's lead-acid battery recycling market.

FIGURE 9 | Africa's lead-acid battery recycling value chain



> Problems regarding lead-acid battery recycling have stimulated regulatory initiatives.

The informal sector plays a vital role in battery collection and trade. Typically, informal players pay for EOL batteries and move them on to scrap dealers who supply local battery recyclers.

Battery recycling currently occurs across three main types of business. Commonly found recyclers in Africa include:

1. Informal battery-breakers and smelters – this type of recycling is mostly small scale and conducted under informal conditions. Informal battery-breaking and smelting have high pollution rates and low efficiency as most recyclers can recover only around 50–60% of the batteries' lead.
2. Battery-breakers – this type of enterprise conducts only part of the recycling. Battery-breaking is commonly conducted manually and the battery acid is drained in an uncontrolled manner. While many of the companies involved work under informal conditions, some are registered or organized in associations such as in the Waste Battery Association of Nigeria.[54]
3. Industrial recyclers – these use medium or large smelting equipment to recover up to 90% of the lead contained in batteries. Industrial recyclers break and drain batteries, but also source lead scrap from local battery-breakers (see above). Battery cases are also recycled and sold to local plastic manufacturers. In addition, there are a few plants using recycled lead and plastic for their own battery production.

Collection and recycling activities are mostly focused on EOL batteries generated locally. Nevertheless, some industrial recyclers also import ULABs from other countries (mostly other African nations) for recycling. Furthermore, importing used vehicles from other world regions also leads to an inflow of used batteries with limited residual lifetimes.

Industrial lead-acid battery recycling is gaining ground in larger markets. ULAB recycling is increasingly attractive for investors who set up industrial-scale facilities in major markets. While this trend supports the formalization of ULAB recycling, collection is mostly still in the hands of informal networks. At the same time, many investors focus on maximizing economic return but fall short in terms of introducing proper emission controls and health and safety standards.

Problems regarding lead-acid battery recycling have stimulated regulatory initiatives. Unsound ULAB recycling is a serious health concern, as already illustrated in the GBA's white paper on ULABs, and notable pollution cases have led to increased public pressure for proper regulation and heightened concerns from environmental authorities (see Box 5). Regulatory initiatives have been launched in Nigeria, Ethiopia and Ghana that are primarily aimed at introducing minimum standards for ULAB collection and recycling.

BOX 5 Pollution issues in relation to ULAB recycling in Nigeria and Kenya

Nigeria and Kenya both wexperience large ULAB volumes, which have attracted investment in industrial recycling facilities, aimed at recovering lead to be sold to the world market. In 2009, Kenya experienced unrest as an industrial ULAB recycling plant had exposed workers and neighbouring communities to high levels of lead, causing many to show symptoms of acute and chronic lead poisoning.[55] In 2018, Nigeria faced a similar situation, implicating ULAB recyclers as the cause of systematic pollution and lead poisoning among workers and residents.[56] The Kenyan government reacted with a zero-tolerance policy and shut down a number of recyclers in 2014 and 2015, while in Nigeria, the government initiated a policy process to improve the sector, but has so far refrained from sanctions against polluting recyclers. These incidents were also recognized by the international market, and a number of lead-consuming industries suspended their relationship with direct or indirect suppliers of lead from African sources.[57] As a consequence, recyclers were forced to reorganize and to find new outlets. Some actively asked for support to make improvements in order to ensure they could comply with future regulations and thus regain access to international lead markets.

3.4 Lithium-ion battery recycling

Volumes of EOL lithium-ion batteries are still small in most African countries, but are expected to increase with growing demand for stationary storage. Lithium-ion batteries used in stationary storage applications, including solar home systems, are still quite new, so have not yet appeared in larger volumes in waste streams.

Lithium-ion batteries vary widely in terms of material composition and attractiveness for recycling. Table 2 gives an overview on the relevant types and properties. Cobalt, with an indicative global price of $28,000–$36,000/t[58] is the major economic driver of lithium-ion battery recycling. Recyclers in other world regions commonly pay up to $1,000/t for high cobalt batteries. Batteries containing less or even no cobalt are significantly less attractive and recycling often generates net costs. LFP batteries have particularly low material values and recycling is associated with net costs of up to $3,500/t.[59]

TABLE 2 World market shares of major African mining countries for battery raw materials

	Battery chemistry	Contains cobalt?	Description
NMC	Lithium-nickel-manganese-cobalt oxide	Yes	High energy densities, mostly used in mobile applications (portable electronics, electric vehicles)
LCO	Lithium-cobalt oxide	Yes	
NCA	Lithium-nickel-cobalt-aluminium oxide	Yes	
LFP	Lithium-iron phosphate	No	Lower energy densities
LMO	Lithium-manganese oxide	No	

There are no lithium-ion battery recycling facilities operating in Africa, which makes environmentally sound recycling very costly. Due to the absence of such infrastructure, batteries would need to be shipped to foreign destinations for recycling, which requires the prior informed consent procedure of the Basel Convention, with transport also posing considerable fire hazards. Shipping agencies are reluctant to transport waste lithium-ion batteries and, if they do so, request heightened fire precautions, such as embedding cargo in sand. Hence, a container with a nominal load of 20 metric tonnes cannot carry more than 5 metric tonnes of waste batteries. While this export-for-recycling model has been tested by some players, the tests confirm that costs far outweigh the financial value of material recovery (see Box 6).[60]

BOX 6 Shipping lithium-ion batteries from Nigeria to Belgium

In the absence of any recycling capacities for lithium-ion batteries in Africa, the Nigerian recycler Hinckley and the Dutch company Closing the Loop organized the collection, packaging and shipment of 5 metric tonnes of lithium-ion batteries from Nigeria to Belgium for recycling in 2020. The batteries were sourced from informal networks and mainly came from old mobile phones. Packaging and shipment were organized in line with all applicable safety requirements and in accordance with the provisions of the Basel Convention, which regulates transboundary movements of hazardous waste. The total costs for this shipment by far exceeded the revenues gained from battery recycling. The costs could only be covered because Closing the Loop uses an e-waste compensation model, where producers of mobile phones pay a fee in order to compensate for the waste generated by their products. In doing so, they achieve commercial value in the form of better branding and employee engagement and resulting in waste reduction in low- and middle-income countries.

The cost balance is even worse with batteries used in most energy access projects. While the recycling of cobalt-containing batteries can generate some revenue, cobalt-free battery chemistries – particularly LFP, the main type currently deployed in energy access applications – are either generally rejected by recyclers, or accepted only after payment of substantial treatment fees.

> “ In Kenya, seven of the biggest solar off-grid providers launched the Kenya Solar Waste Collective aiming at pooling their resources and logistics to collect waste from off-grid installations and direct it to environmentally sound recyclers.

Due to these costs, collection and recycling of lithium-ion batteries is underdeveloped. The cost implications mean that the collection and recycling of lithium-ion batteries is currently not an attractive business proposition. The bulk of generated waste from lithium-ion batteries is not currently collected and is most likely disposed with general municipal solid waste.

Some local e-waste dismantling facilities offer environmentally sound solutions for lithium-ion batteries. These facilities mainly take over obsolete equipment from businesses that aim to comply with national legislation or follow their own corporate social responsibility policies and seek responsible solutions for their waste. Charged management fees typically range from $0.50 to $6.50 per kilo of LFP batteries.[61] Waste battery volumes managed by such methods are currently very small – a few metric tonnes per year and per country. Only a few companies have conducted shipments of waste batteries to recycling facilities and most of them rely on long-term stockpiling.

Despite the cost implications, many off-grid solar companies are interested in sound disposal options. E-waste-dismantling facilities in various African countries report that a disproportionally high share of received e-waste and batteries comes from solar companies. While off-grid solar equipment normally does not make up more than a few per cent of the total e-waste generation, there is a strong indication that the sector is spearheading collection and recycling efforts. A prominent example is Kenya, where seven of the biggest solar off-grid providers launched the Kenya Solar Waste Collective aiming at pooling their resources and logistics to collect waste from off-grid installations and direct it to environmentally sound recyclers. The impetus to find this proactive situation came from the fact that many solar companies have a high awareness of environmental issues and donor policies often tie financial support to reasonable EOL management.

Alternative methods to manage batteries are considered. Due to the significant cost implications, some local recyclers are investigating alternative measures for EOL management, either testing local reuse and repurposing or pre-processing into a substrate that can be shipped without safety risks. Pre-processing can be performed with thermal or mechanical processes. In both cases, there continues to be uncertainty regarding process safety and emission controls.

Regulatory frameworks for improving EOL management have been developed in a number of African countries. Policy development has often started with a view to growing e-waste volumes. One core element of most legislative frameworks is a system of EPR, whereby operators that place equipment and batteries in a national market then have the responsibility for collection and sound EOL management. While such models have been drafted and passed into law in countries such as Ethiopia, Nigeria, Rwanda and South Africa, Ghana has chosen another approach and charges importers a defined eco-levy for each piece of equipment brought into the country (see Box 11). In most countries, implementation and enforcement are still nascent and have not had a large-scale impact on collection or recycling levels yet.

4

Opportunities and challenges of battery repurposing

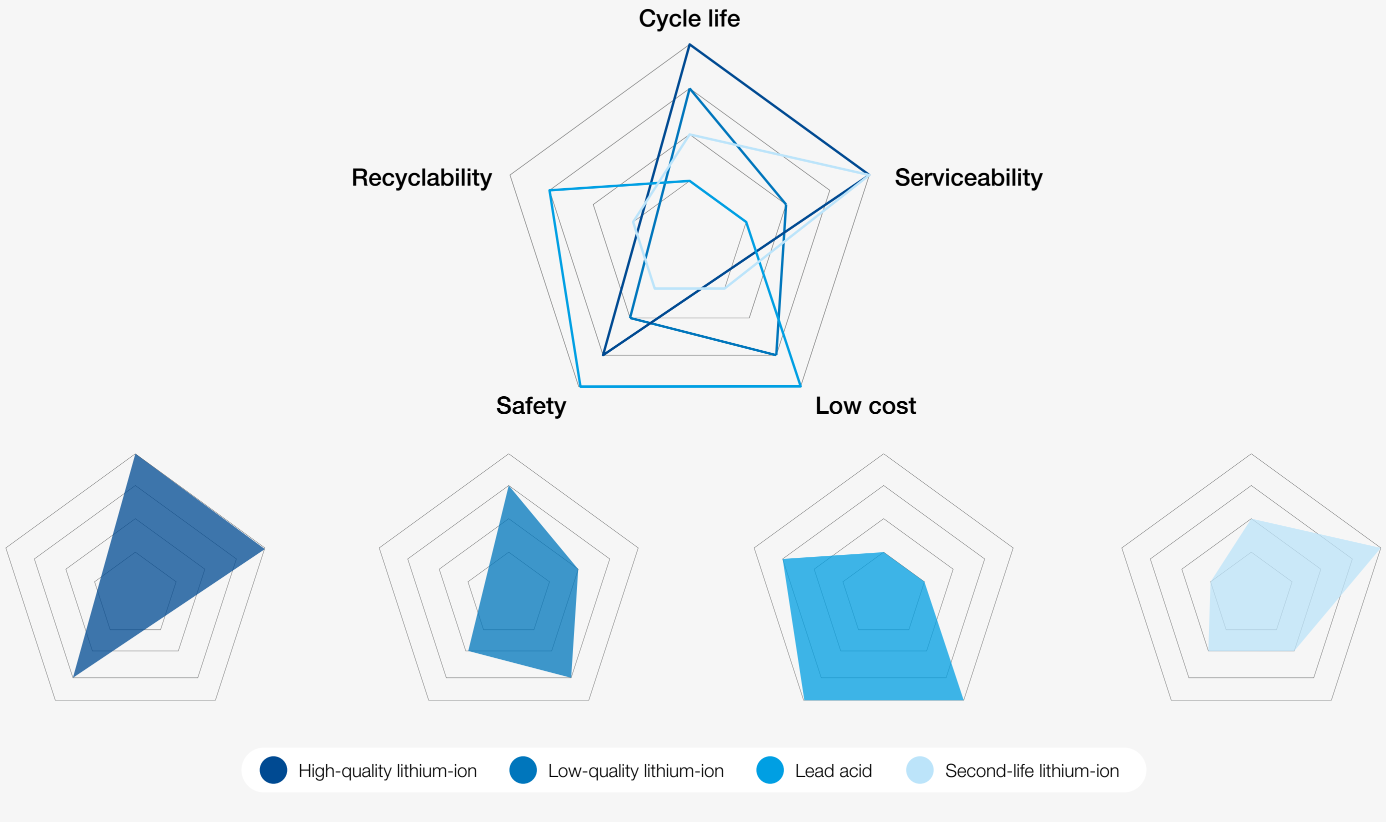
Repurposed batteries could be attractive for the energy access industry if production and adoption challenges are addressed.

4.1 Summary of opportunities

Repurposed batteries have the potential to deliver the quality required for energy access applications at an attractive price (Figure 10). Repurposed batteries deliver a comparable or improved service relative to the average first-life battery sold in energy access markets (typically lower-quality lithium-ion or lead-acid). Though they are likely to come at a higher cost than these batteries (an estimated 11–37% higher), service improvements could make them attractive for the energy access industry.[62,63] Meanwhile, they cost less than the best available lithium-ion batteries – see section 4.2.2, which estimates costs to be 27–54% lower.

To take advantage of this opportunity, two complementary business models will be necessary – each relying on a different EOL waste stream and serving different applications. The economic viability of repurposing relies on minimizing the remanufacturing required, which can be achieved by sizing second-life applications to the EOL battery supply. Local EOL batteries (from consumer electronics and OGS) are best suited to smaller energy access applications, particularly SHSs, while repurposed EV batteries, mainly from outside of Africa, are better suited to larger mini-grid and grid applications.

FIGURE 10 Comparing the average cost and performance of energy access battery alternatives[64]



In the near term, local repurposing is critical to increase political support and consumer confidence. Local repurposing can demonstrate the safety and quality of repurposed batteries in energy access contexts, while delivering co-benefits to local communities through the creation of jobs and a reduction in pollution. This will initially increase political appetite for repurposed batteries, imported or local, and can subsequently encourage regulation that addresses market challenges.

BOX 7

Companies repurposing batteries locally

Aceleron, a UK-based company, produces repurposed batteries in Kenya, relying on the collection of lithium-ion batteries at the Waste Electrical and Electronic Equipment (WEEE) Centre. The centre collects used batteries from local SHS companies and consumer electronic applications, and Aceleron remanufactures them into second-life battery packs. They are planning to expand into Rwanda. Both projects are supported by the Global LEAP Solar Awards.

Hinckley Group is looking to expand into repurposing in Nigeria, in parallel with growing its activities in recycling lithium-ion batteries. The company has recently begun collecting lithium-ion batteries (see Box 6). Repurposing is being developed as a complementary activity to the development of in-house lithium-ion recycling. Experts from Carnegie Mellon University Africa have supported the company in a remanufacturing trial funded by the Solar E-Waste Challenge LEAP Award.

Local repurposing will be unable to meet the energy access gap, however, and therefore imports of repurposed EV batteries continue to play a role in energy access markets. Imports of high-quality repurposed EV batteries are likely to play a role in the near term due to the limited scale of local EOL batteries and technical suitability of local batteries for larger battery applications: local EOL volumes can meet only approximately 18% of the projected market for energy access batteries in 2030, for instance.[65] In the longer term, falling prices of EVs and the regulatory push to set EV targets in several African countries, including Rwanda and Uganda, imply sourcing of used EV batteries could occur locally.

BOX 8

One company is already importing second-life EV battery modules from Europe into Africa

Multinational power management company Eaton is providing second-life batteries for its mini-grid offering. These batteries, provided by Nissan, are tested in Europe before being shipped to Morocco, where Eaton assembles them into second-life packs. Eaton provides this service alongside its first-life battery solutions, but on a very small scale, by comparison. The company has been approached by a number of other EV manufacturers to take on their used batteries.

4.2 Challenges of lithium-ion battery repurposing

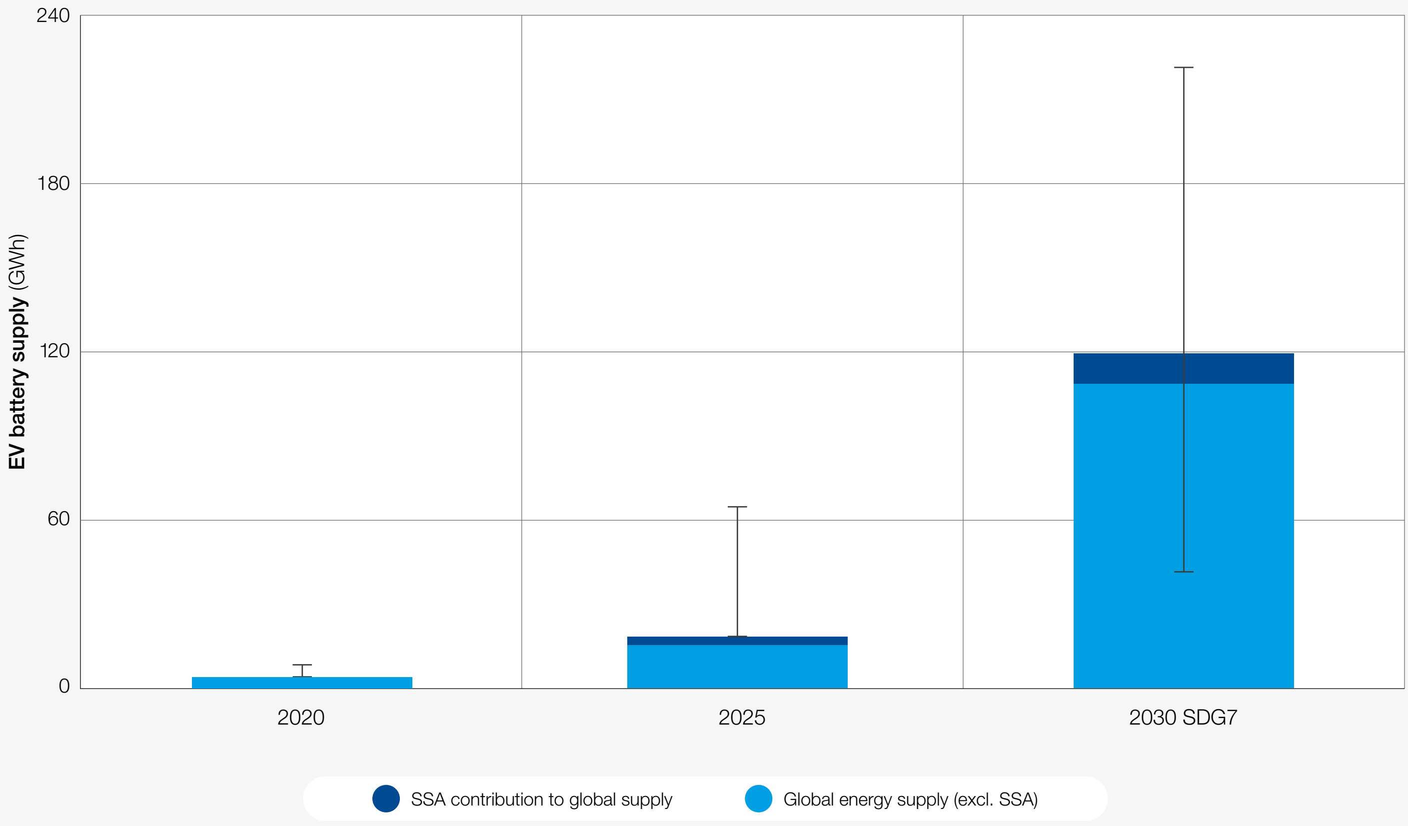
Challenges to production

1. Uncertain supply and logistics costs

Access to a reliable supply of imported EV batteries. Forecasts of the supply of EOL EV batteries vary between 45 GWh and 230 GWh in 2030 due to uncertainty over driving patterns and the extent of an EV second-hand market. Supply of repurposed EV batteries into Africa is uncertain due to the high costs of battery shipments and competing demand outside of Africa.[66]

Limited lithium-ion battery collection locally creates challenges for local repurposing, with supply likely to be lower than market forecasts in the absence of EPR implementation. Supply of EOL batteries from stationary applications in sub-Saharan Africa could be 15–20 GWh by 2030.[67] However, only 1% of batteries currently reach formal recyclers (section 3.4)

FIGURE 11 **Forecasts of global EV battery supply**[68]



2. Technical uncertainty

Continued academic research into the performance of batteries in their first and second life is required to better gauge the potential of repurposing. To date, there has been limited research on battery degradation below 80% battery capacity, and researchers are unsure which metrics best predict future lifespan.

Repurposed battery performance in energy access applications also needs to be better understood. The suitability of repurposed batteries for energy access applications requires additional research as applications to date focused on utility-scale batteries for developed grids.[69] High ambient temperatures in Africa and different cycling requirements for household-level applications could accelerate battery degradation.[70]

3. Limited investor appetite

Investor appetite to enter the market is dampened by the lack of proven, profitable business models. The repurposing market is fragmented across several industries and countries, with few commercial examples to replicate. There is no demonstrated model for financially sustainable lithium-ion battery collection in place, for instance. Instead, operations rely on bilateral agreements with recycling facilities or SHS companies.[71]

Investor confidence is also hindered by high and uncertain remanufacturing costs, often out of a remanufacturer's control (see Box 9). Lack of data sharing between industry on battery health and fundamental technical uncertainties on measuring repurposed battery performance make it difficult to quantify the remaining lifespan of batteries and substantially increase remanufacturing costs through increased testing. Trends in first-life battery manufacturing, meanwhile, inadvertently increase the costs of disassembly and remanufacturing by optimizing batteries for EVs, such as the recent cell-to-pack approach.

The costs of logistics, particularly for the global value chain, are a further barrier to investment. Second-life batteries must be tested for functionality before being shipped, so as to respect both safety requirements for lithium-ion battery shipment and the Basel Convention (Box 4). Testing and shipping costs to Africa can be up to 25% of the price of repurposed batteries (Figure 12).[72]

The uncertainty over consumer demand, due to technical uncertainty and limited consumer confidence (section 4.2.2), also dampens investor appetite.

BOX 9 | Factors affecting remanufacturing costs

The costs of remanufacturing are high due to labour costs, themselves driven by testing requirements and the lack of automation, specifically:

- **The amount of time taken by testing is determined by the availability of first-life battery health data –** the testing time required varies between 1 and 24 hours.
- **The cost of disassembling and reassembling battery packs depends on the joining technology used and the level of disassembly,** with battery packs currently not designed to be taken apart (using welding techniques and adhesives).
- **The standardization (or lack of) in pack configuration across manufacturers** affects the level of automation possible.

Challenges to adoption

1. Limited political appetite

A fundamental challenge to the development of the repurposing industry is the widespread scepticism in many African countries about the use and import of repurposed batteries. Over the past two decades, imports of substandard electrical and electronic equipment have exacerbated environmental challenges related to the management of hazardous waste. The Government of Nigeria issued a ban on the import of used batteries and the Government of Rwanda strongly limited the import of used computing equipment. Historical and ongoing pollution scandals related to battery EOL management imply this scepticism could extend to imported repurposed batteries, unless strong quality assurances are provided.

The standards for repurposed batteries set out in Box 4 aim to address these concerns, but need to be well communicated to increase political appetite for the repurposing industry.

2. Consumer confidence

Uncertainty about the performance and safety of second-life batteries limits consumer appetite. Though an object of academic study for almost 20 years, repurposed batteries are not widespread. Their safety and performance are poorly understood by consumers and consumer appetite is largely untested.

Market appetite in the energy access market is likely to be lower, due to the financial sensitivity of consumers and a preference for tested products. The commercial readiness of storage solutions is a prime concern for energy access companies, which prioritize products with a predictable and demonstrable performance.[73] Industry preferences have historically limited the uptake of new battery types in energy access applications and could similarly reduce the uptake of repurposed batteries.[74]

3. Cost-competitiveness

Cost-competitiveness of repurposed batteries is subject to large uncertainties today, due to:

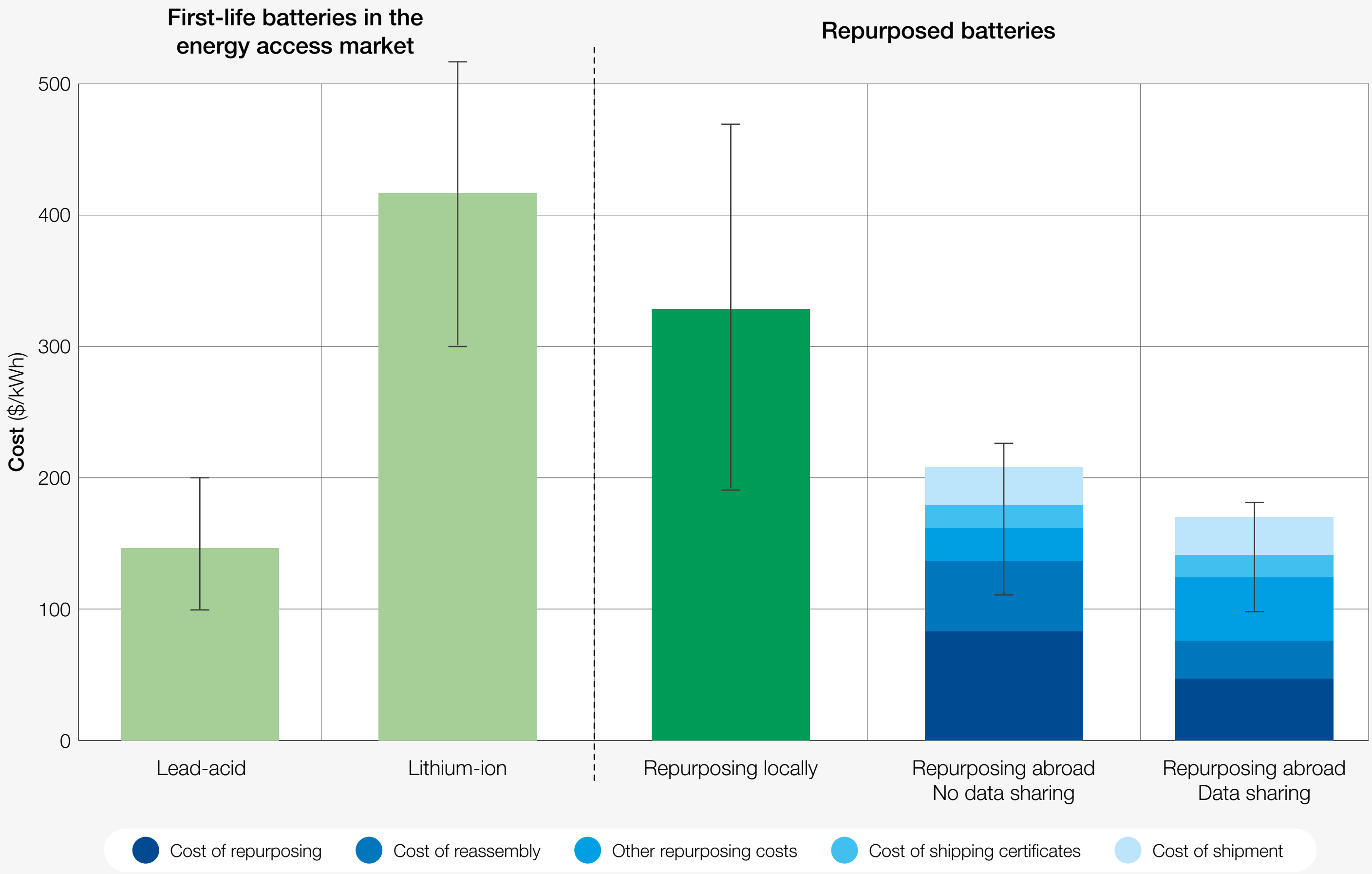
- **The lack of data from real-world applications**
- **The type of dominant battery per application**

Data limitations make cost-competitiveness of repurposed batteries in energy access markets difficult to verify. There are no publicly available cost estimates of repurposed EV batteries in energy access applications; while local repurposing costs are available, the small scale of operations implies that costs change significantly as the market grows.

> Industry insights and modelled estimates suggest that repurposed batteries are 27–54% less expensive than first-life lithium-ion batteries in energy access applications.

Industry insights and modelled estimates suggest that repurposed batteries are 27–54% less expensive than first-life lithium-ion batteries in energy access applications. Figure 12 presents cost estimates either modelled or provided by local repurposing operations. Modelled costs are indicative of EV batteries repurposed and imported from outside Africa and suggest repurposed batteries could be 54% cheaper than first-life batteries in the energy access market ($206/kWh, compared to $450/kWh respectively). Estimates from local industry suggest repurposed batteries are around 27% less expensive, at $330/kWh.

FIGURE 12 **Repurposed batteries are cost-competitive with first-life lithium-ion batteries in the energy access market**[75,76]



All estimates suggest that repurposed batteries are costlier than lead-acid batteries, but could be cost-competitive if factoring in lifespan, weight and serviceability. Though repurposed battery lifespan is uncertain and imperfectly understood, the literature views it to be greater than lead-acid packs' one to two years.[77] Repurposed batteries are also considerably lighter, particularly valuable in the SHS industry.[78]

Despite promising findings on the cost-competitiveness of second-life batteries today, uncertainty over cost-competitiveness increases to 2030 as the target for investors is constantly shifting, due to:

The decreasing costs of lithium-ion batteries – forecast to decline by nearly 40% in energy access applications[79]

The evolution of factors affecting remanufacturing costs (Box 9), which could decrease repurposed battery costs by an estimated 20%, down to $170/kWh[80]

Lack of supportive regulation

Weak or non-existent regulation currently exacerbates production and adoption challenges, and hinders the scale-up of the repurposing value chain. In particular, regulatory structures affect:

The design of first-life batteries. There is currently no policy guidance or industry-led standardization to inform the design of first-life batteries so that they can be easily disassembled.

The supply of batteries for repurposing. There are limited regulatory mechanisms to encourage collection of lithium-ion batteries locally, with very few EPR schemes in place.

The lack of battery data available to repurposing companies. Proposals by the EU on a battery passport signal a positive development towards increased availability of battery health data globally, with potential spillovers in Africa. At the same time, non-regulatory initiatives, such as the GBA's Battery Passport, are working to directly improve traceability over the entire battery value chain in Africa.[81]

The safety of repurposing projects. So far, only one standard exists, UL1974, which provides for the safe repurposing of batteries. Only one company globally, 4REnergy, has been certified by this standard.[82]

Consumer willingness to pay for repurposed batteries. Both first-life and second-life batteries face no minimum standards or required warranties when sold in energy access applications, contributing to concerns about performance.

4.3 Outlook

The extent of market expansion for the local and global value chain will be significantly affected by:

- **Trials on the performance of repurposed batteries in energy access applications:** to engender political support and inform quality standards, which can improve consumer and investor appetite
- **Supply of EOL batteries, especially in the African market:** incentives for lithium-ion collection are low, and collection rates will depend on the development and enforcement of EPR frameworks
- **Improvements in battery traceability and data-sharing, as spearheaded by the GBA's Battery Passport:** which can help reduce repurposed battery costs by an estimated 20%
- **Market linkages and feedback loops across market players:** given market fragmentation, the creation of positive feedback loops will influence the speed at which performance and cost metrics improve

5 Opportunities and challenges of battery recycling

High-quality battery recycling has multiple environmental, economic and societal benefits.

5.1 Summary of opportunities

As indicated in section 2, increased circularity of batteries has multiple benefits. Moreover, battery recycling will have a variety of further specific benefits:

Improving lead-acid batteries recycling:

- **Positive impacts on the health of workers and communities** by reducing emissions and exposure to hazardous substances in workplaces and the environment
- **Reduction of burden of disease and economic costs** by reducing short-, mid- and long-term exposure to lead, subsequently reducing societal and economic losses from childhood lead exposure, which are currently estimated at $134.7 billion per annum in Africa[83]
- **Stimulation of investments** in better ULAB recycling processes by enforcing ambitious mandatory standards. Such standards will not impede the sector's development, but generate a level playing field favouring responsible investments

> **As a member of the GBA and a producer of battery materials for the electric vehicle market, we support the creation of a sustainable life cycle for batteries and the access to clean, reliable electricity. We welcome the report Closing the Loop on Energy Access and look forward to continuing our work with our partners in the GBA to ensure the second life and circularity of batteries.**
>
> Christian Günther, Chief Executive Officer, Battery Materials, Johnson Matthey

Developing collection and recycling of lithium-ion batteries:

- **Contributions to safe and pollutant-free waste streams** by separating flammable and hazardous lithium-ion batteries from municipal solid waste
- **Generation of job and income opportunities** by developing new services, business models and value addition in collection and recycling
- **Stepping stones to more value addition** through developing handling and pre-processing technologies as a nucleus for more complex recycling technologies in Africa

Full environmentally sound battery recycling will **generate outputs for local industrial development**. Environmentally sound lead-acid battery recycling yields a variety of raw materials such as lead, plastic and gypsum that can be used in local manufacturing industries. Sound management of used lithium-ion batteries can yield battery cells for local reuse and repurposing and thereby support local manufacturing.

5.2 Challenges of lead-acid battery recycling

1. Pollution problems from unsound recycling

Unsound ULAB recycling is a major contributor to human lead exposure. Exposure to lead has various detrimental effects on human health (see Box 10). In addition to the direct effects on people's well-being, this has impacts on economic development. Furthermore, modelling exercises suggest that childhood lead exposure lowers the gross domestic product (GDP) of African countries by 4.03%, causing annual economic losses of $134.7 billion.[84] Although not all lead exposure can be attributed to unsound ULAB recycling, it is known that this industry is an important contributing factor. In Senegal, informal battery recycling caused mass lead poisoning in a community close to Dakar, killing at least 18 children, in 2008.[85] Also in industrial recycling, emission controls and health and safety measures are mostly inadequate and many plants are a severe source of pollution,[86] with proven cases of systematic lead poisonings of workers and residents in Kenya, Ghana and Nigeria.[87]

BOX 10

The health effects of lead exposure

Lead is a toxic heavy metal, and exposure through ingestion of particles and fumes can cause a variety of health problems, including impacts on organs and the nervous system. According to the World Health Organization (WHO), there is no safe level of lead exposure; even a low level may have adverse health effects. Lead is also a developmental and cumulative toxicant affecting the central nervous system, which makes children most vulnerable. Even low-level childhood exposure is known to negatively affect cognitive and physical development, with potentially lifelong effects. High-level exposure induces acute lead poisoning that may cause abdominal pains, weakness, anaemia, miscarriage and death. A recent study suggests that one-third of all children globally suffer from elevated blood-lead levels. While lead exposure may have various causes, unsound lead-acid battery recycling is known to be among the most relevant factors in many countries.[88]

> **Lead releases from inadequate recycling of car batteries is one of the most pernicious problems the world faces. And Africa suffers more than most other places. The impact is enormous – loss of intelligence for much of the population, more crime, and more cardiovascular disease. It deserves a focus, and solutions.**
>
> Richard Fuller, President, Pure Earth

2. Competition over batteries for recycling

Lead-acid battery recycling is a profitable business, but differences exist and are based on the type of applied processes. Differences in the level of profitability are mostly rooted in the lead smelting process and the general level of standards of a ULAB recycling facility. Table 3 illustrates that backyard smelting is – despite various advantages of informal operations, such as tax savings – less profitable compared to industrial smelting, which is due to the significantly lower lead recovery rates of the former.

The competition over batteries is a major factor in the prevalence of highly polluting ULAB recycling industries. Collection is mostly in the hands of informal operators and batteries are commonly sold to the highest bidder. A survey conducted in Nigeria suggests that substandard industrial recyclers can offer up to 78% more money for ULABs for recycling compared to the recycling enterprise with the highest environmental standards.[89] While high standards can increase the lead recovery rate to 98% and above, such higher efficiencies are overcompensated by additional investment needs and operational costs.

TABLE 3 **Major types of lead smelting processes**

 **1. Backyard smelting**	 **2. Substandard industrial smelting**	 **3. High-standard industrial smelting**
Investment costs: \$100–\$5,000	Investment costs: \$0.3m–\$2m	Investment costs: \$4m–\$10m[90]
Lead recovery rates: 50%–60%	Lead recovery rates: up to 90%	Lead recovery rates: >98%
Very polluting	Very polluting	Environmentally sound

3. Awareness

Some countries and stakeholders have not yet identified the need to improve lead-acid battery management. Many decision-makers tend to see even low-standard ULAB recycling facilities as investments that primarily generate jobs, income and tax revenues and are unaware of the potentially devastating effects on human health and economic development.

4. Regulation and enforcement capacities

Enforcement capacities are underdeveloped. This mainly affects expert capacities to identify shortcomings and design improvement measures. Lacking expert capacities commonly leads to situations in which problems are either not identified as such or are attributed to the wrong causes. In a similar manner, medical staff are often not educated and equipped to conduct appropriate health monitoring. Subsequently, symptoms of lead poisoning are often not correctly diagnosed and linked to other causes, such as infectious diseases. These shortcomings are a major obstacle to enforcing regulative frameworks and minimum standards.

5. Strategies for integrating the informal sector

Experiences of integrating informal sector operators are still limited. The existing regulatory approaches are mainly based on minimum standards and EPR. While this combination is important to upgrade industrial recycling plants and to ensure that battery take-back systems are built up, collection and breaking of lead-acid batteries are still strongly in the hands of informal networks. Informal networks are diverse and commonly difficult to control: while lead smelters can easily be identified by the size and immobility of their operations, small collection warehouses and battery-breaking workshops can be located virtually anywhere. Initial formalization attempts have been reported in Nigeria, where informal battery-breakers formed the Waste Battery Association of Nigeria.[91] Further recommendations on informal sector integration are given in GBA's report on lead-acid battery management.[92]

5.3 Challenges of lithium-ion battery recycling

1. Safety and pollution risks

Unsound handling and disposal of lithium-ion batteries leads to risk of fire and pollution, as well as a loss of raw materials. As elaborated in section 3.4, the bulk of the generated waste lithium-ion batteries is currently not collected but is disposed of together with general municipal solid waste. As municipal solid waste management is not well developed in many rural areas, uncontrolled dumping is the most likely fate. Considering that poorly disposed lithium-ion batteries have led to a number of fires in waste treatment plants in many countries recently,[93] and, in general, contain a wide range of hazardous substances such as hydrogen fluoride and toxic transition metals, this inevitably leads to fire risks, pollution of soil and water bodies, as well as a loss of battery raw materials. Although there are as yet no reported cases of lithium-ion battery-induced fire outbreaks and pollution cases in Africa's waste management systems, growing EOL battery volumes will also increase the likelihood of such events in the future.

2. Cost implications of collection and recycling

Environmentally sound recycling of waste lithium-ion batteries is associated with increased costs. The costing issue is already laid out in section 3.4 and is a major reason why most lithium-ion batteries are not collected, but are instead managed together with other municipal solid waste.

Additional costs occur in the collection of batteries. Beyond the costs of recycling, environmentally sound management also needs to factor in battery collection. As most off-grid installations are undertaken in remote and rural areas with underdeveloped waste management systems, related costs are in the range of \$0.12–\$0.62/kg.[94] Nevertheless, the costs can be substantially reduced when the servicing logistics of solar companies are also used for take-back of EOL batteries. Another collection model is about to be tested in Ghana (see Box 11).

BOX 11

Incentive-based collection in Ghana

The Government of Ghana passed an e-waste act that mandates the collection of an eco-levy on all imports of electrical and electronic equipment, including batteries. The levy is put into a fund supporting environmentally sound e-waste management. While the levy collection has already begun, the mode of fund-use and distribution is still to be developed. In this context, the Government of Ghana received support from the German Financial Cooperation, through the German banking organization KfW, to pilot an e-waste fund that acts as an interface between informal collectors and registered e-waste recyclers: collectors can deliver defined types of e-waste to a handover centre and receive monetary compensation for their collection efforts via mobile money payment. The system has already been established for electrical and computer cables and there are plans for it to be expanded to batteries from early 2021. It is expected that the monetary incentives will encourage the collection of batteries that would otherwise be neglected and dumped.

> **“ As municipal solid waste management is not well developed in many rural areas, uncontrolled dumping of lithium-ion batteries is the most likely fate.**

3. Lack of cost-efficient handling and pre-processing solutions

While there are currently no other alternatives to exporting batteries for recycling, the total costs of handling, packaging and shipment are prohibitively high. While total EOL volumes are still too small to justify investments in fully fledged lithium-ion battery recycling in Africa, suitable intermediate ways must be identified and realized. Such methods are likely to encompass pre-processing technologies, where some parts of the recycling process are conducted locally. Nevertheless, research for such applied solutions is currently only small scale and mostly conducted by individual recyclers without sufficient funds and R&D capacities.

4. Development of functioning financing mechanisms

Regulative frameworks and financing mechanisms have not yet gained traction. Although regulative frameworks have been developed in a number of countries, they have not yet had large-scale impacts on collection and recycling. While policy-makers agree that additional financing can be achieved via an EPR system, conceptual development and roll-out is still nascent. Starting points – such as a clear definition of responsibilities, a classification of major battery types and applications, and the registration of producers and importers – are complex tasks and require functioning and constant organizational support, either through national administration or in cooperation with producer responsibility organizations. Considering that most countries with functioning EPR systems needed many years to develop and adjust them, progress will most likely be gradual and will strongly depend on whether those approaches consider the local framework conditions and realities of waste management in African countries.

5.4 Outlook

Lead-acid battery recycling

Improvement of lead-acid battery recycling will significantly depend on:

- **Setting and maintaining political priorities to effectively regulate and upgrade the sector.** Lead-acid battery recycling deserves to be high priority. It is both a vital sector to manage this critical waste stream and an industry that may cause disproportionately high health impacts and economic losses for societies. It is in the interest of countries to soundly regulate the sector and steer it towards high environmental performance. To support this process, some countries require targeted awareness-raising among political decision-makers and private-sector stakeholders, as well as in academia and civil society.
- **Developing effective sanctioning mechanisms for unsound and polluting recyclers (push factors).** Steering towards high environmental performance requires sanctions for all players who follow polluting practices and are not willing to upgrade their standards. In this context, it needs to be acknowledged that non-stringent sanctioning will inevitably narrow the scope for responsible investments in this sector.
- **Developing and applying strategies to prioritize high-standard recycling (pull factors).** Next to sanctions, a system is needed in which other market players tie their interrelation with battery recyclers to high standards. This can involve a broad variety of producers and battery-using sectors, including energy access initiatives and companies, and may also include sectors and companies interested in sourcing raw materials, such as lead, from African recycling markets.[95]
- **Elaborating and testing means to integrate informal sector operators.** Push-and-pull factors are most effectively applied to industrial recyclers but will have diminished short-term effects on informal battery collectors and breakers. To achieve improvements in this field, a double strategy can be applied:
  - Allow informal collection networks to become part of an EPR-based take-back and collection scheme on the condition that they do not apply any polluting practices
  - Put in place requirements that industrial battery recyclers accept only complete batteries, including acid. This measure will effectively limit the business niche for small-scale battery-breakers
- **Sharing and developing knowledge about recycling technologies, standards and regulatory measures.** Such capacity development is needed to support individuals and organizations to develop, implement and monitor improved management and recycling systems for ULABs in African countries.[96] Ideally, such capacity development will also be tied to networking activities encouraging exchanges among regional experts.

“ Sound policy development, implementation and enforcement that consider lessons learned from pilots will be decisive for the long-term sustainability of waste battery management.

Lithium-ion battery recycling

Scaling-up of lithium-ion battery collection and recycling will be significantly affected by:

- **Pilot efforts testing new collection models for EOL lithium-ion batteries.** To achieve substantial collection rates, existing warranty-based take-back models will need to be complemented by additional approaches that also target batteries from other sources. Related models will need to be piloted and evaluated to support policy development and larger implementation.
- **Applied research on safe handling, pre-processing and recycling of lithium-ion batteries.** Currently, the only fully responsible EOL solution requires exports to recyclers in other world regions, which is associated with significant efforts and costs. While some recyclers have started to elaborate on alternative management pathways, including local pre-processing and second-best options, such attempts will need to be systemized and substantially supported. Next to cost reduction, mitigation of safety risks and pollution control must be addressed by such R&D efforts.
- **Developing and testing of financing mechanisms, effectively supporting safe battery collection and recycling.** Adequate financing for environmentally sound management is needed and should be based on principles of EPR. EPR modalities suitable for African settings still require piloting to develop lessons learned for wider-scale implementation.
- **Developing effective policies.** While many regulatory elements, including the principles of EPR, are undisputed, translation into effective systems is challenging, with very limited experiences in African settings. Sound policy development, implementation and enforcement that consider lessons learned from pilots will be decisive for the long-term sustainability of waste battery management.

6

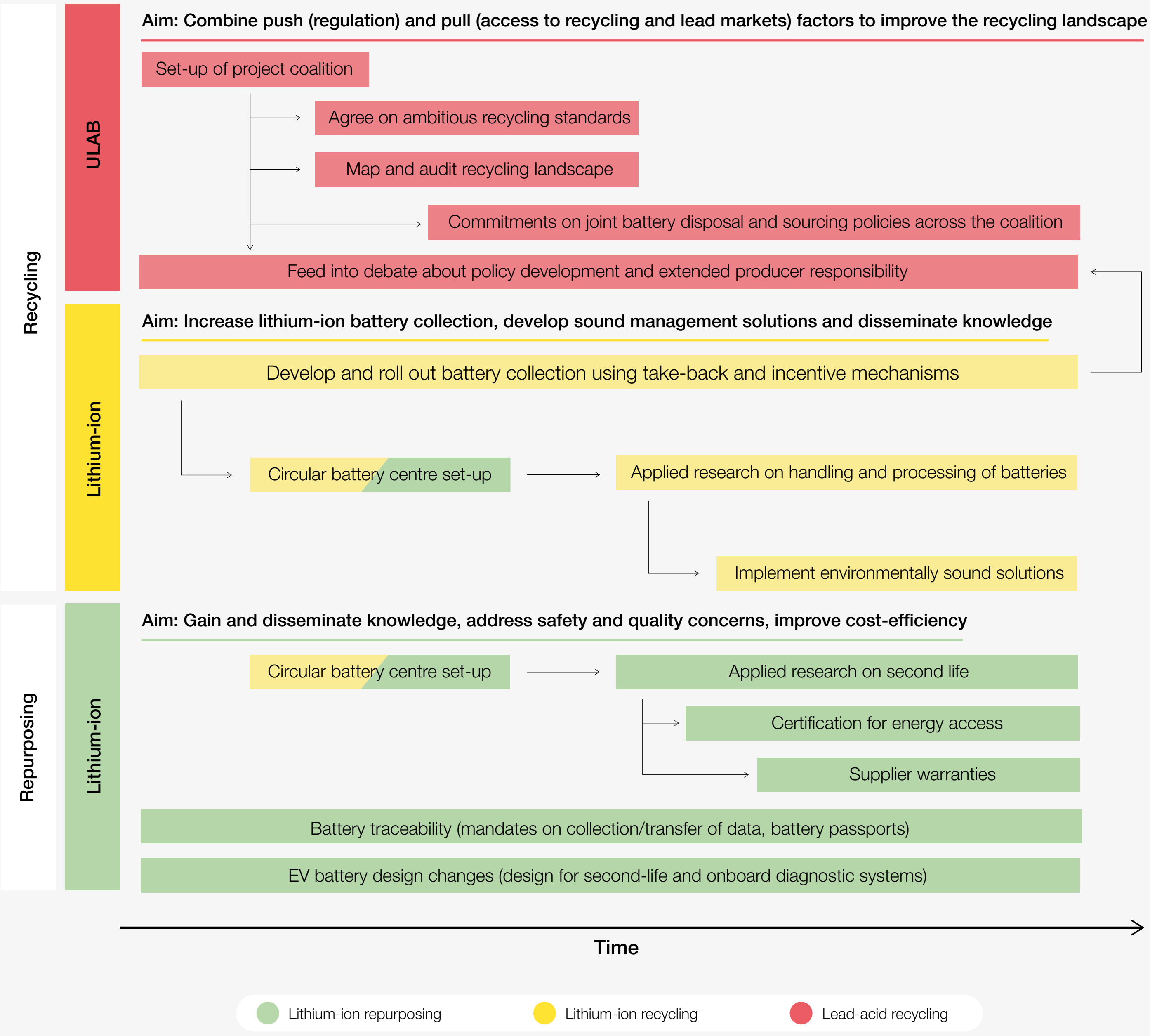
Recommendations

Across each market, there is a need for public and private collaboration, at a pan-African and global level, to support market transformation.

Given the fragmented or immature nature of each market, stakeholder coalitions will be essential to: inform the development of regulation and standards by policy-makers; ensure the creation of sustainable business models and market incentives that align with policy ambitions; and increase awareness of the most effective policies and industry techniques. In all markets, strong government leadership will be a major success factor. The exact activities and stakeholders recommended for each coalition will differ by market, set out below.

FIGURE 13

Recommendations roadmap



6.1 Lead-acid battery recycling

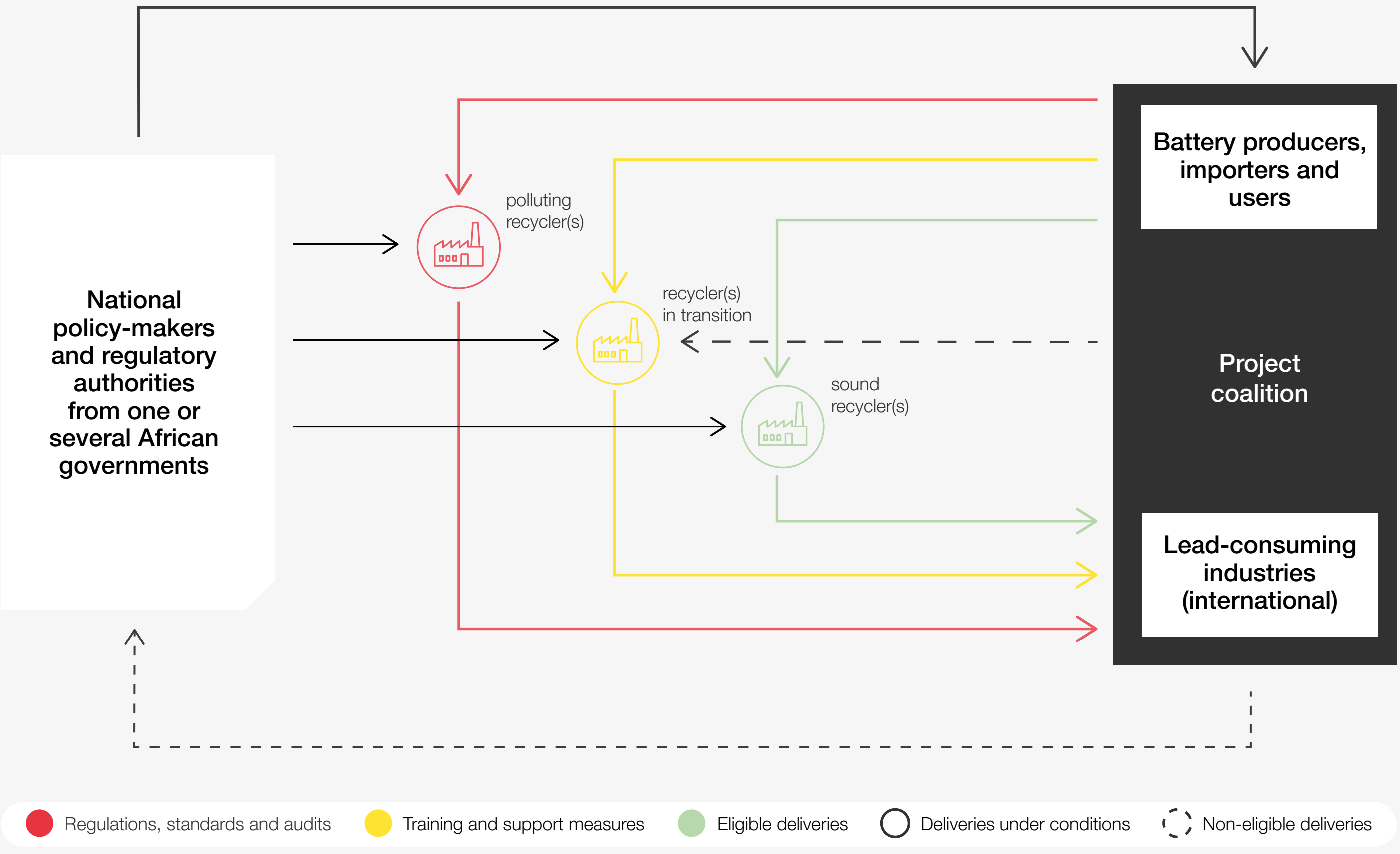
1. Form a coalition with governments, battery-using sectors and lead-consuming industries

A coalition can support the development of standards and regulations, and change the economic framework conditions in a way that supports high-standard ULAB recycling and lowers business opportunities for pollution-heavy recycling. This model is based on experiences in Kenya and Nigeria:

- In Kenya, government enforcement, in combination with a strong demand for sound recycling solutions, has motivated local recyclers to invest in improvements.
- In Nigeria, local battery recyclers currently face an embargo on selling their recycled lead to large parts of the world market, which has generated the willingness to implement improvements.

A coalition can be formed with one or more countries and will need to combine push factors (government regulation, standards, enforcement and compliance), pull factors (market demand) and supporting measures (know-how transfer). The coalition can do this by conducting the activities explored in the next subsections.

FIGURE 14 A coalition of governments, battery-using sectors and lead-consuming industries



2. Policy-makers and industry should adopt and apply ambitious standards

Ambitious standards should be adopted as a mandatory policy tool and benchmark for assessing all ULAB recycling operations in participating countries.[97] They should be applied in government regulations, and proactively by recyclers and other market players in their interactions with ULAB recycling. The standards should also be supported by knowledge transfers that enhance expert capacities in partner countries.

3. Conduct benchmark assessments of domestic lead-acid battery recycling industries

Assessments should combine capacities from national regulators, as well as international experts. Benchmark assessments should document the environmental performance of each recycling operation and facility and classify them according to three categories:

1. Sound recyclers: recommended as the disposal option for nationally generated ULABs
2. Recyclers in transition: conditionally recommended as a disposal option
3. Polluting recyclers: recommended for closure, including site remediation

While recyclers grouped in category 1 already comply with the defined minimum standards, those in category 2 still show shortcomings but have the willingness and capacities to upgrade. With such operations, a binding improvement plan should be worked out and – so long as the companies follow them – they should stay in operation and serve as ULAB disposal options. Operators in category 3 are recyclers where upgrades to minimum standards are either impossible or highly unlikely. Reasons for reaching such a conclusion could be related to plant location (e.g. in densely populated areas) or very rudimentary recycling concepts.

4. Dispose of ULABs only with recyclers committed to ambitious standards

Battery-using sectors, such as energy access companies and projects, telecommunication providers, government car fleets, hospitals and educational institutes using battery backup systems, should jointly commit to give their ULABs exclusively to eligible recyclers classified in categories 1 or 2. This combined market demand would ensure that recyclers and investors conducting responsible ULAB recycling could count on sufficient access to ULABs.

BOX 12

Improvement plan for lead-acid battery recycling in Kenya

The SHS provider ENGIE Energy Access (formerly called Mobisol) uses a lease-to-go business model in which customers acquire the SHS equipment through time-based monthly instalments. In case of technical problems, the users call a service centre and ask for repairs. With this model, the company maintains a close follow-up procedure for the equipment and has established a take-back system for obsolete components. While most e-waste is given to registered local dismantling facilities, the company initially had no solution for its ULABs and resorted to stockpiling. Local recyclers all had poor pollution records and one made news headlines regarding lead poisoning in close proximity to its operations. In 2014 and 2015, the Government of Kenya shut down most of the polluting recycling plants; only one operator – ABM, located near Nairobi – stayed in operation. Although the plant used some modern recycling equipment, it still showed shortcomings. In that situation, ENGIE Energy Access and ABM entered into an agreement: ENGIE financed an international expert from the International Lead Association to assess the plant and to develop an improvement plan. ABM committed to implementing the plan and to accepting regular follow-up inspections. In turn, ENGIE committed to supply its ULABs to ABM.

5. Source lead only from recyclers committed to ambitious standards

Concerns over shortcomings in ULAB recycling in low- and middle-income countries made many lead-consuming companies review their sourcing strategies and follow the guiding principles of the industry's Material Stewardship Initiative and GBA's recommendations on responsible sourcing.[98] Subsequently, recycled lead from African countries is increasingly accepted only after thorough supply-chain due diligence. As such due diligence is demanding for individual companies, many refrain from buying lead from African sources, which leads to de facto embargos. Through joining the project coalition, lead-consuming industries can gain access to lead from African countries while playing a positive role in the market's transformation towards environmentally sound recycling. With their engagement, they can offer reliable business partnerships with recyclers grouped in categories 1 and 2 above and further strengthen the business case of responsible battery recycling in Africa.

> “ By joining the project coalition, lead-consuming industries can access lead from African countries while playing a positive role in the market's transformation towards environmentally sound recycling.

6. Support market transformation with know-how transfer and collaborative learning

The recommended combination of push-and-pull factors needs to ensure that regulatory bodies and operators in the battery recycling chain are fully aware of the challenges and best practices. This requires the transfer of knowledge and development of practical expertise; in addition, country experiences should be monitored to serve as lessons for other countries aiming to improve their lead-acid battery-recycling sectors.

> **Lead batteries will continue to play an important role, giving communities access to reliable and renewably sourced electricity. We fully support the Closing the Loop on Energy Access report recommendation that a multistakeholder approach is necessary to develop standards, regulations and a sustainable economic framework that supports effective and safe lead battery recycling and reduces the influence of informal recyclers with inadequate operations that are prevalent in sub-Saharan Africa.**
>
> Steve Binks, Director of Regulatory Affairs, International Lead Association

6.2 Lithium-ion battery recycling

1. Kick-start collection and recycling of lithium-ion batteries on a large scale

As current economic framework conditions will not lead to any significant collection and recycling of lithium-ion batteries in African countries, there is a realistic scenario that most batteries will be managed together with other municipal solid waste types, contributing to fire and pollution risks. Mitigating these risks will strongly rely on the development and implementation of take-back and recycling policies, as well as associated financing instruments. While many African governments are about to develop policies and financing instruments under EPR policies, most are still in the development stage.

African governments in cooperation with a group of proactive producers and importers, including energy access projects and off-grid solar companies, can greatly advance the collection and recycling of lithium-ion batteries, thereby advancing policy development and implementation. This can be done by implementing the following recommendations.

2. Initiate and roll out lithium-ion battery collection in pilot settings

Governments and a group of proactive organizations can develop and roll out battery collection in one or more pilot settings with the aim of achieving substantial collection rates and creating success stories. Lessons learned should be used for policy-making and collection initiatives across Africa and should also be used to design applicable models for EPR systems for the given contexts.

3. Combine existing take-back systems with incentive models

Such a pilot exercise should build upon existing collection models based on the exchange of batteries and components under warranties. Beyond this, the development of further collection mechanisms, including incentive-based models in which (formal or informal) suppliers of EOL lithium-ion batteries receive a defined monetary compensation for their collection efforts, are also encouraged.

4. Set up a circular battery centre to develop EOL management solutions

Collected batteries should be given to a centre that specializes in developing and implementing solutions for EOL batteries. This kind of circular battery centre still needs to be set up and should be mandated to perform a wide range of tasks, as detailed in Box 13.

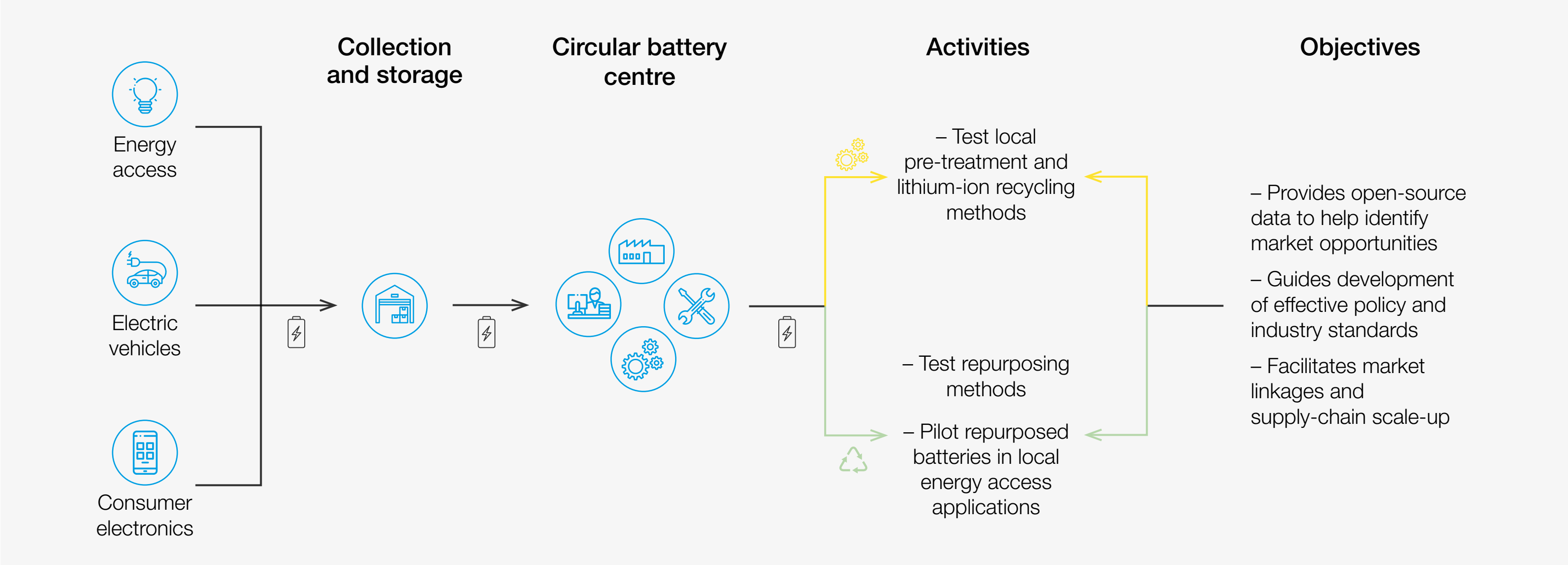
BOX 13 Research for scaleable recycling of LFP batteries

Kyburz Switzerland, a producer of electric tricycles, is cooperating with the Swiss EMPA Material Science and Technology to develop recycling for its LFP batteries. Kyburz uses standardized LFP cells throughout its products and aims to explore the advantages of small-scale, tailor-made recycling solutions. LFP batteries are discharged and semi-automatically disassembled and opened in a controlled atmosphere to separate plastic and electrodes, which are further treated to separate graphite from the copper foil and lithium iron phosphate from the aluminium foil. While the approach primarily targets EOL batteries generated from Kyburz e-vehicles in Switzerland, comparable approaches could be explored for managing EOL LFP batteries from off-grid installations in Africa.

6.3 Lithium-ion battery repurposing

To increase deployment of repurposed batteries, consumer confidence and political appetite need to be strengthened through a local repurposing value chain. A core lesson learned from market intelligence and stakeholder engagement is that local repurposing of batteries will be critical to test approaches that gain buy-in from local policy-makers, the off-grid solar industry and households. While the local volumes of EOL batteries are not sufficient to meet rising battery demand by 2030, they provide a foothold to test repurposed batteries and inform the development of a supportive policy environment.

FIGURE 15 **A circular battery centre (or centres) will be key to lithium-ion recycling and repurposing scale-up**



Policy-makers, the energy access industry and storage manufacturers must work together to support consumer confidence and reduce market uncertainties. Recommended activities for this coalition include:

1. Conduct trials of repurposed batteries in a range of energy access applications

The lack of real-life experience with second-life batteries means performance and safety have not been sufficiently demonstrated and there remain gaps in understanding battery performance. Real-world trials can: help build consumer confidence; improve investor know-how on the design of repurposed batteries and battery management systems; and guide the development of standards and policies. Both grant-funding and industry financing will be critical to ensure trials are sustainable.

2. Set international, industry-approved, quality assurance frameworks for repurposed batteries, including standards and certification processes

A lack of quality standards for repurposed batteries, and the lack of comparable first-life battery standards specific to energy access applications, lower consumer appetite and willingness to pay. Effective standards must use lessons from real-world demonstration projects to provide both: a) clear metrics for assessing second-life performance; and b) minimum performance levels tailored to applications.

3. Disseminate lessons learned across countries, as well as among policy-makers, researchers and industry

Given the fragmented nature of the market, the development of high-quality and safe value chains will depend on the extent to which feedback loops are created between market actors at a global level. For example, government policies will need to be trialled and refined based on industry experience, and examples of successful approaches need to be communicated for others to replicate.

4. Set out targets and white papers on opportunities for repurposing, including viable local business models and end markets for repurposed batteries

Investor confidence in the market is understandably low, given the lack of tried-and-tested business models. Greater clarity on the potential scale of the national market and how businesses can be part of a repurposing value chain (through demonstration projects, recommended above) will be important in order to attract private investment.

5. Facilitate linkages among EOL battery providers, remanufacturers, universities and consumers

Governments can play an important role in reducing investor search costs by convening brokerage events and providing matchmaking services to link buyers and sellers of EOL or repurposed batteries, ensuring local research institutions and SMEs are linked to the growing market.

6. Improve the availability of data on EOL battery health and usage

Access to information on first-life battery usage and EOL state-of-health metrics could reduce the cost of repurposed batteries by an estimated 20%. The GBA's Battery Passport could be a facilitator for battery traceability, underpinned by regulation to mandate access to industry data.

7. Design first-life batteries to reduce remanufacturing costs

Battery packs are designed in hundreds of variations with little consideration given towards the ease of pack disassembly, leading to high remanufacturing costs. Regulatory guidance must prompt circular pack design, given the lack of industry interest and the long lead times it will take to reach end use and affect EOL management.

To help deliver several of these recommendations, a core recommendation is the development of a network of circular battery centres, as set out in Box 14.

BOX 14

Circular battery centres: objectives and activities

The circular battery centre (or centres) would help deliver on several recommendations, with the aim of:

- Increasing collaboration among policy-makers, industry and civil society on EOL management challenges
- Increasing understanding of new technologies and approaches, tailored to the local context
- Informing the development of policies and standards
- Developing local value chains, by training local workers and linking to local businesses

The centre could take advantage of economies of scale in research and ensure knowledge spillovers between otherwise disparate industries and national governments, therefore helping to maximize returns on grant investments and reduce the risk that each player works in isolation with little impact.

To achieve these aims, the circular battery centre would be:

- A public-private entity, co-founded and managed by public and private organizations to ensure broad support and long-term sustainability
- A physical space for carrying out applied research on battery recycling and repurposing. The centre's activities would build on local battery collection and ought to develop and test cost-optimized and environmentally sound transport, sorting, storage and testing of collected batteries. These approaches will feed into two distinct workstreams:
- Testing innovative methods for local pre-treatment and recycling of lithium-ion batteries
- Testing repurposing approaches and piloting deployment in a range of energy access applications
- An open-source data centre, responsible for sharing information on the activities highlighted above, with the aim of informing future research needs and sustainable business models
- A guide to effective policy, regularly disseminating lessons learned with the aim of guiding policy development and industry approaches

“ African governments, industry and researchers have begun to express their interest in pursuing the next steps, laying the foundation for a Closing the Loop on Energy Access network.

6.4 Next steps

Stakeholder consultation throughout the report has informed the development of recommendations that bring together recycling, repurposing and energy access markets. To ensure recommendations are brought to action, two immediate steps include:

- **The creation of working groups focused on the interconnection of energy access and EOL management**. These groups will bring together policy-makers and industry in energy access, recycling and repurposing, with the aim of setting out roadmaps for each recommendation, assigning ownership and setting milestones towards which groups can be accountable.
- **A scoping study on the circular battery centre.** The battery centre's mandate and funding requirements need to be clarified, beyond the ideas discussed in Box 14, to ensure it can address local challenges in a cost-effective and sustainable manner. The centre's location and potential partnerships also need to be explored to ensure activities build on, rather than duplicate, existing EOL management initiatives and infrastructure.

African governments, industry and researchers have begun to express their interest in pursuing these next steps, laying the foundation for a Closing the Loop on Energy Access network.

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This analytical study was prepared in collaboration with the Global Battery Alliance, the Energy Storage Partnership and the Faraday Institution.

The Global Battery Alliance brings together leading businesses along the entire battery value chain with governments, international organizations, NGOs and academics to actively shape a battery value chain that powers sustainable development.

The Energy Storage Partnership is a global partnership convened by the World Bank Group through its Energy Sector Management Assistance Program (ESMAP) to encourage international cooperation to develop sustainable energy storage solutions for developing countries. For more information visit: www.esmap.org/energystorage.

The Faraday Institution is the UK's independent institute for electrochemical energy storage research, skills development, market analysis and early-stage commercialization.

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