The role of energy storage in achieving SDG7: An innovation showcase

ENERGY CATALYST

UK aid from the British people

UKRI Innovate UK

Attribution:

Ankur Agarwal, Energy Expert, Energy Catalyst

Energy Catalyst is an Innovate UK programme with co-funding from the Foreign, Commonwealth and Development Office, Global Challenges Research Fund, the Department of Business, Energy and Industrial Strategy and the Engineering and Physical Sciences Research Council. This material has been funded by UK aid from the UK government; however the views expressed do not necessarily reflect the UK government's official policies.

The role of energy storage in achieving SDG7: An innovation showcase

Contents

Introduction

This Energy Catalyst research presents an overview of the energy storage market, and in particular its relevance to energy access, highlighting the importance of and challenges to scaling energy storage in this sector. The report also highlights a selection of energy storage innovation projects supported by Energy Catalyst and presents relevant learnings and insights.

Energy Catalyst is an Innovate UK programme with co-funding from the Foreign, Commonwealth and Development Office, Global Challenges Research Fund, the Department of Business, Energy, and Industrial Strategy and the Engineering and Physical Sciences Research Council. Energy Catalyst accelerates the innovation needed to end energy poverty. Through financial and advisory support, and by building strategic partnerships and uncovering new insights, Energy Catalyst supports the development of technologies and business models that can improve lives in Africa and Asia. Energy Catalyst aims to accelerate progress on Sustainable Development Goal (SDG) 7 to ensure access to affordable, reliable, sustainable, and modern energy for all. Tied closely to this mission, there is a strong interconnection between energy storage, the transition to renewable energy more broadly and SDG 13 to take urgent action to combat climate change and its impact, furthering climate action, strengthening resilience and adaptive capacity.

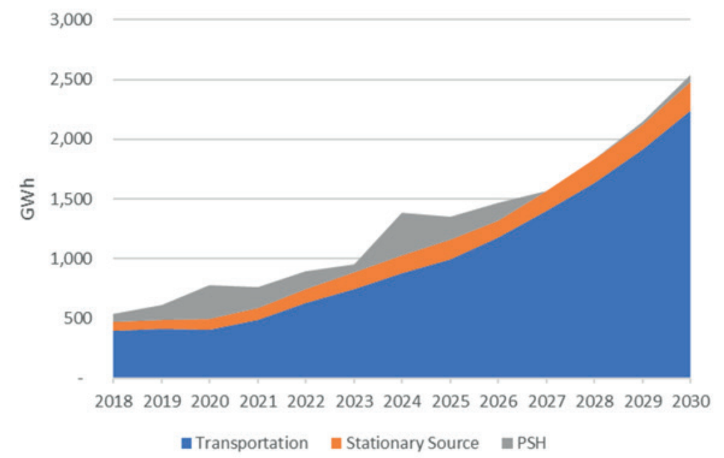
Energy storage sector overview

Energy storage trends at a global level

The global energy market has a pressing need for energy storage, especially in view of the move away from fossil fuels towards electrification of transportation and integration of large amounts of renewable energy into the electricity generation mix. The progress seen in these different use cases can be beneficial to off-grid energy storage applications since the massive scale, stringent quality requirements, performance and safety testing of the batteries will enable significant cost reductions and capacity building for the smaller energy access markets.

The combined global stationary and transportation annual energy storage market projections are summarised in Figure 1 below by a US Department of Energy report[1]. The market is projected to increase fourfold by 2030 to more than 2,500 GWh (Gigawatt hour), from a 2018 baseline. Much of this growth is due to the adoption of electric vehicles (EVs). It was found that annual transportation storage deployments are 2 to 10 times that of stationary, including Pumped Hydro (PSH), depending upon the assumptions for the transportation deployment.

Figure 1: Projected growth in global energy storage capacity; US D.O.E



This growth projection can help explain why the focus of the energy storage industry is so heavily biased towards Li-ion batteries which are the primary storage technology used in EVs.

An indication of how rapidly the market is growing is that the stationary storage estimates by Bloomberg New Energy Finance (BNEF) towards the end of 2021 were about 1 TWh by 2030[2], which is double the estimate 2 years earlier[3] (as seen in the graph above). The United States and China together will account for more than 50% of this projected installed capacity.

BNEF's latest forecast suggests that 55% of energy storage installed by 2030 will be to provide energy shifting (for instance, storing solar or wind energy at the point of generation to be released at a time of need). Co-located renewable-plus-storage projects are becoming increasingly common globally. BNEF also makes the significant prediction that energy storage located at homes and businesses will make up about one quarter of global storage installations by 2030. This bodes well for the energy access sector as smaller, decentralised storage systems being installed in houses that require little to no regular monitoring by technical personnel can be applied to similar engineering solutions at lower costs for the energy access markets in sub-Saharan Africa and Southeast Asia.

Energy storage in developing and emerging economies

Typically, there is a low rate of access to electricity in emerging economies. The latest IEA country-by-country assessment shows that in 2019, the number of people without electricity access had dropped to 770 million, a record low in recent years[4]. However, progress remains uneven, and 75% of the population without access now live in sub-Saharan Africa, a share that has risen over recent years.. This is usually due to insufficient generation, or a lack of coverage by transmission and distribution (T&D) infrastructure. Even in cases where there is sufficient grid coverage, they are usually classified as weak grids. This translates to poor security of supply for the users. A World Bank ESMAP report[5] on energy storage policy and regulatory considerations for developing countries states that this is due a combination of challenges through the entire supply chain: scarce or import dependant energy sources like fossil fuels, insufficient, unreliable, and inflexible generation capacity, underdeveloped or non-existent grid infrastructure, inadequate monitoring and control equipment, and a lack of skilled human resources and maintenance[5]. In view of the multiple challenges, energy storage can be an effective solution to enhance reliability of power supply and maximise power produced from renewable energy sources. Deployed as an integrated solution with variable renewable energy sources like solar, wind, hydro etc. it can also help displace costly and polluting back-up generation based on fossil fuels. In some technical scenarios, large amounts of decentralised storage can also help defer or entirely avoid the construction of new grid infrastructure, which is often a lengthy, capex-heavy, and financially unviable investment.

An increasing share of renewable energy integration on the grid requires long duration energy storage that ranges from tens to hundreds of hours as the share of renewable energy generation increases beyond 50%. Apart from conventional pumped hydro storage systems, flow batteries, chemical (H2, Ammonia etc.) and thermal storage for industrial heat, all have potential to cater to this demand segment which is still in early stages of development. Current electrochemical energy storage technologies are focused on shorter storage durations. This is particularly pertinent to developing countries that might see an increasingly decentralised grid with distributed variable renewable energy generation sources coupled with higher energy and lower power i.e. longer term storage systems to complement the variable generation even in the case of existing systems like small and large hydro.

In many parts of the world, battery storage systems deliver reliable power at about a third of the cost compared to diesel generators whilst also having better supply chain resilience. Secondary benefits from not using diesel, an often poor-quality and contaminated fuel, are reduced pollution and reduction of negative health impacts. The most affected are often consumers in low-income communities where price gouging and lack of quality control can be common[7].

For sub-Saharan Africa, where an estimated 550 million people lack access to electricity and a further 150 million have unreliable connections, a World Economic Forum (WEF) report suggests scaling up battery deployment for all technology applications from pico systems (<10 Watts) to utility scale generation, as a necessary condition to reduce the number of people without reliable access to electricity. The report indicates that stationary battery capacity in Africa alone is likely to grow 22% annually to 83 GWh in 2030 from 11 GWh in 2020. This is a realistic market forecast against a total projected demand for 190 GWh for full energy access. It is important to note that this does not include the need for storage in mobile applications such as electronics or electric vehicles (EVs) in the region which is also projected to see significant growth.

The role of energy storage in achieving SDG7: An innovation showcase

The following data from the Faraday Institution[6] provides a technology performance evaluation of the different storage technologies that are most relevant to weak and off-grid contexts in developing countries.

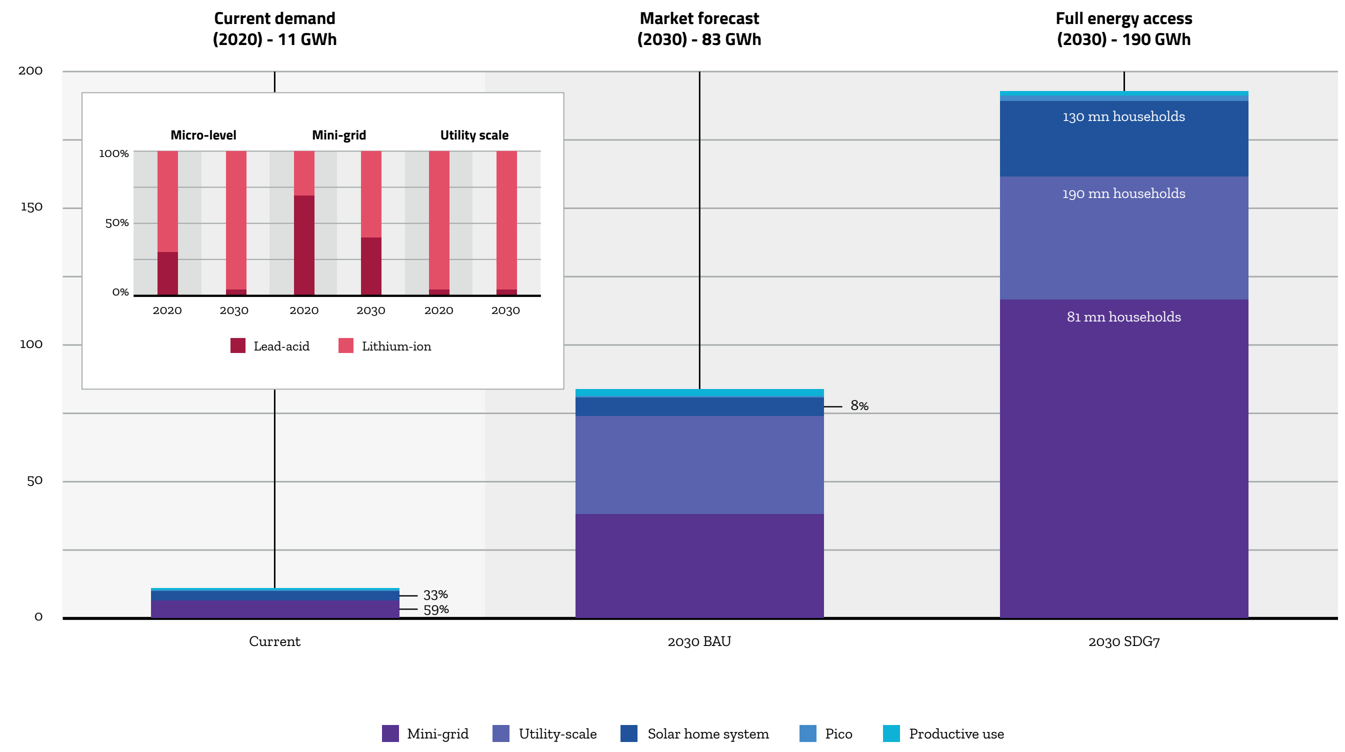
	Lead-Acid	Lithium - Ion	Sodium-Ion	Redox Flow	Pumped Hydro	Thermal	Lithium-Sulphur
Capital Costs	$-$$	$$	$$	$$-$$$	$	$-$$	$$
Maintenance Cost	***(sealed) * (flooded)	***	***	**	**	**	***
Predictability	**	*	**	**	***	***	*
Cycle Life	*	**_***	*_**	***	***	***	*
Depth of Discharge	*	**	***	***	**_***	**	***
Cost per Cycle	$$-$$$	$$-$$$	$$-$$$	$$	$-$$	$-$$	$$$
Ease of Recycling	**	*	*(non-aq.) ***(aq.)	**	**	***	**
Energy Density	**	***	**(non-aq.) *(aq.)	*	*	*	***

Capital costs (GBP/kWh)	-	$ = 10s; $$ = 100s; $$$ = 1000s
Maintenance Costs	-	* = regular maintenance; **=regular inspection; *** = none required
Predictability	-	* = High Risk; ** = moderate risk; *** = low risk
Cycle Life	-	* = 100s; ** = 1000s; *** = 10,000s
Depth of Discharge	-	* = ca. 60%; ** = 80%; *** = 100%
Cost per Cycle	-	$ = <0.01; $$ = 0.01 - 0.1; $$$ = 1-100
Ease of Recycling	-	* = many, partly toxic; ** = few, partly toxic; *** = few, non-toxic

As Figure 2 shows, mini-grids as well as utility-scale storage will form the majority of capacity addition in GWh. However, smaller solutions will have a significant impact based on number of households despite lower cumulative capacity. While lead-acid systems will form a large part of the mini-grid and standalone storage capacity, Li-ion batteries (specifically Lithium Iron Phosphate - LFP technology) will be the leading chemistry of choice due to their better cycle life, energy density and ability to deep discharge, despite higher upfront costs. This is the case for both smaller systems (pico or Solar Home Systems) due to weight and lifespan requirements and larger systems such as mini-grids or utility-scale due to costs and better technical performance. In some mid-sized applications, lead-acid batteries might be preferred due to their strong and existing value chains as well as longstanding experience in harsh conditions and safer operations compared to the thermal management risks of Li-ion.

As well as performance parameters, end-of-life handling is also an important consideration for energy storage technologies. Lead-acid recycling is a well-established market and has the dual advantage of being simple and producing high value extracted material. This contrasts with Li-ion recycling, which is expensive, difficult and poses a higher barrier to entry with regard to safety and training.

Figure 2: Projected growth in storage capacity in SSA along with technology breakdown



The role of energy storage in achieving SDG7: An innovation showcase

According to the WEF report[8], the main challenges that could restrict market scale-up of batteries are financial and supply chain related:

- Prohibitively high upfront costs of batteries in energy access markets. EV manufacturers in emerging markets pay ~ $140/kWh as pack prices fell below $100 for the first time. In contrast, energy access companies pay around $410/kWh. This is due to the smaller size of the energy access market, its smaller capacity requirements as well as additional logistical and supply chain challenges involved with selling in emerging markets.
- Consumers' financial constraints make storage-heavy business models unviable despite promising savings overall.
- At utility-scale, the lack of electricity market regulation and adequate mechanisms to compensate for the ancillary services batteries can provide, weakens the case for battery investment.
- A significant increase in hazardous waste, subsequent pollution and impacts on human health can be expected if end-of-life management is not regulated (which is the case at present, beyond stockpiling old Li-ion cells in the best case).
- Increased demands of extractive raw material and the resulting social and environmental risks that come with it.

Image: The Solveteq prototype

Energy Catalyst funding and portfolio analysis

Image: Installation of the BESS containers at Golomoti

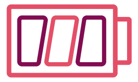
The UK Government actively supports the development of energy storage as one of the important technologies which will propel future growth as it will play a significant role in both the near- and long-term future of the energy sector.

As indicated previously, energy storage is a fundamental requirement to enable affordable, reliable, sustainable, and modern energy for all – the aims of the SDG 7. In addition, energy storage is key to increasing renewable energy generation capacity and moving towards 100% renewable energy generation. Fundamentally and rapidly changing how we produce and consume energy, especially for transportation and power, is amongst the top strategies to combat climate change. Building resilient power systems, distributed (rather than centralised) generation capacity, intelligent and resource sensitive energy reserves will all require significant uptake of energy storage. The Energy Catalyst programme is well placed to support innovations in energy storage. It does this by accelerating progress through funding, incubation support, and knowledge dissemination.
Overcoming the above challenges is central to the mission of Energy Catalyst and its funding partners. Fostering innovation in energy storage technologies is therefore a key area of focus to achieve SDG 7 and accelerate the energy transition globally.

Energy Catalyst is supporting a wide variety of energy storage technologies and applications, as the case studies in the following section will demonstrate. These include:

Battery management systems

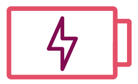
Battery recycling technologies



Flow batteries

Medium scale battery storage for smart grid integration

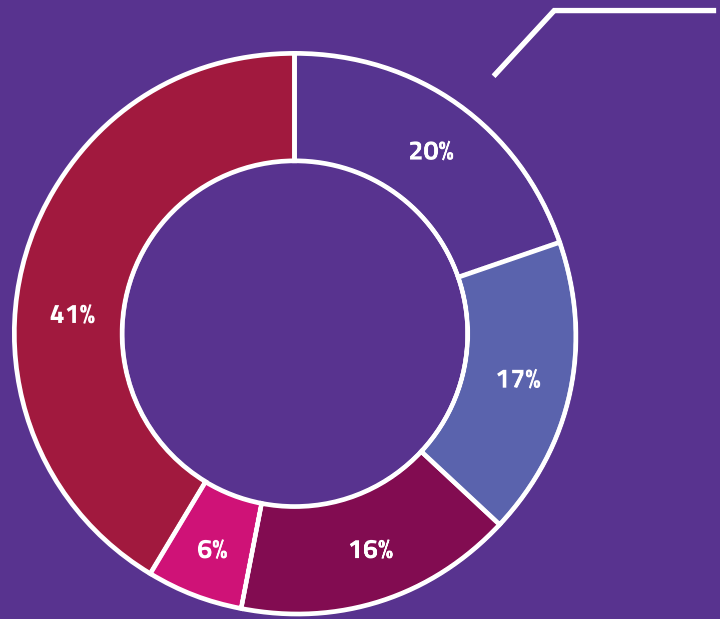
Mechanical gravity storage



Small scale compact storage for mobile / off-grid applications

Utility Scale Lithium-Ion storage

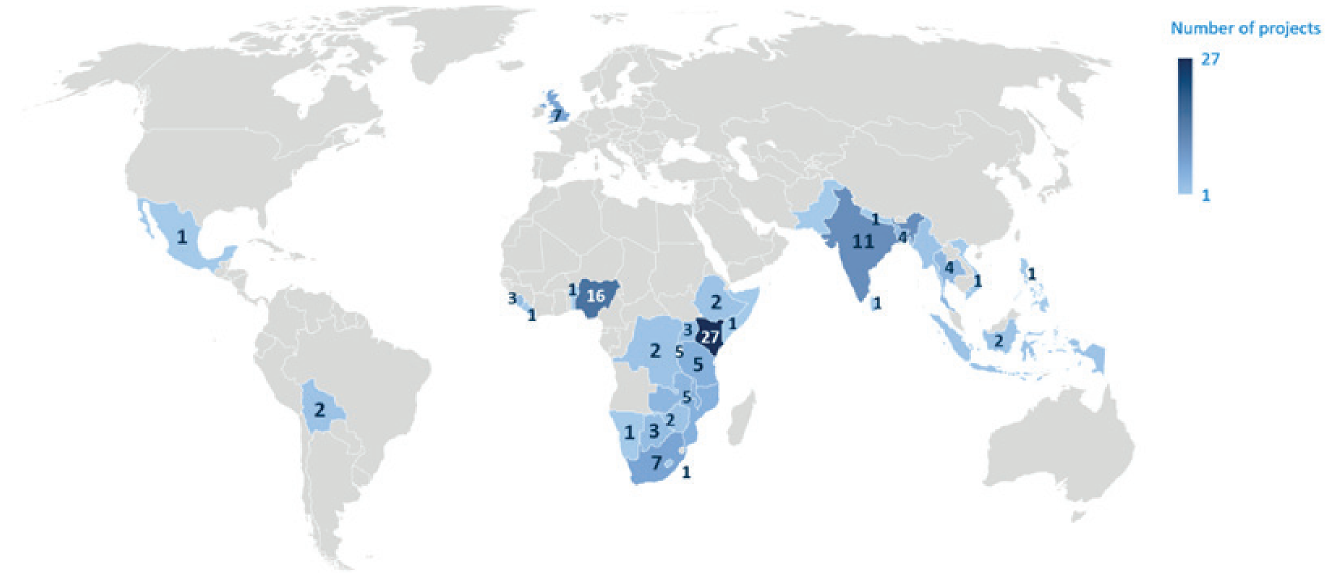
Figure 3: Share of individual energy technologies supported through Energy Catalyst



20% of the approximately 135 Energy Catalyst supported projects over the last 6 funding rounds are classified as storage technologies. With this, energy storage forms the largest technology segment to receive funding across all Energy Catalyst funding rounds. This is followed by projects classified as 'solar energy,' which can typically also contribute to, as well as benefit from, energy storage technologies.

- Energy storage
- Solar
- Biomass, biofuels & waste
- Wind
- Others

Figure 4: Number of supported projects per target country



In terms of geographic spread, the Energy Catalyst projects have seen diverse deployment over the course of the programme and this can be extended to the energy storage projects as well.

Energy Catalyst companies working on energy storage

StorTera

Image: One of many StorTower commercial systems installed in Canada for a smart grid pilot project

StorTera is an Edinburgh-based manufacturer of integrated battery energy storage solutions for decentralised energy applications. The team has been in operation since 2013 and is in the process of commercialising single liquid flow batteries. While carrying out research and development on flow batteries in parallel, StorTera has been focused on assembling lithium iron phosphate (LFP) battery modules into bespoke systems for installation in several target markets. It also develops proprietary battery management systems (BMS) for these batteries as well as energy management systems (EMS) for the projects that they build.

The company received funding through Energy Catalyst Round 4 (project was through an earlier company name Power Migration Partners). The team initially worked on the development of highly mobile 5kW emergency storage 'backpacks' as well as hybrid system controllers for telecom towers in Sri Lanka. More recently, they have focused their effort in the more commercially mature market selling Li-ion storage systems for smart/micro-grids in in the UK and North America. StorTera has seen rapid success, deploying several systems as large as 250kW/500kWh, and is involved in a number of decarbonisation and net zero projects, providing the critical energy storage and system control capabilities.

The company also aims to cater to the long-term storage needs in the UK and is working on a long duration battery energy storage system (BESS) with more than 8 hours of storage. Using intelligent, interactive prediction and management systems, it is able to react to fluctuations on the grid resulting from increased renewable energy capacity which helps maintain power quality.

> **"The most important benefits of such systems are their ability to provide grid services, replace diesel backup systems and reduce grid infrastructure spending. The latter two being of significant relevance for developing markets with weak grids both in terms of supply quality as well as geographical reach. Both of which often lead to energy access deficiencies."**
>
> Gavin Park
> CEO of StorTera

The role of energy storage in achieving SDG7: An innovation showcase

Getting the technology development right is important before deploying it in the tougher, often more demanding applications in developing markets. For this, installing and developing these systems in commercially viable developed settings gives StorTera the ability to improve the technology while scaling up the deployment. Through this process of cost reductions from scaling up and technology maturation, StorTera targets a cost of GBP 50/kW and GBP 100/kWh at scale. The targeted levelised cost of storage is less than GBP 10/MWh.

Funding and support from Energy Catalyst opened many doors for StorTera and gave them access to real world customers. Their initial customers in the Telecom segment triggered the development of other products beyond the mobile storage backpack into hybrid controllers, microcontrollers as well as their fully commercialised product, the StorTower.

Image: Smaller scale hybrid microwgrid applications with Li-ion modules & StorTera inverters, in a rural setting in the UK

Additionally, through the acceleration support provided by Energy Catalyst, StorTera were able to find new suppliers for their components as well as potential system integrators who can manufacture the entire system offshore, closer to where they source their components. This will allow StorTera to focus on their core competence of product development and engineering.

Image: Smaller scale hybrid microwgrid applications with the SLIQ Flow battery demonstrator, in a rural setting in the UK

The main challenges at present are supply chain issues due to COVID-19. The resulting factory closures, order backlogs and shipping challenges are impacting their ability to deliver on time while maintaining high quality testing standards. The global shortage of integrated circuits is also impacting their ability to produce controllers in time. Over the long term, Li-ion batteries are going to remain challenging to ship given their hazardous nature, which is especially relevant to geographies such as sub-Saharan Africa. Flow batteries offer more energy security for the region especially given local electrolyte manufacturing and lower dependence on a single market for raw materials. This also improves supply chain resilience which is critical to building sustainable electricity infrastructure. With this in mind, StorTera are committed to continuing the development of their flow battery technology while concentrating on increasing sales of their Li-ion systems which are already commercially viable in the short term.

The role of energy storage in achieving SDG7: An innovation showcase

JCM Power

JCM Power is a Canadian developer and independent power producer that develops utility-scale renewable and storage projects. Although they started with a focus in North America, they have been operating in emerging markets since 2013. In December 2021 JCM successfully commissioned a 20 MW solar PV along with a 5MW/10MWh Li-ion battery storage system in Golomoti, Malawi. This represents the first utility scale solar PV+ BESS (Battery Energy Storage Systems) in sub-Saharan Africa. This project was supported through Energy Catalyst Round 7.

This project enables the Malawian utilities to understand the opportunities that large scale renewable and storage integration can bring. The knowledge generated from this project will directly influence policy and market development, not just in Malawi but in the entire region. It was a remarkable feat to manage the installation and successful commissioning of the BESS given the logistical bottlenecks of shipping hazardous material and large payloads to remote sites. This was further exacerbated by COVID-19 related supply chain disruptions. The engineering team of the BESS supplier were unable to travel to site and therefore the system commissioning was carried out by the local onsite team with remote support from the system supplier.

Additionally, the lack of project implementation skills, capacity building as well as gaining a deep understanding of firming renewables (the use of storage to reduce renewable energy output fluctuations) are all addressed through this project.

The addition of storage provides a broad range of benefits and support functions to the power grid, such as frequency regulation and voltage support, by allowing excess solar energy to be stored and used at a later time. Since Malawi, like most developing and some developed markets, does not have a policy for energy storage yet, there are no other sources of revenue at present. This lack of incentives negatively impacts the viability of storage solutions. The following simplified economic breakdown highlights this challenge:

20%	Increase in investment (due to adding storage and additional solar)
13%	Additional energy produced and delivered as a result of this addition
10%	Increase in total investment due to additional solar capacity
10%	Increase in energy delivered due to solar addition
10%	Increase in total investment due to BESS
3%	Increase in energy delivered due to BESS

Image: The Golomoti Solar Project with the large-scale grid interactive Li-ion BESS

Hence the ratio of increase in solar capacity to generation is 1:1 but for the BESS, this 7% deficit would not be commercially viable in the absence of the Energy Catalyst grant.

Making this technology commercially viable requires a reduction in storage costs, which long term market predictions suggest is quite likely. Additionally, multiple revenue streams need to be made available from the utilities in order to capitalise on the many advantages that BESS offer, beyond energy delivery. Such revenue stacking requires fundamental policy creation for which the local skills are currently lacking. This project is seeking to directly address this key knowledge gap to build local capacity.

For JCM Power, this project offers them recognition by virtue of being the first such system installed in the region. It gives them experience and an important reference that will help install further systems by demonstrating effectiveness and attracting further investment. JCM is also in charge of operating the system which will give them and its local Malawian team first-hand insights into the operation and maintenance aspects of such a system.

For Malawi, this system offers two distinct benefits. Firstly, given the capacity shortages in the grid, it directly provides clean and high quality 'firm' renewable energy which the grid requires.

The PV+BESS system can provide up to 10% of Malawi's electricity production and even significantly more in the dry season when the hydroelectric capacity can see significant reduction. In 2020, storms and flooding knocked out much of the country's 320 MW generation capacity, reducing it to 50 MW[9]. Distributed renewables and storage such as this project are more resilient to such events. Secondly, the storage system specifically improves the quality of the grid electricity which is plagued with frequent outages and other power quality issues. Improving the reliability reduces the need for consumers to invest in expensive and environmentally polluting backup systems and offers all the economic benefits that come with having access to reliable, continuous electricity.

Benefits such as income generation and local employment, both short and long term, which are direct consequences of large infrastructure projects are also seen in Golomoti.

The main challenges foreseen by JCM remain the lack of a viable business model for utility-scale storage systems without proper value assigned to firm renewables. Reduction in storage costs, coupled with improved revenue generation through ancillary services and utilities assigning value through off-take agreements, will make the market commercially feasible. This project directly helps address the latter.

Images: Installation of the BESS containers at Golomoti and the planned system layout (right)

Modularity Grid

Modularity Grid is a start-up formed in 2018 with a core team from Imperial College London. It has developed a cloud-based platform that couples predictive modelling of electricity data, with dynamic control and management of electricity distribution. The company is focused on off-grid, standalone power systems for energy access, as well as aerospace applications.

Within micro-grid applications, Modularity Grid's offering helps to predict and manage energy consumption in a resilient way more accurately. This allows renewable and storage systems to compete with diesel gensets through helping to better size micro-grids and bring down system costs.

Modularity Grid was selected for Round 7 of Energy Catalyst funding and successfully installed a mini grid in Uganda. The installed hybrid system is comprised of 75kW PV + 32kW Gasifier along with a 65kWh Li-ion battery. This system powers over 100 households and small businesses including a health centre and a school. Additionally, 50 batteries were used for distribution to houses that were too far to be connected to the grid, whilst an EV charging station powers a small electric goods carrier that is used for battery delivery. During the COVID-19 pandemic this carrier was retrofitted for emergency use as an ambulance. This was not only helpful on the ground but also a suitable alternative usage of resources since battery delivery was restricted due to initial uncertainties around social distancing norms and restrictions.

The project demonstrated a reduction in operations and maintenance costs by 30-40%. This was done through automating performance and system (primarily battery) health monitoring which reduced the need for manual interventions. In addition, as more data becomes available, the system will also work on failure identification, root cause analysis, issue analysis as well as failure prediction.

For Modularity Grid, the storage system forms a significant proportion of overall cost (up to 30%), while also representing a higher risk than the rest of the assets.

At a technological level, getting the battery management system right is still a challenge given the complex chemistry of the Li-ion cells. This makes it difficult to optimise the health and performance of the cells which requires fine tuning parameters to detailed levels as well as demand-side management.

The other main challenges with storage systems encountered by Modularity Grid in energy access settings include:

- **Warranty Management** – This is typically very hard to enforce given the logistical challenges as well as lack of options
- **Insurance** - Not easily available for batteries
- **Recycling & disposal** - While this is easier for mini-grids given their centralised storage compared to solar home systems, there is still a lack of options for end-of-life product management.

Some industry challenges are related to the lack of transparency from cell manufacturers. This makes it difficult to develop accurate physical models for these batteries. Furthermore, attracting talent with the skills for detailed battery modelling and related power electronics is also proving challenging.

Based upon Modularity Grid's experience, it can be inferred that the market would benefit from open protocols which separate the BMS from the batteries themselves. Through this, end users will not have to depend on manufacturer specific BMS solutions. Pack level BMS currently available are not fit for purpose and cell level analysis should be standardised. This will also enable a change in the physical building configuration. Moving away from cell – module – pack architecture to a cell – pack setup will be beneficial. At present, when a cell is faulty the entire module is typically replaced. This is both wasteful and expensive.

Support from Energy Catalyst during the project enabled the company to grow, moving from seed funding to preparing for a Series A financing round.

RFC Power

RFC Power is a start-up founded in 2018 comprised of a core team from Imperial College London. The company has developed a unique battery technology by combining fuel cell and flow battery concepts and offers cost and operational advantages such as higher power densities, very long lifecycles and highly competitive costs compared to existing technologies. The cathode side of the cell contains aqueous electrolyte while the anode uses hydrogen. A major advantage of this Manganese-Hydrogen Flow Battery technology is that unlike a fuel cell, the system does not need an ongoing supply of hydrogen. Hydrogen is produced during the charging cycle and used up during the discharge cycle. As such, it is a liquid-gas hybrid flow battery.

The technology is patented by Imperial College and RFC Power has obtained the rights to develop it. While the technology is still in its early stages, the Energy Catalyst project helped progress its maturity from a Technology Readiness Level (TRL) of 4 to a 6.

RFC Power was able to demonstrate the potential of the process on a 300 cm^2 reactor stack, up from a 5 cm^2 proof-of-concept device. The Energy Catalyst grant allowed it to validate the chemistry, increase the size as well as scale up by multi-stacking the reactors, which increases the power output.

This technology has enormous potential especially for developing markets as they will begin to build storage into renewable generation. As with many flow battery technologies, it aims to solve the long duration energy storage problem which is key to increasing the share of renewable energy on the grid through peak shifting.

Flow batteries are better suited to long term storage applications compared to Li-ion technologies since their power rating and storage capacity can be decoupled and scaled independently. RFC Power foresees a $10/kWh incremental cost of energy in large scale systems using their flow batteries. This would translate to a cost increase of only around 20% for every 3x increase in energy.

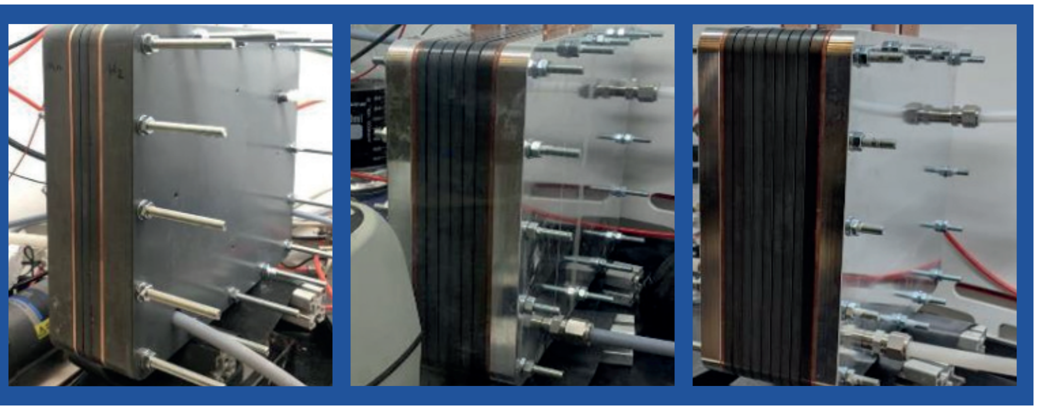
Cooling costs are a large source of inefficiency and operational costs for Li-ion batteries. However, RFC's technology performs well in even 50°C ambient temperature, making it better suited for warmer climates.

Finally, since many of the raw materials such asmanganese and platinum are distributed in geographies such as in South Africa, this also represents a more balanced supply chain reducing the need to rely on importing entire storage systems. RFC was able to develop a relationship with a South African supplier through the support provided by Energy Catalyst.

RFC's immediate challenges are to quickly demonstrate scaling potential and commercialise this technology. While the technology has a much lower cost of storage over its lifetime compared to Li-ion, it also needs to have a low upfront cost and a short return on investment period to be truly competitive. Hence cost reductions to compete with projected Li-ion costs are also an important objective.

RFC Power has experienced investor interest attracting both seed funding and subsequently equity from a technology partner, Ceres Power, with whom it has a joint development agreement to scale up technology for field trials.

Image: Stack design iteration of larger active area cells from 2 cell, 5 Cell and finally achieving 8 cell stack that can deliver 250W



Solveteq

Solveteq develops a solvent-based, low-temperature and low-pollution alternative to the industry standard process for recovering lead from used lead-acid batteries. It is a recent spin-out from Imperial College, operational since 2021 and funded through Energy Catalyst Round 8.

The company is exploring an alternative to the existing smelting-based recycling process which is a very energy intensive industrial process that is highly polluting, producing toxic lead fumes and dust. To avoid risks to human health and environmental contamination, smelting requires expensive pollution controls. The process followed by Solveteq dissolves the lead in "deep eutectic solvents"- next generation ionic liquids that are more environmentally friendly, more affordable, and easier to handle.

Lead recycling is a large industry, estimated at around $17 bn per year, accounting for just the lead value[10], although it does not get as much attention. Lead-acid batteries are very popular, and by virtue of being installed in every car and commercial vehicle (including the next generation EVs) for starting, lighting and ignition, they form a large total installed capacity. Large, centralised Li-ion systems are only just beginning to overtake lead-acid batteries' global installed share. Lead-acid batteries are among the most recycled products in the world, with about a 99% recycling rate, however, the recycling process is both energy intensive and polluting.

This is made worse in the informal sector, which can account for up to 50% of total recycling in low- and middle-income countries, where the smelting and recovery is both extremely toxic to both workers and the environment. A UNICEF report published in 2020[11] estimates that nearly 1 in 3 children in the world suffer from lead poisoning, finding that lead-acid battery recycling was one of the major contributors. Additionally, smelting requires temperatures of about 1000°C and produces carbon emissions both due to the energy used to achieve the high temperatures as well as due to the inherent chemical reactions of the smelting process. For comparison, the solvent-based approach can be used at temperatures as low as 50°C.

Lead-acid batteries are a mature and relatively simple energy storage technology and therefore very widespread. They will form a significant part of the future stationary storage technology mix and addressing their recycling challenges is crucial to energy access and energy security. Notably, lead-acid batteries have a functioning circular market economy given the important levels of recycling and repurchase by battery manufacturers. This is in stark contrast to the massive influx of Li-ion batteries for which most countries, including developed ones, do not have a comprehensive waste management plan. This situation is likely worse for developing countries which are often the target of many second life battery applications and therefore farther away from the manufacturer and country of origin.

Figure 5: The Lead-acid recycling process using deep eutectic solvents (DES)

Image: The Solveteq prototype in operation

As part of the Energy Catalyst project, Solveteq is currently working on improving the technology, after demonstrating its feasibility in the lab to a demonstration level (TRL 4 to TRL 6/7). In parallel, the company is working on the financial case and business model to make the eutectic solvent-based approach commercially competitive with existing processes so that even the informal sector will be drawn to its use. The formal sector is quite good with its recycling standards given that about 30% of the cost lies in environmental regulation compliance, in this context the main value proposition of the eutectic solvent-based approach is the potential cost savings.

One of the main challenges Solveteq face is public (and investor) perception and the lack of interest in this older technology versus Li-ion systems, which are perceived to be state-of-the-art and more appealing.

Advancements in incumbent technologies are often not seen as being innovative or forefront technology, which is a lost opportunity especially when it brings advantages in supply chain, consumer trust and experience in development settings. It is important for the sector to explore a multitude of different technologies depending on the needs, especially for developing markets. In addition, the lack of focus on end-of-life and waste management in the battery storage sector needs to change to highlight the true impact and benefits of different technologies.

In addition to this selection of companies, there are several other ventures working on innovative storage technologies including hydrogen, battery management systems, Li-ion repurposing, leasing business models for storage, battery rental, etc. Many of these are in the initial stages of their Energy Catalyst journey and will be able to report their project progress and results in late 2022.

Gravitricity

Gravitricity is an Edinburgh based company formed in 2011. It develops and aims to commercialise mechanical grid scale storage technology. The aim is to deploy this in vertical or near vertical underground shafts such as disused mineshafts. The technology is able to provide long term energy storage (>8 hrs) while also being able to respond to short term power needs such as grid balancing or frequency regulation.

Gravitricity was a part of Energy Catalyst Round 7, targeting a project in South Africa due to its abundantdisused mine shafts as well as challenges with continuous electricity supply and large demand for grid scale energy storage.

The company has successfully commissioned a concept demonstration system in the UK indicating a high technology readiness level for new project sites and aims to set up lighthouse projects in developing countries where existing disused mineshafts can be readily accessed to demonstrate this unique aspect of their value proposition. It emphasises that large-scale storage is more important in developing markets with weak grids, increasing renewable energy shares and few grid stabilisation systems compared to developed countries that typically have oversized grids and many existing grid response systems that can ensure power quality and reliability. A smarter, leaner approach towards building decentralised but connected grids with decentralised generation sources will require distributed energy storage as well. There is currently a dearth of long-life energy storage solutions to support peak shaving and load shifting as well as energy arbitrage which their systems will aim to address. In addition, mechanical storage can also support with more short-term power demand such as capacity firming especially for renewable energy plants.

While digitisation is an important aspect of making grids smarter and more efficient, it does not replace the massive amount of physical hardware that is required. A large amount of transmission and distribution cost savings can be achieved simply through lean sizing of new grids that consider distributed renewable generation coupled with energy storage. These cost savings are essential to maximising grid coverage in developing markets with limited resources and are especially important to enabling reliable electricity access. Hence affordable utility scale energy storage is in some ways one of the most important requirements for such markets.

One of Gravitricity's main challenges in the market is the narrow focus on Li-ion storage technology at the expense of other storage solutions. While Li-ion batteries are frontrunners in the space, they are often temporary stopgap measures that do not address the long-term strategic needs of the grid. Future grids will require a mix of different storage solutions that can offer longevity and affordability over longer time horizons. Gathering investor interest while having to evangelise such technology diversity is not easy. However, as the logistical challenges, supply chain bottlenecks, safety and recycling considerations for chemical batteries become more prevalent, the need for alternative energy storage technologies should become more apparent.

The role of energy storage in achieving SDG7: An innovation showcase

Learnings

Increased support is needed to get innovative energy storage technologies and business models commercially ready. This refers to commercial readiness even in developed markets that often have the financial, technical, and operational means to implement them. For energy access markets, a steep developmental curve needs to be traversed for energy storage systems to be implemented at scale. The knowledge gained from implementing such projects in developing countries can and will directly inform the development of these technologies in the UK and elsewhere and help benchmark those requirements. An iterative process involving assessment-development-deployment has already helped many projects that have been part of Energy Catalyst. Newer energy storage companies will also benefit from continued support if longer term projects can be identified that continually build upon intermediate developmental milestones.

Identifying business models for individual energy storage technologies is important since they differ vastly, and a one-size-fits-all approach does not work. While some energy storage technologies have high upfront costs, others are more maintenance heavy. Similarly, end-of-life can either represent costs or value depending on the specific use case. Hence the type of financing and financing structure will need to take those technology characteristics into account.

There is an urgent need for energy storage globally and across different applications. Energy storage is not just a technology sector that is poised to grow but rather a sector that is already growing and is currently underserved. Affordable technologies that are readily available are being used in applications for which they are not well suited due to a lack of alternatives, whilst commercial market mechanisms will not suffice to meet the demands of the developing economies' future energy paradigm. Hence there is a lot of room to support the deployment of energy storage technologies through market driven interventions such as blended finance, enabling partnerships, local capacity building, standardisation, norms and regulations, waste management, energy storage driven policy etc. For developing countries to truly adopt renewable energy and divert away from the fossil fuel-based growth pathway followed by OECD countries, exponential increase in energy storage capacity will have to be ensured. This will help reduce the development-related emissions that are projected to increase as these countries reduce their poverty levels by, in-part, increasing their per-capita energy consumption.

The role of energy storage in achieving SDG7: An innovation showcase

Conclusion

The companies working in energy storage and supported by Energy Catalyst are leading the market with innovative research and innovative project implementation. Apart from the breadth of technologies in the energy storage value chain that they represent (see section 3), they are also staggered across various levels of technical innovation and commercial readiness. They are working on development of storage technologies that are still concepts to early prototypes all the way to commercially ready solutions.

The host of storage projects in Energy Catalyst including those not profiled in this research tackle aspects such as cost reduction, affordability, energy access to those at the base-of-the-pyramid, battery management, better raw materials, long duration storage, waste management, second life repurposing, utility support, smart urban grids, and electric mobility. Some key areas of development that can best serve the energy storage companies and the market at large were identified through this research and are elaborated in the following section.

Where the sector should head

The companies working on energy storage have a diverse set of ideas on how best to develop the sector, both from an energy access but also from the developed markets perspective. The recommendations received from these companies are:

Promote multi-front development across technologies and look beyond Li-ion

Different storage technologies will all have a significant role to play in the overall energy mix. As such there is no clear winner. For less mature technologies, this can be done by enabling more partnerships, and seeding many more demo sites to enable policy and regulatory frameworks to be developed in local contexts. While lithium ion is understandably in the limelight at present, it is the right time to aim towards a more long-term change in thinking.

Identify service providers and industry partners

Manufacturing, engineering, and supply chain support is still lacking even in developed economies. Hence many companies are being forced to take on aspects of product development that are not their core competence. This problem is possibly amplified due to COVID 19 and the reduced number of trade fairs, exhibitions and industry symposia which are important opportunities for networking, identifying partnerships and exploring avenues for co-operation.

Work on an integrated vision of electricity grids of the future

The energy storage market is currently engaged in individual, opportunistic innovation and deployment rather than identifying future grid infrastructure needs, working backwards from there and supporting technologies that address specific needs that can be identified (such as storage duration, power/energy ratios, levelised costs, services, location, distributed vs centralised, geographical etc.). This requires looking 20-30 years into the future and accounting for a renewable energy based, decentralised, integrated generation+storage power infrastructure rather than ad-hoc centralised storage system deployments as is the case in developed grids.

Generate awareness for energy storage-specific business models

The increase in energy storage deployments which require large capital investments, long payback periods and provide supporting services which are harder to quantify compared to direct energy generation will need to be supported with appropriate revenue models. Most utilities, especially those in emerging markets, have not had to factor in ancillary service purchases as separate service providers and therefore lack the capacity and skills to develop appropriate regulatory policies that enable these markets locally.

Consider the entire life cycle of energy storage

It is paramount to think about the end-of-life, decommissioning and disposal challenges of energy storage technologies. Not only do many of these pose environmental and social hazards but also geopolitical challenges and natural resource constraints. Given the market is still at its initial stages of growth, this is an opportunity to build in a sustainability focus from the outset.

Endnotes

1 Energy Storage Grand Challenge: Energy Storage Market Report; U.S. Department of Energy; Dec 2020

2 https://about.bnef.com/blog/global-energy-storage-market-set-to-hit-one-terawatt-hour-by-2030/#_ftn1

3 https://about.bnef.com/blog/energy-storage-investments-boom-battery-costs-halve-next-decade/

4 Access to electricity – SDG7: Data and Projections – Analysis - IEA.

5 ESMAP. 2020. Deploying Storage for Power Systems in Developing Countries. World Bank.

6 https://www.vivideconomics.com/wp-content/uploads/2019/11/191025-Rapid-market-assessment-of-storage-in-developing-countries.pdf

7 https://blogs.scientificamerican.com/observations/how-a-key-energy-technology-can-help-developing-countries/

8 Closing the Loop on Energy Access in Africa, 2021, World Economic Forum

9 https://www.reuters.com/business/sustainable-business/inconvenient-truth-droughts-shrink-hydropower-pose-risk-global-push-clean-energy-2021-08-13/

10 https://www.reuters.com/world/china/start-ups-aim-change-car-battery-recycling-clean-up-worlds-most-polluting-2021-04-20/

11 https://www.unicef.org/rosa/press-releases/third-worlds-children-poisoned-lead-new-groundbreaking-analysis-says

ENERGY CATALYST