rehlko

Emerging Energy Storage Technologies

AUTHOR
Hakeem A. Dairo
Product Manager

INTRODUCTION

The adoption of renewable energy generation has accelerated in recent years, particularly solar and wind, and therefore the requirement to store generated energy is necessary to improve overall energy efficiency and capture excess energy. Multiple technologies exist to achieve these, including battery systems, capacitors, and a host of other storage technologies employing mechanical or thermal means of storing energy.

The growth in lithium-ion (li-ion) batteries is expected to continue to dominate the energy storage system (ESS) market globally over the next decade mostly due to reduced cost in the supply chain of this technology. This paper is intended to review some other energy storage technologies (by no means an exhaustive list) which are having an increased share of the stationary energy storage market aside li-ion batteries.

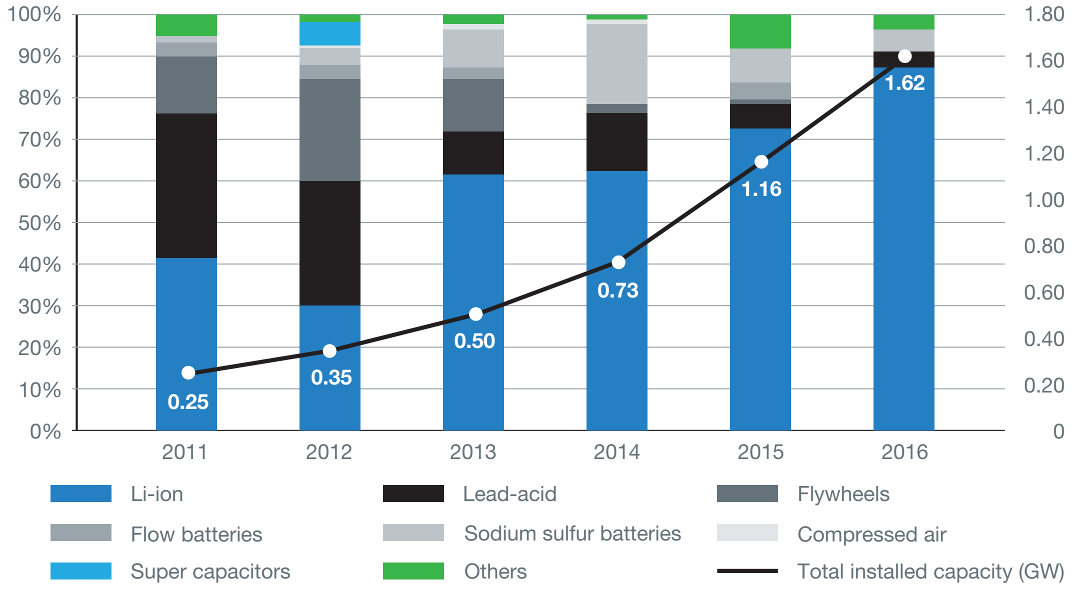
INTRODUCTION (CONT.)

Despite the strong outlook, even faster renewable energy development will be required to reach global net-zero targets by midcentury and keep global warming under 1.5˚C by 2100. Significant adoption and application of energy storage systems in the energy mix is key to reaching the levels of renewable energy penetration required to meet global warming targets.

The increased use of renewable energy generation has led to rapid growth in energy storage developments over the last couple of years and will continue to do so going forward, with both short- and long-duration energy storage systems being hugely essential to the green energy transition. *Figure 1* below highlights the energy storage technologies market share over a period of six years showing the huge installed capacity of lithium-ion (li-Ion) batteries compared to other storage technologies, and this trend has mostly continued to this day.

Figure 1

Energy storage share of li-ion in annual battery storage capacity additions globally*



*Data from IRENA (2019)

LONG DURATION VS. SHORT DURATION

LONG–DURATION ENERGY STORAGE

An important topic in the sector today is the role long–duration energy storage (LDES) systems play in the energy mix with most people accepting that one–four–hour discharge times are insufficient to maximize the efficiency and flexibility of renewable energy generation.

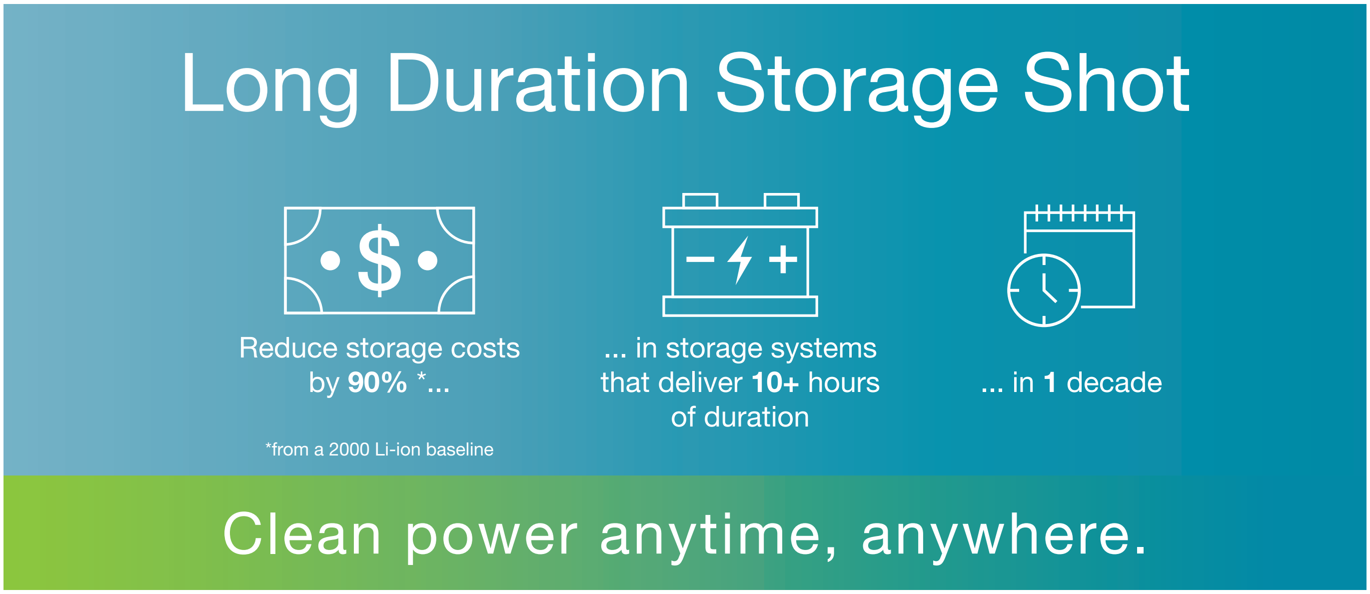
LDES systems can be classed as those having an energy output ranging from ten hours to days, weeks, and even seasons, providing enhanced grid reliability compared to short–duration energy storage systems. These systems have been with us for decades mostly in the form of pumped storage and hydro power systems. The cost, permissions, regulations, and environmental footprint/impact of these technologies has prevented widescale adoption.

REACHING GLOBAL NET–ZERO TARGETS

To reach global net–zero power sector targets, LDES must be scaled up by an estimated 400x from present–day levels to 85–140 TWh by 2040. This scale–up equates to a $1.5– $3.0 trillion investment opportunity [3]. Government interest in LDES is growing, including in countries like the U.S where in July 2021, the U.S. Department of Energy (DoE) announced an initiative called the Long Duration Storage Shot, which seeks to reduce costs for LDES by 90% by 2030.

In a net–zero world, up to 46 GWh of electricity storage is needed by 2035, with up to 24 GWh of LDES required to effectively manage the intermittency of renewable generation [3]. LDES have the potential to manage system constraints by reducing strain on the transmission network through locational balancing and to provide other system services, includingvoltage and stability control, required to meet security of supply objectives.

Figure 2



SHORT–DURATION ENERGY STORAGE SYSTEMS

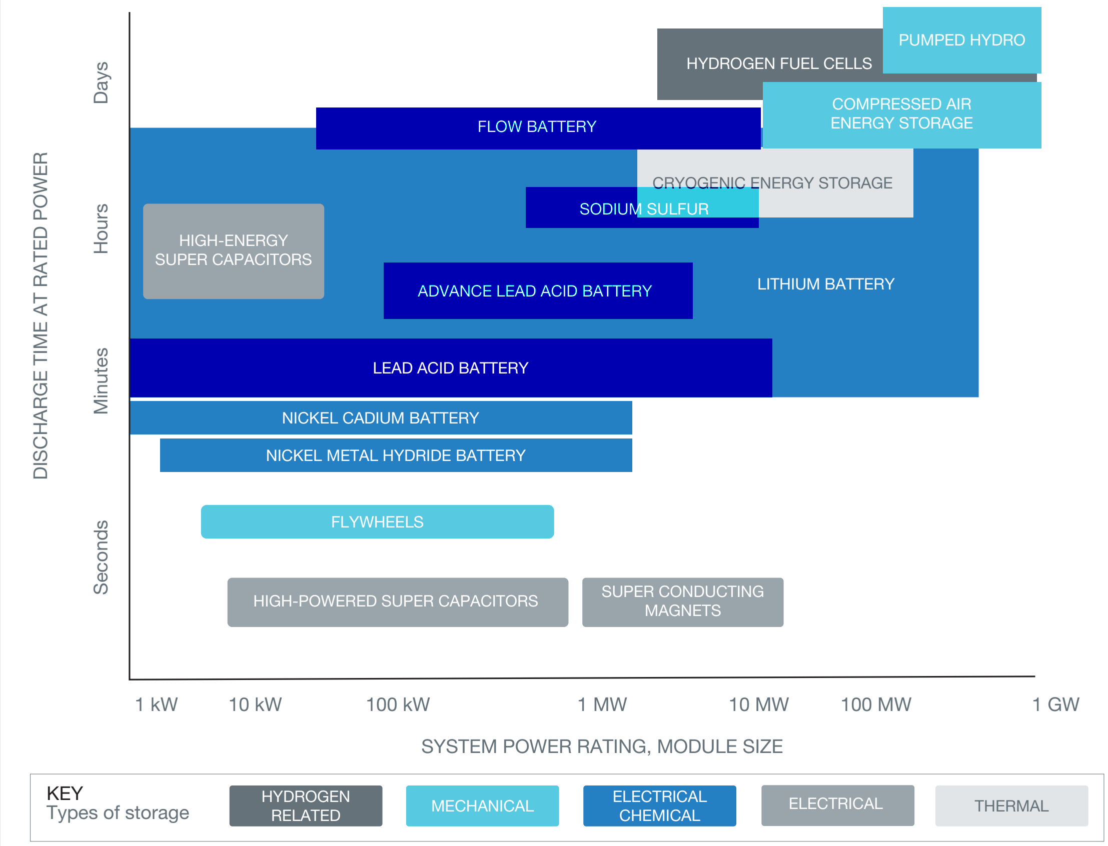
OUTPUT FROM SECONDS TO HOURS

Short-duration energy storage systems refer to the systems which have an energy output ranging from seconds to a couple of hours (varies depending on specific storage technology). These systems are used to provide a multitude of services to utilities and commercial and residential users. Frequency management, peak shaving and shifting, and reduced curtailment are major functions these systems support. Over 90% of installed energy storage capacity in the United States came from li-ion systems as of 2019, and this is not too dissimilar to the rest of the world.

See *Figure 3* to illustrate how different storage technologies compare in terms of storage capacity and power delivery.

Figure 3

Energy storage technologies power and time characteristics [4]



FLOW–BASED BATTERIES

PRINCIPLES AND POPULARITY

Flow–based batteries have increased in popularity in stationary application, despite the age of the technology.

These batteries work on the principle of flowing electrolyte through a set of electrochemical cells from one or more tanks. When the electrolyte makes contact with the electrodes, electricity is produced.

Typical flow battery chemistries use first row transition metals like vanadium (V), zinc (Zn), and iron (Fe) (e.g., iron–chromium, zinc–bromine, zinc–cerium, and zinc–ion). However, current commercial flow batteries are mostly vanadium– and zinc–based.

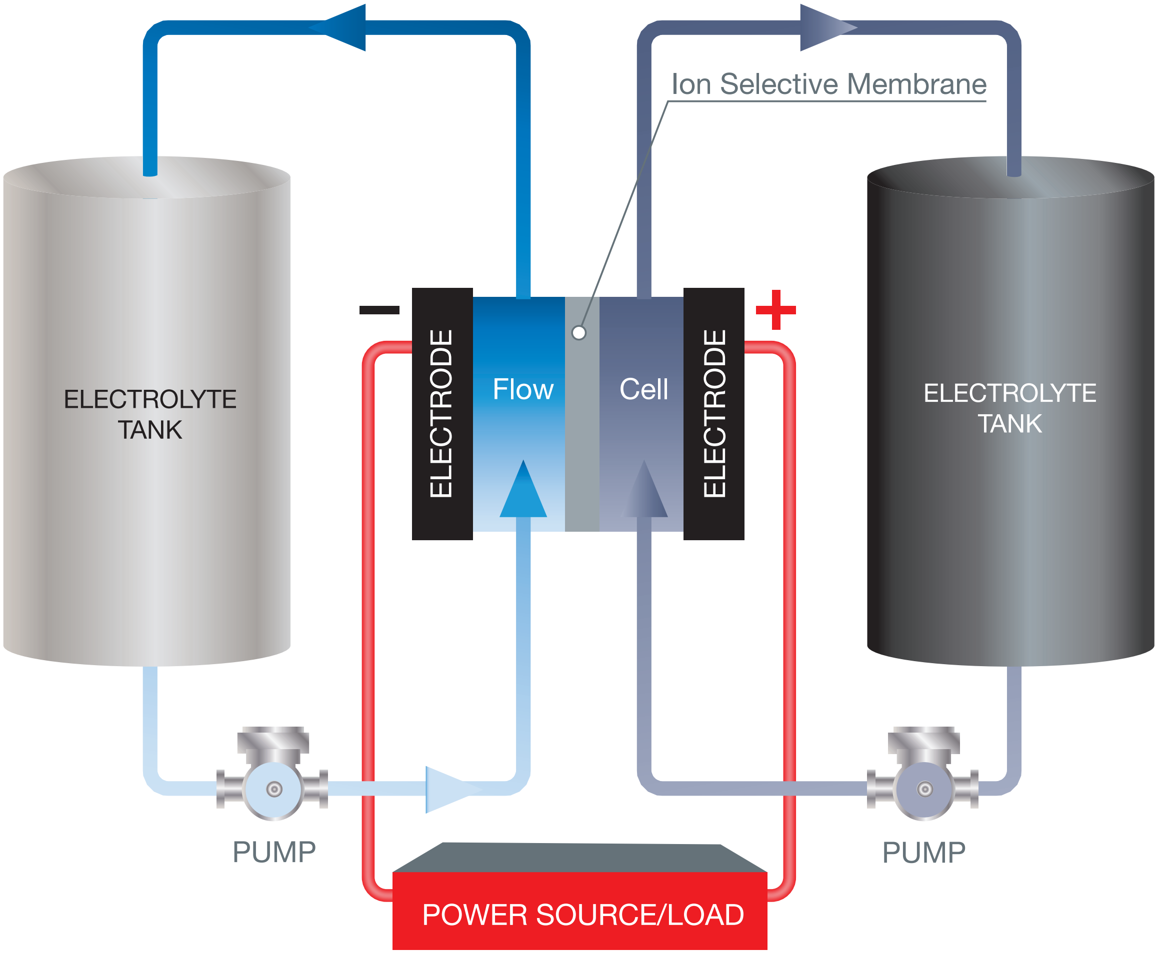
BENEFIT OF NO DEGRADATION

Flow–based systems have the benefit of no degradation, no thermal runaway risk, and improved cost over life of operation or levelized cost of system (LCOS). The lack of active material on the electrodes means there is minimal degradation and no fire risk, as the electrolyte is continually flowed through the system.

On the other hand, the relatively low gravimetric energy density of circa 10 Wh/kg compared to the more common li–Ion, as well as lower round–trip efficiency and higher $/kWh prove to be barriers for adoption of this technology. It is worth mentioning that there are generally three classes of flow batteries including redox, hybrid, and membraneless systems all of which alter the overall performance of the battery system.

Figure 4

Workings of a flow-based system



CAPACITORS (SUPER/ULTRA)

COMPLEMENTARY TECHNOLOGIES

Flow – The capacitor technology is one of the oldest storage devices that has been used across a very diverse range of industries. Batteries and capacitors can be seen as complementary technologies: batteries provide energy for the long term (being able to store for extended periods) while capacitors provide fast reaction and high power to deal with demand fluctuations.

Inside the capacitor, terminals connect to two metal plates separated by some sort of insulator or dielectric. In theory, the dielectric can be any nonconductive material. However, for practical applications, specific materials are used that best suit the capacitors' function. Mica, ceramic, cellulose, porcelain, Mylar, Teflon, and even air are some of the nonconductive materials used [6].

The dielectric employed dictates what kind of capacitor it is and for what it is best suited. Depending on the size and type of dielectric, some capacitors are better for high-frequency uses, while some are better for high-voltage applications.

CAPACITOR MANUFACTURING

Capacitors can be manufactured to serve any purpose from the smallest plastic capacitor in your cell phone to super and ultra capacitors that can power vehicles and support HV/EHV power requirements. The terms super and ultra are used interchangeably but in effect represent higher power applications compared to the traditional capacitor.

TECHNOLOGY APPLICATIONS

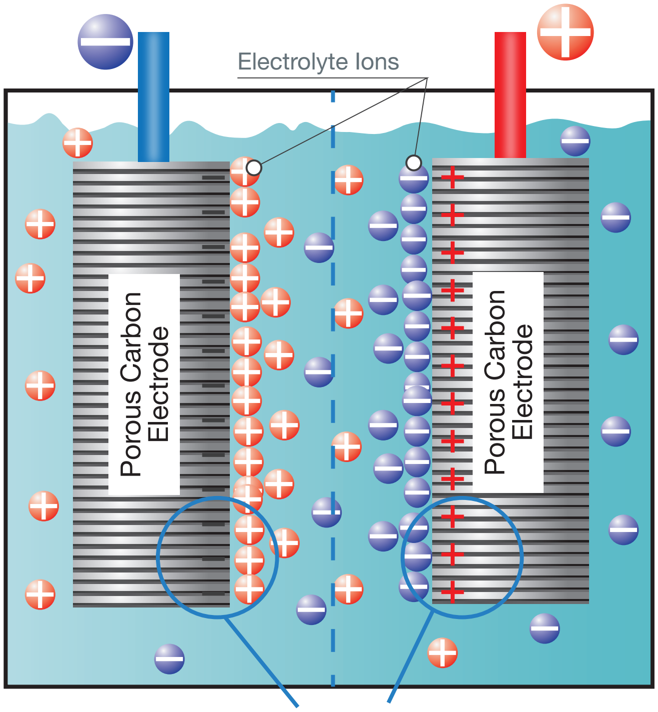
Capacitors – As alluded to earlier, capacitors are ideal for demanding environments that require high power and constant cycling, such as in hybrid electric vehicles. A good example are kinetic energy recovery systems (KERS), where braking energy is stored and reused for acceleration or lighting.

Capacitors fast reaction times are also ideal in environments that require a stable power quality, where even a tiny disturbance of a few microseconds in power quality can lead to damage in the system. Capacitors are able to protect equipment, infrastructure, and the wider grid with instant response.

Capacitors do, however, have a significant self-discharge characteristic meaning they cannot store energy for long periods of time.

Figure 5

Capacity Working[5]



Double-Layer Capacitors
(Adsorbed layers of ions and solvated ions)

AIR–BASED BATTERIES

Air–based batteries have about 3–30 times the theoretical energy density of li–ion batteries and are classed into aqueous and non–aqueous based on the nature of the anode employed. The anode can be an alkaline earth metal (magnesium, aluminum), first row transition metals (iron, zinc), or an alkali metal (lithium, sodium) with good electrochemical equivalence.

ZINC AIR

Out of all the air–based batteries, zinc–air batteries (ZABs) have gained the most mass adoption with the most popular applications for these being in the medical industry for hearing aids, button cells, and electric fences (generally longer duration of more than hours). They have the highest potential theoretical specific energy density (~1350 Wh/kg) among the non–air–cathode primary batteries, and one of the highest specific energy densities among the other metal–air battery systems [8]. They are used in extremely long–duration operations.

Figure 6: Schematic configuration of zinc–air batteries including the GDE structure, different candidate materials for cathode electrocatalysts and different forms of zinc anode material.

METAL-AIR BATTERY ASSEMBLY

Generally, metal–air batteries are assembled from a metal anode, a porous cathode (which permits continuous oxygen supply from the surrounding air), and an electrolyte solution.

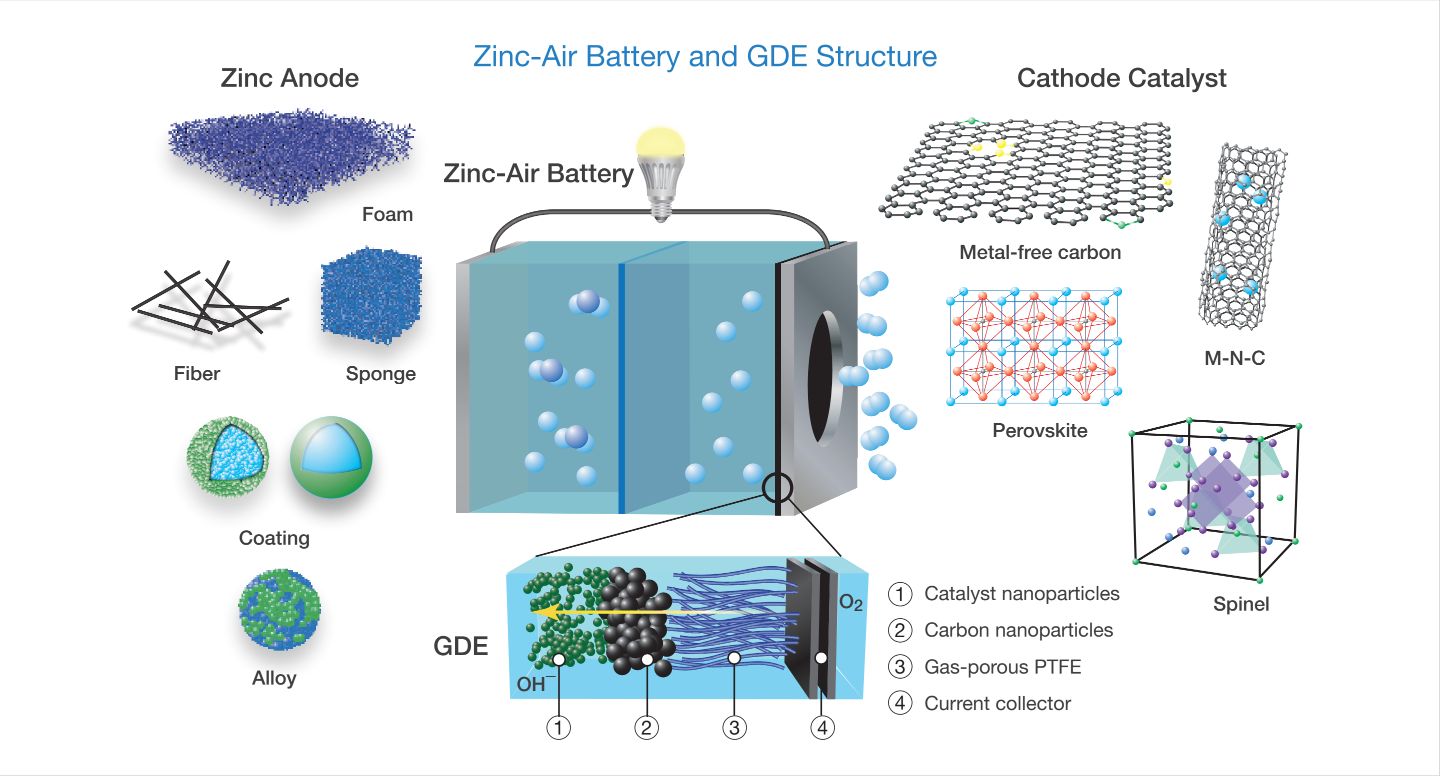
Zinc–air/oxide batteries utilize oxygen in the atmosphere as the positive active material, and accordingly, no positive active materials are necessary to be loaded. This enables the loading of additional negative active mass in the same volume, which can result in a longer service life. However, it must be installed with a catalytically active material on which oxygen gas is adsorbed and dissociated, ready to be reduced in the discharge reaction.

BIFUNCTIONAL OXYGEN ELECTROCATALYSTS

This is often realized using bifunctional oxygen electrocatalysts, or the combination of different oxidation reduction reaction (ORR) and oxygen evolution reaction (OER) electrocatalysts.

Due to the large ORR and OER overpotentials, rechargeable zinc–air batteries using state–of–the–art cathode electrocatalysts have a low round–trip energy efficiency of <65% under real working conditions which is significantly lower than ~90% seen in li–Ion batteries.

Figure 6



AIR–BASED BATTERIES (CONT.)

CYCLABILITY OF ZINC–AIR BATTERIES

Another challenge associated with zinc–air batteries (ZAB) is the poor cycling stability of the air cathodes as well as the cyclability of zinc anodes.

The harsh electrochemical environment during the OER in concentrated alkaline solution is severely detrimental to the ORR–active component by corroding the carbon support and leaching transition metals [8].

CURRENT COMMERCIAL FORM

Its current commercial form has undergone over a century of development, as its size and energy density characteristics have evolved according to the applications and needs of the consumer market where these systems are now seeing practical energy densities of 300–500 Wh/kg.

FLYWHEEL STORAGE

Flywheel energy storage (FES) has grown more popular in the last couple of years mostly due to improvements in the materials used to build them. FES is one of the most efficient technologies for storing electric energy and can bridge the gap between short–term ride–through power and long–term energy storage with excellent cyclic and load following characteristics [9].

CURRENT COMMERCIAL FORM

Its current commercial form has undergone over a century of development, as its size and energy density characteristics have evolved according to the applications and needs of the consumer market where these systems are now seeing practical energy densities of 300–500 Wh/kg.

KEY COMPONENTS

Figure 7: FES stores energy by constantly spinning a disk or the rotor of a flywheel which is in the form of kinetic energy. The key components of FES systems are a rotating cylinder, bearings, a generator or motor, and an enclosure to accommodate the flywheel.

Generally, when using high speed flywheels, the cylinder (rim) material choice affects the cost, performance, and mechanical characteristics of the flywheel. The choices typically available today are either carbon composites or solid steel. Composites are lighter and stronger and therefore can have much higher rotational speeds, which is desirable as energy stored is a function of the RPM. In turn, this option is much more expensive than the steel counterpart. Today 2 kW/6 kWh systems are being used in telecommunications applications. For utility–scale storage a "flywheel farm" approach can be used to store megawatts of electricity for applications needing minutes of discharge duration.

CHARGING PROCESS

The charging process requires high acceleration spinning of the rotor as it acquires the electrical energy given to the motor. This electrical energy is stored in the flywheel by keeping the body rotating at a constant speed. During the discharge process, i.e., when electrical energy is required, the disk rotates the shaft connected to the generator to produce electricity.

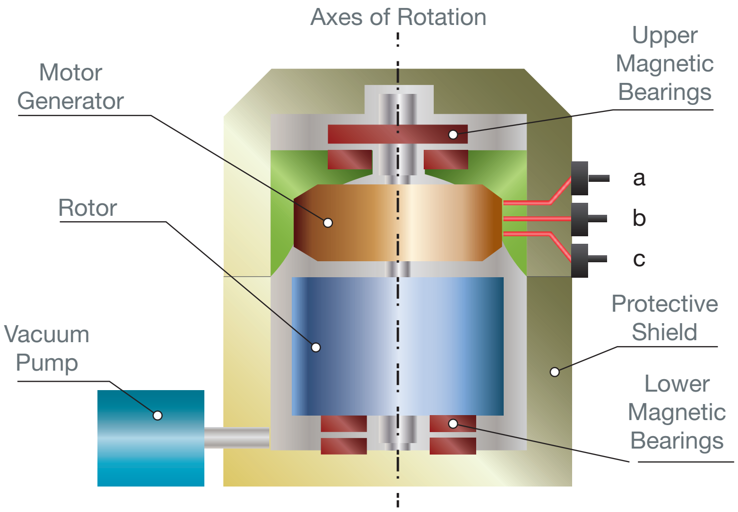
LIFE

An FES system comes with a relatively long life, low maintenance, and high–power density compared to electrochemical batteries.

The storage system can also operate under a wider range of temperatures and has no toxic impact on the environment. Design complexity and mechanical fatigue losses, as well as the short discharge time, are reasons the commercial adoption of these systems has been relatively slow.

Figure 7

Schematic of FES



COMPRESSED-AIR ENERGY STORAGE

Since the 1870s, compressed-air energy storage (CAES) systems have been deployed to provide effective, on-demand energy for cities and industries. While many smaller applications exist, the first utility-scale CAES system was put in place in the 1970s with over 290 MW nameplate capacity. CAES offers the potential for small-scale, on-site energy storage solutions as well as larger installations that can provide immense energy reserves for the grid [9].

CAES plants are very similar to pumped-hydro power plants in terms of their application. Instead of pumping water from a lower to an upper pond during periods of excess power, ambient air or another gas is compressed, and this pressurized gas is stored in an underground cavern or container. When electricity is required, the pressurized air is heated and expanded in an expansion turbine to drive a generator for power production.

COMPRESSION PROCESS

With compressed air storage, the air heats up when being compressed from atmospheric pressure to a storage pressure of approximately 70 bar. Standard multistage air compressors use inter- and after-coolers to reduce discharge temperatures to around 300/350°F (149/177°C), and cavern injection air temperature reduced to around 110/120°F (43/49°C).

GENERATED HEAT

The heat generated during compression can be extracted or removed through an intermediate cooler. The loss of this heat energy can then be compensated for during the expansion turbine power generation phase by heating the high-pressure air in combustors using natural gas.

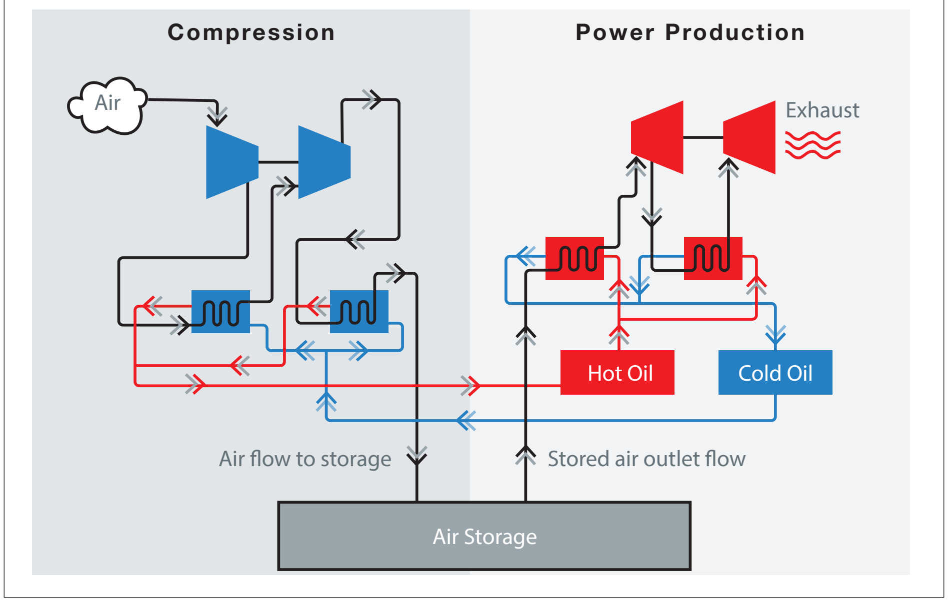
Alternatively, the heat of compression can be thermally stored before entering the cavern and used for adiabatic expansion, extracting heat from the thermal storage system.

This system can provide significant power at relatively low cost with quick ramp-up time, but the geology and site limitations mean it cannot be easily built.

Figure 8

Figure 8

Workings of CAES



CONCLUSION

Renewable energy sources, primarily wind and solar power, are set to account for most of the growth within the power sector over the coming years. But to take full advantage of this potential growth, we require reliable energy storage systems that can bolster energy grids already under pressure from increasing variability and climate change. We can expect investment opportunities to materialize across the energy storage and renewables sectors, including miners of critical minerals, manufacturers of energy storage system technologies, and renewables developers.

Choosing a storage solution for a given application can sometimes be obvious but other times more care must be taken to ensure the most effective solution is selected both from a cost and performance perspective. Longer-term, we also expect the potential that long-duration energy storage systems finally gain traction, accelerating in the sector, and delivering a significantly improved energy mix which minimizes emissions and facilitates the move toward net zero.

REFERENCES

1. International Energy Agency (IEA). (2021, December 1). Renewables 2021: Analysis and forecast to 2026. https://www.iea.org/reports/renewables-2021
2. IRENA (2019), Innovation landscape brief: Utility-scale batteries, International Renewable Energy Agency, Abu Dhabi.
3. Short- and Long-Duration Energy Storage Essential to the Clean Energy Transition: https://www.globalxetfs.com/short-and-long-duration-energy-storage-essential-to-the-clean-energy-transition/
4. TNEI Group. "Introduction to Energy Storage Systems" TNEIgroup.com, 2021.
5. Electrochemical capacitors: https://energystorage.org/why-energy-storage/technologies/electrochemical-capacitors/
6. What are ultracapacitors and supercapacitors: https://www.nanowerk.com/what-are-ultracapacitors-and-supercapacitors.php
7. Zinc–air batteries: are they ready for prime time?: https://pubs.rsc.org/en/content/articlelanding/2019/sc/c9sc04221k
8. Li, Yanguang, and Lu, Jun. 2017. "Metal-Air Batteries: Future Electrochemical Energy Storage of Choice?". United States: https://www.osti.gov/servlets/purl/1373737
9. Mechanical energy storage: https://energystorage.org/why-energy-storage/technologies/mechanical-energy-storage/
10. Top flow battery companies: https://wwwblackridgeresearch.com/blog/top-flow-

ABOUT THE AUTHOR

Hakeem A. Dairo works as a Product Manager responsible for energy storage technologies at Clarke Energy, a Rehlko company. Holding multiple engineering degrees across both the electrical and electromechanical fields, Dairo has spent over six years working with energy storage systems across both the automotive and energy sectors. His specialties include battery design, systems engineering, and product strategy.

ABOUT POWER SYSTEMS

Power Systems, Rehlko's largest division, delivers worldwide energy solutions designed to ensure resilience for mission-critical applications of all sizes. Building on more than a century of expertise and dedication, the company offers complete power systems, including industrial backup generators (HVO, diesel, gaseous), enclosures, hydrogen fuel cells systems, automatic transfer switches, switchgear, monitoring controls, genuine parts and end-to-end services. As a global company with service partners in every country, Power Systems provides reliable, cutting-edge technology to keep industries and businesses running.
www.powersystems.rehlko.com

ABOUT REHLKO

A global leader in energy resilience, Rehlko delivers innovative energy solutions critical to sustain and improve life across home energy, industrial energy systems, and powertrain technologies, by delivering control, resilience and innovation. Leveraging the strength of its portfolio of businesses – Power Systems, Home Energy, Uninterruptible Power, Clarke Energy, Heila Technologies, Curtis Instruments, and Engines, and more than a century of industry leadership, Rehlko builds resilience where and when the grid cannot, and goes beyond functional, individual recovery to create better lives and communities, and a more durable and reliable energy future.

rehlko

REHLKO.com