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Advanced Batteries: Outlook & Impact

Energy Industry Report

The Al-Attiyah Foundation

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INTRODUCTION

Advanced batteries are intended to reduce cost, weight and charging time, while increasing lifetime and safety. How do new technologies such as flow batteries, sodium ion and solid-state meet these criteria? Where are the key applications of different types? What are the main areas of future improvement and how would this advance the deployment of batteries?

ENERGY REPORT

This research paper is part of a 12-month series published by the Al-Attiyah Foundation every year. Each in-depth research paper focuses on a current energy topic that is of interest to the Foundation's members and partners. The 12 technical papers are distributed to members, partners, and universities, as well as made available on the Foundation's website.

- Batteries as storage systems have advantages over traditional energy storage systems (such as pumped hydro and compressed air energy storage (CAES)) as they cross-cut different sectors, have quite high round-trip efficiency, and can provide rapid, dispatchable, and cost-effective bursts of stored energy over a short time at high power levels.
- They can level electricity loads, save fuel, improve plant efficiency, reduce emissions, and reduce the mechanical wear on cycling units. They can also control reactive power, voltage, and power factors; reduce power and frequency oscillations; and reduce the need for new transmission capacity by storing electricity close to peak loads.
- Batteries can play a revolutionary role in the energy transition by helping meet the 'Leave No One Behind' agenda of the Sustainable Development Goals (SDGs), which are intertwined with climate goals. Small Island Developing States (SIDs) and climate vulnerable countries, particularly, can take advantage of advanced battery storage systems to make up for variable electricity produced by renewables through resilient storage technologies and supporting infrastructure.
- However, traditional and established battery technologies have various problems. These include the use of scarce materials; long charging times; limited energy density; unpredictable loss of battery life; sloping discharge curves; self-discharge over time; a limited number of charging and discharging cycles, with diminishing capacity; safety, toxicity and flammability; and the need for special operating conditions. Advanced batteries (ABs) may resolve some of these concerns.
- Solid-state batteries have become a new research hotspot of advanced batteries (ABs) for high safety and high energy-density batteries. Others include flow batteries, sodium-ion (Na-ion) batteries, and hydrogen / ammonia storage, which can potentially disrupt the business case for new projects, or for "peaking" services.
- The discovery of fast ionic conduction in solids and the possibility of solid electrolytes in place of liquid ones, the concept of the use of materials with insertion reactions as high-capacity electrodes, and the discovery of materials that can produce lithium-based batteries with unusually high voltages have led to innovation, both technological and chemical, in the development of advanced batteries.

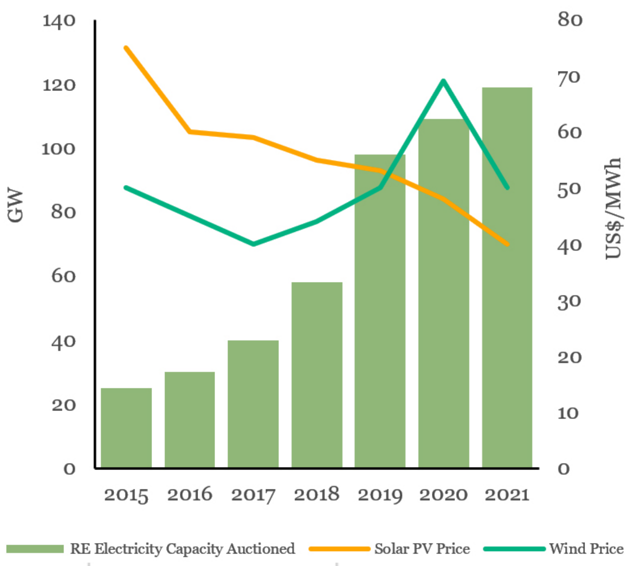
To overtake current battery technologies, ABs need to address factors including cost, environmental friendliness, toxicity, critical minerals requirements, recyclability, funding, manufacturing scale-up, and public perception.

- The three main challenges to the uptake of advanced batteries, when compared to traditional Li-ion or lead acid, are further reducing battery costs (both initial and life cycle), eliminating dependence on critical materials, and developing safe batteries that can be charged rapidly (in under 15 minutes).
- Governments and state-owned energy companies can fund high-reward/high-risk R&D endeavours in battery technology for both advanced mobility technologies and storage requirements to drive electrification and decarbonisation.

05 BATTERIES CAN COMPLEMENT TRADITIONAL ENERGY STORAGE TO MEET CLIMATE GOALS

2021 was a record year for global renewable energy deployment, despite the twin challenges of the pandemic-induced economic disruption, and rising costs of raw materials. The key enabler of the rise of renewable energy in power systems has been the declines in cost –for wind, solar photovoltaic, and other renewables, and most recently, battery storage technologies[i].

Figure 1 Renewable electricity auctioned capacity and costs for solar PV and wind, 2015-2021[ii]

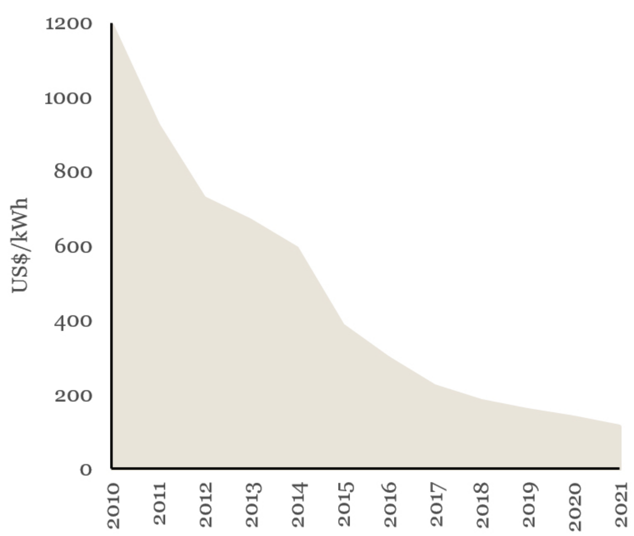


Although prices have risen in the short term, so have fossil fuel prices, and the trend of improving renewable and battery competitiveness is unlikely to reverse. The drive to decarbonise in the run-up to critical mid-century climate goals, including the Paris Agreement's 1.5°C global warming temperature limit and various net-zero emission goals, will continue to increase the share of variable renewable energy sources compared to fossil fuels across all sectors.

This puts the spotlight on energy storage as a balancing asset to provide grid resilience and flexibility to renewable power generation, and meet the high power, low storage, and frequent cyclability needs of heavy industry, commercial and industrial (C&I), construction, manufacturing, and the petrochemical sectors in their run-up to electrification. The transport sector already boasts a growing share of battery-run electric vehicles (EVs) that require high energy density, lower cost, and longer cycle life to be at par with traditional internal combustion engine (ICE) vehicles.

Meeting rising flexibility needs while decarbonising these sectors, therefore, is a central challenge of the energy transition. The use of energy storage in national networks for power is not new, but battery storage has emerged in recent years as a key piece of the decarbonisation puzzle.

Figure 2 Li-ion battery prices are nearing US$ 100/kWh (for 4-hour battery storage), volume-weighted average, all sectors (real 2020 dollars)[iii]



Batteries as storage systems have advantages over traditional energy storage forms as they cross-cut different sectors and can provide rapid, dispatchable, and cost-effective bursts of stored energy over a short time at high power levels. This makes them well-suited to the power, transport, C&I and heavy industry sectors.

BHowever, present-day batteries struggle with long-duration storage (days to months) because of their self-discharge and the high-capacity cost per unit of storage, which is even more problematic. For seasonal storage (e.g. storing summer-time solar power for winter heating), the economics of batteries are poor since they would only charge and discharge a few times per year. Batteries show sloping discharge curves: i.e., the voltage declines as the battery is discharged; the effective capacity drops as the battery is discharged more rapidly; and the effective capacity also falls when the battery is operated outside its optimal temperature range (too cold or too hot)[iv].

Traditional energy storage forms, on the other hand, are almost entirely suited to the power sector, and in particular the renewable power sector (Table 1). These include pumped hydro, thermal energy storage (TES), and compressed air energy storage (CAES) among others.

Batteries, therefore, provide unique advantages to both fossil fuel-based and renewables-based markets that conventional energy storage systems may not be able to.

Table 1 Conventional energy storage

Type	Advantages	Disadvantages	Applications	Status
Pumped hydro	• High storage capacity • High durability	• Low specific power • Typically requires suitable geography (either close to river or other reservoir) – which can be expensive and complex in challenging geology, although there are some engineered pumped hydro schemes, such as GHD's 250 MW Kidston Pumped Storage Hydro project at an abandoned gold mine, and others, like artificial islands, such as the proposed Green Power Island in Denmark[v] • Hydrological, economic, environmental and social concerns limit reach	• Energy balancing on hourly to seasonal time-frames	Mature
Compressed Air	• High storage capacity	• Relatively lower specific power • Low efficiency than batteries and flywheels • High capital costs • Risk water loss through evaporation	• Load-shifting • Power grid stability	Mature

Flywheels		• High efficiency • High energy density • High power density • Long cycle life • Suitable for fast response, short duration, and high cycle capability applications	• Expensive • Require more space than batteries and fuel cells • Safety concerns about flywheels rotating at high speeds • Short discharge time	• Uninterruptible power supplies (UPS) • EV applications • Isolated hybrid grid applications to increase RE penetration	Mature
Supercapacitors		• High specific power • Durability (cycle durability) • Lower cost • Simple charging and discharging circuit	• Low energy density • High self discharge rate	• Regenerative braking • Short-term energy storage • Burst-mode power delivery • Can efficiently and rapidly balance supply and demand in distributed energy systems supplemented by RE[vi]	Mature, but advancing
Thermal Storage	Sensible (water and rock, molten salt)	• Low cost • Driver of CSP • High storage efficiency • Non-flammability	• Dependent on properties of storage medium • Storage capacity can be limited by the specific heat of the medium • Require large volumes • Low energy density • Thermo-chemical TES is expensive and has barriers to market entry – requires cost improvements, stability of storage performance and materials properties	• Long-term storage • District heating / cooling • Building elements • Industrial applications	Mature
	Latent (water/ice and salt hydrates)	• High storage density • Minimal temperature change			
	Thermo-chemical	• Higher energy density • Lower heat losses • Compact systems			
Hydrogen		• Very high storage capacity • High energy density • High energy efficiency • Good volumetric capacity for chemical hydride and cryo-compressed storage systems	• High compression / liquefaction energy • Heat management required during charging • Safety concerns • Low volumetric densities for other storage systems, such as sorbent and carbon-based, metal hydrides	Balancing seasonal variations from RE generation Hydrogen fuel cells	Niche / pilot

One of the two leading forms of conventional energy storage – pumped hydro – has specific geographic and geological requirements, while the other, CAES, leads to an unwanted temperature increase that not only reduces operational efficiency but can also damage the energy storage system.

Batteries bypass this since they have no particular geographic or geologic requirement, and typically do not contribute to temperature increases in their external environment. They can be deployed at all scales from very small to large simply by combining additional units.

In markets characterised by conventional fossil fuel-based generation, batteries can level electricity loads by saving off-peak power for peak demand periods, thereby reducing the need for peak generation units, and ultimately delaying or bypassing the need for investment into new generation capacity altogether. They can reduce the need for spinning reserve[vii], save fuel, improve plant efficiency, reduce emissions, and reduce the mechanical wear on cycling units.

In markets characterised by a higher share of renewables, energy storage can provide significant improvements in power output and quality, by controlling reactive power, voltage, and power factors; by reducing power and frequency oscillations; by reducing the need for new transmission capacity by storing electricity close to peak loads; and by providing firming.

Transport systems based on stationary battery energy storage (BES) can also provide a solution for efficiently delivering smooth and predictable power for usage or back to the grid via "vehicle-to-grid" operation.

Batteries also provide the possibility of off-grid applications, such as providing power to remote settlements, agricultural farms, and military bases; islands without grid connections; energy site camps and installations; oilfield installations and pipelines; irrigation systems; telecommunication towers; and construction sites and labour camps. Low-cost, high energy-density batteries can enter new niches include long-distance trucking, and short-range aviation and shipping (some battery-powered ferries already operate in Scandinavia, and small electric passenger aircraft have been demonstrated).

In this way, they can play a revolutionary role in the energy transition by helping meet the 'Leave No One Behind' agenda of the Sustainable Development Goals (SDGs), which are intertwined with climate goals. Small Island Developing States (SIDs) and climate vulnerable countries, particularly, can take advantage of advanced battery storage systems to make up for variable electricity produced by renewables through resilient storage technologies and supporting infrastructure.

For example, renewable electricity generation from wind combined with energy storage in the form of ammonia and batteries has been demonstrated to be cost competitive with imported fossil fuels (such as LNG, coal, and oil) in the Caribbean island of Curaçao. Nickel-iron (Ni-Fe) batteries were used to store excess energy produced from wind turbines to stabilise energy output, and subsequently helped perform electrolysis to produce green ammonia when fully charged[viii].

These countries can also benefit from batteries for transportation needs, mainly through battery electric vehicles (BEVs) for remote and offsite locations or construction sites.

WHAT ARE THE DIFFERENT TYPES OF BATTERIES IN USE TODAY?

Energy storage has primarily been driven by R&D for EVs. Lithium-ion (Li-ion) batteries currently take up the majority of new energy storage capacity, installed and under construction. The dominance of Li-ion batteries (LIBs) can be attributed to their maturity, falling cost as well as the intricate understanding of associated commercial scale manufacturing processes for their cathode and anode materials (mainly nickel, manganese, and cobalt). Rising costs for some critical materials have been addressed by re-engineering them to use alternatives, sometimes at the cost of a reduction in performance.

Demand for LIBs for EVs and energy storage applications has seen exponential growth, increasing from 500 MWh in 2010 to 526 GWh in 2020[ix], and is poised to further grow 17-fold by 2030, bringing costs of storage well-under the US$ 100/kWh mark

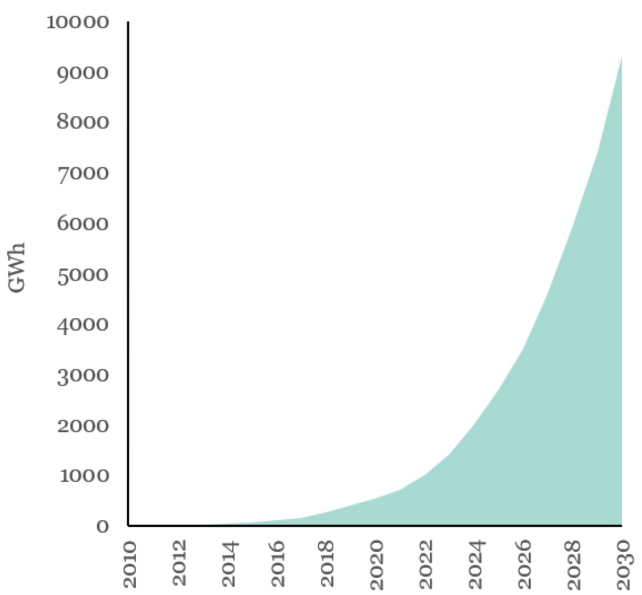
However, even though LIBs have enabled tremendous technological advancements, they are characterised by lower energy density compared to other secondary batteries representing electrochemical energy storage technologies (EES) (Figure 3), which could restrict their ability to meet growing demand, particularly beyond 2030.

Some workarounds include stacking LIBs in larger quantities for long duration applications, and increasing energy density from the current estimates of 100-265 Wh/kg to >300 Wh/kg by 2030 through persistent engineering optimisation of production methods, tooling, speeds, and efficiency.

Great effort has been focussed on alternative battery chemistries, such as lithium-sulphur (Li-S) batteries, nickel-related batteries, sodium-related batteries, zinc-related batteries, aluminium-related batteries, lithium-air batteries, and redox flow batteries, with R&D into Li-S batteries developing rapidly in the last five years due to their very high energy density and low-cost materials.

However, current Li-S batteries cannot be recharged enough times before they fail to make them commercially viable, and charging a Li-S battery causes dendrite build-up that degrades the cell and shortens its lifespan[xvii].

Figure 3 Cumulative Li-ion battery demand for electric vehicle / energy storage applications, GWh[x]



Other battery chemistries, such as sodium-sulphur (NaS) require very high operating temperatures to liquefy the sodium, which is difficult to operate and increases costs. These batteries also suffer from 'shuttling', a dynamic where the intermediate compounds formed from sulphur dissolve in the liquid electrolyte and migrate between the two electrodes of the battery. Shuttling leads to material loss, degradation of components, and dendrite formation[xiv].

Nickel-cadmium (Ni-Cd) batteries boast good specific energy and good pulse power performance, but are environmentally unfriendly. Cadmium is a toxic heavy metal, hence posing issues associated with the disposal of Ni-Cd batteries. These batteries also suffer from "memory effect", a dynamic where the batteries take full charge only after a series of full discharges[xv].

Table 2 Conventional battery technologies

Type	Advantages	Disadvantages	Applications	Status
Lead Acid	• Lowest self-discharge rate • Low capital costs • Technological maturity • High power output capability • Easily rechargeable • 97% of lead can be recycled • Can be used for both off-grid and on-grid storage applications	• Very heavy and large • Low specific energy, poor weight to energy ratio • Repeated deep cycling reduces battery life • Environmentally unfriendly	• Small scale storage (UPS) • Starting lighting and ignition power sources for automobiles • Lighting • Emergency lighting / power	Mature
Lithium-ion	• High specific energy • Rechargeable multiple times • Stable • High energy density, voltage capacity • Lower self-discharge rate • Suitable for stationary storage	• Short life cycle • Sensitive to high temperatures • Once completely discharged, can no longer be recharged • Relatively expensive to lead-acid and Ni-Cd • Fire concerns if separator gets damaged	• EVs • Critical equipment power: computers, communication technology, medical technology • Peaking capacity • Energy shifting • Ancillary services • Renewable power storage • Residential, C&I energy storage • Remote and off-grid applications	Advancing
Nickel-Cadmium	• Good specific energy • Good pulse power performance • Relatively tolerant of overcharging	• Environmentally unfriendly • Prone to memory effect	• Portable computers, drills, camcorders • Other small battery-operated devices requiring an even power discharge	Mature
Nickel Metal Hydride	• High specific energy • Generates high peak power • Less prone to memory effect • Simplified incorporation into products using Ni-Cd batteries due to design similarities • Can operate at temperatures as low as -20°C[xi]	• High self discharge rate • Lower efficiency	• Typically small battery-operated devices, such as electric razors, toothbrushes, cameras, camcorders, mobile phones, pagers, medical instruments/equipment	Mature
Sodium-sulphur	• High specific energy • Long cycle life • Fabricated from inexpensive materials • Time durability comparable with that of supercapacitor technology	• Cycle durability is low compared to supercapacitors • Operating temperature has to maintained between 300-350°C • Suffers from shuttling	• MW-scale NaS batteries have been used for load levelling, standby power sources and stabilising fluctuating power from renewable energy resources	Mature, but advancing

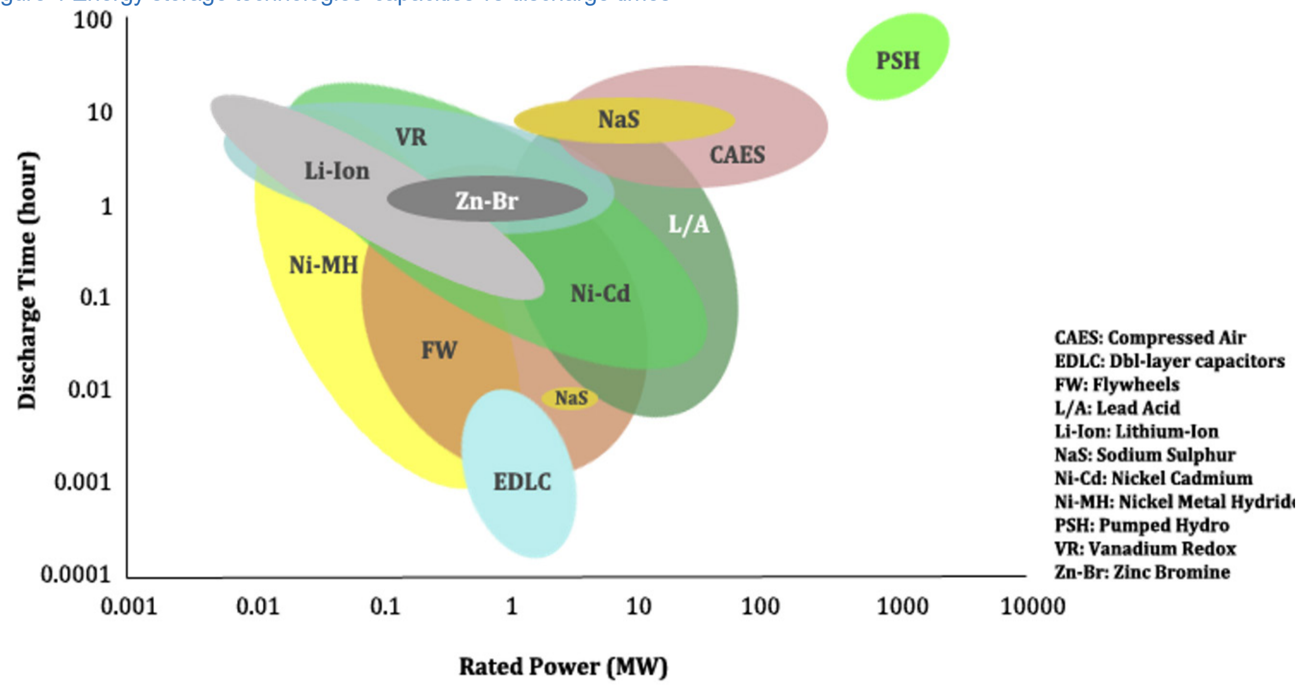
Others like zinc-bromine (Zn-Br) exhibit relatively high energy density, deep discharge capabilities and good reversibility, but suffer from relatively low cycle efficiencies. Although the high volubility of bromine allows for diffusion and direct reaction with the zinc electrode, potentially triggering a short-circuit of the cell, Zn-Br batteries perform well in applications requiring stationary energy storage, as they do away with the need for expensive cooling and maintenance systems. More importantly they don't catch fire, making them ideal for solar batteries due to slower charging times[xvi].

Still, their commercial uptake remains hindered by problems of material corrosion and dendrite formation.

Redox flow batteries (RFBs) are a different type of battery as their active material is in the form of two reduction-oxidation (redox) solutions that are stored in external tanks, and pumped through a stack of electrochemical cells, where the charge and discharge reactions take place at inert electrode surfaces. They boast of flexible modular design and operation, good scalability, moderate maintenance, and long-life cycling, but only for certain types, such as vanadium RFBs.

Zinc-based RFBs (ZRFBs) struggle with poor cycling life and unsatisfactory stability and energy density of the catholytes[xvii], while iron-based RFBs (known as an all-iron redox flow battery) are suspect to corrosion. Moreover, vanadium-based RFBs have concerns over the relatively high toxicity of oxides of vanadium, although the batteries are designed to contain any electrolyte spills. The balance of system costs for RFBs is also relatively high, along with the parasitic load needed to power the pumps for utility operations.

Figure 4 Energy storage technologies' capacities vs discharge times[xiii]



Lithium-air (Li-air) batteries are another type possessing significant potential for efficient energy storage applications, and have attracted a lot of research in the early 2000s due to their extremely high theoretical energy density, their highly specific surface area and porosity, their light weight, and a low cost of fabrication. They differ from other batteries as they can have non-aqueous, aqueous, and solid electrolytes, which can make them suitable for a variety of applications. For example, non-aqueous Li-air batteries are best suited for use in EVs. However, non-aqueous Li-air batteries still have critical issues to be addressed to realise the practical use for EVs, such as a low practical areal capacity, low round-trip energy efficiency, and air purification. The aqueous and solid lithium–air systems do not have the critical issues observed in the non-aqueous system; however, they have not shown capacity for high power density and extended deep cycling[xviii].

All of these batteries (with the possible exception of Ni-Cd which is quite mature, but continues being researched) can be considered advanced, but suffer from concerns about their safety, stability, and cycling life. A key reason is that they mostly all use liquid electrolytes which can be flammable and lend to toxic gassing.

From a supply chain perspective, NCM-based batteries also strain the world's supply of cobalt. Over 55% of global cobalt reserves are concentrated in the Democratic Republic of Congo, raising concerns of increasing constraints due to rising demands, as well as environmental, social and sustainability concerns associated with the mining process[xix], and the political risk of potential supply interruptions. Chinese companies have a high stake in Congolese cobalt mining, creating exposure for countries whose relations with China may deteriorate.

Solid-state batteries have therefore become a new research hotspot of advanced batteries (ABs) for high safety and high energy-density batteries, with solid-state LIBs (SSLIBs) taking the charge for change in liquid electrolyte-based batteries. They have the potential to improve almost all of the concerns with present day LIBs.

Other advanced batteries include flow batteries, such as the three mentioned above, sodium-ion (Na-ion) batteries, potentially zinc-air and aluminium-air batteries, and hydrogen / ammonia storage, which can potentially disrupt the business case for new projects, or for "peaking" services, particularly in natural-gas importing areas, or regions where new-build gas generation is no longer being pursued (such as California).

WHAT DIFFERENTIATES ADVANCED BATTERIES FROM OLDER TECHNOLOGIES?

Advanced batteries intend to overcome the challenges of more traditional energy storage systems and older stationary storage, particularly with respect to costs, weight, charging time, lifetime and safety. The discovery of fast ionic conduction in solids and the possibility of solid electrolytes in place of liquid ones, as mentioned above, the concept of the use of materials with insertion reactions as high-capacity electrodes, and the discovery of materials that can produce lithium-based batteries with unusually high voltages have led to innovation, both technological and chemical, in the development of advanced batteries.

Advancement in battery technology R&D can be categorised according to near-term, medium-term, and long-term requirements.

Table 3 Innovations in advanced battery R&D[XX]

Technological and chemical innovation in advanced batteries R&D
Metal hydrides
Lithium-carbon alloys
Intermetallic alloys
Lithium-transition metal oxides
Polymeric components, in both electrolytes and electrodes
Liquid electrodes
Crystalline and amorphous solid electrolytes
Organic solvent electrolytes
Mixed-conductor matrices
Protective solid electrolyte interfaces in organic electrolyte systems
Soft chemistry to produce non-equilibrium electrode compositions
New fabrication methods, cell shapes, sizes
Fabrication of lithium-based batteries in the discharged state

R&D into advanced battery technology in the near-term aims to improve the performance of existing conventional technologies for use within the next 2-3 years; in the medium-term to complete the development of those advanced battery technologies that are not commercialised, but, with necessary progress, can be introduced to the market within 5-10 years, and; in the long-term to develop new electrochemical technologies, such as refuellable batteries and fuel cells, which offer the potential of higher energy and power, but which require significant development before commercialistion.

Table 4 The main types of advanced batteries

Type	Description	Main Chemistries	Applications	Advantages
Advanced aqueous electrolyte system (Flow Batteries)	Flow batteries have the advantage of operating close to ambient temperatures, and can increase their energy output (kWh) without increasing their power output (kW), which cannot be done in Li-ion batteries, thereby saving significant cost on long-duration (multi-hour) applications.	Zinc-Bromine (Zn-Br)	• Stationary energy storage	• Good specific energy • Design flexibility • Low-cost battery stacks • Readily available materials • Conventional manufacturing • Complexed polybromide provides added safety benefit
		Redox batteries, mainly vanadium redox battery (VRB) and all- iron redox battery	• Large stationary energy storage (1 kWh – 10 MWh)	• Long cycle life • Design flexibility • Quick response times • No need for "equalisation charging" • Good safety as they do not contain flammable electrolytes and electrolytes can be stored away from the power stack • Iron is abundant and cheap
High-temperature system (including solid-state Batteries)	High-temperature battery systems operate in the range of 160-500°C, and have high-energy density and high specific power compared to most conventional ambient-temperature systems. Aqueous electrolytes cannot be used in these systems because of the chemical reactivity of water with the alkali metals. Molten salt or solid electrolytes are used instead, i.e. solid state.	Sodium-sulphur (NaS)	• Stationary energy storage • Proposed for space applications • Previously proposed for heavy transport and machinery	• High ionic conductivity, needed for high power density • Insensitivity to ambient temperature conditions • High efficiency charge / discharge • Long cycle life • Fabricated from inexpensive and non-toxic materials
		Glass Solid-State (alkali-metal anode of Li, Na, or K); solid state $LiFePO_4$	• EVs (Tesla has already switched all standard-range vehicles to $LiFePO_4$) • Heavy road transport and shipping • Aerial vehicles • Potential for space applications	• Very high energy density • Long cycle life • Non-combustible or resistant to self-ignition • Low risk of thermal runway • High design flexibility • High volumetric density • Increased energy conversion efficiency • $LiFePO_4$ particularly high safety, with a flat discharge curve

High-temperature system (including solid-state Batteries)	High-temperature battery systems operate in the range of 160-500°C, and have high-energy density and high specific power compared to most conventional ambient-temperature systems. Aqueous electrolytes cannot be used in these systems because of the chemical reactivity of water with the alkali metals. Molten salt or solid electrolytes are used instead, i.e. solid state.	Sodium-sulphur (NaS)	• Stationary energy storage • Proposed for space applications • Previously proposed for heavy transport and machinery	• High ionic conductivity, needed for high power density • Insensitivity to ambient temperature conditions • High efficiency charge / discharge • Long cycle life • Fabricated from inexpensive and non-toxic materials
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Ambient temperature lithium batteries	Different approaches are being undertaken to develop higher energy density Li-ion batteries with the cycle life required to maintain the high degree of safety needed in transport and storage applications. These consist mainly of solid inorganic intercalation materials, or solid polymer electrolytes in place of traditional aqueous electrolytes.	Varied, but can include manganese dioxide (MnO_2) as the positive electrode and an organic liquid electrolyte	• EVs • HEVs • Electric utility energy storage • Potential for space applications	• High energy density • Fast charging • High degree of freedom in shape • Long lifespan • Can withstand low to high temperatures
		Solid polymer Li-ion		

Advanced rechargeable batteries can be classified into three main types:

1. Advanced aqueous electrolyte systems, or flow batteries;
2. High-temperature systems, including solid-state batteries, and;
3. Ambient-temperature lithium batteries, including solid inorganic intercalation materials, or solid polymer electrolytes

WHAT FACTORS CAN SUPPORT THE UPTAKE OF ADVANCED BATTERIES?

Although advanced batteries address some of the concerns associated with older or traditional energy storage systems, they do not all address these concerns equally. To overtake current battery technologies and long-term energy storage solutions, they need to address not only costs, safety, and lifetime, but more importantly:

- Environmental friendliness
- Toxicity of metals used for solid polymers, and liquids for aqueous electrolytes, and their disposal
- Demand for critical minerals and/or rare earth elements
- Funding for continued R&D, scaling, and large-scale or several small-scale demonstration projects across multiple applications
- Public perception

Figure 5 Current and future demand for batteries in the consumer electronics sector under the IEA's Sustainable Development Scenario[xxii]

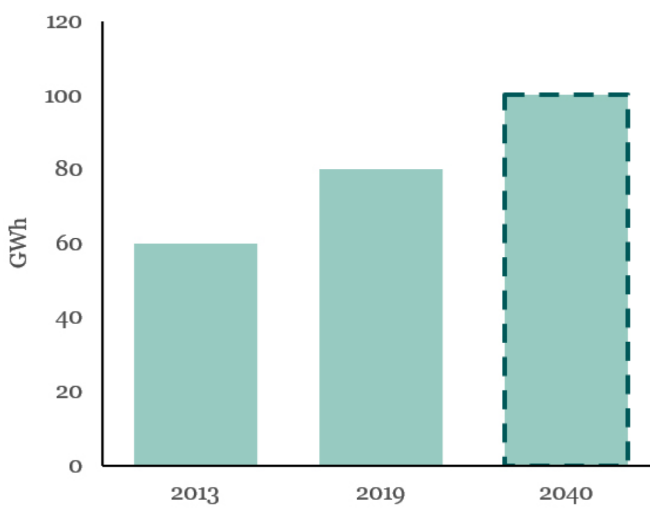


Figure 6 Current and future demand for batteries in the passenger EVs sector under the IEA's Sustainable Development Scenario[xxiii]

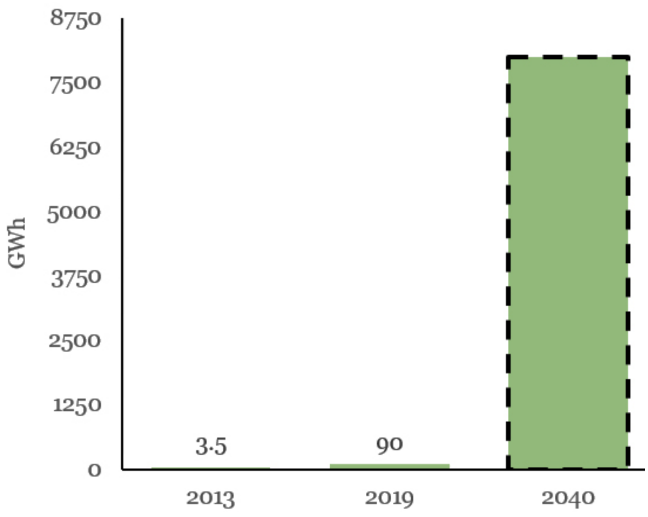


Figure 8 Current and future demand for batteries in the stationary storage sector under the IEA's Sustainable Development Scenario[xxv]

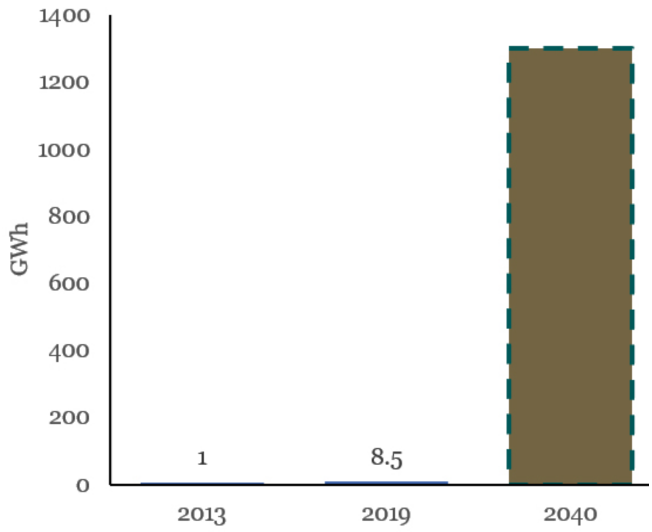


Figure 7 Current and future demand for batteries in the trucks, buses and other EVs sector under the IEA's Sustainable Development Scenario[xxiv]

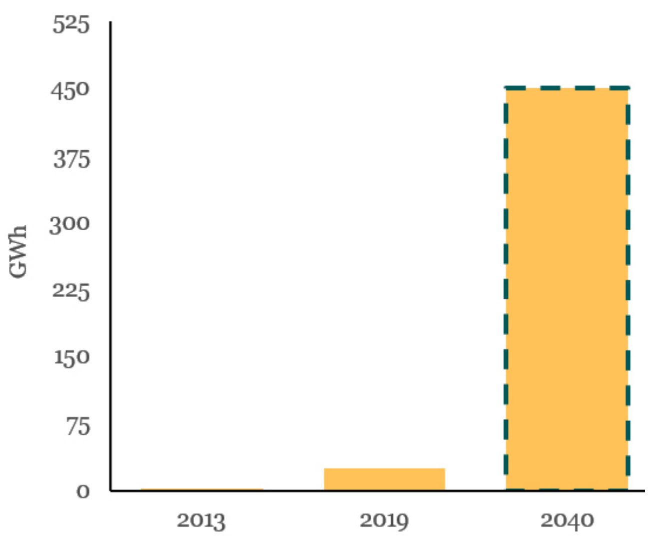
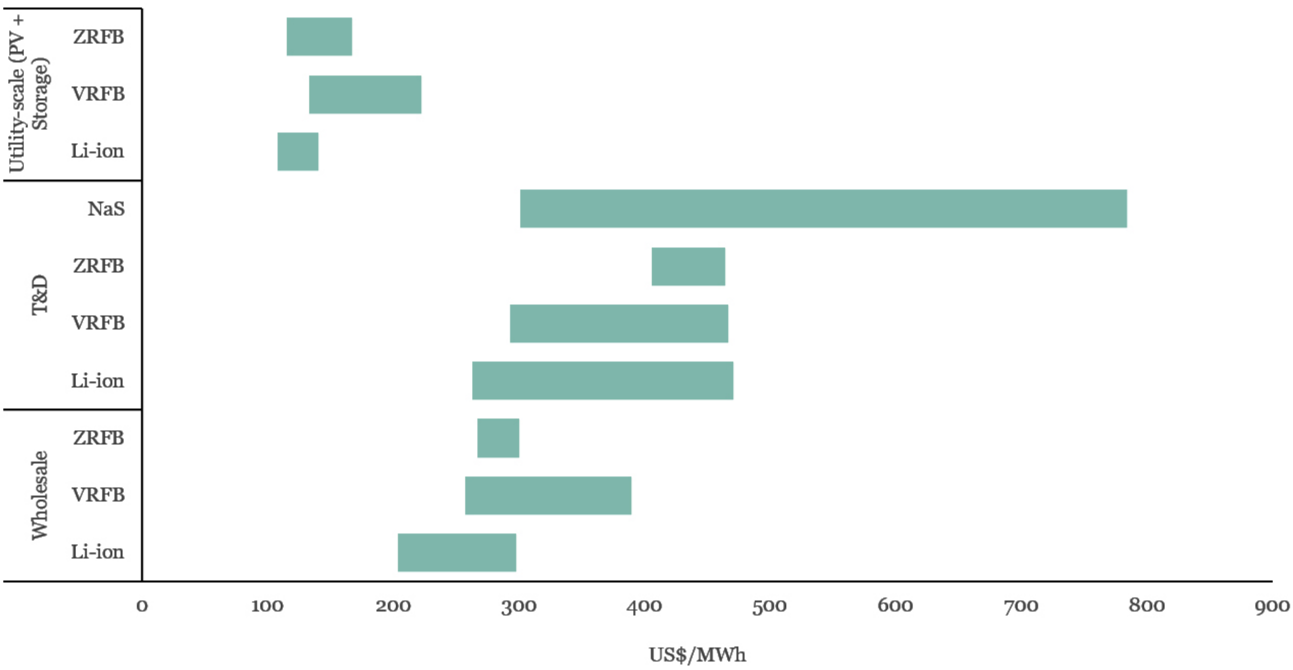


Table 5 Summary of key characteristics of advanced batteries

Factor	Li-ion	Vanadium Redox	Zinc Redox	NaS	Glass solid-state	Solid-state Li-ion
LCOE / LCOS	●	●●●	●●●	●●	●●●●	●●●●
Lifecycle	●●	●●●●	●●●●	●●●●	●●●●	●●●
Energy Density	●●●	●	●	●●	●●●●	●●●●
Charging Time	●●●	●	●	●●	●●●●	●●●●
Environmental Friendliness	●●	●●	●●●	●●●	●●●	●●●●
Toxicity & Waste Disposal	●●●	●●	●●●	●●	●●	●
REEs / CM demand	●●●●	●●●	●●	●●	●●●	●●●
Funding & Demonstration	●●●●	●●	●●	●●●	●	●
Public acceptance / perception	●●●	●	●	●●	●●	●●●

Key	Low	Medium	Medium-High	High
	●	●●	●●●	●●●●

Figure 9 LCOS comparison of various advanced batteries[xxvi]



These considerations will also determine whether advanced batteries can play the crucial role they need to in order to support the energy transition. Under the IEA's Sustainable Development Scenario, nearly 10,000 GWh of batteries will be required to meet demand across all sectors[xxi] (Figure 5, Figure 6, Figure 7, Figure 8). Advanced batteries will lead this race, overtaking all other storage technologies by 2040. Access to clean energy for mobility and electricity can become a reality to underserved populations if deployment rates for advanced batteries increase to meet those outlined in energy transition scenarios.

Figure 9 shows a comparison of the levelised costs of storage (LCOS) of some of the leading advanced batteries for in-front-of-the-meter applications. Energy storage systems designed to be paired with large solar PV facilities are led by li-ion battery technologies, which are the most cost-competitive compared to advanced flow batteries.

For T&D and wholesale applications (such as replacement of peaking gas turbine facilities, quickly meeting rapidly increasing demand for power at peak, quickly taken offline as power demand diminishes, or deferring T&D upgrades to provide flexible capacity and maintain grid stability), advanced flow batteries trump li-ion, although they have higher upfront capex costs.

Hydrogen could potentially reach competitive LCOS for grid applications, particularly when stored in depleted oil/gas fields, salt caverns, or as ammonia, costs for which range between US$ 0.97/kgH2 for salt cavern storage, to US$ 2.83/kgH2 for depleted fields, and US$ 3.79/kgH2 for ammonia[xxvii]. To balance daily supply and demand, hydrogen could be stored in pressurised containers, at an LCOS of US$ 1.19/kgH2, or as liquid hydrogen at US$ 6.65/kgH2, although liquid hydrogen would be better suited to applications requiring fewer cycles.

- Offshore and remote onshore oil and gas producers face two challenges in the near future: increased regulations on emissions, and the increasing costs of operations, particularly in challenging geologies.
- Hybrid power systems, enabled with Li-ion batteries featuring solid state electrolysers, can help address both these challenges better than traditional liquid electrolyte Li-ion batteries, by overcoming safety and technology qualification needs.
- Hybrid power systems enabled by solid state Li-ion batteries and/or other ambient temperature lithium-based batteries can help level out transient power loads for efficient urea management to reduce nitrogen oxide (NO2), sulphur oxides, and particulates emissions.
- E&P companies exploring deepwater assets are required to comply with stringent safety measures, meaning subsea equipment will require increased reliability by means of backup power and self-sustaining power systems[xxviii]. Advanced batteries with reasonable LCOE costs, long lifecycle, good environmental credentials, and solid electrolyte can be particularly suitable.
- Oil and gas operations may also have need for high power applications such as drilling or lifting, cranes or elevators, dynamic positioning, or actuation of valves and chokes, requiring batteries with high power, low storage, many cycles, and non-flammability. In addition, environments are less controlled, entailing large swings in temperature, speaking to the temperature resistance of solid-state batteries.
- With operators increasingly switching to renewables-enabled power for site operations, sustained performance and increased total energy output become critical to avoid variability and fluctuations. Solid-state batteries typically require lower maintenance, making them ideal for use in such environments, as well as in remote locations where a lack of infrastructure requires a reliable and efficient power source.
- Mission-critical facilities such as O&G data centres can benefit from alternate battery chemistries such as LiFePO4, which is one of the most durable lithium batteries, with high safety, a flat discharge curve, and high cycle life. It can also contribute to reduced footprint in offshore applications, compared to conventional lead-acid batteries.
- Advanced batteries could also help meet the UPS demand requirements of the oil industry (refineries, petrochemicals, offshore platforms, etc.). Current demand for UPS systems struggles to be met adequately due to lack of availability of fire-proof, hazard-ready UPS systems that can provide reliable backup in emergency outages.

CONCLUSIONS

Continuous R&D activity into battery technology will lead to further increases in cost reductions, lifecycle, safety, and charging requirements, making advanced battery tech an integral part of the energy transition. Governments and state-owned energy companies can fund high-reward/high-risk R&D endeavours in battery technology for both advanced mobility technologies and storage requirements to drive electrification and decarbonisation across their countries' economic sectors.

Cost reductions and safety improvements need to be coupled with environmental (ESG) considerations, and HAZID risks to achieve cost competitiveness. The three main challenges to the uptake of advanced batteries, when compared to traditional Li-ion or lead acid, are further reducing battery costs (both initial and life cycle), eliminating dependence on critical materials, and developing safe batteries that can be charged in under 15 minutes, particularly for applications that require short, immediate bursts of power, such as in the residential, commercial, industrial, construction, manufacturing, and petrochemical sectors. These applications may benefit from advanced lithium-based systems and solid-state batteries, while renewable energy storage appears to be a better fit for technologies like redox flow.

Advancements in battery tech also requires close cooperation and partnership with the automotive industry to increase the penetration of EVs in the transport sector, and further R&D into modifying battery chemistries for use in alternate sectors. Policymakers should work with technology and innovation centres to establish demonstration projects for batteries with significantly better environmental credentials and REEs requirements.

Funding for these projects can also lead to the development of new materials and manufacturing processes by using advanced material models, scientific diagnostic tools and techniques. Advancement in material performances, designs, and processes can propel the battery segment beyond Li-ion technologies to meet the energy transition successfully, yet how quickly remains to be seen.

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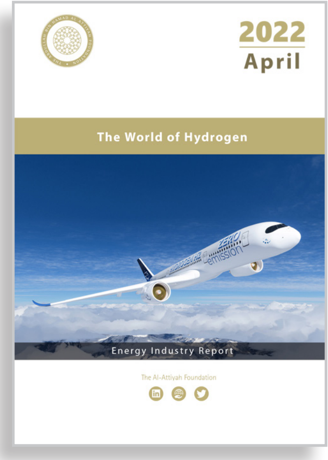

April – 2022

The World of Hydrogen

Hydrogen has emerged as an important fuel and energy carrier in the global race to tackle climate change and to reach net-zero emissions by mid-century. Global regulatory policies, technological developments, affordability, and scalability are converging to create an unprecedented drive for the expansion of the low carbon hydrogen economy.

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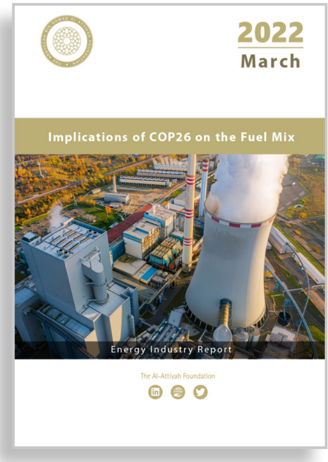

March – 2022

Implications of COP26 on the Fuel Mix

The outcomes from COP26 included major milestones such as the commitment to phase-down coal and fossil fuel financing, and the global pledge to reduce methane emissions by 30% by 2030. How will these pledges impact the sources of energy in the future?

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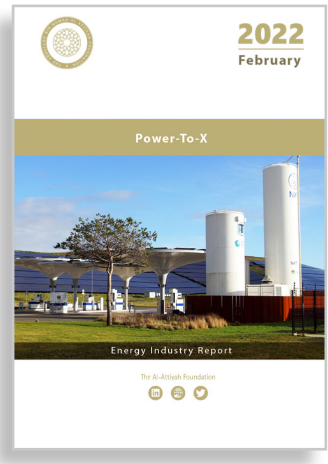

February – 2022

Power-To-X

'Power-to-X' is the concept of using electricity to produce useful fuels and chemicals from air, water and other basic inputs. Although hardly available today in a commercial manner, Power-to-X has gained interest for two main (and related) purposes: to convert excess renewables to a storable commodity, and to produce

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Our partners collaborate with The Al-Attiyah Foundation on various projects and research within the themes of energy and sustainable development.

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