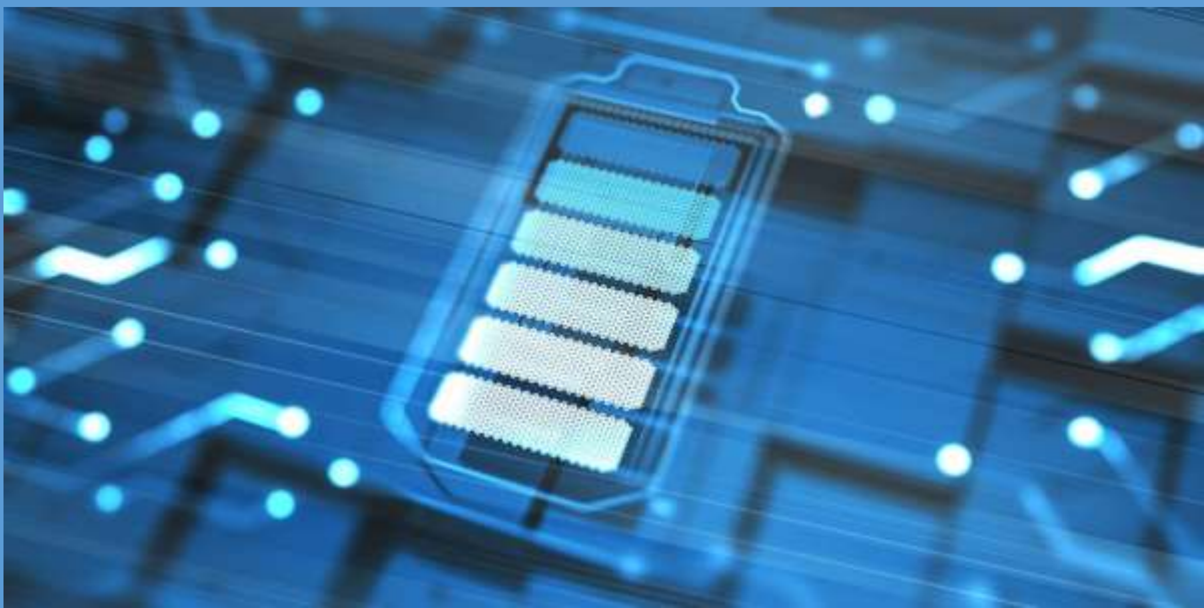
A SHORT GUIDE TO BATTERIES



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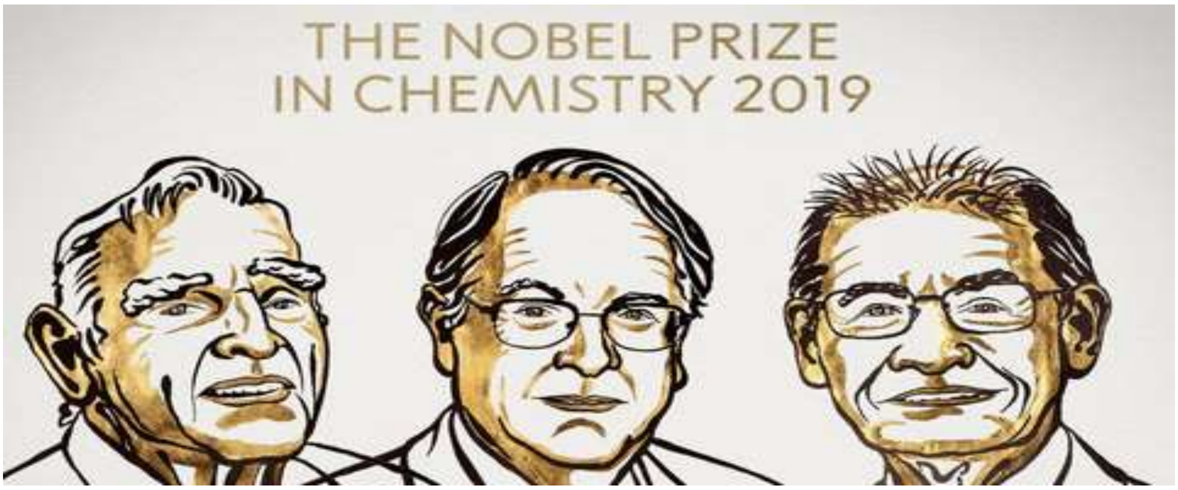
Why Battery Technology?

"This lightweight, rechargeable and powerful battery is now used in everything from mobile phones to laptops and electric vehicles," the Royal Swedish Academy of Sciences said on awarding the 2019 Nobel Chemistry Prize to John Goodenough of the US, Britain's Stanley Whittingham and Japan's Akira Yoshino for the invention of lithium-ion batteries [1].

These scientists rightfully deserved The Nobel Prize in Chemistry 2019 for the development of lithium-ion batteries because their invention have enabled the development of laptop computers, mobile phones, electric vehicles and the storage of energy generated by solar and wind power. In short, invention of lithium-ion batteries have accelerated our pathway towards modern, wireless, and fossil fuel-free society.



2019 Nobel Chemistry Prize laureates

What is a Battery Technology?

Even though the term battery is often used, but the fundamental electrochemical unit that is responsible for storing chemical energy and converting it to electricity is called Cell. Cells can be connected in series or in parallel depending on the kind of operating voltage (V), and the total ampere-hour (Ah) is required [4]. A cluster of cells make up a battery module and a cluster of battery modules make up a battery pack.

How Battery Technology works?

Main components of an electrochemical cell include; electrodes e.g. anode and cathode, and an electrolyte. The chemical reactions that occur inside a battery involve the flow of electrons from one material (electrode) to another, through an external circuit. To balance the flow of electrons, charged ions also flow through an electrolyte solution that is in contact with both electrodes. Nature and type of chemical reactions that are produced inside the cell depends primarily on the type of materials i.e. electrodes and electrolytes in the cell which determines how the battery works, how much energy it can store and its voltage [2].

For instance, most popular lithium-ion batteries use intercalation phenomenon (Figure 1). In lithium-ion batteries, electrodes are made of solid materials with atom-sized spaces in which charged ions can attach and an electrolyte is needed to enable migration of those charged ions back and forth between electrodes as the cell is charged and discharged.

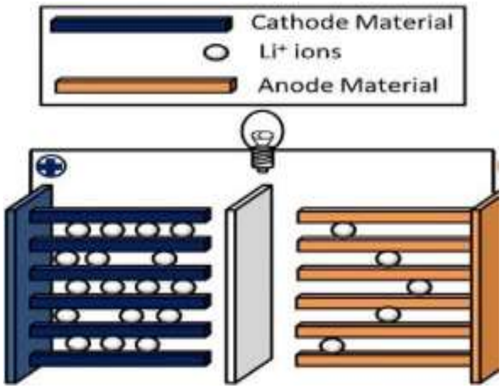


Fig. 1 Intercalation phenomenon of li-ion

Classification of Batteries

Basically, all battery types are classified into two major categories:

- Primary (non-rechargeable)
- Secondary (rechargeable)

In simple terms, primary batteries are non-rechargeable batteries i.e. they cannot be recharged electrically while the secondary batteries are rechargeable batteries i.e., they can be recharged electrically. For the purposes of this publication, we only focus on the Secondary Batteries that are rechargeable batteries.

Major types of Secondary Batteries

There could be many battery technologies that can fall under the category of secondary batteries but these are the major types of secondary batteries.

- Lead Acid Battery technology
- Nickel-based Batteries (i.e. Nickel–cadmium and Nickel–metal hydride battery)
- Lithium-ion batteries

Lead Acid Battery Technology

A lead acid battery (Figure 2) was the first rechargeable battery developed in late 1850's. Currently, a well-established and mature battery technology, therefore, one of the key advantages of lead acid battery over other battery technologies is that they are the most commonly used battery type for the most rechargeable battery applications (i.e. photovoltaics systems, Starting, lighting and ignition (SLI) applications for automotive sector).

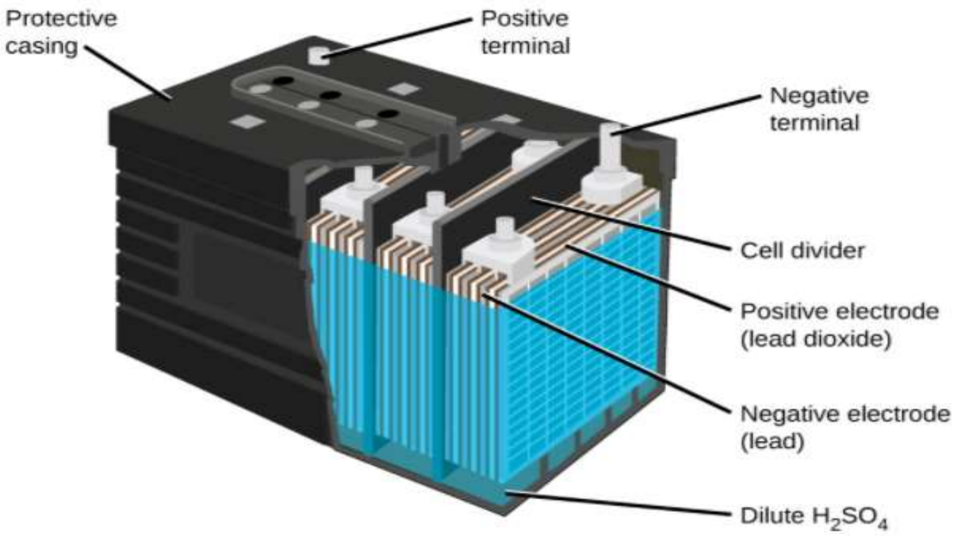


Fig. 2 Lead Acid Battery

The key features that have enabled the lead acid battery to become the most commonly used battery type for the most rechargeable battery applications include: low cost, and capability of producing the high current required by automobile starter motors.

On the other hand, the downside of lead acid battery is low energy density (35–40 Wh/kg), but despite having low energy density, low cost makes lead acid battery technology an ideal candidate for non-portable and large scale stationary storage applications where space is abundant and energy requirements are low [10].

The other key limitation of a lead acid battery is that their cycle life greatly depends on the operating temperatures. For instance, higher temperatures (35°C and up) cut lead-acid batteries' lifetime in half. The optimal operating temperature for lead acid battery which is around room temperature (20-25°C), if this optimal operating temperature is maintained then lead acid battery can last for two to five years [10].

Nickel-based Battery Technology

Two major batteries that fall under the umbrella of Nickel-based Batteries include: Nickel–cadmium and Nickel–metal hydride battery (Figure 3).

When nickel-cadmium battery was introduced in 1899, it was the only realistic competitor to the lead-acid battery. Key advantages of nickel-cadmium battery over lead acid battery included: improved energy density (40–60 Wh/kg), a high temperature range, higher recycle life with recharging 3 to 5 times more than lead acid, long shelf life, and less maintenance requirements.

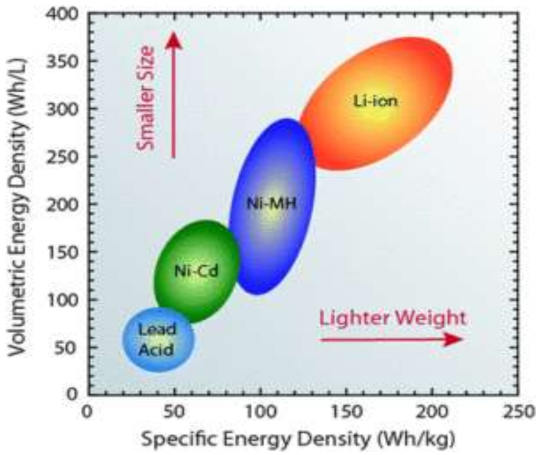
Fig. 3 Nickel–cadmium (L), Nickel–metal hydride battery (R)

Due to these advantages, portable devices e.g. power tools, medical equipment, and toys, relied almost exclusively on nickel-cadmium (NiCd) for 50 years. But in the 1990s, nickel-metal-hydride (NiMH) took over the reign to solve the toxicity problem of the otherwise robust NiCd.

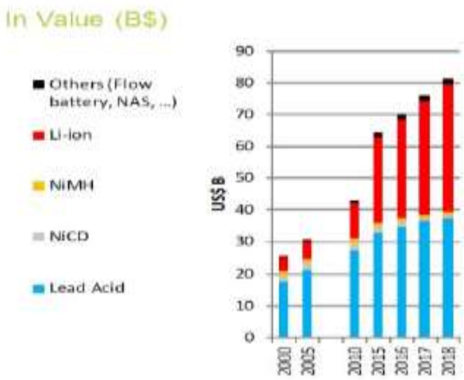
Generally, NiMH batteries are superior to NiCd batteries in three ways: NiMH use environmentally friendly chemistry than NiCd, NiMH can have higher capacities (60–120 Wh/kg) than NiCd, NiMH also suffer from memory effect explained below but not as bad as NiCd batteries [12].

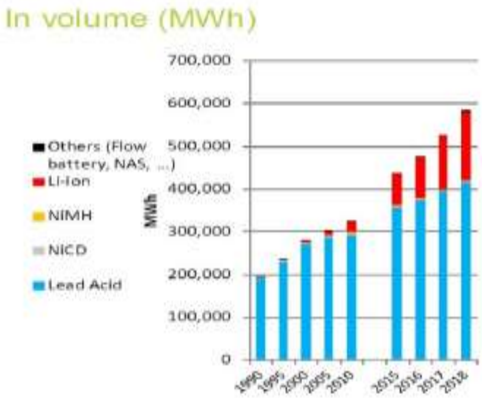
One of the key drawback of both of these battery technologies is that they have memory effect which means if they are recharged when not fully discharged. The battery appears to remember the previous energy delivered and once a routine has been established, it does not want to give more [12].

Li-ion Battery Technology



Lithium-ion batteries, commercialized in 1991, are the fastest growing battery technologies and currently dominating rechargeable battery market in value and, thanks to its explosive growing at compound annual growth rate (CAGR) of >15%, it is expected to break-even with such a well-established and mature battery technology as lead-acid also in volume in the near future.





How Lithium-ion batteries work?

All modern Li-ion batteries have two electrodes e.g. anode and cathode, and an electrolyte. Positive and negative electrodes are needed to host lithium ions while liquid based electrolyte is needed to enable migration of lithium ions back and forth between positive and negative electrodes as the cells are charged and discharged.

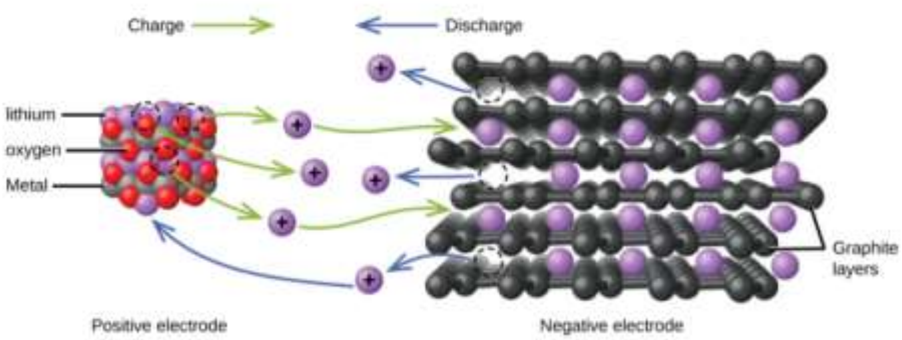


Fig. 4. Working principle of Li-ion batteries

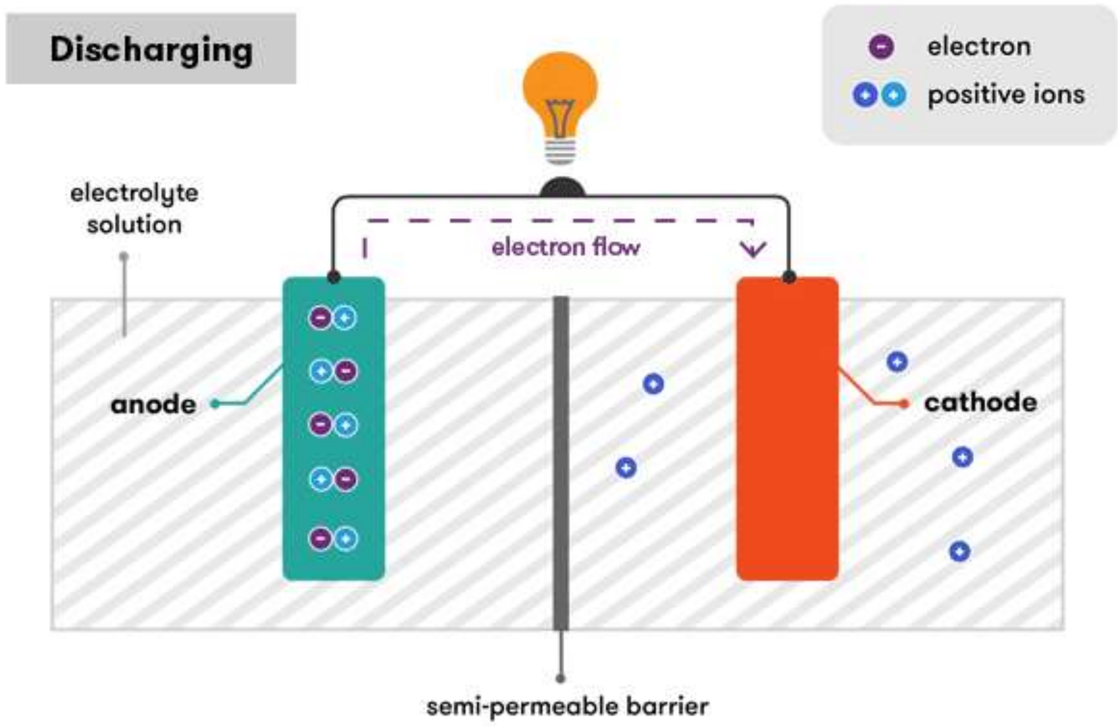


Fig. 5. Discharging mode of Li-ion batteries

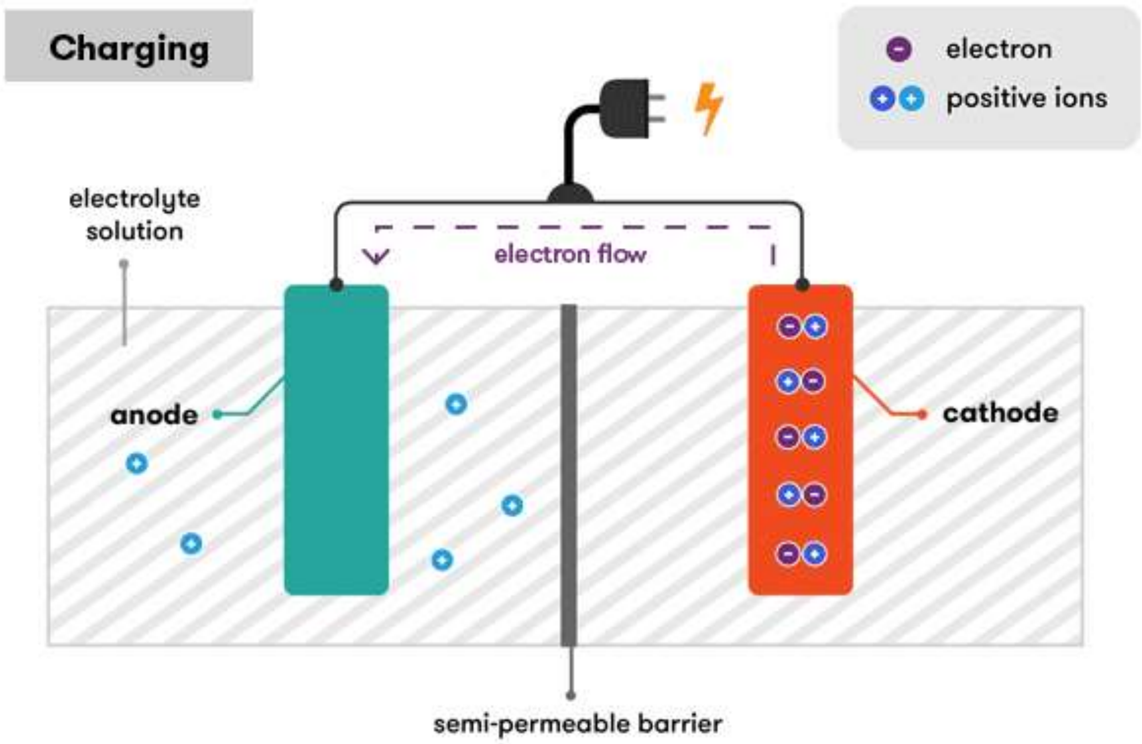


Fig. 6. Charging mode of Li-ion batteries

Why Lithium-Ion Battery dominating global battery market share?

Well-established and mature battery technologies i.e. lead-acid, Nickel–cadmium and Nickel–metal hydride battery are losing market share to Lithium-ion batteries for following reasons:

- Lithium-ion batteries have higher energy densities compared to others batteries
  - Lithium-ion batteries (100-265 Wh/kg or 250-670 Wh/L)
  - Lead-acid (35–40 Wh/kg)
  - Nickel–cadmium (40–60 Wh/kg)
  - Nickel–metal hydride battery (60–120 Wh/kg)

- Lithium-ion batteries are more powerful compared to others batteries
  - Li-ion battery cells can deliver up to 3.6 Volts i.e. 3 times higher than technologies such as Ni-Cd or Ni-MH.

- Lithium-ion batteries prices
  - Lithium-ion battery prices, which were above $1,100 per kilowatt-hour in 2010, have fallen 87% in real terms to $156/kWh in 2019, according to the latest forecast from research company BloombergNEF (BNEF) [14].

- Other important characteristics of Lithium-ion batteries
  - Long lifetime (i.e. as a rule of thumb Li-ion last for seven to twelve years).
  - Experiencing very low self-discharge rates (i.e. 1.5-2% per month).
  - Large choice of cell designs and battery chemistries.
  - Better cycling performances, typically thousands of charging/discharging cycles.
  - Highly scalable and it can be adapted to practically any voltage, power and energy requirement.

Is Lithium-ion a single battery type?

No, Li-ion battery technology is not a single battery type rather it covers wide range of chemistries mostly variations on the cathode side while anode most of the time made up of carbon material i.e. graphite, and organic liquid based electrolytes.

Following are the names of major Lithium-ion battery chemistries. Their names indicates the chemistry of cathode material.

- Lithium Cobalt Oxide($LiCoO_2$) — LCO
- Lithium Iron Phosphate($LiFePO_4$) — LFP
- Lithium Nickel Manganese Cobalt Oxide ($LiNiMnCoO_2$) — NMC
- Lithium Nickel Cobalt Aluminum Oxide ($LiNiCoAlO_2$) — NCA
- Lithium Manganese Oxide ($LiMn_2O_4$) — LMO
- Lithium Titanate (Li_2TiO_3) — LTO

Amongst Li-ion Battery Family: Who has a better future (i.e. Li-ion NMC vs LFP)?

Li-ion battery cells with high nickel content dominated the market during 2020 in terms of global market share (~80%), number of manufactures, and geographic diversity. However; several major manufactures in China increased LFP battery cell production capacity, increased energy density, retained very good longevity, retained low cost to produce advantage, passed standardized penetration & crush tests to verify superior safety, emphasized the advantages of eliminating all strategic metals from the formulation, and more aggressively advertised the outstanding safety record of LFP battery cells in avoiding fires [20].

There are several indications that LFP batteries will gain a sizable market share of the planned ~$25,000 EV market that is expected to emerge before 2025. Companies such as Tesla and Volkswagen are developing models and are considering LFP batteries for these lower cost EV markets. Tesla is already buying LFP batteries from CATL and Volkswagen has some ownership in Guoxuan, a recognized leader in high energy density LFP battery technology and manufacturing [20].

The demand for nickel rich Li-ion cells is rapidly increasing driven by several fast growth global markets. Based on market dynamics, the higher the price paid for refined nickel, the more incentive to buy and produce the lower cost LFP batteries. Many EV customers are willing to pay extra for the longer driving ranges made possible by using nickel rich cathodes. Powersports is another specialized market where high-energy and high-power densities is a customer priority [20].

Customers in different regions have different cost sensitivities, range expectations, and vehicle size preferences. The expanding use of LFP batteries in EVs will provide affordable and safe transportation as well as help reduce the risk of a shortage of nickel resulting in a rapid rise in pricing. Governments and consumer groups should encourage the growth of both cathode chemistries to optimize the many potential benefits of EVs [20].

Difficulties and challenges for Lithium-ion batteries

Cost reductions

Lithium-ion battery prices, which were above $1,100 per kilowatt-hour in 2010, have fallen 87% in real terms to $156/kWh in 2019, according to the latest forecast from research company BloombergNEF (BNEF) [14]. Even though Lithium-ion batteries have seen tremendous price reductions but still we are not yet at the point where battery costs could allow renewables with storage to be competitive with a fossil fuel alternative for grid application or allow EVs to be at cost parity with an ICE engine across.

For grid scale applications, some researchers have estimated that energy storage would have to cost $10 to $20/kWh for a wind-solar mix with storage to be competitive with a nuclear power plant providing baseload electricity. And competing with a natural gas peaker plant would require energy storage costs to fall to $5/kWh [8]. Therefore, Lithium-ion battery has a long way to go before hitting that price tag.

Improvements in performance

Despite the Li-ion batteries have high energy density (100-265 Wh/kg or 250-670 Wh/L) compared to other kinds of batteries, Li-ion batteries are still around a hundred times less energy dense than gasoline (which contains 12,700 Wh/kg by mass or 8760 Wh/L by volume). Therefore, there is a need to have Li-ion batteries have with even higher gravimetric and volumetric energy densities, i.e. up to 700 Wh/kg and 1400 Wh/l, which is possible by using high capacity electrode materials (i.e. use of Li metal anode or SiO_2 anode instead of graphite based anode) [16]. Improved gravimetric and volumetric energy densities would accelerate the wide scale adoption of Li-ion batteries for mobility and utility scale stationary storage applications.

PNNL is leading Battery500, a DOE-sponsored consortium that is developing higher energy lithium-metal batteries. The goal is to create a battery with a specific energy of 500 watt-hours per kilogram — about two-times more juice than today's EV batteries [15].

Improvements in Safety

Even though modern Li-ion batteries boast superior energy density and power density compared to various well-established and mature battery technologies such as e.g. lead-acid, Ni-Cd, Ni-MH, etc. Li-ion batteries have some inherent safety issues mainly due to the use of highly flammable organic liquid electrolytes. Due to this reason, Li-ion batteries have a tendency to overheat and in some cases this can lead to thermal runaway and combustion (i.e. notably the grounding of the Boeing 787 fleet after onboard battery fires). These organic liquid electrolytes also limit the possibility of using high voltage electrode materials because electrolytes can be damaged at high voltages [16]. One solution is to use solid electrolytes but that means other compromises. It's much harder to transfer anything from solids. Safer polymer or inorganic electrolytes could be a viable alternative to the high flammable organic liquid electrolytes currently used in Li-ion batteries.

Recyclability of Li-ion batteries

Industry analysts predict that by 2020, China alone will generate some 500,000 metric tons of used Lithium-ion batteries and that by 2030, the worldwide number will hit 2 million metric tons per year [18]. If current trends for handling these spent batteries hold, most of those batteries may end up in landfills even though Li-ion batteries can be recycled. These popular power packs contain valuable metals and other materials that can be recovered, processed, and reused. But very little recycling goes on today. In Australia, for example, only 2–3% of Li-ion batteries are collected and sent offshore for recycling, according to Naomi J. Boxall, an environmental scientist at Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO). The recycling rates in the European Union and the US—less than 5%—aren't much higher.

Definitely, there are many reasons and challenges why Li-ion battery recycling is not yet a universally well-established practice that includes technical constraints, economic barriers, logistic issues, and regulatory gaps. But opportunities always coexist with challenges.

Other challenges for Li-ion batteries

- Finding alternatives to scarce electrode materials to improve energy density and decrease the impact on the environment and society
- Implement self-healing mechanisms to improve battery life
- Develop more efficient manufacturing lines to decrease cost
- Convergence of synthesis, advance characterization, human insight and scientific machine learning technologies to accelerate the battery development process.

Can a single battery technology type fit all applications?

Simple answer is No. Because no two battery chemistries are same or will have the same characteristics. Nature and type of chemical reactions that are produced inside the cell depends primarily on the type of materials i.e. electrodes and electrolytes in the cell which determines how the battery works, how much energy it can store and its voltage [2]. Therefore, even different battery chemistries (i.e. Li-ion NMC vs LFP) within the Li-ion battery family can have completely different characteristics (i.e. energy density, voltage, round trip efficiency, number of charge/discharge cycles, depth of discharge, speed of charge/discharge, operating temperature). Therefore, it’s difficult to find one battery technology that can fit all applications. Because each application will have its own requirements. The selection of battery technology can be influence by many factors and priorities including customer’s energy and power density requirements, sensitivity to pricing, risk of physical damage during use, purchase volume, safety issues, climate of end use region, distribution options, government regulations & incentive programs, operational peak power demands, potential tariffs & trade quotas, etc.

For Outer Space applications: Metal-hydrogen battery has a 30-plus-year history of successful operation in Outer Space, metal-hydrogen battery has been used by NASA on space missions, including in the Hubble Space Telescope, the Mars Curiosity rover, and the International Space Station. For this kind of application you need a battery technology that could withstand the harsh climate of outer space, meaning super high temperatures, super low temperatures, and then have basically an infinite cycle life (i.e. 30,000 cycles) and require no maintenance even if you have to pay $20,000/kWh for this battery [19].

For mobility applications: Although there could be many factors companies need to account while deciding which battery technology to use in their electric vehicle; the two major factors are the cost and the energy density of the battery technology. Cost is important because battery cost makes up huge fraction of current electric vehicles in the market, therefore, further cost reductions in the battery technology (i.e. as per some estimates $80/kWh) can help electric vehicles reach price parity with internal combustion engine vehicles. In terms of energy density, a typical EV battery pack stores 10-100 kilowatt hours (kWh) of electricity. For example, the Mitsubishi i-MIEV has a battery capacity of 16 kWh and a range of 62 miles, and the Tesla model S has a battery capacity of 100 kWh and a range of 400 miles [17]. Therefore, further improving the energy density of these battery technologies can lower the cost of battery pack and also allow you to have more range of miles in the same kilowatt hours (kWh) of electricity battery pack.

For grid level energy storage applications: The cost is the single most important factor while talking about grid level energy storage applications because you need to install huge capacity ranging from around a few megawatt-hours (MWh) to hundreds of MWh. For grid scale applications, some researchers have estimated that energy storage would have to cost $10 to $20/kWh for a wind-solar mix with storage to be competitive with a nuclear power plant providing baseload electricity. And competing with a natural gas peaker plant would require energy storage costs to fall to $5/kWh [8]. Currently, prices of lithium-ion battery, the most popular candidate for grid level energy storage applications, are in the range of $150/kWh which still needs significant reductions for winning the grid level energy storage market.

Key Metrics for Battery storage Technologies

There are many metrics to consider when comparing different battery technologies such as:

- Energy density of a battery technology (i.e. Megawatt-hours MWh)
- Power rating of a battery (i.e. Megawatts MW)
- Round trip efficiency
- Number of charge/discharge cycles
- Depth of discharge
- Speed of charge/discharge

What is Post-Li and non-Li-ion Battery Technologies Future?

Firstly, It is clear that despite Li-ion batteries have improved the state-of-the-art battery storage technology and has many advantages over other battery technologies today but still Li-ion is not a clear winner in the race to power mobility and utility scale stationary storage applications. Therefore, there is a need to further improve Li-ion batteries and also develop other high performance batteries.

Secondly, need for a variety of fit-to-purpose batteries to satisfy the requirements of broad range of applications, and availability and price issues of Li-ion basic raw materials have stimulated the research interest and development of other types of batteries. Some of the promising post-Li and non-Li-ion battery technologies include:

- Solid-state batteries with Li metal anodes.
- Lithium-sulfur batteries (Li-S).
- Sodium-ion batteries (Na-ion).
- RedOx flow batteries, including these with organic shuttles (organic RedOx).
- Multivalent ion batteries, based on e.g. Mg2+, Zn2+, Ca2+ and Al3+, f).
- Metal-air batteries, including Li-air, Na-air, Mg-air, Al-air, Si-air, Fe-air and Zn-air.

It is good to see that there is a lot of interest in the research and development of future battery technologies. But the problem is that the commercialization of a battery storage technology is a slow process. For instance, it took 40 years to get the current lithium-ion batteries to the current state of technology. Most of these post-Li and non-Li-ion battery technologies are still in the lab scale and would take a lot of time before could compete with current lithium-ion batteries. It is clearly known in the battery circles that once you have a breakthrough in any battery technology, you need probably three years to set up high-volume manufacturing, and then you need another three years to do durability testing. So even if any of these post-Li and non-Li-ion battery technologies see some breakthrough today, it would be at least six years before they achieve any sort of high-volume production.

Solid State Battery Technology

The key difference between Li-ion batteries and solid-state batteries is that solid-state batteries replace organic liquid electrolytes of Li-ion batteries with Li-ion conducting solid electrolyte. On the electrodes side, solid state batteries can have conventional intercalation electrode materials, currently used in the conventional Li-ion batteries or can have completely new materials like thin layer of metal lithium serving as an anode.

Why Solid state batteries?

- Improved safety (no flammable, toxic or corrosive electrolyte present).
- Possibility to have higher gravimetric and volumetric energy densities, i.e. up to 700 Wh/kg and 1400 Wh/l (thanks to high specific capacity of Li metal anode).
- Ability to have a wider operating cell voltage window because many solid electrolytes are chemically more inert and more stable over a larger potential window, enabling also the use of high-voltage cathode materials).
- Higher power density (related to wider operating cell voltage window as well as to higher thermal conductivity) enabling fast charging.

- Broader operational temperature range, also due the ability to operate at elevated temperatures up to >100°C.
- Longer shelf life (low self-discharge rate)

Difficulties and Challenges of solid state batteries

- Finding a solid electrolyte that can exhibit sufficient conductivity for Li+ (at least >10-4 S/cm and better >10-3 S/cm), while being non-conductive electronically <10-12 S/cm (i.e. Li transference number as close as possible to 1).
- Finding a solid electrolyte that must be chemically and electrochemically stable in contact with Li metal and cathode materials in a broad range of operating temperatures and cell voltages.
- From the point of view of manufacturing, handling of metallic lithium poses great concerns.

On ground applications of solid state batteries

Bolloré is the only company who has introduced solid state batteries with lithium metal anode to the mobility market and stationary energy storage applications. Bolloré Li Metal Polymer (LMP) batteries use polymer based solid electrolyte, LiFePO4 (LFP) cathode. The use of LiFePO4 (LFP) cathode operating at a low voltage of 3.6 V explains why LMP battery has a relatively low energy density of 120 Wh/kg at the pack level and 240 Wh/kg at the cell. LMP battery also require higher temperatures i.e. 60-80°C to operate because of the limited ionic conductivity of polymer based solid electrolyte at room temperature. Therefore there is a need to find ways to incorporate high-capacity electrode materials with well-functioning solid state electrolytes to unlock full potential of solid state batteries.

How close are solid state batteries?

Solid state batteries definitely promise step change for batteries in terms of safety, improved energy densities, enabling faster charging rates. But in reality solid state batteries are not yet ready for the prime time because they have many engineering and manufacturing challenges that need to overcome before wide commercialisation of these batteries is possible. It is commonly agreed that a noticeable market uptake of the solid state batteries with lithium metal cannot be expected before 2030, especially in electrification of mobility and stationary energy.

Lithium-Sulfur Battery Technology (Li-S)

Lithium-sulfur (Li-S) battery technology is another interesting and promising battery technology. Lithium-sulfur (Li-S) battery technology use sulfur in the positive electrode and metallic lithium as the negative electrode.

The working principle of Lithium-sulfur (Li-S) battery technology is very complicated and somehow still under debate. Because unlike the conventional intercalation type electrode materials used in traditional Li-ion batteries, Lithium-sulfur (Li-S) battery technology use active materials that works via alloying and conversion reactions. This is complicated because unlike the materials intercalation reactions occurring with minor modifications of the crystal structure, the alloying and conversion reactions will completely reconstruct the crystal structure of the host material to form new phases.

In simple words, unlike Li-ion batteries, which need host structures for storing lithium ions during charge and discharge. Lithium-sulfur (Li-S) batteries need no host structures. While discharging, the lithium anode is consumed and sulfur transformed into a variety of chemical compounds; during charging, the reverse process takes place [6].

Why Lithium-sulfur (Li-S) battery technology?

- Low cost is the biggest advantage of Lithium-sulfur (Li-S) battery chemistry attributed to the price of sulfur and world wide availability particularly when comparing to other cathode materials.
- Li-S batteries can have a high gravimetric capacity (theoretical capacity of the sulfur cathode is 1,675 mAh/g).
- Environmental battery friendly compared to lithium-ion batteries as they do not require heavy metals such as cobalt and are free of critical raw materials.

Difficulties and Challenges of Lithium-sulfur (Li-S) battery technology

- Electrolytes are the central problem of Li-S batteries. As conventional electrolytes cannot be used, there is a need to find electrolytes that can fulfil the requirements for Li-S batteries.
- From the point of view of manufacturing, handling of metallic lithium poses great concerns.
- Sulfur as cathode material is non-electrically conductive, so it requires significant amounts of additives (typically carbon materials) up to 20-30wt.%, which reduces the amount of active material in the electrode.
- Big gaps in research and development to be addressed by academic researchers before advancing to industrial scale production.

- Insights into phase transformation, mechanical degradation, and SEI layer evolution are required for exploiting the full potential of Lithium-sulfur (Li-S) battery technology.

How close are Lithium-sulfur (Li-S) battery technology?

Saft, a French battery manufacturer, claims that major technical challenges for Lithium-sulfur (Li-S) battery technology have already been overcome and Lithium-sulfur (Li-S) battery technology quickly heading towards full scale prototypes. But if we are talking about applications requiring long battery life, we are at least 5 years away from making it happen.

Sodium-ion Battery Technology (Na-ion)

The sodium-ion battery works exactly similar to that of Li-ion batteries. The key difference between sodium-ion battery and Li-ion batteries is that In sodium-ion battery, instead of lithium ions, sodium ions (Na^+) ions are stored in active materials acting as stable host structures (known as cathode and anode) during charge and discharge.

The cell design of Na-ion batteries is also similar to that of Li-ion – in short, the cell is composed of a cathode containing a sodium compound and an anode able to accept the sodium atom. Despite many chemical similarities of Li^+ and Na^+ ions, the latter one has a larger ion radius, causing that graphite, the dominant active anode material in Li-ion batteries cannot be used in Na-ion chemistry due to a very low Na^+ ion storage capacity [6].

Why Sodium-ion battery Technology?

- Sodium is a cheaper alternative to lithium and the sixth most abundant element on the planet (security of future supplies).
- Sodium-ion batteries can significantly lower battery technology cost.
- Generally, Na-ion batteries are considered environmentally friendly because they do not contain elements like Co, Ni, Mn, Cu, and Li.

Difficulties and Challenges of Sodium-ion battery Technology

- Development of suitable active materials (i.e. electrodes, electrolytes)

How close are Sodium-ion battery Technology?

The technology readiness level of Na-ion batteries depends on the development of active materials, cell designs and validation of manufacturing processes. It is still in the learning phase. Commercialising sodium-ion batteries is expected to begin in the next five to 10 years.

RedOx flow Battery Technology

Redox flow batteries consist of two tanks of liquid commonly called electrolytes or working fluids. When pumped into a chemical reactor, chemical energy of working fluids is converted into electrical energy through reversible oxidation and reductions reactions back and forth during charging and discharging [6].

Redox Flow batteries offer a variety of benefits. The most singular advantage redox flow batteries have other battery technology is the architecture of redox flow batteries that allow decoupling of energy rating and power rating which means that power and energy capacity of the system can be scaled independently from each other by separate sizing of the tank volume and the cell stacks (reaction cells).

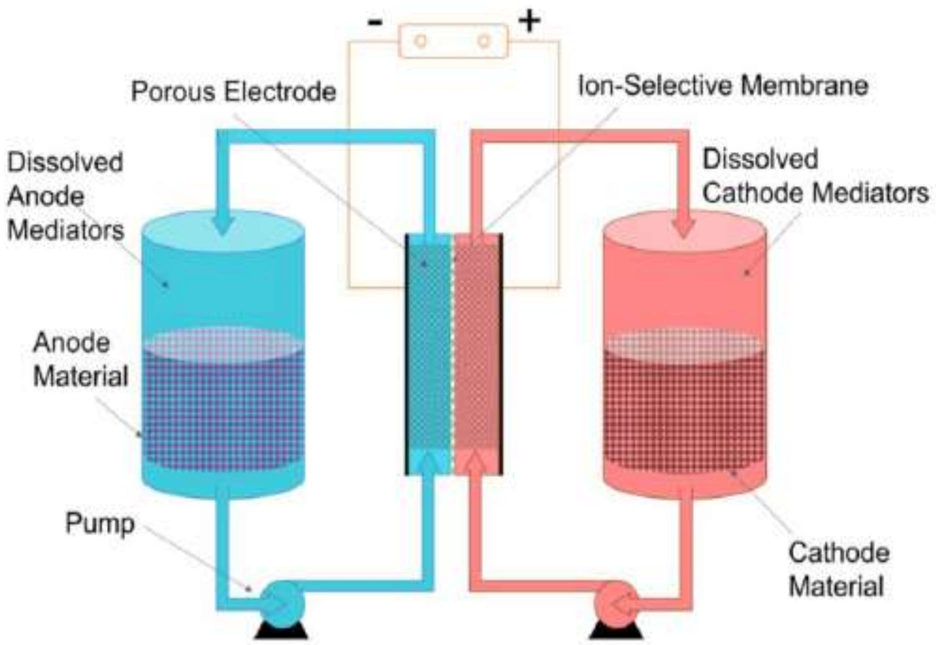


Fig. 7. Redox flow battery

Why redox flow batteries?

- Decoupling of energy rating and power rating i.e. the power and energy capacity of the system can be scaled independently from each other by separate sizing of the tank volume and the cell stacks (reaction cells).
- Common flow batteries rely on aqueous electrolytes that are not flammable, and therefore a safe battery operation is guaranteed.
- Discharge 100% of the stored energy each cycle without losing any capacity.
- Do not degrade for more than 20 years.

Difficulties and Challenges of redox flow batteries

- Vanadium redox flow battery, most advanced and close to commercialization amongst redox flow battery chemistries, suffers from high cost of the vanadium and relatively low energy densities (i.e. 25 Wh/L).

How close are redox flow batteries?

Redox flow batteries are considered to be the promising candidate, particularly for the grid scale battery storage applications due to its exceptional scalability and flexibility to improve the stability, efficiency, and sustainability of the power grid.

Most commonly used chemistries for redox flow batteries are based on materials like vanadium, zinc, and iron. Vanadium and Zinc-based flow batteries are the most advanced and close to commercialization amongst redox flow battery chemistries, but high cost of the vanadium and relatively low energy densities (i.e. 25 Wh/L) are still some key challenges standing in the way of further commercial and industrial application of Vanadium RedOx Battery (VRB).

Conclusion

Battery storage technology is a critical technology for realizing a climate-resilient energy future. This is because battery technology has an essential role in transforming mobility, power generation, power distribution, & power consumption etc.

Despite unprecedented growth by battery technology, the reality is that battery technology not yet good enough to efficiently store large amounts of electricity. This is because despite batteries widespread use, battery technologies are essentially considered a black box during operation, harbouring mysteries that prevent researchers from unlocking their full potential. Therefore, there is a further need to leverage synthesis, advanced characterization, and machine learning technologies to understand the fundamental reactions that occur within the battery to better understand the battery process and design better battery systems i.e. optimizing battery materials, understanding cell degradation mechanisms, and ultimately improving the overall battery performance.

On the deployment side, Lithium-ion batteries are anticipated to have a high rate of deployment in the coming decades. Ideal applications of Lithium-ion batteries would be energy storage systems for renewables and transportation. The downside of Lithium-ion batteries is that Lithium-ion batteries have significant associated adverse impacts, including human rights and pollution impacts during mining, fire risk, and are a future waste management challenge owing to the lack of established recycling systems. Therefore, planning and decision-making influencing the deployment of current and future Lithium-ion battery technologies need to acknowledge and manage these short and longer-term impacts as they pose a significant risk to the viability of the industry and could hinder the transition to a renewable energy system.

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