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# Smart Battery Management Systems and Comprehensive Comparison of Batteries for Electric Vehicles

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## ABSTRACT

The automotive industry has a strong demand for electric vehicles because of their exceptional ability to compete with internal combustion engines. In any electric car, batteries are an essential part. They basically act as the heart of the car. Controlling the battery system can significantly speed up the creation of an electric vehicle. Our study and research provide insight into the present battery scenario, namely Lithium-ion batteries, which are currently driving the era. Nonetheless, there are superior alternatives to lithium-ion batteries due to their variable downsides. Flow batteries are a worthy competitor to Li-ion batteries, as they give various advantages over current conventional batteries. The study also covers the benefits and advancements of batteries for high-voltage applications. Our research examines the replacement of Li-ion batteries with Vanadium redox flow batteries and analyses the results to support the decision to employ flow batteries. The flow batteries will significantly enhance electric vehicles.

**Keywords—** Electric Vehicles (EVs), Lithium-ion Battery, Vanadium Redox Flow Battery (VRFB), Battery Management System (BMS), Energy Storage, High-Voltage Applications, Sustainable Energy, Battery Technology, Flow Batteries, Renewable Transportation.

## INTRODUCTION

Electric vehicles run on electric motors. The vehicle's collector system may use electricity from other parts or a rechargeable battery. When gasoline is charged, it is transformed to energy via a generator, fuel cells, or solar panels.

[1]. The reduction of carbon footprints and the depletion of fossil fuels are greatly aided by electric automobiles. By the end of the century, commercialized electric cars were widely accessible, having first been introduced in the 1830s. The first rudimentary but working electric motors, complete with rotors, commutator, and stator, were constructed in 1827 by Anyos Jedlik, a Hungarian priest, and used to drive tiny cars the year before. [2] In the early 1900s, the United States of America saw the introduction of the first surplus electric propelled vehicle. In 1902, the Studebaker Automobile Company debuted the first electric vehicle; nevertheless, in 1904, it expanded into the gasoline vehicle market. The appeal of electric automobiles was greatly diminished when Ford Motor Company introduced minimal production line cars. 3] Meanwhile, the era of electric vehicles is already well underway, and demand has increased. As of December 2020, 14,978 electric vehicles were registered in India. According to  the figures, 42,055 electric vehicles were registered in India in November of last year. [4] Over time, the advancement of EV technology has played a significant role. This aspect of view has appeared in technical writing [5]–[7] in trade media [8]. Plug-in hybrids, fuel-cell EVs, hybrid EVs, and all-electric

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vehicles are among the several varieties of electric vehicles. Different principles govern how vehicles operate. While certain sections and Some gadgets are exclusive to electric vehicles, while others are used by all of them. The essential parts of any electric car are power electronics and battery management. The field of power electronics is based on power conversion and control operations.

[9] The need for more effective motor control in industrial drives and the development of highly reliable switching power supplies made of lightweight materials for sophisticated computer and communication devices have propelled power electronics advancement in recent years. [10] Because they are essentially inconspicuous and do not produce any exhaust emissions in the local environment, electric vehicles are preferred over internal combustion engines. This makes the electric car ideal for places like golf courses, warehouses, and interior buildings where noise and pollution are prohibited. Whenever a combustion engine becomes poisonous and unproductive, they maintain their efficiency in start-stop drive. Electric vehicles, like the well-known British milk float, are therefore interesting options for distribution. Electric vehicles rely heavily on power electronics and batteries. Traditional electric vehicles rely solely on batteries for electricity, which can be expensive, bulky, and heavy. Hybrid vehicles require constant consumption and discharge of electrical energy, making recharge ability a crucial feature. Early fuel cell vehicles often use larger batteries and operate in a hybrid mode, similar to internal combustion engines. In conclusion, knowledge of battery performance and technology is essential for anyone working with electric vehicles. How does an electric battery work and what is it? Two or more connected electric cells make up a battery. A battery's cells transform chemical energy into electrical energy. The cell's positive and negative electrodes are joined by an electrolyte. When electrodes and electrolytes come into hydrophobic contact, DC electricity is produced. The reaction mechanism of secondary or rechargeable batteries can be improved by changing the direction of current flow, enabling many charging cycles. Although there are different types of recharging batteries, the most common is the "lead acid" battery.

The first electric automobile to use rechargeable batteries was developed 25 years before the rechargeable lead acid battery, and there are many other materials and electrolytes that can be used to make batteries. Lithium-polymer, lead-acid, nickel-iron, nickel- cadmium, nickel-metal hydride, sodium- sulphur, and sodium-metal chloride are some of the additional battery kinds that are available. In the battery industry, lithium- ion batteries are commonly utilized in industrial applications, television remote controls, and electric cars. Lithium-ion batteries first appeared in the early 1990s. While the negative electrode is composed of lithiated carbon, the positive electrode is composed of intercalation oxide with transition lithiated metal. Crystalline or liquid polymers can make up electrolytes.

[11] The main component of electric vehicles, lithium-ion batteries have completely changed mobility. They contribute to a more sustainable future by strengthening the link between distributed generation and power system networks. Two electrodes are used to create a sophisticated lithium-ion battery. EC, at least one linear carbonate from dimethyl carbonate (DMC), diethyl carbonate (DEC), ethyl methyl carbonate (EMC), and other additives are all present in the porous separator, which is submerged in a non-aqueous electrolyte (liquid). On the anode side, lithiated graphite (LiC6) is produced by lithium ions as they pass through the LiCoO2 crystalline lattice during charging. Ions return to the Cobalt 2 oxide framework host upon discharging, whereas electrons are expelled to the external circuit. The rocking-chair chemistry phenomenon, also referred to as shuttling, has significantly impacted our lives today [12] Carbon and lithium metal oxides, together with electrical energy, are produced when carbonated lithium and lithium metal oxides react.

The battery's total chemical process is:

"C6Lix + MyOz ←−−→ 6C + LixMyOz".

Battery innovations that can assist us in overcoming current obstacles are the main focus of our study. For electric vehicles, efficient battery management and design are essential. Both now and in the future, there will be a great need for batteries that are more economical, efficient, long-lasting, compact, and manageable.

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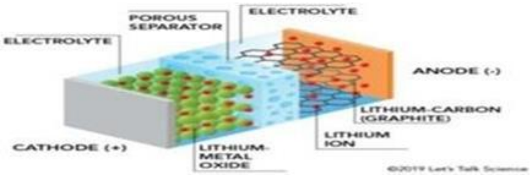
*II. The operation of the LI-ION battery*

Batteries made of lithium ions and their molecularly equivalent polymers have long been successfully manufactured for use in laptops, computers, and other basic consumer electronics. Because of their extended lifespan and great energy density, they are arguably the most popular battery type for use in electric cars. John Goodenough and Akira Yoshino followed N. Godshall's 1979 demonstration of a graphite anode and lithium cobalt oxide. [13] [14] [15] [16].




Lithium is an extremely reactive element in its elemental state. Because of this, elemental lithium is not used in Li batteries. Conversely, Li batteries typically comprise a Li- based metal oxide, such as Li-cobalt oxide ($LiCoO_2$). This is where lithium ions come from. Li-metal oxides are used at the cathode, whereas Li-carbon compounds will be used mostly at the anode. These chemical combinations are commonly used because they encourage intercalation. "Intercalation" is the term used to describe molecules' capacity to insert something into themselves.

A lithium-ion battery undergoes oxidation-reduction. [17] The cathode is where reduction occurs. Li-ions react with cobalt oxide to form Li-cobalt oxide ($LiCoO_2$). The response is provided by:

“$CoO_2 + Li^+ + e \longrightarrow LiCoO_2$“

Oxidation takes place at anode. Graphite ($C_6$) and Li-ions are formed through the graphite intercalation complex $LiC_6$. The half-reaction will be:

“$LiC_6 \quad > C_6 + Li^+ + e^-$ “

Thus the full reaction will be (left to right = discharging, right to left = charging):

“$LiC_6 + CoO_2 \rightleftarrows C_6 + LiCoO_2$

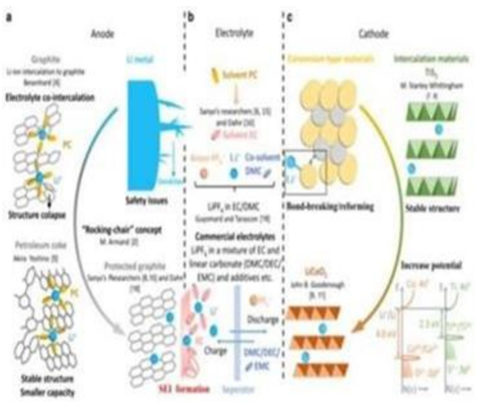



Figure 3: Charging and Discharging of Li-ion battery

III Innovations in Lithium Ion Batteries:

Discoveries that helped develop the conventional batteries of Lithium-ion: The enlargement of (i) anode materials such as GRAPHITE, PETROLEUM COKE, and LITHIUM METAL,

(ii) electrolytes containing the a mixture of ETHYLENE CARBONATE (EC), SOLVENT PROPYLENE

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CARBONATE (PC) and at least one linear carbonate chosen from DIETHYL CARBONATE (DEC), DIMETHYL CARBONATE (DMC), ETHYL METHYL CARBONATE

(EMC), and many additives, and (iii) cathode materials such as conversion-type materials (LiCoO2). [18]

Discharging: Lithium atoms oxidise to produce Li+ ions and electrons during the initial stage of discharge, while through the electrolyte and separator, Li+ undergoes process of diffusion to the positive electrode. On the external circuitry, electrons reach positive electrode via negative electrode, and the obtained current flow can be employed for an application. Electrons recombine with Li+ ions at positive electrode and are stored in the active material's molecular structure. [19]

Charging: If an external voltage of the same polarity is supplied between the current collectors, the charging process is initiated. Lithium atoms depart the metal oxide framework and ionize into Li+ ions when an electron is released. In the same manner like they do during the discharge process Li+ ions diffuse to the negative electrode. At the surface of graphite particles, Li+ ions and electrons recombine to form neutral lithium atoms, which are subsequently re intercalated further into chemical structure of the graphite particles. [19]

For next-generation rechargeable batteries Lithium metal is a potential anode, however its non-uniform electrode position is a major stumbling block. Although their morphologies might vary, these non-uniform deposits are typically referred to as lithium "dendrites". During the charging process, metallic microstructures called lithium dendrites develop on the negative electrode. The production of these dendrites will diminish the battery's electrochemical performance**.** At extreme temperatures, electrolytes react violently with lithium dendrites to generate gases, causing the internal pressure of the batteries to constantly rise, producing safety concerns such as battery explosion and electrolyte leakage. SEI films lack their thermal stability when lithium dendrites emerge. They have the tendency to create a short circuit or perhaps an explosion in the long haul.

Dendrite development is considered to be generated by mass transfer and Li ion reduction rate competition nearer the cathode surface. When the rate of ion reduction is substantially rapid than the rate of mass transfer, it develops an electro neutral gap near the cathode termed the space-charged layer, which is devoid of ions. Dendrite growth is assumed to be caused by the instability of this layer, therefore minimizing or eradicating it might limit dendrite formation and hence prolong the battery's life. The objective was to restore a charge and offset the gap by moving ions past the cathode in a microfluidic channel. Increasing the flow of ions into the cathode has indeed been found to be an effective tactic for suppressing dendritic proliferation, with this flow of ions inhibiting dendrite growth by up to 99 per cent. [20] This beautiful solution was given by a study made by Wan

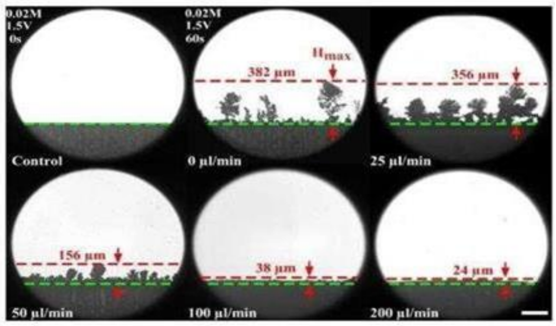


Figure 4: Wans microscopic view of his experiment

The battery is the most essential part of an electric vehicle. The batteries can be charged rapidly, thanks to the high voltage. Understanding the behaviour of batteries at high voltage is essential for investigating the analogies of batteries throughout charging. For cost-effective operation, Li-ion batteries should be able to sustain high voltage. Let's look at some of the Li-ion battery's high- voltage uses. VOLTAGE PER EACH CELL: The nominal voltage of lithium-ion batteries is 3.7 volts per cell. A battery pack can include any voltage in 3.7 volt increments by interconnecting the cells in series. Ex. Lithium-Ion batteries have three cells

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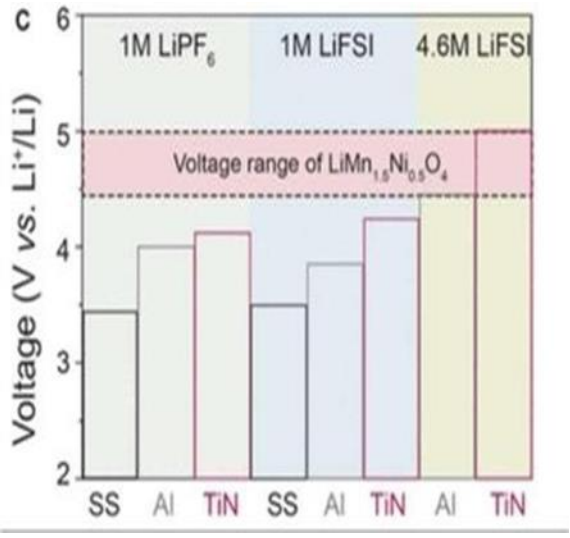
for an 11.1- volt battery, four cells for a 14.8-volt battery, and ten cells for a 37-volt battery. [21] They offer one of the greatest energy densities (250-670 Wh/L or 100-265 Wh/kg) of any battery technology available today. Furthermore, Lithium-ion batteries can deliver up to 3.6 volts, which would be three times more than Ni-Cd or Ni-MH batteries. Thus, it implies for high-power applications they can supply a lot of current, which is a beneficial move. Li-ion batteries are also reduced maintenance because they do not need to be recharged on a regular basis. [22] High voltage in batteries will dramatically enhance battery capacity. There are numerous sources of high voltage that can be used productively in a battery system. The energy density of a battery represents how much energy it can retain per unit volume. The LiHv batteries use more energy than conventional LiPo batteries, and each one could be charged to a maximum voltage of 4.35V. It's the combination of a battery's nominal voltage and capacity divided by the weight or volume of the battery. Due to the limited space and weight of the power source, the battery's energy may be boosted by increasing the charging voltage, which is why the completely charged voltage has risen from 3.7V to 3.8V or even 3.85V. This innovation is bulk producible and has the potential to increase battery capacity by 15%

[23] A major stumbling block to the commercialization of high-voltage Li-ion batteries is the dearth of oxidative viable and inexpensive current collectors that can operate at potentials of up to 5 V vs Li+/Li. The impact of higher cathode overcharging, which leads current collector oxidation and corrosion, has yet to be tackled. Cathode current collectors made of aluminium (Al) and stainless steel (SS) are not effective for high-voltage solicitation because they oxidize at low voltages as 3.9 volts. [24][25] Because its corrosion is frequently moderate enough, Al can still be employed for most research applications, however, it is not suitable for use in commercial high- voltage batteries. On our assessment, titanium nitride at the cathode can be employed for high voltage commercial applications since this is highly electrically conductive material. It is highly suited for commercial application as a high- voltage current collector due to its excellent oxidative stability in LiPF6- and LiFSI-based electrolytes. We could see from the experiment in [26] that titanium nitride can work at a high voltage level. The initiation of electrochemical oxidation in LiPF6/LiFSI electrolytes occurs at 3.44 V/3.49 V, 4.0 V/3.85 V, and 4.12 V/4.24 V against Li+/Li, respectively, for Al, SS, and TiN current collectors




X-ray diffraction tests confirmed the creation of a highly crystalline cubic TiN coating on stainless steel (space group Fm3m, a = 4.241, JCPDS 038-1420) oriented in the [111] direction. The extraordinary oxidative stability of Tin current collectors might be attributable to the Tin film's preferred

(111) orientation. [27]

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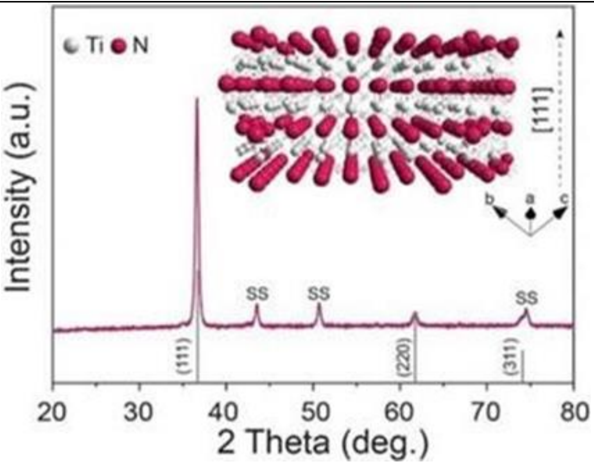


Titanium nitride can be employed in lithium ion batteries for commercial high voltage applications, according to this research and survey. Another significant benefit of quick charging is the availability of high voltage. Improving charging and discharging enhances the vehicle's other characteristics, which are detailed below. In addition to significant weight and bulk reductions, higher voltage systems provide a range of other conveniences. Copper reduction is one illustration of this. Electric motors are constructed far more simply than combustion engines, with a rotor that rotates in response to a rotating magnetic field provided by power from the battery. To do this, electrical systems typically use up to four times the proportion of copper used in internal combustion engines. Using higher- voltage systems can result in a massive reduction in the quantity of copper consumed in motors. An 800-volt system offers the extra benefit of decreasing the bulk of motors in addition to lowering their weight. Because the greater voltage allows the motors to spin at 20,000 rpm, they have a higher power density than their 400- volt counterparts. This means they convert electrical power to mechanical power at this pace rather than at a high torque. When employing fast chargers that can function at up to 270 kilowatts, charging time can be drastically minimized. "If the charger delivers 800 volts and a minimum of 300A, the Taycan can charge from 5% to 80% in 22.5 minutes". Only 50kW is commonly provided by 400V chargers. It would take 90 minutes to charge to the same capacity," Bitsche explained. The business promises that their four-door coupe-styled saloon has a 420-kilometer range between charges, claiming to be the prime company to commercialise an 800-voltage electrical system.

[27]One feature of 800-volt electrical systems is that they allow for the preservation of more power, which is typically lost owing to heat generated during charging. When charging the battery, a lower current is to be used which is provided by a higher voltage system protecting the device from overheating and enabling it to hold onto more power. The driving range could be enhanced by employing this additional power.

Flow Batteries:

Type of battery that uses vanadium to store energy are called as vanadium redox battery (VRB), also known as the vanadium flow battery (VFB) or vanadium redox flow battery (VRFB). It's a form of rechargeable battery in which the charge carriers are vanadium ions.[28] Because of their incredible reversibility, constant presence of the active species in solution during charge/discharge cycling, and relatively high power output, vanadium redox flow battery (VRFB) systems are the most established among flow batteries

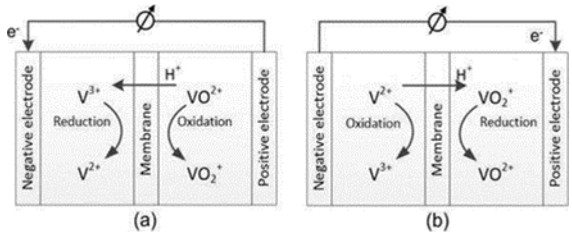


Figure 5: Schematic diagram of a vanadium redox flow battery: (a) charging reaction and (b) discharging reaction.

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The cathode undergoes reduction whereas the anode undergoes oxidation during discharge. These redox reactions involve the spreading of protons across the membrane and the movement of electrons through the external circuit.

At Cathode: ‘V2+ <        > V3+ + e-‘

At Anode: ‘VO2+ + 2H+ + e- < > VO2+ + H2O’

The resultant reaction:

‘V2+ + VO2+ + 2H+ <> VO2+ + V3+ + H2O’

The all-vanadium redox flow batteries type standard cell voltage is 1.26 V. The voltage of the cell may be computed utilising the ‘Nernst Equation’ for a particular temperature, pH value, and vanadium species concentrations:

‘E=1.26V–RT/F ln([VO2+]·[V3+])/([VO2+]·[H+]2·[V2+])

At Cathode:

‘V2++ VO2+ + 2H+ ---> V3+ + H2O’ ‘2V2+ + VO2+ + 4H+ --->3 V3+ + 2H2O2’ ‘V3+ + VO2+ ---> 2VO2+’

At Anode:

‘V2++ 2VO2+ + 2H+ ---> 3VO2+ + H2O’ ‘V3+ + VO2+ ---> 2VO2+’

‘V2++ VO2+ + 2H+ ---> 2V3+ + H2O’

Vanadium-vanadium, Bromine-polysulfide, iron- chromium, vanadium-bromine, zinc-cerium, zinc-bromine and soluble lead RFB are some of the vanadium-based flow batteries type that has been innovated over time. However, as previously stated, all flow batteries function in the same way. Flow batteries have a wide spectrum of uses, including electric vehicles, due to its multiple advantages.

Flow batteries provide a substantial bump on the battery management of electric automobiles, offering several advantages such as cost, efficiency, mobility, versatility, and user friendliness. Modularity, transportability, and flexibility of operation are all advantages.

[30] Furthermore, the electrolyte and reactants (therefore referred to as "the electrolyte") are maintained separate (with the exception of flooded soluble lead RFB, which has a homogeneous electrolyte), limiting self-discharge, prolonging the battery's life span[31], and lowering maintenance and operating expenses. Rapid response from idling and strong output performance over a brief time span for HEV applications [32] are also remarkable advantages. An RFB is an electrochemical energy storage device that allows for a significant separation of system power and storage capacity. The former is governed by the stack's design of cell and size, whereas latter is identified by the dimension of the storage tanks, the electrolyte proportion, and the reactant concentration. The negative and positive electrochemical half- cells of the battery are separated by an ion exchange membrane. The electrolyte is circulated across the cell stack using a pump. The insoluble lead-acid Redox Flow Batteries use a single electrolyte instead of a membrane

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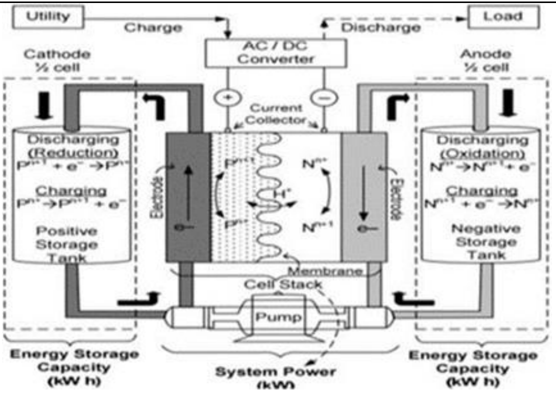


Figure 6: Typical diagram of a flow battery

RFBs are typically more identical to FCs, with the exception that in the RFB system, the electrolyte flows over the cell stack to permit redox reaction, whereas in the FC system, the electrolyte remains within the cell stack. By emptying the depleted electrolyte solutions and replacing them with fully charged electrolytes, the RFB may be quickly recharged. It might be done at quick refuelling/recharging stations in the same way that gas stations are. Additionally, system power depends on the intended vehicle's acceleration capabilities, and energy storage capacity depends on the distance travelled. The flexibility of the vehicle designer is increased by the RFB's ability to disconnect its energy and power components. The size of the power and energy components may be customized by the designer to fit the layout of the vehicle and satisfy predetermined performance parameters, in contrast to the flexibility of storage tanks and cell stack physical architecture. [33] The below table gives the casual comparison for various batterytypes.(taken From7). Another important consideration is refuelling or recharging. System of Flow batteries offer an interesting refuelling mechanism that eliminates the limited autonomy of modern batteries as well as their high cost, allowing EVs to compete on pricing; Additionally, they provide seamless access to carbon-free renewable energy sources and the most effective utilization of off-peak base-load grid electricity. If the power density of aqueous electrolytes can be raised, redox flow batteries will be a great choice for meeting EV energy storage demands and might possibly open up much bigger global markets in the future. Flow batteries need on electrolytes to function. Electrolytes are used throughout the battery system. Nano fluids are a significant advancement in the fluids used in flow batteries [surveyed from paper 34]. Researchers from 'Argonne National Laboratory and Illinois Institute of Technology' (IIT) collaborated to develop a revolutionary electrical energy storage system. The researchers used Nano fluid technologies and flow batteries to build a battery rechargeable in liquid form that is equivalent to gasoline in terms of convenience. The battery system uses Nano electro fuel, a specific liquid in which Nano-scale battery-active particles are continuously suspended and may even undergo repeated charging and discharging in a specialized flow battery cell. In rechargeable Nano electro fuel technology, the unique physical properties of electro active (rechargeable) nanoparticles floating in fluids are employed: The reduction/oxidation of nanoparticle material allows for rapid response times, excellent charge/discharge efficiency, and a lengthier fuel life cycle. This approach is not limited by redox materials' solubility, and with adequate nanoparticle surface preparation, volume concentrations of up to 80% may be achieved while retaining pump ability. As a result, Nano electro fuels have a 10-30 times higher volumetric energy density than standard redox electrolytes. They have a large area of solid/liquid interface (capacitors) at the Nano scale, whereas energy may be stored and distributed using

| Battery Types | Equipment's | State of Electrolyte | Storage of Energy |
|---|---|---|---|
| Static batteries (Secondary batteries) | Materials of Active Electrode | Held within the cell in static condition | Electrode within the structure could be reversible |
| Redox Flow Batteries | Aqueous electrolyte within reservoir | Electrolyte which flow within the cell | Redox species that migrate within the cell and irreversible electrode reactions |
| Fuel Cells | Sum of air and liquid or gaseous fuel | Within the cell polymers of solid and ceramic acts as solid electrolyte | non-reversible and from inside reactants outside of the cell |

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a recoverable nanoparticle material using electrochemical (red/ox) processes similar to solid state batteries. Nano-sized battery materials have been shown to have considerably quicker discharge/charge rates than micron-sized cathode and anode materials. [35] Nano electro fuel technology carries its charge in a liquid electrolyte containing a substantial percentage of redox nanoparticles, which boosts energy density while assuring battery low resistance flow and stability. When pushed via custom-designed flow cell(s), Nano scale electrode materials that are durable in electrolyte and charge/discharge efficiently give a high-energy-density rechargeable, regenerative, and recyclable electrochemical fuel. They provide outstanding pump performance and flow (refuelling time is equivalent to gasoline refuelling), which not only enhances the convenience of refuelling for electric vehicle owners, however, it has a minor influence on the present electrical grid infrastructure in the country Nano electro fuel flow batteries may allow for the separation of charging and storage of liquid Nano electro fuels, as well as long- term storage of charged fuel and improved energy distribution pathways. Nano electro fluids, as a result, perform better in flow battery systems.

High-voltage applications Rechargeable semi flow batteries made of vanadium – metal hydride have been developed. Graphite felt positive electrode and a metal hydride negative electrode operate in 0.128 mol/L positive $VOSO_4$ electrolytes in 2 mol/L $H_2SO_4$ solution and 2 mol/L KOH

aqueous solutions, respectively, and are separated by a bipolar membrane. At 25 C, a single Vanadium Redox Battery cell provides a standard voltage of 1.26 V. 'Skyllas-Kazacos et al'.[36] reported a hybrid Vanadium-$O_2$ redox fuel cell that removes the positive side's bulk by storing oxygen freely in air. The reported specific energy [36] is larger than 40 Wh kg-1, which is around 1.6 times the practical specific energy of a typical Vanadium Redox Flow battery (25-35 Wh kg-1) [37, 38], while the open circuit voltage (OCV) was kept between

1.10 and 1.24 V. Due to the irreversibility of the four electron oxygen reaction, the lack of a competent bi-functional electro catalyst results in low voltage efficiency. To boost the specific energy, the same group developed a vanadium chloride/polyhalide redox flow battery [21], which gave an experimental OCV of 1.3 V. During operation, ion crossing through the membrane was decreased remarkably. Both attempts provide an OCV that is comparable to that of a traditional VRF battery. As a result, when used at high voltage, flow batteries have a major benefit. A semi-flow Vanadium- Metal Hydride (V- MH) system with 3.5 times the theoretical specific energy of a conventional all VFRB (200 Wh kg-1) was described (60.5 Wh kg-1). The issue of $V^{2+}$ oxidation is eliminated when the $V^{4+}/V^{5+}$ pair is hybridized with metal hydride, as in a VRF battery. The V-MH battery system's average discharge voltage is somewhere around 1.70 V, which is higher than the 1.2–1.4 V of solitary all vanadium redox flow batteries. The Vanadium- MH battery system's reversibility and efficiency in voltage (88.1%), columbic (95%), and energy (83.7%) are critical for its potential usage. Based on the lab-scale cell and low current density, the rough predictor of this rechargeable semi- flow battery's current practical energy and power density is 46.5 Wh kg-1 and 9.89 W kg-1, respectively) [based on the experimental detail of 39].

LI – Ion Battery Versus Redox Flow

Batteries:

Cost: One major disadvantage of lithium ion batteries is their high cost. Manufacturing them is approximately 40% more costly than nickel cadmium cells. This is a crucial factor to take into account when thinking about their use in mass- produced consumer items, since any additional costs are a major worry.

Protection required: It's possible that lithium ion batteries and cells won't last as long as other rechargeable technologies. They must be protected against being overcharged and discharged excessively. Furthermore, the current must not exceed permissible limits. Because of this, lithium ion batteries have the drawback of requiring safety circuitry to make sure they operate within their safe working range.

Ageing: One of the most significant problems with lithium ion batteries used in consumer products is their age. The number of charge- discharge cycles the battery has undergone is also taken into consideration, in addition to

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the current time and the calendar.

Batteries typically only have a capacity limit of 500 to 1000 charge-discharge cycles. As li-ion technology develops, this number is increasing, but batteries ultimately need to be changed, which might be a concern if they are built into equipment.

Highly fragile: Lithium-ion batteries are not suitable for heavy-duty applications due to their lack of robust technology.

Because Li- ion batteries contain liquid polymerized electrolytes, they may perforate fast and with little force.

The problems with Li-ion batteries outlined above are only a few of them. Despite the fact that batteries have been for a long time and that research and technology are being created in these batteries, problems still exist. Using flow batteries is a better and more efficient solution to overcome these problems. The main advantages of flow battery technologies are the decoupling of power and energy capacity. Even though the stored energy in electro active species present in electrolyte, the device's output power is a function of the numbers and compactness of the electrodes that make up the electrode stack. The two components that account for energy and power, respectively, are electrolyte content and electrode stacking.

➢ Additionally, the benefits of a decoupled energy capacity, RFB feature a low leveled Cost of Storage (LCOS) and a high cycle life of 20,000 to 25,000 cycles. The characteristics of redox flow batteries make this technology ideal for energy storage applications.

➢ Longer duration: Large-scale Li-ion systems typically last not more than four hours, but small-scale Li- ion systems last up to 12 hours.

➢ Enhanced safety: Flow batteries made of Iron are non-combustible, non-poisonous and pose no threat of detonation. The similar cannot be said about Li-ion batteries.

➢ Longer asset life: Over a 25-year working life, iron flow batteries have an infinite cycle life and no capacity decline. Lithium- ion battery has an average life cycle of 7,000 intervals and a lifespan of 7 to 10 years.

➢ Less concern with ambient temperatures: Without the need of heating or air conditioning, iron flow batteries may perform in temperatures ranging from –10C to 60C (14F to 140F). Utility-scale projects nearly usually need ventilation systems. Lithium-ion batteries.

➢ Reduced levelled storage costs: Due to the 25-year lifespan of iron flow batteries, a capital expense that is comparable to Li-ion, and cost of operation that are significantly lesser than Li-ion, the total ownership cost can be as much as 40% cheaper.

➢ Because no cell-to-cell or stack-to-stack balancing is needed, flow batteries possess easier monitoring and controls and less deterioration than Li-ion batteries.

➢ Flow batteries can increase their energy production (kWh) without expanding their power output (kW), something Li-ion batteries can't do, and thus works out cheaper in long-duration (multi-hour) applications.

Flow batteries have near-zero time-dependent deterioration (calendar fade)

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| Batteries | % $\eta_V$ | % $\eta_C$ | % $\eta_E$ | W h $L^{-1*}$ | W $L^{-1**}$ | $j$ / mA $cm^{-2}$ |
|---|---|---|---|---|---|---|
| Bromine-polysulphide | 75 | - | 77 | 20-35 | 60 | 60 |
| Vanadium-vanadium | 81 | 90 | 73 | 20-35 | 60-100 | 60-100 |
| Iron-chromium | 82 | - | 66 | 20-35 | 6 | 10 |
| Vanadium-bromine | 80 | 83 | - | 20-35 | 50 | 50 |
| Zinc-/bromine | - | - | 80 | 20-35 | 40 | 40 |
| Zinc-cerium | - | 83 | - | 20-35 | 50 | 50 |
| Soluble lead-acid | - | 79 | 60 | 20-35 | 25 | 25 |
| Conventional lead-acid | - | - | 68 | 60-80 | 230 | - |
| Lithium-ion | - | 100 | 80 | 150-200 | 275 | - |
| Nickel metal hydride | - | - | 75 | 100-150 | 330 | - |

In terms of voltage, capacity, energy, weight, and power, the table above [adapted from] compares vanadium flow batteries to other traditional flow batteries. [40] As a result of the foregoing comparison of flow batteries with lithium ion batteries, flow batteries outperform lithium ion batteries in terms of performance and other factors. Lithium ion batteries pose a major hazard to the environment. The procedure of disposing of lithium batteries may be tricky, and not everyone is aware of the danger. Flow batteries are a better alternative for replacing lithium ion batteries in all of these instances.

Cost: One major disadvantage of lithium ion batteries is their high cost. Manufacturing them is approximately 40% more costly than nickel cadmium cells. This is a crucial factor to take into account when thinking about their use in mass-produced consumer items, since any additional costs are a major worry.

Protection required: It's possible that lithium ion batteries and cells won't last as long as other rechargeable technologies. They must be protected against being overcharged and discharged excessively. Furthermore, the current must not exceed permissible limits. Because of this, lithium ion batteries have the drawback of requiring safety circuitry to make sure they operate within their safe working range.

Ageing: One of the most significant problems with lithium ion batteries used in consumer products is their age. The number of charge- discharge cycles the battery has undergone is also taken into consideration, in addition to the current time and the calendar**.**

Batteries typically only have a capacity limit of 500 to 1000 charge-discharge cycles. As li-ion technology develops, this number is increasing, but batteries ultimately need to be changed, which might be a concern if they are built into equipment.

Highly fragile: Lithium-ion batteries are not suitable for heavy-duty applications due to their lack of robust technology. Because Li- ion batteries contain liquid polymerized electrolytes, they may perforate fast and with little force.

The problems with Li-ion batteries outlined above are only a few of them. Despite the fact that batteries have been for a long time and that research and technology are being created in these batteries, problems still exist. Using flow batteries is a better and more efficient solution to overcome these problems. The main advantages of flow battery technologies are the decoupling of power and energy capacity. Even though the stored energy in electro active species present in electrolyte, the device's output power is a function of the numbers and compactness of the electrodes that make up the electrode stack. The two components that account for energy and power, respectively, are electrolyte content and electrode stacking.

Additionally, the benefits of a decoupled energy capacity, RFB feature a low leveled Cost of Storage (LCOS) and a high cycle life of 20,000 to 25,000 cycles. The characteristics of redox flow batteries make this technology ideal for energy storage applications.

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