INNOVATIONS IN BATTERY MANAGEMENT SYSTEMS AND A THOROUGH COMPARISION OF THE BEST BATTERIES FOR ELECTRIC VEHICLES.

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Abstract— *Electric vehicle is a major demand in the automobile industry due to its impressive competitive behavior with internal combustion engines. Batteries are the key component in any electric vehicle. More or less they are the heart of the vehicle. Managing the battery system can effectively boost the overall development of an electric vehicle significantly. Our survey and review briefs the current scenario of the batteries that is Lithium-ion batteries which is ruling the era now. Nevertheless there are better options compared to lithium – ion batteries due to its variable drawbacks. Flow batteries are a worth competitor for Li-ion battery as they give lot of benefits compared to the present conventional batteries. The paper also describes the benefits and advancement of batteries for high voltage applications. Our paper analysis describes the replacements of Li-ion with Vanadium redox flow batteries and a comparison of the same to justify the reason to adopt flow batteries. The flow batteries will remarkably improve the electric vehicles.*

Key Words: Lithium Ion Battery, Flow Battery, Voltage

I. INTRODUCTION

An electric vehicle is a vehicle that runs partially or fully on electricity via electric motors. Collector system that includes electricity from elsewhere in the vehicle or by a rechargeable (sometimes charged, fuel is converted to electricity by the usage of a generator or fuel cells and sometimes by a solar panel).[1] Electric vehicles serve a big and crucial part in reducing carbon footprints and the extinction of fossil fuels. Electric vehicles first emerged in the 1830s, and by the end of the century, commercialized electric vehicles were ubiquitous. In 1827, Anyos Jedlik(Hungarian priest) created the primary rudimentary although operational electric motors, equipped with the rotors, commutator, and stator; in preceding year, Anyos utilized them to propel small automobile.[2] In United States of America, during early 1900s, the first surplus electric propelled vehicle appeared. In 1902 the first electric vehicle joined the automobile industry by “The Studebaker Automobile Company“, nevertheless it expanded subsequently in 1904 towards the market of gasoline vehicle. The electric cars popularity dropped substantially when Ford Motor Company launched minimal assembly line automobiles. [3] Meanwhile, the age of electric vehicles is now in high gear, and demand has skyrocketed. In December 2020, in India there were 14,978 electric vehicles registered. According to the data, 42,055 electric vehicles were registered in India in November of last year. [4] EV's technology advancement has been a driving force over the decades. This viewpoint has not been limited for technical writing [5]-[7] but also in trade publications [8]. Electric cars come in a number of different forms i.e. all electric vehicle, hybrid EV's, fuel-cell EV's plugin-hybrid vehicles, etc. Different vehicles operate on various principles. Few components and gadgets are common to all electric vehicles, while some are unique. The basic field for any electric vehicle is Power electronics and Battery management. The discipline of power electronics is built on the premise of power conversion and control operations. [9] Power electronics innovation has been pushed forward towards recent years by the desire for more efficient motor control in industrial drives, and for complex computer and communication equipment the creation of much dependable switching power supply of lightweight materials. [10] Electric vehicles are appreciated over IC engines because they generate no exhaust pollutants in the immediate surroundings and are fundamentally unobtrusive. This renders the electric vehicle excellent for settings where pollution and noise are not permitted, such as golf course, warehouses, and within buildings. They keep their efficiency in start-stop drive, whenever a combustion engine becomes unproductive and toxic. As a consequence, electric vehicles, such as the renowned British milk float, are intriguing as delivery vehicles. As previously said, power electronics is a basic field in electric vehicles of all varieties, as well as the battery plays a critical role as well. The only source of energy is batteries in a traditional electric vehicle, and even equipment with the costliest prices, increased volume, and weight. Hybrid automobiles are rechargeable, which should consume as well as discharge electrical energy on a constant basis, is also a critical component. Several vehicles of fuel cells have indeed been developed using similar size batteries that are nothing bigger than those used in combustion engine(internal combustion) vehicles, but most early FC vehicles are likely to have larger batteries and function in a hybrid battery mode/hybrid fuel cell. In summary, everyone working with electric vehicles has to understand battery technology and performance.

What is an electric battery and how does it work? A battery is comprised with 2 cells or more than 2 electric cells that are interconnected with each other. The cells in battery transform chemical energy into electrical energy. An electrolyte bridges the negative and positive electrodes of the cells. DC electricity is produced by a hydrophobic interaction in between electrodes and the electrolyte. The reaction mechanism in secondary or rechargeable batteries might well be complimented by altering the current flow direction, and the battery can be charged repeatedly. The most well-known recharging variety is the 'lead acid' battery, even though there are many other variants. The very primary electric vehicle incorporating batteries which are rechargeable has been invented a quarter-century before the rechargeable lead acid battery, and there are many other substances and electrolytes which can be used to make a battery. There exsist other batteries such as lead-acid, nickel- iron, nickel-cadmium, nickel-metal hydride, lithium-polymer, lithium iron, sodium-sulphur and sodium-metal chloride etc. However, lithium-ion batteries are dominating the battery industry, not just in electric automobiles, but in all fields utilizing batteries, from television remotes to industrial batteries. In the time of early 1990s, Lithium-ion batteries were presented, with a positive electrode comprised of intercalation oxide with transition lithiated metal and a carbon that is also lithiated is used to make a negative electrode. Electrolytes may be a organic mixture of liquid or crystalline polymer.[11] Batteries of Lithium-ion have created revolution in movable devices, which are also the dominant technique in technology of EV's. These play an integral part in ensuring for better connection of distributed generation in power system networks, which will lead to a future that is sustainable. An advanced lithium-ion batteries is composed with 2 electrodes differentiated with separator that is porous and immersed in non-aqueous electrolyte(liquid) conjured up of ethylene carbonate (EC) and at least one linear carbonate from dimethyl carbonate (DMC), diethyl carbonate (DEC), ethyl methyl carbonate (EMC), and a wide assortment of additives. In the process of charging, Lithium-ions travel through the LiCoO2 crystalline lattice towards the side of anode, forming lithiated graphite (LiC6). In the process of discharging, the ions return to the framework host of Cobalt 2 oxide, during electrons expelled to external circuit. Our modern lives have indeed been changed by this shuttling phenomenon, sometimes referred as rocking-chair chemistry.[12] Carbon and lithium metal oxide are generated when carbonated Lithium and metal oxides of lithium are reacted, correspondingly ,electrical energy is also obtained. The overall chemical reaction for the battery is:

"C6Lix + MyOz ←−−→ 6C + LixMyOz"

Our study focuses on battery innovations that can assist us overcome the prevailing obstacles. Even though batteries are quite an important component of electric vehicles, appropriate battery design and management is necessary. Batteries with even more efficiency, reduced cost, better durability, compact structure, and easier component handling are mostly in demand now and for the future.

II. LI – ION BATTERY AND ITS WORKING:

Lithium-ions (& the molecular mechanisms equivalent polymers of lithium) batteries have traditionally been successfully developed for its usage amongst laptops, computers and basic user electronics. They are perhaps, most preferred type of battery for employment in electric automobiles for their high energy density and prolonged life cycle. N. Godshall in 1979 demonstrated a graphite anode and a lithium cobalt oxide, accompanied by 'John Goodenough' and 'Akira Yoshino' shortly after. [13] [14] [15] [16]

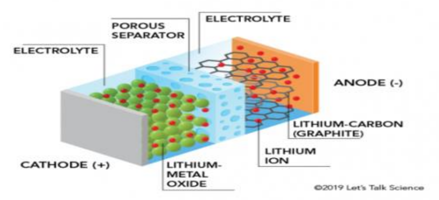


Figure 1: Parts of Li-ion battery

In elemental state, Lithium is tremendously reacting element. Due to this fact lithium in elemental form isn't employed in Li batteries. Li batteries, on the other end, generally consist of a metal oxide made of Li, such as Li-cobalt oxide (LiCoO2). Lithium ions originate from this. At cathode, Li-metal oxides are employed, while in the anode, Li-carbon compounds will be mostly utilised. Since these chemical combinations promote for intercalation, they are widely employed. The ability of molecules to insert something into them is termed as 'Intercalation'.

Oxidation-Reduction takes place within a Lithium-ion battery.[17]

Reduction takes place at cathode. Li-cobalt oxide (LiCoO2) is obtained when Li-ions reacts with cobalt oxide. The reaction is given by:

"$CoO_2 + Li^+ + e^- \dashrightarrow LiCoO_2$"

Oxidation takes place at anode. Graphite (C6) and Li-ions are formed through the graphite intercalation complex LiC6. The half-reaction will be:

"$LiC_6 \dashrightarrow C_6 + Li^+ + e^-$"

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

"$LiC_6 + CoO_2 \rightleftarrows C_6 + LiCoO_2$"

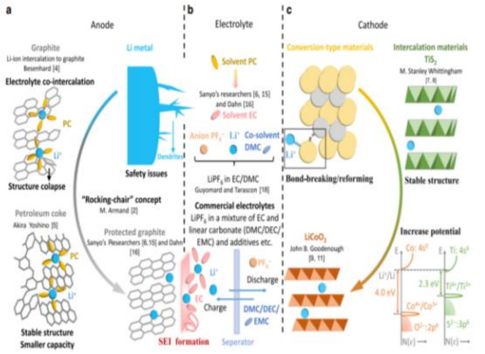


Figure 2: Modern Li-ion battery cycle

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 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 ionise 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]

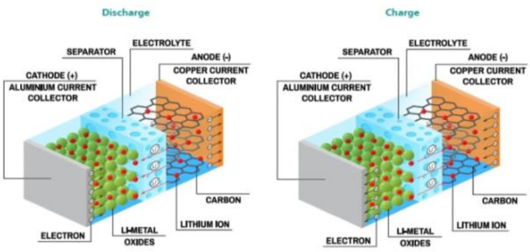


Figure 3: Charging and Discharging of Li-ion battery

III. INNOVATIONS IN LITHIUM ION BATTERIES:

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.

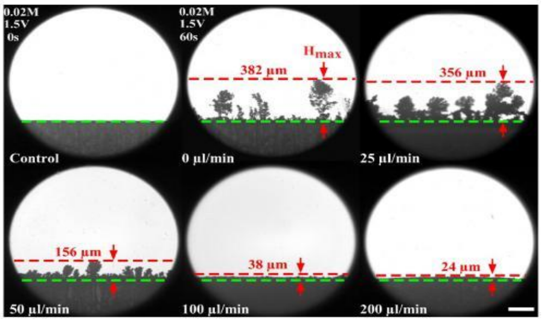
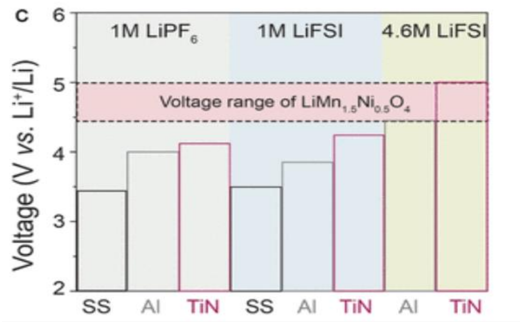
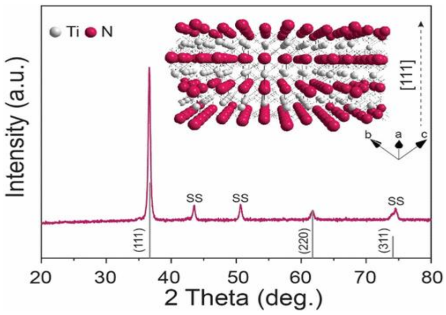


Figure 4: Wans microscopic view of his experiment

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 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 oxidatively 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 oxidise 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]



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.

IV. 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.

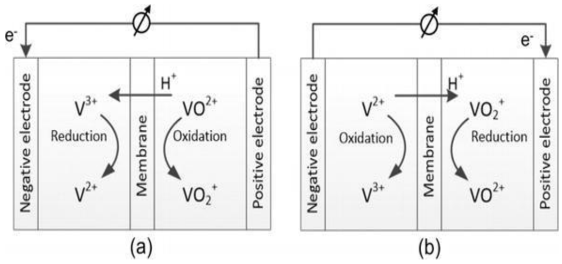


Figure 5: Schematic diagram of a vanadium redox flow battery: (a) charging reaction and (b) discharging reaction.

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: ‘$V^{2+} \longleftrightarrow V^{3+} + e^-$‘

At Anode: ‘$VO^{2+} + 2H^+ + e^- \longleftrightarrow VO^{2+} + H_2O$’

The resultant reaction:

‘$V^{2+} + VO^{2+} + 2H^+ \longleftrightarrow VO^{2+} + V^{3+} + H_2O$’

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:

‘$E= 1.26\ V - RT/F \ln([VO^{2+}]\cdot[V^{3+}])/([VO^{2+}]\cdot[H^+]^2\cdot[V^{2+}])$’

Vanadium ions may permeate the membrane, yielding in self-discharge and undesirable combination of species of vanadium on either sides of cell, as shown in diagram. [29]:

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.

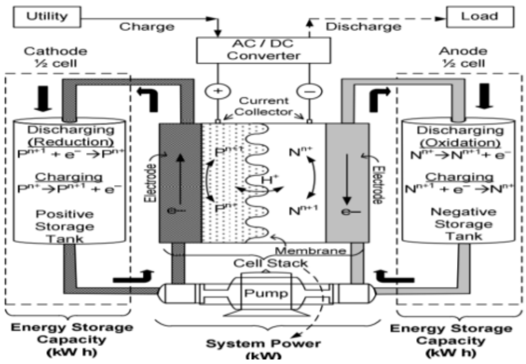


Figure 6: Typical diagram of a flow battery

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 refueling/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 battery types.(taken from 7).

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

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 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].

V. 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 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).

Batteries	% η_V	% η_C	% η_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.

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