1.1 Introduction

The growth in portable electronics devices such as cellular phones and laptop computers during the past two decades has created great interest in compact, light-weight batteries offering high energy densities that show good recharge ability and reliability. In addition, strengthened environmental regulation and a more rational use of available energy resources prompt the development of advanced batteries for electric vehicles [1].

In order to obtain battery systems of high energy density, highly reactive components should be used, i.e. anode materials of lowest redox potential possible, and cathode materials whose redox potential is sufficiently high compared with that of anode, enabling the composition of battery systems of high working potentials. Natural candidates for anode materials for high energy density batteries are active metals such as lithium, magnesium and calcium [2]. Magnesium metal possesses a number of characteristics which make it attractive as a negative electrode material for rechargeable batteries highly negative standard potential (−2.375V versus SHE), relatively low equivalent weight (12 g per Faraday), high melting point (649 C), low cost, relative abundance, high safety, ease of handling, and low toxicity which allows for urban waste disposal[3].

Solid polymer electrolytes (SPEs) fulfill the requirements and overcome the limitations of conventional liquid electrolytes by addressing drawbacks such as electrolyte leakage, flammable organic solvent, and electrolytic degradation of electrolytes. When compared with gel polymer electrolytes (GPEs), SPEs are typically less reactive toward the electrodes. Additionally, they provide higher safety, prevent the build-up of internal pressure and can be designed in many desirable sizes and shapes. High ionic conductivity, adequate chemical and mechanical strength, extended thermal stability, and low price are the favorable characteristics of polymer electrolyte membranes [4].

Solid acid membranes are a fascinating class of materials built upon hydrogen bonded oxyanion groups. These compounds conduct protons without the assistance of mobile water molecules, opening new technological possibilities and scientific avenues [4].

In order to enhancement electrical conductivity of polymer electrolyte at ambient temperature without affecting their stability properties to an undesirable level, various approaches are currently in vogue such as copolymerization and plasticization. The essence of plasticization is to enhance the conductivity of polymer electrolyte by means of additives of low molecular weight and high dielectric constant such as propylene carbonate (PC) ethylene carbonate (EC) and poly ethylene glycol (PEG). The addition of plasticizers could enhance the conductivity and better contact between the electrolyte\electrode [4]. The role of plasticizer should be enhancement in the fraction of amorphous phase and increasing flexibility in the polymeric segments [5]. EC has a high dielectric constant and therefore can weaken the columbic force between cation and anion and lead to ion dissociation [6].

One of the most promising ways to improve the morphological and electrochemical properties of polymer electrolytes is by the addition of ceramic fillers[8].The addition of inorganic fillers, like glasses, aluminas, silica or other ceramics, to the polymer electrolyte generally improves their transport properties, the resistance to crystallization and the stability of the electrode–electrolyte interfaces. Whereas the latter two effects are always observed, the conductivity enhancement depends on the filler used and also on the particle dimensions. The increase in conductivity with respect to the corresponding unfilled electrolytes was attributed to the enlargement of the amorphous phase in the polymer matrix [9]. Addition of Si into plasticized solid acid polymer electrolytes has attracted considerable attention due to its enhanced ionic conductivities and electrolyte/electrode interface stability. The increase in conductivity has been found to depend upon the concentration.

1.2 Aim of the Present Work

Our research is proceeding to develop novel nanocomposite polymer electrolyte based on polyvinyl alcohol, $NaHSO_4$, EC plasticizer and Si as filler. PVA was used as host matrix for $NaHSO_4$: EC: Si to produce polymer electrolyte. The study will extend to characterization of polymer composite to optimize the electrical properties to be the electrolyte for magnesium battery.

1.3 Literature Survey

(I) Electrical and Dielectric Properties of PVA

P. B. Bhargav et al [10], studied the structural and electrical properties of pure and sodium bromide (NaBr) doped poly (vinyl alcohol) (PVA) polymer electrolyte films for solid state battery applications. XRD and FTIR studies confirm the complexation of salt with the polymer. DC conductivity was found to increase with the increase of dopant concentration as well as temperature. Transference number data suggests that the charge transport in this polymer electrolyte system is mainly due to ions. Electrochemical cells were fabricated with configuration Na/(PVA:NaBr)/V_2O_5 and Na/(PVA:NaBr) /(I_2+C+electrolyte). The fabricated cells give capacities of 4.85mAhg^{-1} and have an internal resistance of 900Ω.

P. B. Bhargav et al [11], studied structural and electrical studies of sodium iodide (NaI) doped poly (vinyl alcohol) polymer electrolyte films for their application in electrochemical cells. The XRD results revealed that the amorphous domains of PVA polymer matrix was increased with the increase in NaI salt concentration. The conductivity was found to increase with the increase in dopant concentration as well as temperature. Measurement of transference number data showed that the charge transport in these polymer electrolyte systems was predominantly due to ions.

M. Hema et al [12], studied structural, vibrational and electrical characterization of PVA–NH_4Br polymer electrolyte system. The maximum ionic conductivity (5.7×10^{-4} S. cm^{-1}) has been obtained for 25mol% NH_4Br-doped PVA polymer electrolyte. The temperature dependence of ionic conductivity of the prepared polymer electrolytes obeys Arrhenius law. The ionic transference number data showed that the charge transport in these polymer electrolyte systems was predominantly due to ions

M. Hema et al [13], studied FTIR, XRD and ac impedance spectroscopic for PVA polymer electrolyte doped with NH_4X (X = Cl, Br, I) polymer electrolyte. The XRD patterns of all the prepared polymer electrolytes reveal the amorphous nature of the films. From ac impedance spectroscopic studies, it has been found that PVA doped with NH_4I have high ionic conductivity (2.5×10^{-3} $S.cm^{-1}$) than PVA doped with NH_4Br (5.7×10^{-4} $S.cm^{-1}$) and NH_4Cl (1.0×10^{-5} $S.cm^{-1}$) polymer electrolytes. This is due to the large an ionic size and low lattice energy of NH_4I (in comparison with NH_4Br and NH_4Cl).The temperature dependence of ionic conductivity for all the PVA: NH_4X (X=Cl,Br,I) polymer films obey Arrhenius equation. Ionic transference number measured has been found to be in the range of 0.93–0.96 for all the polymer electrolytes proving that the total conductivity is mainly due to ions.

M. Hema et al [14], studied proton-conducting polymer electrolytes based on (PVA; 88% hydrolyzed) and (NH_4I) has been prepared by solution casting method with different molar ratios of polymer and salt using DMSO as solvent. The ionic conductivity has been found to increase with increasing salt concentration up to 25mol% beyond which the conductivity decreases and the highest ambient temperature conductivity has been found to be 2.5×10^{-3} $S.cm^{-1}$. The temperature- dependent conductivity follows the Arrhenius relation.

E.Sheha et al [15], studied a high voltage magnesium battery based on sulfuric acid H_2SO_4 (SA)-doped poly (vinyl alcohol) $(PVA)_{0.7}$ sodium bromide $(NaBr)_{0.3}$ solid polymer electrolyte. The highest conductivity of $(PVA)_{0.7}(NaBr)_{0.3}$ matrix at room temperature was 1.12×10^{-6} $S.cm^{-1}$ and this increased to 6×10^{-4} $S.cm^{-1}$ with doping by 2.6M sulfuric acid. The electrolyte with the highest electrical conductivity was used in the fabrication of a magnesium battery with the configuration $Mg/SPE/MnO_2$.

S.Badr et al [16], studied structural and electrical properties of pure and sulfuric acid (SA) H_2SO_4 doped poly(vinyl alcohol) $(PVA)_{0.7}$ sodium iodide $(NaI)_{0.3}$ solid polymer electrolyte. The XRD data revealed that sulfuric acid disrupt the semi-crystalline nature of $(PVA)_{0.7}(NaI)_{0.3}$ and convert it into an amorphous phase. The highest conductivity of $(PVA)_{0.7}$ $(NaI)_{0.3}$ matrix at room temperature was 10^{-5} $S.cm^{-1}$ and this increased to 10^{-3} $S.cm^{-1}$ with doping by 5.1 M sulfuric acid. The electrolyte with the highest electrical conductivity was used in the fabrication of a sodium battery with the configuration $Na/SPE/MnO_2$. The fabricated cells give open circuit voltage of 3.34 V and have an internal resistance of 4.5 kΩ.

C. U. Devi et al [17], studied electrical properties of pure and silver nitrate-doped polyvinyl alcohol (PVA) films. The electrical conductivity increased with increasing dopant concentration up to 0.5 wt. % of the dopant and then showed a decrease beyond this concentration. The increase in conductivity for dopant concentration up to 0.5 wt. % is attributed to formation of charge transfer complexes while the decrease for concentrations above 0.5 wt. % may be due to segregation. The variation of electrical conductivity with temperature showed two regions of activation with activation energies 0.8 and 0.3eV for undoped films and 1.3 and 0.3eV for doped films. *I–V* characteristics indicated that Schottky emission is the dominant charge transport mechanism in both undoped and $AgNO_3$-doped films.

M.E. Ferna´ ndez et al [18]**,** studied impedance spectroscopy of the polymer electrolyte based on poly (vinyl alcohol) (PVA)– (NaI + 4AgI)-$2H_2O$. The polymer electrolyte exhibited an ionic conductivity of ~10^{-1} $S.cm^{-1}$ and shows to best able and constant in a wide temperature range (10–70 °C) for the hydrated samples. There are three dielectric relaxations appear in both the imaginary and real part of the permittivity. These relaxations are related with the cooperative segmental movements of the macromolecular chains, normal-mode relaxation and localized motions of the structural units.

(II) Plasticized Solid Polymer Electrolyte

M. E. Gouda et al [19], studied the impact of ethylene carbonate (EC) on electrical properties of poly (vinyl alcohol) PVA/ ammonium sulfate $(NH4)_2SO_4$/ sulfuric acid H_2SO_4 proton-conductive membrane PCM. The XRD patterns of polymer electrolytes reveal the amorphous nature of the films. A maximum conductivity of 7.3×10^{-5} S. cm^{-1} has been achieved at ambient temperature for PCM containing 0.25 g of (EC). Measurement of transference number data showed that the charge transport in these polymer electrolyte systems was predominantly due to ions. The electrolyte with the highest electrical conductivity was used in the fabrication of a solid-state electrochemical cell with the configuration (Mg/PCM/PbO_2). The fabricated cells gave capacity of 650 μAh and have an internal resistance of 11.6 kΩ.

S. A. Suthanthiraraj [20], studied the impact of ethylene carbonate on ion transport characteristics of polyvinylidene fluoride (PVdF)–silver triflate $(AgCF_3SO_{3)}$ polymer electrolyte system. Addition of silver triflate has resulted in an increase in the room temperature (298 K) electrical conductivity of the polymer from 10^{-6} to 10^{-5} S.cm^{-1} where as incorporation of EC as the plasticizer has further enhanced the conductivity value by an order of magnitude to 10^{-4} S.cm^{-1} owing to the possible decrease in crystallinity of the polymer matrix.

M.F.Z.Kadir [21]**,** studied the plasticized chitosan–PVA blend polymer electrolyte based proton battery. In this work, 36 wt. % PVA and 24 wt. % chitosan blend doped with 40 wt. % NH_4NO_3 exhibited the highest room temperature conductivity. The conductivity value obtained was 2.07×10^{-5} S.cm^{-1}. EC was then added in various quantities to the [60 wt. %

PVA–40 wt. % chitosan] composition in order to enhance the conductivity of the sample. The highest conductivity obtained was 1.60×10^{-3} $S.cm^{-1}$ for the sample containing 70 wt. % EC. The highest conducting sample in the plasticized system was used to fabricate battery with configuration $Zn//MnO_2$.The open circuit potential (OCP) of the fabricated battery was between 1.6 and 1.7 V.

M. Kumar et al [22], studied the role of plasticizer's on conductivity of polyethylene oxide (PEO) – ammonium fluoride (NH_4F) polymer electrolytes. The addition of dimethyl acetamide as a plasticizer with dielectric constant ($\varepsilon \sim 37.8$) higher than that of PEO ($\varepsilon \sim 5$) results in an increase of conductivity by more than three orders of magnitude where as the addition of diethylcarbonate as a plasticizer with dielectric constant $\varepsilon \sim 2.8$ lower than that of PEO does not enhance the conductivity of $PEO–NH_4F$ polymer electrolytes. The increase in conductivity has further been found to depend upon the concentration of plasticizer, the concentration of salt in the polymer electrolyte as well as on the dielectric constant value of the plasticizer used.

H. M. J. C. Pitawala et al [23], studied the effect of plasticizers (EC or PC) on the ionic conductivity and thermal properties of the $(PEO)_9LiTf$: Al_2O_3 nanocomposite polymer electrolyte system. The incorporation of plasticizers alone will yield polymer electrolytes with enhanced conductivity but with poor mechanical properties. However, mechanical properties can be improved by incorporating ceramic fillers to the plasticized system. Nanocomposite solid polymer electrolyte films (200–600μm) were prepared by common solvent-casting method. It was shown that the incorporating 15 wt. % Al_2O_3 filler in to PEO: LiTf polymer electrolyte significantly enhanced the ionic conductivity [σ_{RT} (max) $=7.8\times10^{-6}$ S. cm^{-1}]. The conductivity enhancement with EC is higher than PC. However, mixture of plasticizer (EC+PC) showed maximum conductivity enhancement in the temperature range interest, giving the value [σ_{RT} (max) $=1.2\times10^{-4}$ S. cm^{-1}]. Al_2O_3 filler would contribute to conductivity enhancement by transient hydrogen bonding of migrating ionic species with O–OH groups at the filler grain surface.

(III) Mg Anode

G. G. Kumar et al [24], studied solid-state Mg/MnO_2 cell employing a gel polymer electrolyte of magnesium triflate. A capacity value of about 40 mAh g^{-1} of MnO_2 is obtained. The $Mg/GPE/MnO_2$ cells are subjected to about 20 charge–discharge cycles with a consistent capacity of about 20 mAh g^{-1} cycle-life data is limited by surface passivation of the magnesium negative electrode and poor recharge ability of the MnO_2 positive electrode.

D. Aurbach et al [2], studied a comparison between the electrochemical behavior of reversible magnesium and lithium electrodes. In the case of lithium, the active metal is always covered by surface films. Li dissolution-deposition is reversible only when the surface films contain elastomers and are flexible. In contrast to lithium, magnesium electrodes are reversible only in solutions where surface film free conditions exist. Mg does not react with ethers, and thus, in ethereal solutions.

D. Aurbach et al [25], studied a short review on the comparison between Li battery systems and rechargeable magnesium battery technology. Magnesium is relatively cheap, much safer to use and handle than lithium, and its compounds are usually non-toxic. Similar to lithium, magnesium is covered by surface films in any 'inert' atmosphere that contains atmospheric contaminants, and in most of the relevant electrolyte solutions for batteries. In contrast to lithium where the surface films covering the active metal are Li-ion conductors, surface films formed similarly on magnesium cannot conduct the bivalent Mg^{-2} ions.

Ji.Oh et al [26], studied preparation and characterization of gel polymer electrolytes for solid state magnesium batteries. Solid state magnesium cell employing magnesium anode, GPE, and vanadium oxide cathode was assembled and its cycling characteristics were investigated. The $Mg/GPE/V_2O_5$ cell showed low initial discharge capacity of 58 mAh/g based on active V_2O_5 material and poor cycling characteristics.

(IV) Manganese Dioxides Cathode

Christpher et al [27], studied development and utility of manganese oxides as cathodes in lithium batteries. There are two topics researched at Argonne over the last 12 years are highlighted. First, the addition of lithia (Li_2O) as a stabilizing component in 3V alpha-MnO_2 is examined. Second, an overview of the evolution of layered–layered composite-structured electrodes derived from the lithium-manganese oxide (Li_2MnO_3) layered rock-salt phase is presented.

M. Freitas et al [28] studied recycling manganese from spent Zn-MnO_2 primary batteries. Energy dispersive X-ray analysis of the cathode surface also shows the presence of zinc from the anode and chloride from the electrolyte. The charge efficiency by electrode position was 85% at 25.0 mAcm^{-2}. In the anodic process, the material oxidizes at the electrode/solution interface and precipitates to the bottom of the cell. Only a fraction corresponding to 20% of the charge density is deposited onto the electrode. This happens because Mn^{2+} oxidizes to Mn^{3+}, which then suffers disproportionate.

S. Lee et al [29], studied the characterization of MnO_2 positive electrode for Fuel Cell/Battery (FCB). A positive electrode containing MnO_2 was fabricated and its performance was evaluated for Charge/discharge behavior in three different systems: (i) secondary battery positive electrode, (ii) positive electrode in an alkaline fuel cell, and (iii) positive electrode performance in an FCB system by performing half cell tests. The *I–V* characteristics of MnO_2 material were measured to check the feasibility of the fuel cell system by supplying H_2 into the negative electrode and O_2 into the MnO_2 positive electrode, respectively. The MnO_2 electrode also showed that it functioned as an FCB positive electrode, which was confirmed by continued production of current when the O_2 supply was terminated. These results suggest that MnO_2 is a good candidate for an FCB positive electrode material.

M. Manickama et al [30], studied the discharge characteristics of manganese dioxide (γ-MnO_2 of electrolytic manganese dioxide (EMD) type) as a cathode material in a Zn–MnO_2 battery containing saturated aqueous LiOH electrolyte. The X-ray diffraction (XRD) and X-ray photoelectron spectroscopy (XPS) data on the discharged material indicate that lithium is intercalated into the host structure of EMD without the destruction of its core structure. The XPS data show that a layer of insoluble material, possibly Li_2CO_3, is deposited on the cathode, creating a barrier to H_2O, thus preventing the formation of Mn hydroxides, but allowing the migration of Li ions into the MnO_2 structure. The cell could be reversibly charged with 83% of voltaic efficiency at 0.5 mA/cm^2 current density to a 1.9V cut off voltage. The percentage utilization of the cathode material during discharge was 56%.

(V) Pyrite Cathode

J.Choi et al [31], studied the electrochemical characteristics at room temperature of Li/FeS_2 batteries with natural pyrite cathode. The organic electrolytes used were 1M lithium bis(trifluoromethylsulfonyl)imide (LiTFSI) in tetra(ethylene glycol) dimethyl ether (TEGDME) or a mixture of TEGDME and 1,3-dioxolane (DOX), and 1M $LiPF_6$ in a mixture of ethylene carbonate (EC) and dimethyl carbonate (DMC). The discharge capacities of Li/FeS_2 cells with 1M LiTFSI dissolved in TEGDME were 772 mAh g^{-1} at the 1st cycle and 313 mAh g^{-1} at the 25th cycle. The cycling performance could be improved by using a mixture of TEGDME and DOX as the electrolyte. It was found that TEGDME contributed to high initial discharge capacity, whereas, DOX contributed to better stabilization of the performance. The first discharge capacities of Li/FeS_2 cells showed a decreasing trend with higher current densities (615 and 534 mAh g^{-1}). Li/FeS_2 cells with the battery grade electrolyte 1M $LiPF_6$ in EC/DMC had lower initial discharge capacity and cycling capability compared to the TEGDME system.

T.B.Kima et al [32], studied electrochemical properties of sodium/pyrite battery at room temperature. They investigated sodium/pyrite battery because sodium and pyrite (natural FeS_2 ore) were very cheap materials. The sodium/pyrite battery showed high discharge capacity of 630 mAh g^{-1}-FeS_2 with $50mAg^{-1}$-FeS_2 at room temperature, which was higher than that of Li ion battery and Na/synthetic FeS_2 battery. The discharge capacity decreased continuously by repeated charge–discharge cycling, and remained 85 mAh g^{-1} FeS_2 after 50th cycles.

E. Peled et al [33], studied the development and characterization of bipolar lithium composite polymer electrolyte (CPE)-FeS_2 battery for applications in electric vehicles. The battery has several advantages over other state-of-the-art polymer electrolyte batteries: (i) low-cost cathode, pyrite, is a natural ore, therefore environmentally friendly, (ii) small prototype cells exhibited very high specific energy, (iii) this battery has an internal electrochemical overcharge protection mechanism (which is essential for bipolar batteries), and (iv) for CPE, the Li/electrolyte interracial resistance is low and stable up to 3000 h at 120 °C.

E. Strauss et al [34], studied of phase changes during 500 full cycles of Li: composite polymer electrolyte: FeS_2 battery. The Li: composite polymer electrolyte (CPE): pyrite battery, which has a high theoretical energy density (about 810 Wh kg^{-1} based on 2.8e:FeS_2), and is made of cheap, non-toxic and green compounds is a good candidate for EV applications. Materials cost is estimated at 50$ kWh^{-1} five times lower than that of other lithium and lithium-ion batteries. Charge–discharge processes in the Li/LiI_ (PEO) $_{n}$_Al_2O_3-based CPE: pyrite battery during long-term cycle life has been analyzed. Up to seven phases have been identified and found to change during the first 50–100 cycles. These phases do not change much over the subsequent 400 cycles.

Y. Horn et.al [35]**,** studied chemical composition, physical characteristics and structural features of a natural FeS_2 powder and a synthetic FeS_2 sample were correlated with their specific discharge capacities in lithium cells. The levels of impurity elements, primarily present as second-phase oxides and sulfides, were significantly higher in the natural FeS_2 than in the synthetic sample. These impure second-phases were electrochemically inactive, and they did not have any significant effects on the discharge of Li/FeS_2 cells. Trace amounts of impurity elements were detected in solid solution of FeS_2 pyrite and the pyrite structure was nearly ideal for both the natural and synthetic samples. A sulfur-deficient pyrrhotite $FeS_{1.3}$ phase was found in the center of some large synthetic FeS_2 particles, which was electrochemically active at 1.5 V versus lithium. The superior rate capability of Li/synthetic FeS_2 cells was attributed primarily to the smaller grain sizes within synthetic FeS_2 particles in comparison to the natural FeS_2 sample.

E.Strauss et al [36], studied lithium polymer electrolyte pyrite rechargeable battery: comparative characterization of natural pyrite from different sources as cathode material. As determined by thermo gravimetric measurements, the pyrite samples of ‘‘vendors A and G’’ were highly stable up to 500°C. The decomposition of the ‘‘vendor E’’ sample, including eight phase transitions, starts at about 100°C and is caused by the surface impurities of pyrite, such as iron oxides, hydroxides and sulfates. It is noteworthy that the performance characteristics, such as Li/Fe ratio, faradaic efficiency and charge–discharge over potential of the Li/composite polymer electrolyte (CPE)/10µm-thick cathode pyrite cells were found to be almost independent of the degree of contamination and, consequently, of the pyrite source during 30 cycles.

E. Peled et al [37], studied Li/Composite polymer electrolyte (CPE) / FeS_2, 10 µ-thick-cathode battery had a cathode reversible capacity of 625 mAh/g (2.8 e/FeS_2), which is five times that of the Li_xCoO_2 cathode (120 mAh/g). The theoretical energy density of the Li/FeS_2 couple, based on 2.8e / FeS_2 and on an average voltage of 1.6 V, is close to 860 Wh/kg, which is almost twice that of the Li/$LiCoO_2$ cell. For 45 µ-thick cathodes, 3.9 mAh/cm^2 reversible capacities were achieved. On the basis of this value, the projected specific energy for a bipolar Li/CPE/FeS_2 battery is 170 Wh/kg and 250 Wh/kg is the long-term projection value.

S. Kostov et al [38], studied x-ray absorption fine structure of FeS_2 cathodes in lithium polymer electrolyte batteries. They have performed synchrotron x-ray absorption measurements on a series of sealed Li/composite polymer electrolyte (CPE)/FeS_2 cells charged or discharged to various potentials.

G. Ardel et al [39]**,** studied rechargeable lithium/hybrid-electrolyte/pyrite battery. Ionic conductivity of (0.1–2.5) $\times 10^{-3}$ S/cm at room temperature (RT) was achieved for hybrid polymer electrolyte (HPE) and 5 $\times 10^{-3}$ S/cm for gel polymer electrolyte (GPE). The specific capacity of the first discharge Li/pyrite cells with both HPEs and GPEs varied from 650 to 1000 mAh/g.

A.G. Ritchie et al [40], studied lithium-ion/iron sulphide rechargeable batteries. Iron would be preferable on grounds of cost and safety but unfortunately lithium iron oxides cannot be cycled. Iron compounds are cheap and iron sulphides can readily be obtained as minerals, without the need for chemical synthesis. However, to make a lithium-ion battery, the cathode material must contain lithium so the iron sulphide must be lithiated to use this as a cathode material. This can be synthesised by literature methods involving solid state syntheses at high temperature for long times.

E. Strauss et al [41], studied the charge–discharge mechanism in the all solid state lithium/composite-polymer-electrolyte/pyrite battery operating at 120°C. Analysis of the experimental XRD, XPS and electrochemical data suggests that creation of sulfur vacancies in pyrite suppresses a sudden jump of charge voltage, which is associated with slow mass transport of iron (II) cations through the Li_2FeS_2 phase. They believe that experimental findings show considerable promise of creating sulfur-deficient pyrite structures for cathodes to be used in high-energy-density all solid state lithium batteries. The nature and exact composition of a 1.2–1.3 V discharge plateau is still unclear.

V. Livshits et al [42]**,** studied the development of a bipolar Li/composite polymer electrolyte/pyrite battery for electric vehicles. The long-term projection for a prototype sealed bipolar Li/composite polymer electrolyte/pyrite ($Li/CPE/FeS_2$) battery, with a 45 µm-thick cathode is 250 Wh/kg specific energy.