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Nanomaterials for Energy Storage Applications: Current Status and Future Outlook

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During the last 28 years the evolutionary improvements in lithium-ion battery (LIB) technologies increased LIB volumetric and gravimetric energy densities by over 3 times and reduced cell price by up to 50 times. As a result, LIBs mostly replaced other rechargeable battery technologies for most portable applications. Na-ion, K-ion, Mg-ion or Ca-ion will unlikely be able to replace LIBs for most applications even in the long run because relatively small reduction in alkali metal substitution costs (<3 % as a fraction of the total battery prices) does not compensate for the LIB pack cost increase related to reduced cell energy density (15-40%). As a result, energy-normalized cell, and battery management system cost increases by 12-37% to the levels where these novel technologies become not economical.

Fig. 1 illustrates the key factors that should be improved significantly to attain affordable electric transportation with LIB packs: (i) mineral abundance for electrode materials, (ii) low raw materials' processing cost, (iii) good cell performance characteristics and (4) efficient pack design.[1] Very large future demand is projected based on the gradual cost reduction in LIB cells from the current \$100-250 kWh^{-1} to below \$70 kWh^{-1}. To accelerate the transition to renewable energy economy and electric transportation the cost of LIBs should be reduced rapidly and drastically. This can become feasible if traditional intercalation-type active electrode materials (e.g., graphite anodes and lithium nickel cobalt aluminum oxide (NCA) or lithium nickel cobalt manganese oxide (NCM) cathodes) in LIB construction are replaced with low-cost, broadly available, high-capacity conversion-type active materials, such as silicon (Si)-based anodes and metal fluoride (e.g., 3LiF/Fe)-based or sulfide (Li_2S)-based cathodes.

A transition to "revolutionary" conversion-type LIB chemistries should enable cost reduction down to \$30 kWh^{-1}. However, conversion active materials suffer from multiple limitations, such as large volume changes, low conductivity and unfavorable interactions with liquid electrolytes (e.g., active material dissolution or electrolyte decomposition during cycling), commonly leading to low attainable energy density, significant impedance growth, rapid capacity decay and premature cell failure. The use of nanostructured composite materials may overcome such limitations.[2-4] Nanotechnology proved to be capable of (i) improving kinetics of electrochemical reactions, (ii) preventing localized mechanical failure and degradation of the solid electrolyte interphases due to volume changes, and (iii) preventing dissolution of active materials during cycling. Precise control over nanocomposite chemistry and dimensions is commonly needed to attain the desirable material characteristics. However, for practical applications, synthesis methods need to additionally be inexpensive at scale and rely on the use of low-cost, broadly available precursors. In addition, it is important that novel materials remain fully compatible with currently operating and planned LIB giga-factories. Increase in the volumetric cell energy density enabled by such materials improvements will result in larger output of giga-factories without any additional investments in equipment or operating expenses. As a result, not only active materials, but also the cell fabrication costs will be reduced substantially. Furthermore, the move to higher energy density conversion-type cells will additionally improve the energy efficiency and reduce CO_2 emission during LIB cell production.

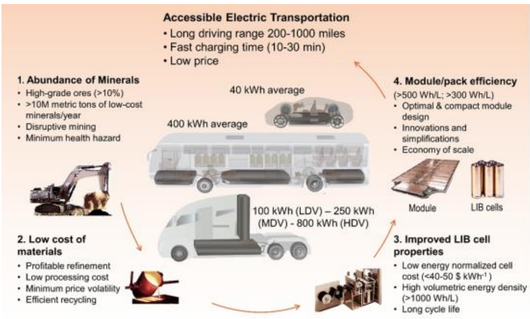

Fig. 1. Key improvement areas for affordable electric transportation. Reproduced from [1].

In my talk I will review the key materials' challenges in LIB industry and will provide multiple examples how novel nanotechnologies may enable successful commercialization of conversion-type cathode and anode materials. Conversion-type Si anodes have already started to gain commercial traction in the marketplace this year. I expect that Si-dominant anodes will take over most of the market in the next decade, while conversion-type cathodes will start dominating the market by 2030-2040.

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