



# The Development of Advanced High Voltage, High Specific Energy and High Power Li-ion Cells with Improved Low Temperature Performance

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Program: FY22 R&TD Topics

Strategic Focus Area: Energy storage

## Objectives

The objective of the proposed research is to develop advanced small format Li-ion chemistries that can provide high specific energy (175-225 Wh/kg at  $-40^{\circ}\text{C}$  at a C/5 rate), good rate capability (up to C/2 rates), and the capability to operate over a wide temperature range, ( $-60^{\circ}\text{C}$  to  $+50^{\circ}\text{C}$ , including charging at temperatures down to  $-40^{\circ}\text{C}$ ). Current state-of-art small format cells generally display 180-230 Wh/kg specific energy at ambient temperature and have poor performance below  $-20^{\circ}\text{C}$ , especially at high rates. The objective will be achieved by coupling high voltage systems (i.e., LiNiMnCoO<sub>2</sub> (NMC), LiCoPO<sub>4</sub>, LiCoO<sub>2</sub>) with advanced lithium ion electrolyte solutions, which will be incorporated into prototype cells that will be manufactured by a vendor (i.e., E-One Moli Energy and/or Quallion). The focus will be upon the design of novel electrolytes that inherently have increased stability at high voltage and the use of additives to improve the electrode kinetics and limit the propensity of lithium plating occurring and enhance the charge characteristics. The developed wide voltage range and operating temperature range electrolytes will be incorporated into experimental and prototype high specific energy aerospace quality Li-ion cells manufactured by a vendor.

## Background

Current state-of-practice (SOP) Li-ion batteries, such as the large format InSight Chemistry consisting of Graphite/LiNiCoAlO<sub>2</sub>, can operate from  $-30^{\circ}\text{C}$  to  $+35^{\circ}\text{C}$ . At  $-40^{\circ}\text{C}$ , the cells can deliver 105 Wh/kg at a C/5 rate when charged at room temperature. In contrast, commercial 18650 cells perform very poorly at temperatures of  $-30^{\circ}\text{C}$  and below, providing negligible capacity at  $-40^{\circ}\text{C}$ . Rechargeable batteries that can provide high specific energy (175-225 Wh/kg at  $-40^{\circ}\text{C}$  at a C/5 rate), good rate capability (up to C/2 rates), and the capability to operate over a wide temperature range ( $-60^{\circ}\text{C}$  to  $+50^{\circ}\text{C}$ , including charging at temperatures down to  $-40^{\circ}\text{C}$ ) are increasingly desirable for a number of JPL future missions. Furthermore, Li-ion batteries configured in a small cell format (similar to SMAP or the Europa Clipper) are becoming more attractive compared to large cell formats, due to enhanced safety characteristics and improved specific energy. Future applications that will be enabled or enhanced by the developed technology include: (i) future Mars landers, (ii) future Mars rovers, including the Mars Sample Return mission, and (iii) future planetary aerial vehicles, where high specific energy, high power and wide operating temperature range is desired.

## Approach and Results

The approach of the research program consists of designing lithium-based organic electrolytes that contain electrochemically stable solvents and functional additives, which are targeted at stabilizing the electrode interfaces to achieve enhanced voltage stability and improved kinetics. The key innovative element of this proposed effort is designing of Li-ion electrolytes tailored to support high voltage operation and very low temperature battery operation. The electrolytes feature mixtures of organic carbonates (EC, DEC, DMC, EMC, and FEC), organic esters (methyl formate, methyl acetate, methyl propionate, ethyl propionate, and methyl butyrate), lithium conducting salts (LiPF<sub>6</sub>, LiBF<sub>4</sub>, LiDFOB, and LiBOB) and electrolyte additives intended to improve the properties of the anode Solid Electrolyte Interphase (SEI) (such as LiFSI, vinylene carbonate (VC), LiPO<sub>2</sub>F<sub>2</sub>, ethylene sulfite, and propane sultone).

- Performed three-electrode experimental cell studies with graphite and LiNi<sub>0.80</sub>Mn<sub>0.10</sub>Co<sub>0.10</sub>O<sub>2</sub> (NMC 811) electrodes. Improved performance observed at C/5 (Fig. 1) at  $-40^{\circ}\text{C}$ .
- Evaluated available in-house high specific energy E-One Moli ICRM and Quallion 18650-size cells that contain JPL electrolytes, as reported previously.
- The best performing electrolyte at lower temperatures and higher rates was the MP-based solution with FEC, namely 1.20M LiPF<sub>6</sub> in EC+EMC+MP (20:20:60 vol %) + 2 wt% FEC
- Over 174 Wh/kg at a C/20 rate at  $-40^{\circ}\text{C}$  (Goal = 175 Wh/kg at C/5), was achieved with the E-One Moli cells. Results represent dramatic improvement over SOA of 105 Wh/kg at C/5 rate (InSight).
- Excellent results have also been achieved with Quallion Graphite/NMC 811 18650-size prototype cells with JPL electrolytes, shown in Fig. 2.
- Good cycle life performance has been obtained, with less than 3% capacity loss after completing >100 cycles, as shown in Fig. 3.
- Excellent results have also been achieved with Quallion Graphite-Si/NCA 18650-size prototype cells, with over 127 Wh/kg being delivered at  $-50^{\circ}\text{C}$ , as shown in Fig. 4.

## Significance/Benefits to JPL and NASA

Since this program was successfully completed, a number of future applications can potentially benefit from the developed technology, including: (i) future Mars landers, (ii) future Mars rovers, including the Mars Sample Return mission, and (iii) future planetary aerial vehicles, where high specific energy, high power and wide operating temperature range is desired. Upon successful completion of the work, we will plan to contact the Planetary Science Directorate (PSD) to explore any future opportunity to infuse the technology into a future mission. Furthermore, the developed technology will have promise for future mission to the Icy Moons of Jupiter and Saturn, which require high specific energy and wide operating temperature range.

## Publications

- Marshall C. Smart, F. C. Krause, J. -P. Jones, B. V. Ratnakumar and Mark Shoesmith, "Ester and Carbonate-Based Low Temperature Electrolytes in High Specific Energy and High Power 18650 Li-ion Cells for Future NASA Missions," ECS PRIME 2020 Joint International Meeting, (Virtual Meeting), Oct. 8, 2020.
- M. C. Smart, F. C. Krause, and J. -P. Jones, "Development of Low Temperature Electrolytes for Operation of Lithium-ion Batteries in Extreme Environments for NASA Missions", Center for Research in Extreme Batteries (CREB) Bi-Annual Meeting, University of Maryland, December 10, 2021

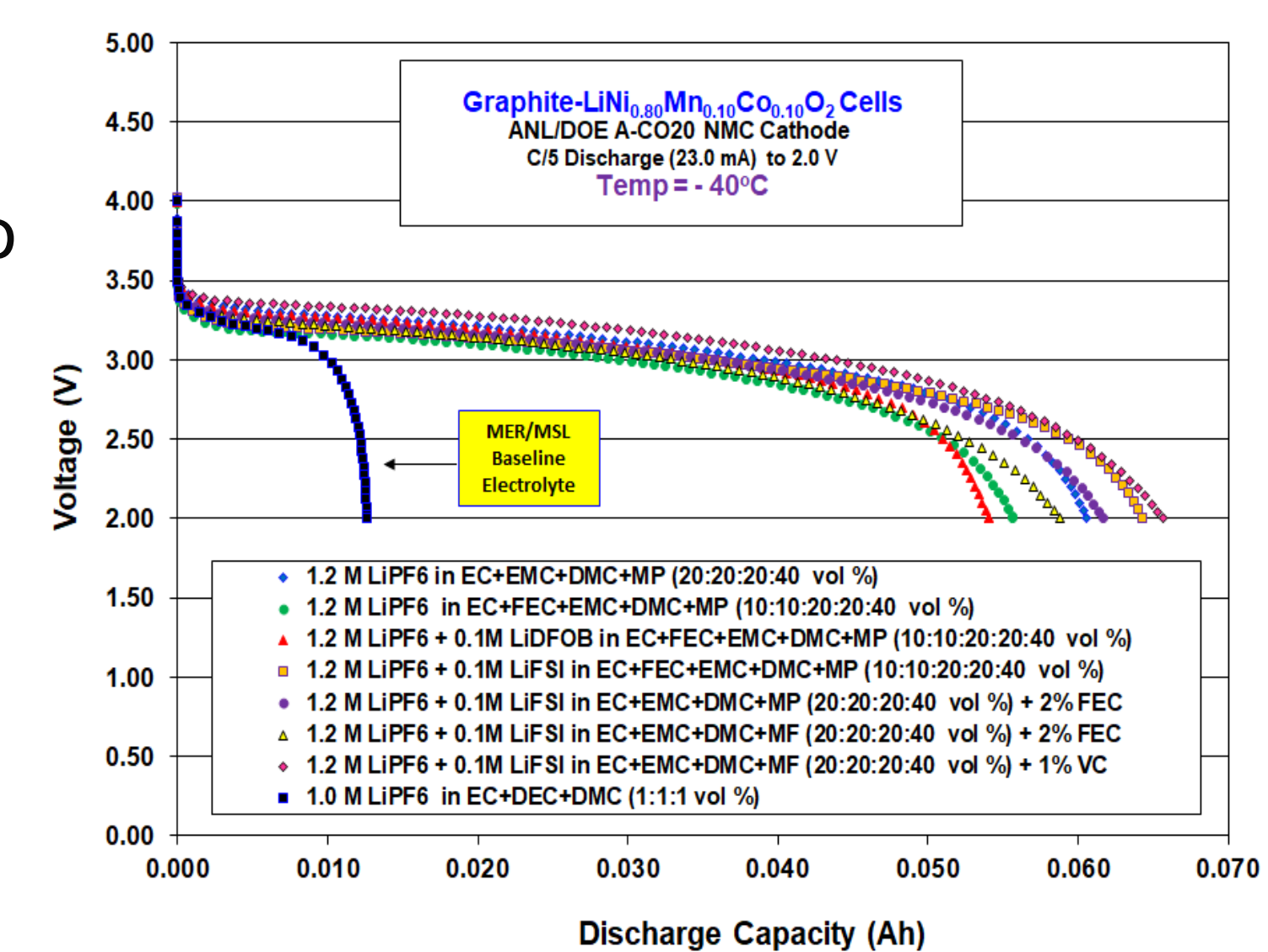


Figure 1

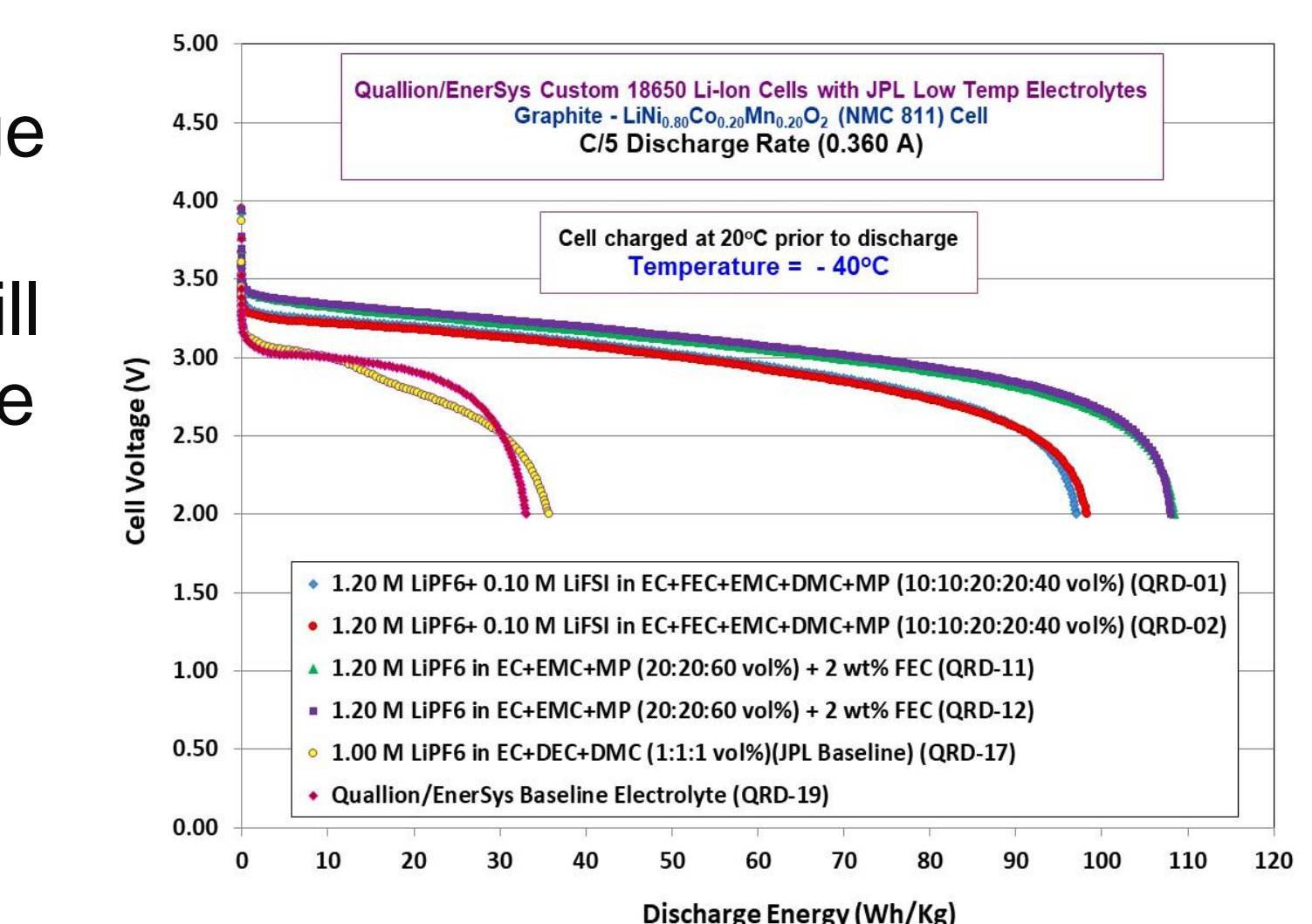


Figure 2

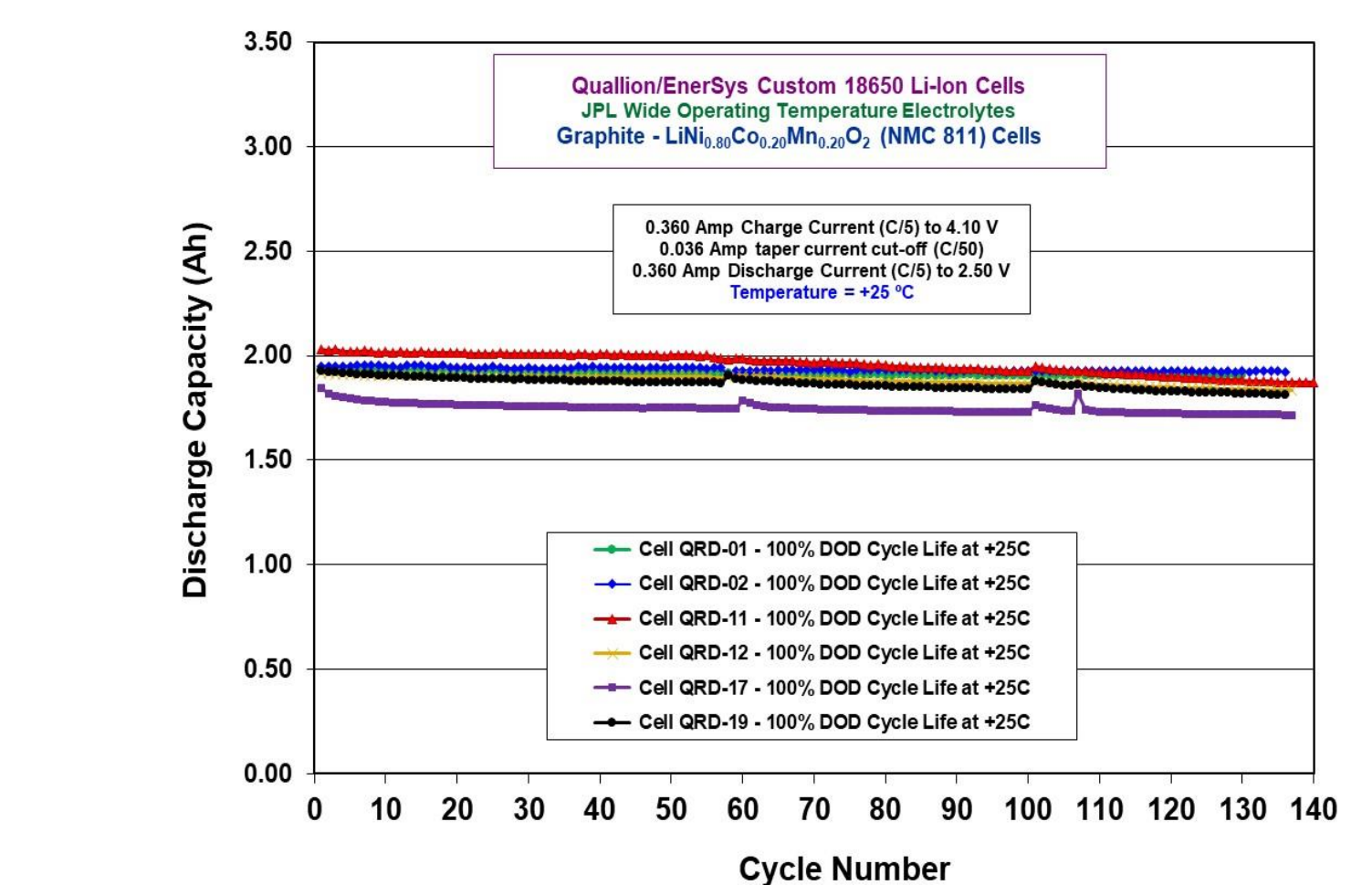


Figure 3

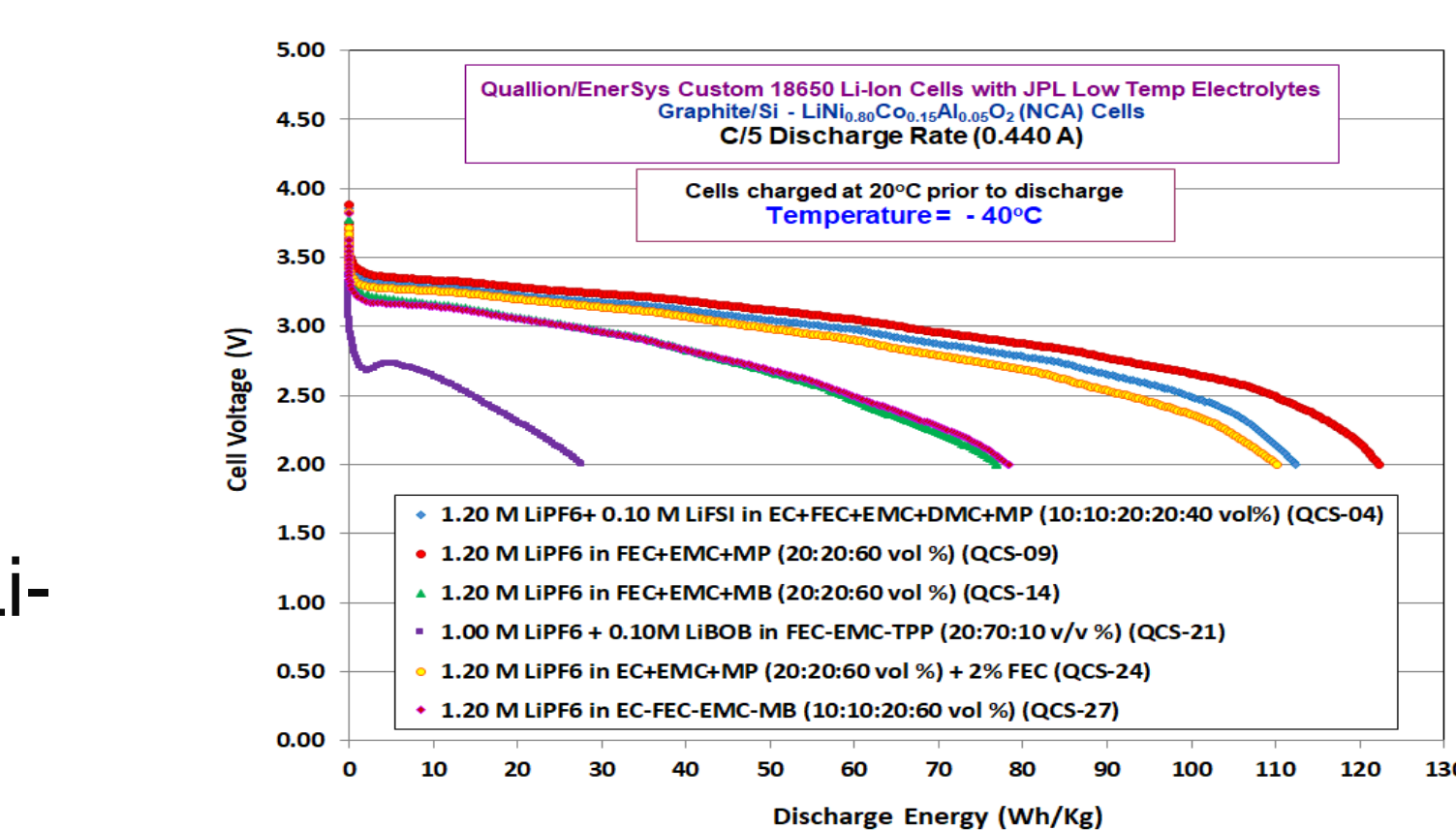


Figure 4

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