Background and Capabilities Memo

Active Battery Management Solutions

Improved Formation	Ultra-Fast Charge	Long Cycle Life	Real Time SoH
(~20% cost reduction)	(2-10C charge rate)	(2x improvement)	(Dedicated hardware)

January 2020

INTRODUCTION

The electrification revolution is moving full speed ahead and the need for better batteries that can charge faster, live longer, have higher energy density and lower cost has never been higher. Most new solutions are focused on improving battery chemistry and materials, creating engineered trade-offs between power and energy densities. A successful balance of features without significant trade-offs are unlikely to happen in the next 5+ years at the traditional material cell / electrode level.

GBatteries is an advanced battery technology company that is operating at the intersection of algorithm intelligence, electrochemistry, signal processing, and high-power electronics. GBatteries developed an Active Battery Management System (ABMS) – a combination of software and hardware that can be deployed as a stand-alone Battery Management Solution or part of a charger. Consisting of highly capable hardware and adaptive software algorithms, the technology value proposition is rapid development and maintenance of a pristine SEI (Solid Electrolyte Interphase) layer. As a result, GBatteries became the first and only company to demonstrate ultra-fast charging of off-the-shelf lithium-ion batteries without compromising its cycle life.

Based on the aforementioned achievements, GBatteries is able to address three parts of the battery life cycle:

- **Formation**;
  - accelerating formation process, reducing energy consumption, enhancing battery performance and potential reduction of overall battery cost up to ~20%.
- **Rate of Charge** and **Cycle Life**
  - accelerating charge rate (e.g. 2-10x) and increase (e.g. 2x) or maintain cycle life of off-the-shelf battery cells.
- **State of Health (SoH)**.
  - fast (<4hrs.) and accurate SoH determination for real-time safety and 2nd life applications.

GBatteries originated in 2012 as a result of the founders' disappointment with the limited capability of battery technology and their passion for achieving a sustainable, electrified and clean future for planet Earth. Starting as a small research project in a basement laboratory, GBatteries quickly attracted passionate and talented individuals, and achieved successful results – we are now a team of 20, consisting of highly capable and experienced engineers with diverse backgrounds and have a number of proof of concept projects with leading consumer electronics, electric vehicles and battery manufacturers.

This document outlines GBatteries' background and capabilities, technology overview, details on the aforementioned value propositions and business model.

TABLE OF CONTENTS

COMPANY BACKGROUND

GBatteries is an advanced battery technology company that is operating at the intersection of algorithm intelligence, electrochemistry, signal processing, and high-power electronics.

HISTORY

GBatteries originated as a result of the founders' disappointment with how quickly cell phone batteries lost capacity and the founders' passion for the sustainable, electrified and clean future of planet Earth.

In Spring 2012, Nick and Tim built the first prototype using a relay switch and a desktop computer. Two years later, the world-renowned start-up incubator, Y Combinator, along with top tier Silicon Valley investors, shared our vision and provided financial support.

In 2015, we successfully crowdfunded and shipped our first commercial product – The *BatteryBox* – that became a sensation for MacBook users. Over the next two years, we deployed over 25,000 batteries powered by ABMS v1.0 to over 38 countries.

In 2016, the company entered a stealth-mode to focus on ABMS v2.0 development and a business-to-business commercial, technology licensing model, with a mission to enable electric vehicles to charge as fast as it takes to fill up a tank of gas.

In 2019, following three years of intensive research and development, GBatteries launched out of stealth-mode with novel technology enabling ultra-fast charging of off-the-shelf Li-ion batteries, without compromising the battery cycle life.

First commercial product built by GBatteries – the "BatteryBox"

Launching out of the stealth-mode with ABMS v2.0 at the Detroit auto show (NAIAS), January 2019.

Team

GBatteries consists of 20 team members, formed by a unique blend of experienced business leaders, world-class engineers, and expert scientists, covering a diverse background in all aspects of the engineering suite, such as hardware, firmware, software, mechanical, power electronics, machine learning, electrochemistry, chemistry, and material science.

Some team members have nearly 30+ years of battery management, power electronics and material science experience, and some have 20+ years of management as C-level executives.

GBatteries' success and achievements are based on the strong foundation of the team and their capability, commitment, culture and competitiveness.

The GBatteries Team in the Ottawa, Canada headquarters.

Investors

GBatteries is funded by some of the world's leading Silicon Valley and European investors and is supported by both federal and provincial Canadian government agencies.

SVAngel | Y Combinator | AIRBUS VENTURES | initialized()

10x | SUSTAINABLE DEVELOPMENT TECHNOLOGY CANADA | Ontario | NRC·CNRC

LEADERSHIP

Kostyantyn Khomutov, Chief Executive Officer – is a seasoned executive with more than 15 years of experience in the global technology sector. Kostyantyn's focus is to deliver advanced battery technology, while driving operational excellence. He has a Master of Applied Science in Aerospace Engineering from Carleton University. Prior to GBatteries, Kostya was the founder of several organizations including Wolna, a SatCom company and Smart Rotor Systems (SRS), an organization that develops vibration and noise reduction technology for helicopters.

Tim Sherstyuk, Chief Commercial Officer – is a dynamic entrepreneur with 10 years of combined C-level experience as a Chief Operations Officer, Chief Executive Officer, and Chief Commercial Officer. Tim is driving the growth of the business. His role encompasses operations, marketing, business development, sales, and recruiting. He has been granted five patents during his work at GBatteries.

Alex Tkachenko, Chief Engineer – is a technology visionary, leading all the engineering aspects of the company. Alex has 15 years of experiences in system design and hardware development with deep electrochemical and battery knowledge. Alex is involved in all phases of projects, from planning to design, procurement to development, to integration of technology into customer's products. Alex graduated with distinction from the Electrical Engineering program at Carleton University. Prior to GBatteries, Alex served as a RF Hardware Developer at Ericsson and a Digital Hardware Developer at Nortel. Alex has been granted five patents during his work at GBatteries.

Nick Sherstyuk, Chief Technical Officer – is a critical thinker and experienced electrical engineer. He has over 30 years of experience working in battery management, analog and mixed signal circuit design. Nick's role involves research and development of active battery management algorithms, and battery testing. He has nine years of patent deconstruction and licensing experience and has been issued 14 patents, nine of which are with GBatteries. Before founding GBatteries, Nick was a Senior Systems Engineer at WiLan and the Director of Engineering at IMC (Information Mediary Corporation), a medical compliance technology company.

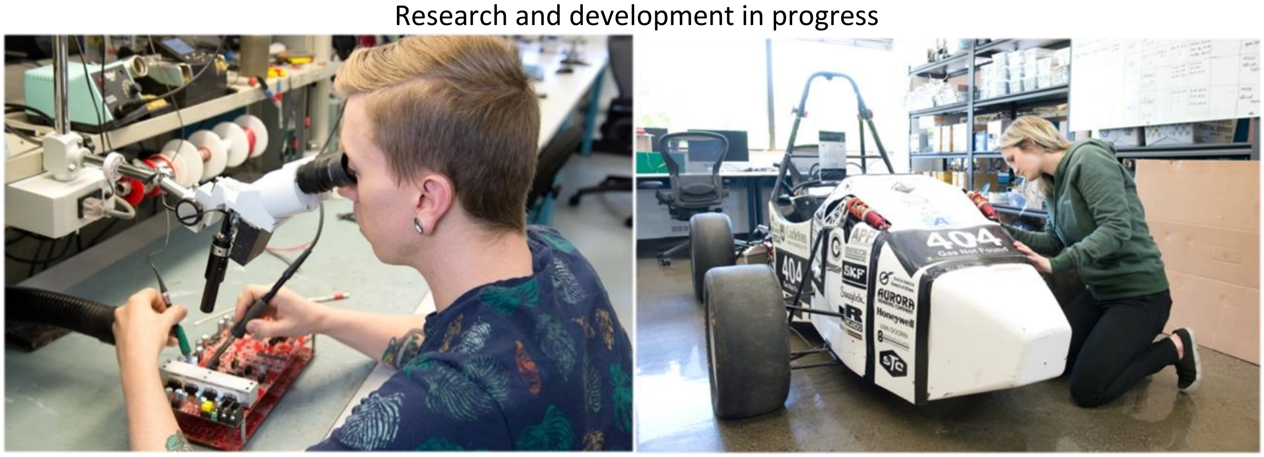
Dr. Bart Riley, Technical Director – a founder and former CTO at A123 Systems - Boston's largest IPO in the past decade and one of the world's largest automotive Li-ion suppliers with revenue exceeding $500M in 2016. He is a successful hard tech entrepreneur with over 25 years of experience leading projects, teams and businesses taking tech from lab to market. With senior management experience at AMSC, A123 Systems and Quantumscape, Bart has a track record solving complex technical and business problems to launch products in multiple verticals, including industrial equipment, consumer electronics, automotive, and grid. Dr. Bart Riley has a PhD in Materials Science from Cornell University, 85 publications and 62 US patents.

GBatteries is located in a 5,000 sq. ft. facility that has been built to accommodate research, design and the development of hardware and software tools for ABMS v2.0. In addition, it houses a laboratory with capability of testing 150+ battery cells (from 100mAh to 60Ah) simultaneously.

GBatteries has built a unique expertise and capability to design and develop all necessary tools and equipment in-house, including battery cyclers, test stands, active battery management systems, and advanced data collection and analysis software tools. GBatteries has the capacity to expand to meet additional test volumes as necessary.

Battery test laboratories

Research and development in progress



Traditional materials are reaching the limit
The electrification revolution is moving full speed ahead and the need for better batteries that can charge faster, live longer, have higher energy density and lower cost has never been higher.

Most new solutions are focused on improving battery chemistry and materials (structured electrodes, novel materials, new electrolytes, etc.), creating engineered trade-offs between power and energy densities. A successful balance of features without significant trade-offs are unlikely to happen in the next 5+ years at the traditional material cell / electrode level.

Electrode designs for high energy density cells require a thick, heavy loaded electrode structure, which creates a more indirect and obtrusive path for lithium diffusion. This structure creates significant concentration gradients across the thickness of the electrode during charge and discharge.

High concentration gradients, particularly in the anode, place undue stress on the particles themselves, leading to both rapid contraction/expansion of particles (i.e. additional SEI formation), as well as lithium plating in severe cases, and ultimately loss of capacity / degradation.

Background of pulse charging
Early in the development of electrochemical storage, pulse charging was recognized as a possible way to improve battery performance. Initial attempts to rapidly pulse charge batteries were done by applying a discharge current interspersed with rest periods, thus allowing relaxation of polarization within the electrodes[1].

Since then, many groups have investigated pulse charging of Li-ion batteries, but with limited success. These demonstrations were not commercialized, typically due to the lack of available control systems at scale, speed and the cost necessary for mass adoption. This began to change with the advent of pulse charging of Nickel-Cadmium (NiCd) batteries by the military in the 1990s; but, lithium-ion quickly displaced NiCd as the chemistry of choice, displacing the need for pulse charging techniques.

Nearly 30 years later, the current combination of traditional battery electrode designs and conventional charging approaches are at their limits. This has led to small historical improvements of lithium-ion batteries of only ~3% year-over-year, while on the contrary the cost of control systems, switching speeds and computational power are becoming affordable and ready for commercial mass adoption.

GBatteries solution is the next logical leap
GBatteries invented and developed a novel software and hardware solution that actively stimulates and samples cell response in time and frequency domains. The technology analyzes the cell in real time with self-learning algorithms and stops each energy pulse before severe irreversible chemical reactions take place during the charge.

GBatteries has developed and demonstrated an Active Battery Management System (ABMS), consisting of novel hardware, firmware and software, on a variety of consumer and EV battery cells. GBatteries has proven that an adaptive, rapid pulse charging method is capable of fast charge on commercially available cells without detriment to battery cell performance attributes, by maintaining a pristine SEI layer.

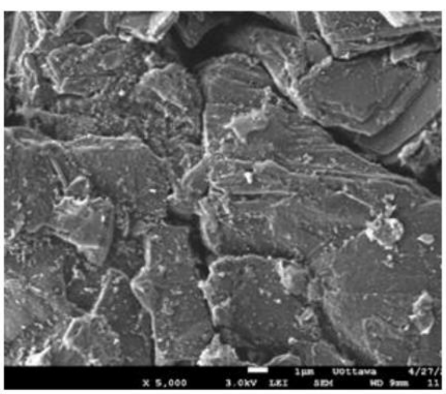
[1] (US Patents 3,609,503 & 3,597,673, Burkett et al).

GBatteries has developed a proprietary Active Battery Management System (ABMS) that utilizes adaptive energy pulses as an alternative to the CCCV (Constant Current, Constant Voltage) charging protocol. It takes into consideration real-time electrochemical and micro-kinetic processes that occur within both of the battery electrodes, electrolyte, separator, and SEI layer on top of the anode, enabling improved performance for off-the-shelf Li-ion batteries during their entire life cycle.

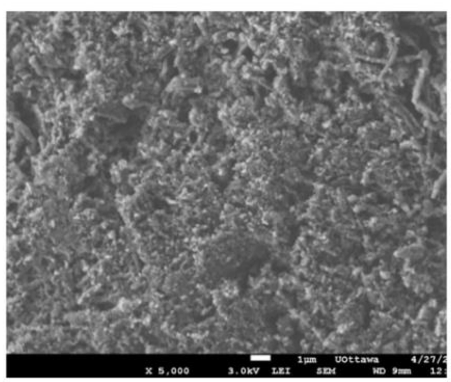
GBatteries technology is focused on suppression and prevention of dendrite growth, reduction or prevention of Li plating on the surface of an electrode, improving the diffusivity of Li ions in electrolyte and stabilization of pristine SEI layer evolution. In other words, energy pulses reduce ion concentration polarization levels in electrolyte, electrodes and SEI layer.

This includes progression of the electrode material's elastic deformations and mechanical impedance changes during different sections of charge/discharge pulses and relaxation periods between pulses. Models of a battery, Electrochemical Impedance Spectroscopy (EIS) including parasitic double layer capacitance formed on electrode surfaces are used in real time calculations.

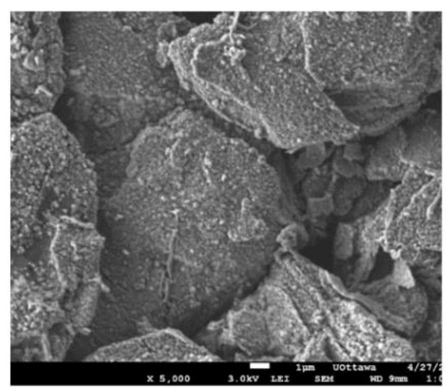
GBatteries has demonstrated the benefits of ABMS on a microscopic cell chemistry level. Unlike the conventional CCCV protocol, test data has revealed that the ABMS protocol does not result in additional formation of a SEI layer composed of organic species, and the significant cell impedance growth associated with SEI layer thickening. The figure below shows the difference in negative electrode surface composition after it was cycled at a 3C rate of charge using conventional CCCV and GBatteries' methods. A more detailed case study, performed on LG HG2 18650 battery cell, is outlined in Appendix A.



New
3 cycles (very slow)



CCCV, 3C charge
21 cycles



ABMS, 3C equivalent charge
1056 cycles

Images of SEM comparison of small (63mAh) LCO Pouch cell, where ABMS resulting in pristine SEI layer evolution after 1000+ cycles at 3C rate of charge

PRODUCT OVERVIEW

1. **Software:**
   - self-learning algorithms designed to generate unique pulse charge profiles based on real-time battery response in time and frequency domains.

2. **Hardware + Firmware:**
   - efficiently generate and dynamically adjust high frequency arbitrary waveform power stimulus;
   - acquire and process in real time and frequency domain V(t), I(t) and Z(f) data;

Example of novel hardware implementation for R&D in a laboratory environment.

TECHNOLOGY VALUE PROPOSITION

Improved Formation	**Ultra-Fast Charge**	**Long Cycle Life**	**Real Time SoH**
(10~20% cost reduction)	(2-10x charge rate)	(2x improvement)	(Dedicated hardware)

TECHNOLOGY APPLICATIONS

GBatteries envisions for the technology to be applied to three phases of the life cycle of a battery: (i) formation; (ii) charging and cycle life; and (iii) state of health (SoH) for real life safety and 2nd life applications.

FORMATION

Importance of formation

One of the most critical steps in battery manufacturing is a sensitive formation process. Formation is a necessary step to guarantee battery cell cyclic performance. It is achieved through the initial slow charge/discharge cycling of a newly built battery to activate battery chemistry/materials and initiate SEI layer growth.

The battery cell formation is a lengthy process that may last from one day and up to several weeks. It may account for ~10-20% of the total cost of the battery cell.

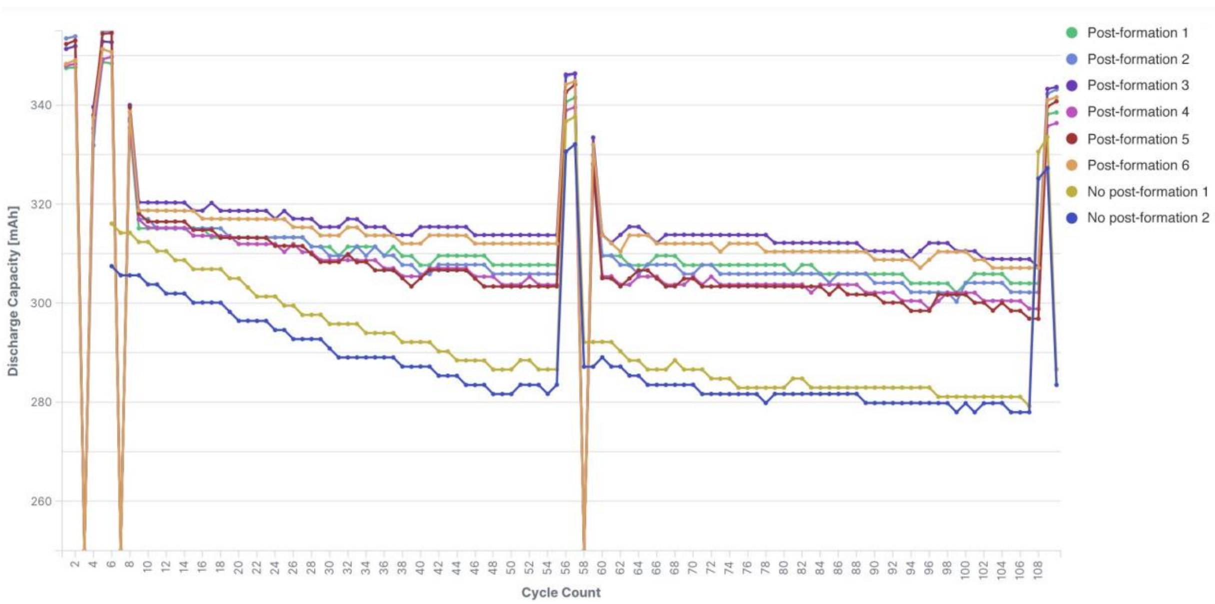
The emphasis in this process is placed on growing the most uniform and pristine SEI layer throughout complete anode active material. Success in this process is a critical step to ensure repeatability in battery performance, reliability and safety.

Based on the demonstrated capability of GBatteries' technology to maintain a pristine SEI layer evolution, GBatteries is developing a formation protocol and hardware that can be used by battery manufacturers for every cell produced, regardless of its final application – pack or single cell.

Validation

GBatteries developed a post-formation protocol and demonstrated improved battery performance on a batch of small commercial LCO pouch cells that underwent GBatteries' proprietary post-formation procedure.

Cycle life data, demonstrated in the graph below, shows that the battery cells that underwent the post-formation procedure did not lose an initial capacity of ~5%, unlike the cells that were cycled with no post-formation procedure.



Discharge capacity loss versus cycles of six battery cells with and two battery cells without GBatteries' post-formation protocol.

Formation Value Proposition

1. **Reduction of battery production cost:**
   - Faster formation time;
   - Smaller energy consumption.
2. **Improvement of battery performance:**
   - Increase of cell cycle life by growing pristine SEI layer;
   - Increase of cell energy and power density by minimizing Li consumption.

ULTRA-FAST CHARGE & LONG CYCLE LIFE

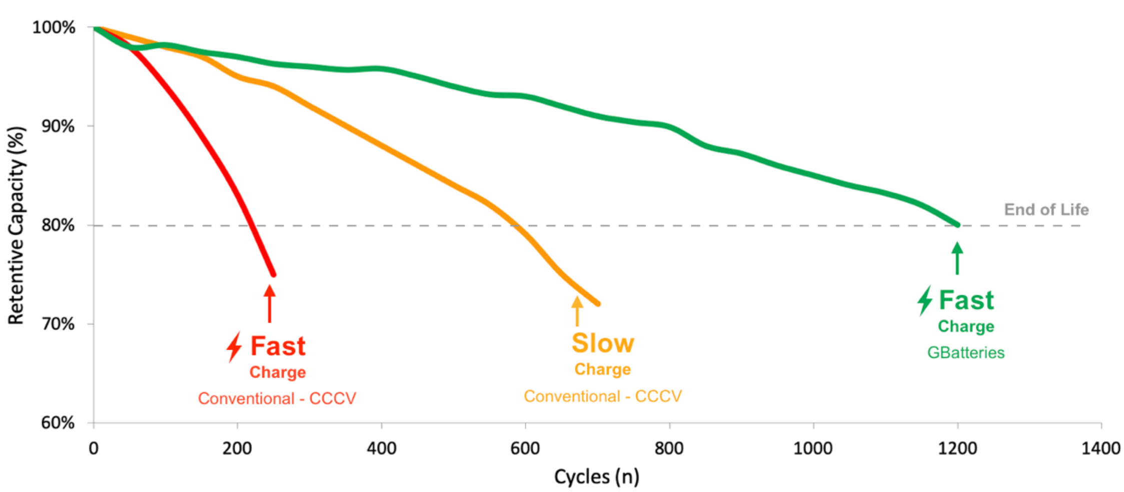
From Tesla's Supercharger to Samsung's Adaptive Fast Charging, manufacturers in every industry are working to improve charge time to reduce downtime and maximize productivity. Li-ion batteries lose capacity due to the irreversible chemical reactions they undergo during the charge/discharge process with increased degradation happening at accelerated rates of charge.

GBatteries has successfully demonstrated a proprietary charging method using adaptive pulse algorithms and precision high-power electronics to ultra-fast charge commercially available Li-ion batteries without compromising cell cycle life, and for certain cells, extension of cycle life. The CCCV vs ABMS charged battery cycle life is shown below.

Companies working on new battery solutions plan to deliver "a better" battery, which can meet the industry needs, in the next 5-7 years, however, the future of such a battery is still unknown.

Using its proprietary technology, GBatteries demonstrated, in a laboratory environment, charging of certain off-the-shelf commercial cells in 5 minutes to 50%, and in 10 minutes to 80%, without compromising their cycle life.

GBatteries extrapolates that a typical 60kWh EV battery pack with a 238-mile range would be charged to 119 miles (192km) of range within 5 minutes with GBatteries technology, compared to 15 miles (24 km) possible with current conventional charging.



Overview of capacity fade of Li-ion battery at different rates of charge over a number of conventional slow and fast charge cycles versus GBatteries' approach.

Ultra-Fast Charge and Long Cycle Life Value Proposition

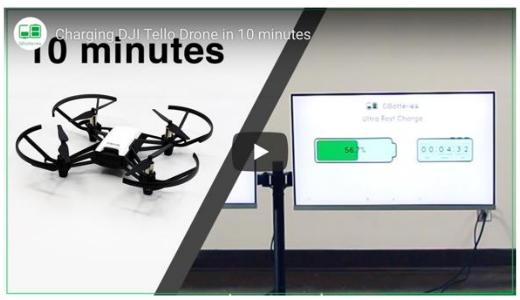
Ultra-fast charge deployment would enable electric vehicle fleets to become economically feasible on a shorter timescale, as opposed to “over the life of the vehicle”.

For consumer products such as smart phones, wearable devices, vacuums, drones, etc., ultra-fast charge will act as a significant competitive advantage to differentiate the product from the competition.

For power tools and industrial robotics, fast charge would mean less downtime, maximized productivity, and a reduced inventory of batteries and chargers needed on commercial jobsites.

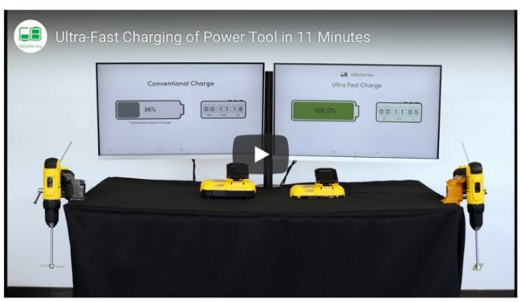
GBatteries has demonstrated capability to enhance charging rate and cycle life of both energy and power cells.

Ultra-Fast Charge Demonstrations



DJI Tello Drone
Charging time: 10min 19sec to 100%

View on YouTube



DeWalt Power Tool
Charging time: 9min 32sec to 100%

View on YouTube

Xiaomi M365 Kick Scooter
Charging time: 11min 05sec to 100%

View on YouTube

Problem and current solution

Bloomberg New Energy Finance (BNEF) predicts that by 2040, 57% of all passenger vehicle sales and over 30% of the global passenger vehicle fleet will be electric. If these predictions are accurate, there are going to be terawatt-hours of batteries that no longer meet required specifications for EV applications.

At this stage, the used batteries have three options: (i) disposal, (ii) recycle; or (iii) reuse for less demanding applications (i.e. energy storage systems).

EV batteries are subjected to a severe and demanding environment, with difficult operational conditions and unpredictable usage through their life.

Quickly and accurately determining the state of health (SoH) of each battery module and the pack overall after its usage in an EV is critical to determine applicability for a 2nd life application.

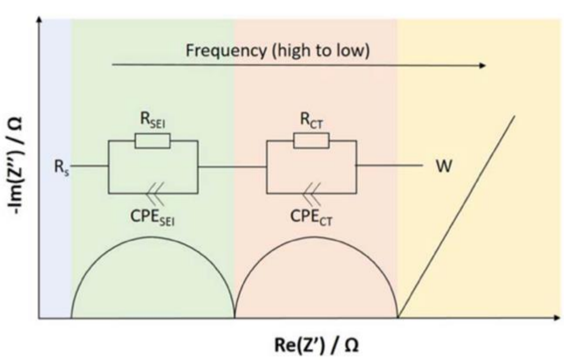
Furthermore, determining SoH of the battery in real time will guarantee safety. The current processes used to determine the SoH can be lengthy (~10hrs).

GBatteries solution

GBatteries has developed powerful and inexpensive measurement equipment that performs Electrochemical Impedance Spectroscopy (EIS) based on a battery model, in real time. This enables precise determination of the state of health of the battery. In particular, GBatteries sees its technology deployment as a stand-alone tool (Spectrometer) for fast and accurate SoH measurement, as well as an embedded feature in a commercial product, to continuously monitor SoH of the battery throughout the life.

State of Health Value Proposition

GBatteries proprietary methodology, allows for fast (in less than 4 hours) and accurate measurement of the SoH of the battery. This provides precise and rapid determination of the state of health of the used battery for secondary life applications, including backup / UPS (minimal cycling capability), renewable energy storage (slow charge and discharge) or for peak-shaving applications (intensive charge and discharge). GBatteries technology is also applicable for real-time SoH analysis during all life cycle operation phases of energy storage batteries.



EIS visualization via Nyquist plot used for SoH analysis.

GBatteries mobile hardware prototypes.

INTELLECTUAL PROPERTY

All GBatteries' intellectual property (IP) is owned and developed by GBatteries. GBatteries has 45 patent fillings, which includes 10 granted patents.

A list of publicly available and/or published patents and patent applications related to this document is presented below.

S. No	Application No.	Type	Country	Title	Link to granted patent/pre-grant publication
1	14/386,889	Patent	US	Extended life battery	https://patents.google.com/patent/US9966780B2/en
2	14/596, 400	Patent	US	Systems and methods for enhancing the performance and utilization of battery systems	https://patents.google.com/patent/US10084331B2/en
3	15/913,838	Patent	US	Systems and methods for enhancing the performance and utilization of battery systems	https://patents.google.com/patent/US10218200B2/en
4	15/483,324	Patent	US + Other jurisdictions	Battery charging based on real-time battery characterization	https://patents.google.com/patent/US10291048B2/en
5	16/372,567	Application (Pending)	US	Battery charging based on real-time battery characterization	https://patents.google.com/patent/US20190229537A1/en
6	15/644,498	Patent	US + Other jurisdictions	Charging a battery with frequency-modulated pulses based on battery measurements	https://patents.google.com/patent/US10135281B2/en
7	15/939,018	Patent	US	Modulated pulse charging for a reconfigurable battery pack	https://patents.google.com/patent/US10069313B2/en
8	16/190,236	Application (Pending)	US	Battery charging with charging parameters sweep	https://patents.google.com/patent/US20190081486A1/en
9	15/861,610	Patent	US + Other jurisdictions	Method and system for a battery pack	https://patents.google.com/patent/US10250045B2/en
10	16/365,478	Application (Pending)	US	System and method for battery pack	https://patents.google.com/patent/US20190222037A1/en
11	15/861,593	Patent	US + Other jurisdictions	Active battery management system	https://patents.google.com/patent/US10193369B2
12	PCT/CA2018/050683	Application (foreign filings pending)	PCT (WO)	Battery charging through multi-stage voltage conversion	https://patents.google.com/patent/WO2018227278A1/en

BUSINESS MODEL

GBatteries' Active Battery Management System (ABMS) commercialization strategy is a business-to-business model that anticipates strategic partnerships and licensing of the technology to consumer electronics, electric vehicles and battery manufacturing industry leaders. Based on the envisioned business model, GBatteries anticipates low operational costs and annual total addressable market of over $10 billion.

ADDRESSABLE MARKETS

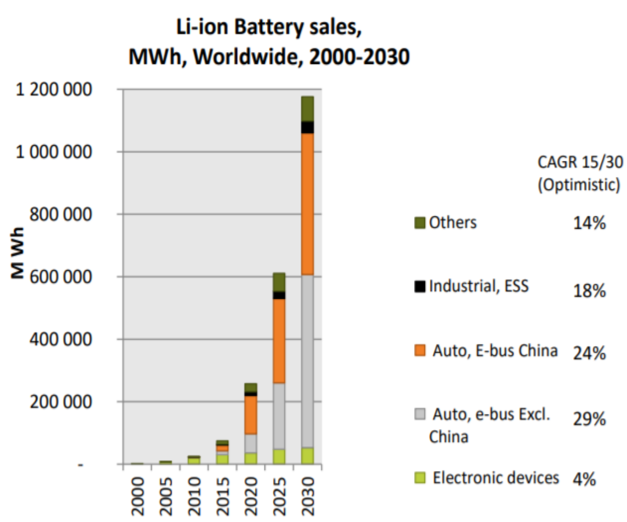
GBatteries' technology is novel. We are not attempting to develop a new chemistry or design for a new type of battery, which requires a long development phase and high capital expenditures. The ABMS is designed and capable to be integrated into a life cycle of off-the-shelf battery, from production to primary cycling use to second life applications, without changing battery chemistry composition or manufacturing process.

We are focusing on the battery production process of formation, as well as the charging of portable electronic devices and electric vehicles. These market opportunities will yield the most growth over the next few decades. Meanwhile, we assume that the use of Li-ion batteries will continue to expand beyond the industries listed above with frontier markets, such as energy storage systems for back-up power and/or peak shaving applications, electric water and air travel.

LITHIUM-ION BATTERY PRODUCTION MARKET

Lithium-ion (Li-ion) is the most dominate battery technology currently available. Li-ion powers devices ranging from portable electronics to electric vehicles to stationary energy storage systems. A growth in demand for lithium-ion batteries over the next 10 years is expected to grow by ~10 times, from 151GWh in 2019 to 1,748GWh by 2030[2].

According to a recent Avicenne Energy report, the worldwide Li-ion battery market in 2018 was made up of an estimated volume of 8.2 billion cells, with Samsung SDI, Tesla, and LG Chem, holding a market share of 17%, 15% and 14% respectively. They estimate that the worldwide Li-ion battery market in 2018 was valued at closer to $40 billion USD.



Others: medical devices, power tools, gardening tools, e-bikes...
Source: AVICENNE Energy 2019

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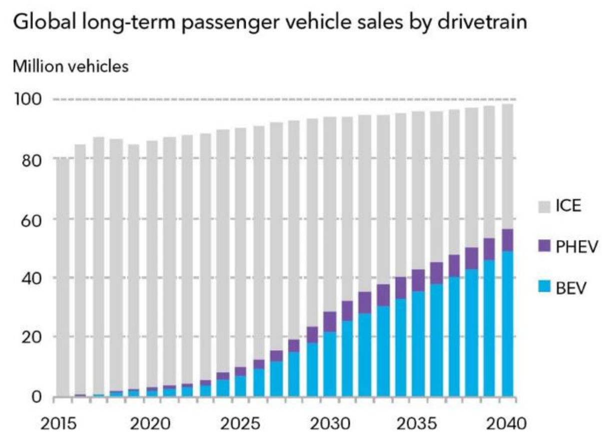
2 Bloomberg New Energy Finance

Electric Vehicles market

The Bloomberg New Energy Finance (BNEF) Electric Vehicle Outlook 2019 reports that over 2 million electric vehicles were sold worldwide in 2018, which was a dramatic increase since the 2010 EV sales were in the thousands. They predict annual passenger EV sales to rise to 10 million in 2025, 28 million in 2030 and 56 million in 2040.

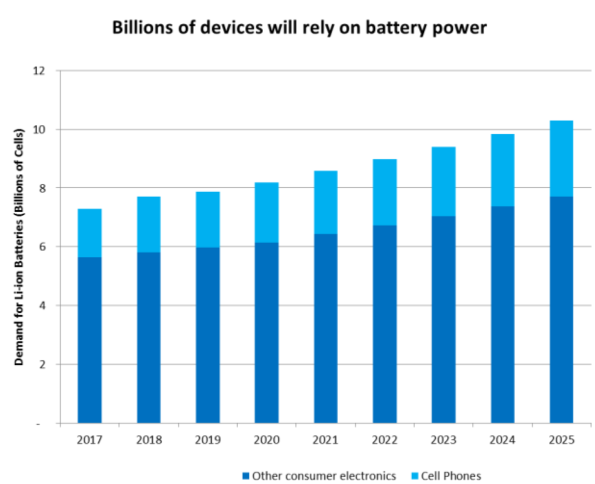
Currently, electric vehicles (EVs) make up approximately 1% of the global automotive market and yet, EVs consume 60% of the available Li-ion batteries [3]. By 2040, BNEF predicts that 57% of all passenger vehicle sales worldwide and over 30% of the global passenger vehicles on the road will be electric. This translates to 500 million passenger EVs on the road in 2040. They also estimate that 40 million commercial EVs will be in use during this same time period.



Portable Consumer Electronics market

Consumer electronics have become an instrumental part of our daily lives over the past decade. The product catalogue encompasses a wide number of devices ranging from smart watches to virtual reality headsets.

In the coming years, billions of devices demanding higher power are projected to be produced, which will be relying on batteries. Based on market projections, some 10 billion batteries will be embedded in consumer electronics by 2025. According to the Portable Electronics - Global Forecast 2023 published by Market Research Future, the global portable electronics market is expected to reach over $770 billion USD by 2023.



Source: Avicenne Energy, Daewoo Securities, Deutschebank

[3] Avicenne Energy

TRACTION

We have secured paid, proof of concept projects with major automotive OEMs, leading electronics and battery manufacturers, which are currently on-going.

We received a commercial term sheet for licensing of ABMS into a portable consumer product and anticipate for ABMS to be deployed in their commercial product within 18-24 months.

We anticipate a contract with EV and battery manufacturers also within 24 months, upon completion of proof of concept and demonstration projects with them.

FINANCES

GBatteries has a lean operating structure, with most expenses related to salaries of 20 R&D personnel. The business model involves licensing of ABMS technology and a royalty fee, with no manufacturing handled directly by GBatteries at the moment.

In 2020 we are seeking to:

- close investment round of $10 million to scale the team of experts, expand laboratory capability, accelerate R&D and commercial deployments;

- receive $700 thousand from Canadian government <u>(already approved)</u> for development and demonstration of formation algorithm with battery cell manufacturers;

- receive $3.6 million funding from an automotive OEM (already committed with a contingency) and Canadian government for development and demonstration of ABMS deployment on an EV battery pack;

- receive $1 million as non-recurring engineering fee from industry leaders for development and demonstration of SoH stand-alone Spectrometer.

AWARDS & RECOGNITION

- MobilityXlab participating company (2019)
- 6 Innovative Electric Car Startups to Keep an Eye On (2019)
- GBatteries CCO selected as 2020 Forbes 30 Under 30 (2019)
- Top 10 Start-up at LA Automotive Show (2019)
- Rice Energy & Cleantech Venture Forum: Top 10 Most Promising Startups (2019)
- SAE Global Automotive & Mobility Innovation Challenge Finalist (2019)
- Startup Autobahn Top Participant (2018)
- CIX Top 20 Most Innovative Canadian Tech Companies (2017)
- IEEE Ottawa Outstanding Clean Tech Company (2017)
- Y Combinator W14 Company (2014)
- VentureBeat – Top 5 Best Startups from YC Demo Day (2014)
- TechCrunch – Top 8 Startups from Y Combinator W14 Demo Day (2014)
- Silicon Valley Business Journal Paul Graham's 6 Top Picks (2014)

RECENT NEWS

- **MotorTrend** - New EV Recharging Tech Lets Electrons Flow Like Gasoline
- **Financial Times** - Father-and-son scientists aim to slash car recharge times
- **Charged EV** - GBatteries says its AI-powered protocol can charge an EV in 5 minutes
- **InsideEVs** - GBatteries Claims Amazingly Fast Charging Times For Electric Cars
- **Axios** - 1 big thing: New player claims EV charging leap
- **GreenCarReports** - Company claims to harness AI for quicker electric-car DC fast charging

The project was focused on understanding Li-ion degradation during cycling, in particular the difference between Active Battery Management System (ABMS) and the conventional Constant-Current Constant-Voltage (CCCV) charged cells.

In this study, new LG HG2 18650 commercial Li-ion battery cells were first screened based on discharge capacities at slow charge/discharge rates and impedance data to ensure minimal cell to cell variation for the study.

Significant difference in discharge capacities was observed between CCCV and ABMS charged cells, at 3C rate of charge. The CCCV cycled cells reached 80% original capacity on average at cycle 400, while 3C equivalent ABMS cycled cells attained 900 cycles, on average (Figures A1 & A2).

Battery Model:	LG HG2
Chemistry:	NMC
Form Factor:	Cylindrical
Type :	18650
Gravimetric Density:	**240 Wh/kg**
Volumetric Density:	**615 Wh/L**
Nominal Capacity:	3000 mAh (0.2C Discharge, at 25°C)
Ambient Test Temp.:	25±5°C
Discharge Current:	1C
Depth of Discharge:	98% (3C CCCV) 98% (3C ABMS)
Rate of Charge:	45-48 min to 100% SoC (3C CCCV) 47-49 min to 100% SoC (3C ABMS)
Observations:	30.2 min to 80% SoC (3C ABMS, Cell 1) 15.7 min to 50% SoC (3C ABMS, Cell 1) 31.3 min to 80% SoC (3C ABMS, Cell 2) 17.9 min to 50% SoC (3C ABMS, Cell 2)

*Depth of Discharge is defined with respect to nominal discharge capacity.

*100% SoC is defined as the maximum capacity obtained for the given profile and its exit conditions.

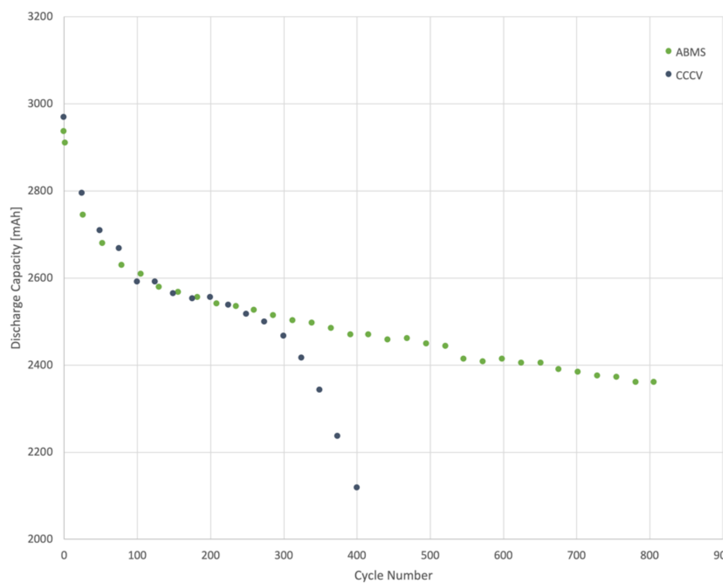


Figure A1: Overview of cycle life of LG HG2 18650 cells, charged with 3C CCCV and ABMS equivalent charge rates.

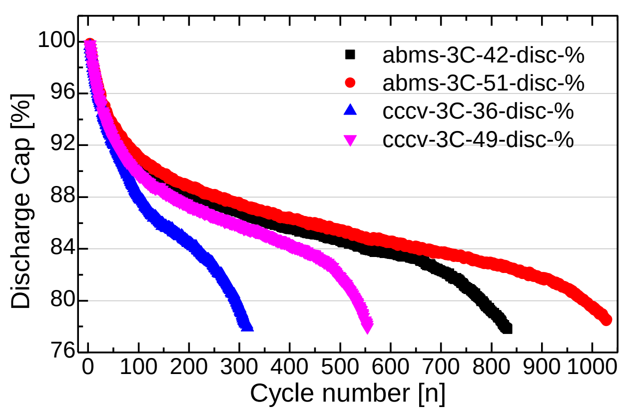


Figure A2: Discharge capacity of cells #36, 42, 49, & 51 charged with 3C CCCV and ABMS equivalent charge rates.

At the end of life (80% retentive capacity) of the cells #36, 42, 49 and 51, the impedance was measured, and the cells discharged to 2.0V for post-mortem analysis. The discharge step is important to ensure the integrity of the electrodes after opening the cells. Otherwise, the electrode materials will delaminate from the current collector and disintegrate. The batteries were opened in the Argon atmosphere environment glove box for post-mortem characterization. The positive and negative electrodes were separated, and pieces cut off from each electrode. The cut pieces were put in vials and added the washing solvents (i.e. diethyl carbonate (DEC) for one sample and dimethyl carbonate (DMC)) for another. Another set of vials were reserved to be washed with isopropanol once taken out of the glove box. The vials with the samples were air-tight closed for taking out of the glovebox. After ~10 minutes, electrodes in DEC/DMC were air dried for characterization. Two hours later, the electrodes in isopropanol were air dried for characterization and the solutions were characterized by mass spectrometry.

The post-mortem analysis revealed that the cells charged with ABMS protocol does not form SEI layer composed of organic species, unlike CCCV protocol. The SEM images (Figure A3) demonstrate surface of the negative electrodes of the new, CCCV and ABMS charged cells.

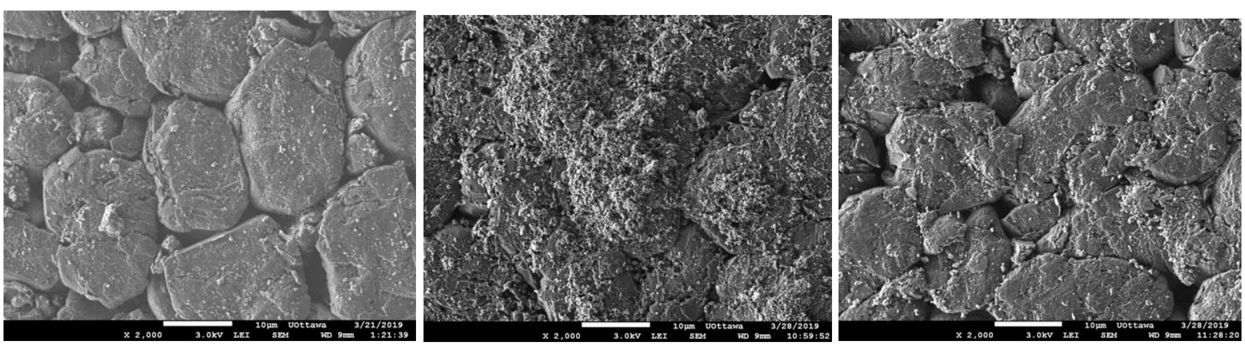


Figure A3: SEM images of negative electrodes of the cells (left to right) - New (31), CCCV (36), ABMS (42)

In particular, it was determined that the surface of the negative electrode of ABMS charged cells exposes Phosphate and Fluorine containing species, which are known to attribute to pristine SEI layer. However, the CCCV, on the other hand, generates organic carbonate layer of electrolyte decomposition that covers Phosphate and Fluorine layers underneath. Figure A4 shows the scan of the negative electrode surface for Fluorine containing species.

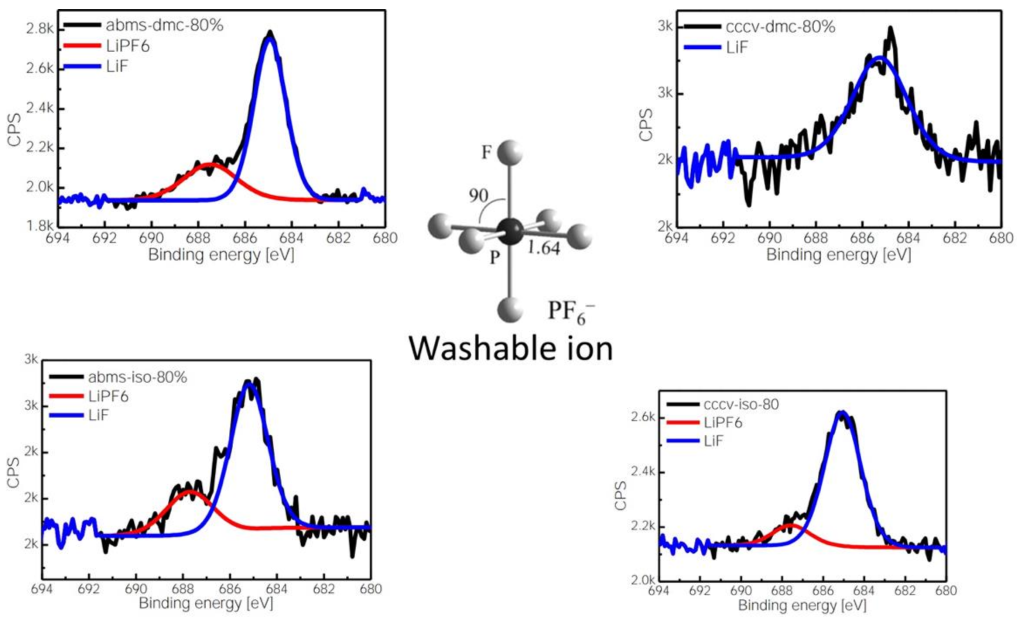


Figure A4: Scan of negative electrode surface for Fluorine containing spices. Top figures represent electrode after DMC wash and bottom figures after ISO-propanol wash.

Another study was performed on cells #73,74,75 and 76 that were also charged at 3C rate and cycled for 400 cycles (Figure A5), while measuring their impedance every 50 cycles using conventional Electrochemical Impedance Spectroscopy (EIS) process. This study revealed that for the CCCV charged cells, at cycle 400, the impedance attributed to SEI layer (Rp) has more than doubled, while ABMS charged cells impedance increased by less than 1.5x times (Figure A6).

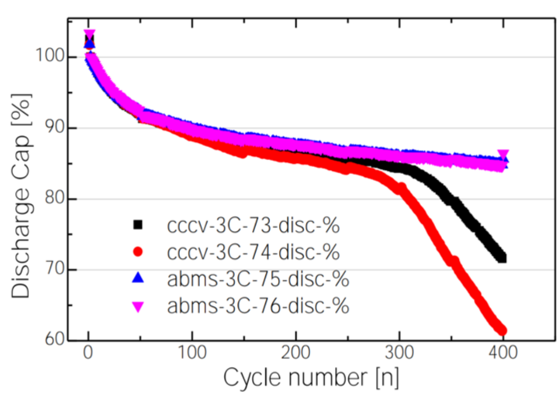


Figure A5: Discharge capacity of cells #73, 74, 75 & 76 charged with 3C CCCV and ABMS equivalent charge rates.

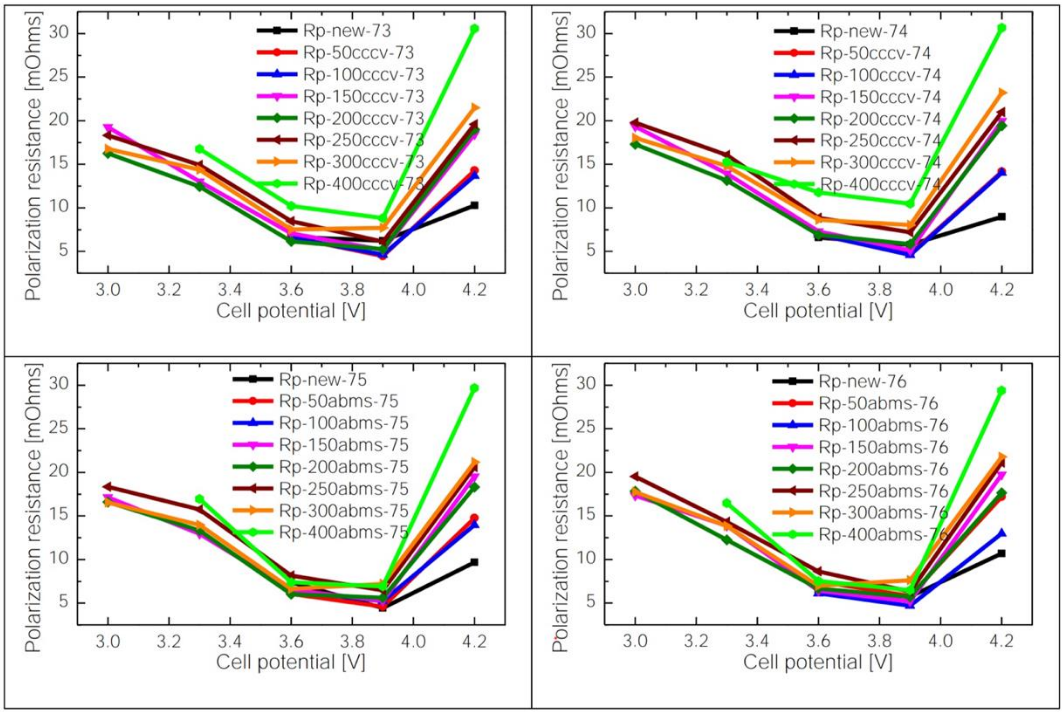


Figure A6: EIS measurement, at 50 cycles intervals, for the cells #73, 74, 75 & 76, charged with 3C CCCV and ABMS equivalent charge rates.

SUMMARY:

ABMS

Forms pure phosphate species:

- soft polymeric ionically conductive material;
- **not possible** to wash away with DMC;
- **not possible** to wash away with Isopropanol;
- non-organic;
- fluorine rich (from salt).

CCCV

Forms brittle crust material:

- ionically insulating material;
- **not possible** to wash away with DMC;
- **possible** to wash away with Isopropanol;
- organic in nature;
- carbonated species: O, C, Li.