BINDER-FREE ELECTRODES: A PATH TO HIGH ENERGY, HIGH POWER DENSITY AND RELIABLE ENERGY STORAGE

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Nanoramic™ LABORATORIES

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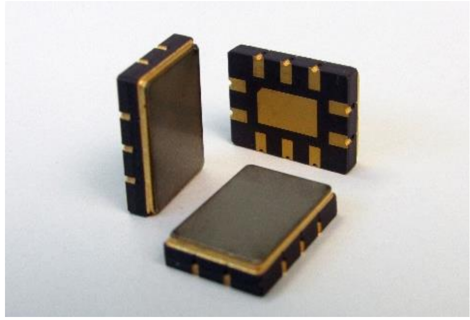
BUSINESS LINES

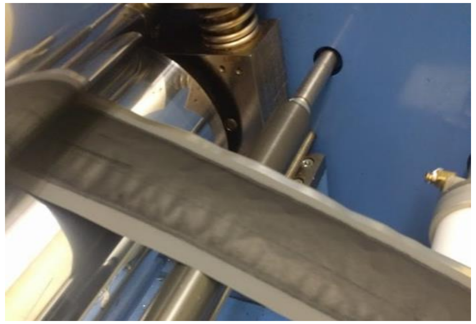
Extreme Environment Ultracapacitors
Oil & Gas
Aerospace & Defense

Chip Ultracapacitors
High Volume
Electronics



FASTCAP ULTRACAPACITORS® A DIVISION OF NANORAMIC

Nanocomposite Electrode
Electrodes for Ultracapacitors
& Batteries



Thermal Interface Materials
Advanced Polymer
Nanocomposite

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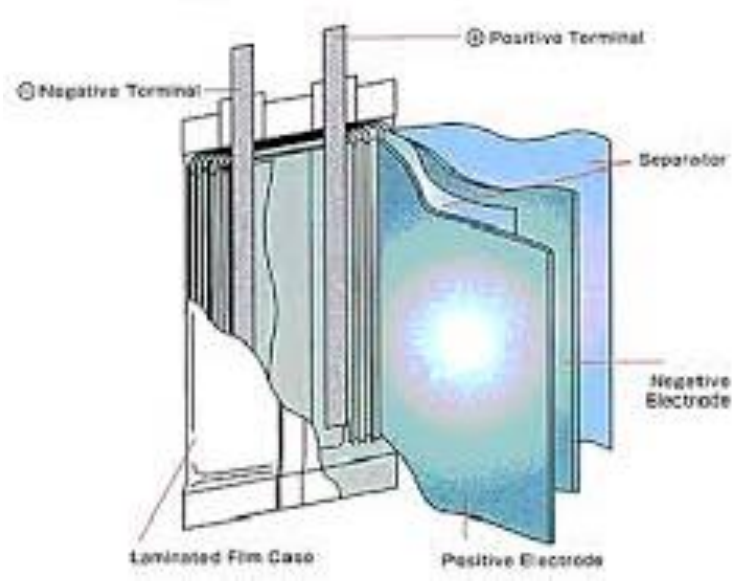
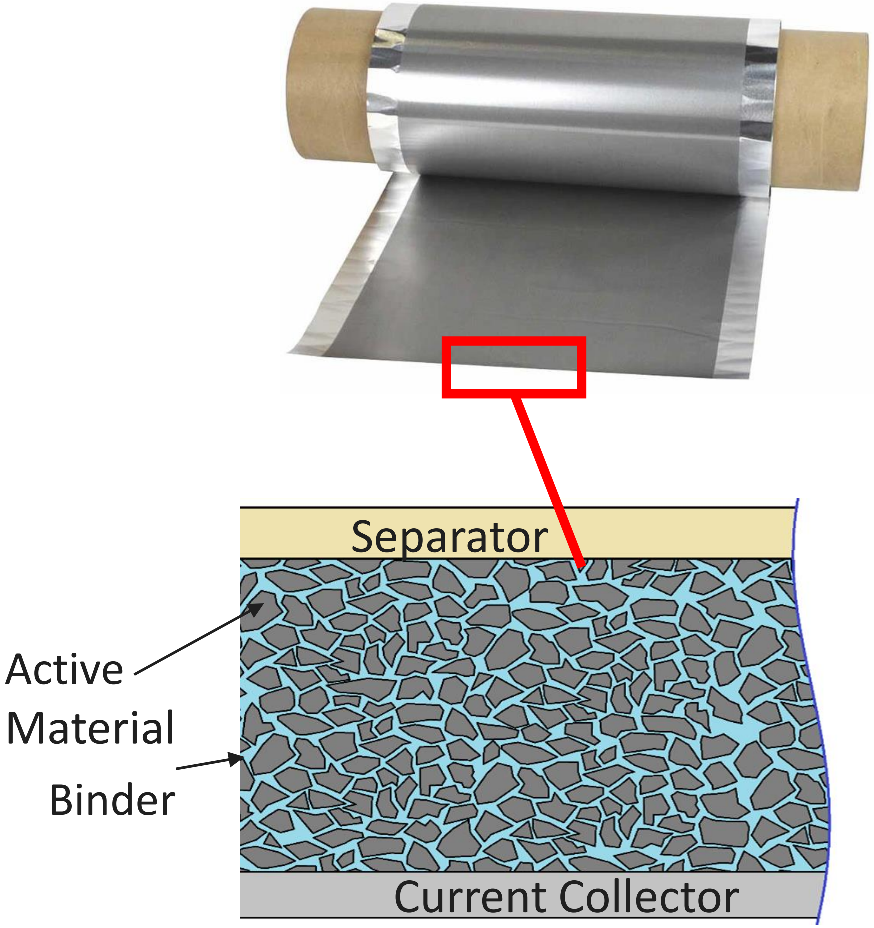
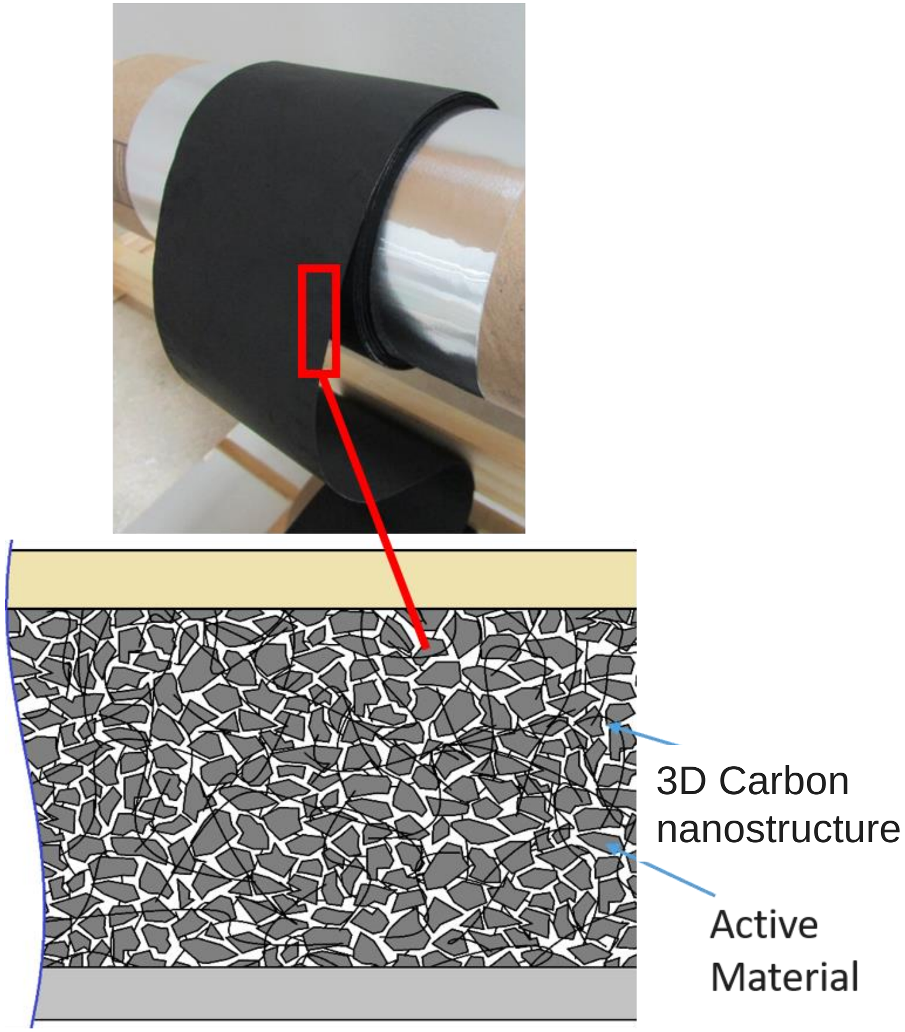
LIMITATIONS OF STANDARD ELECTRODE STRUCTURE



Spiral Wound Cylindrical Cells

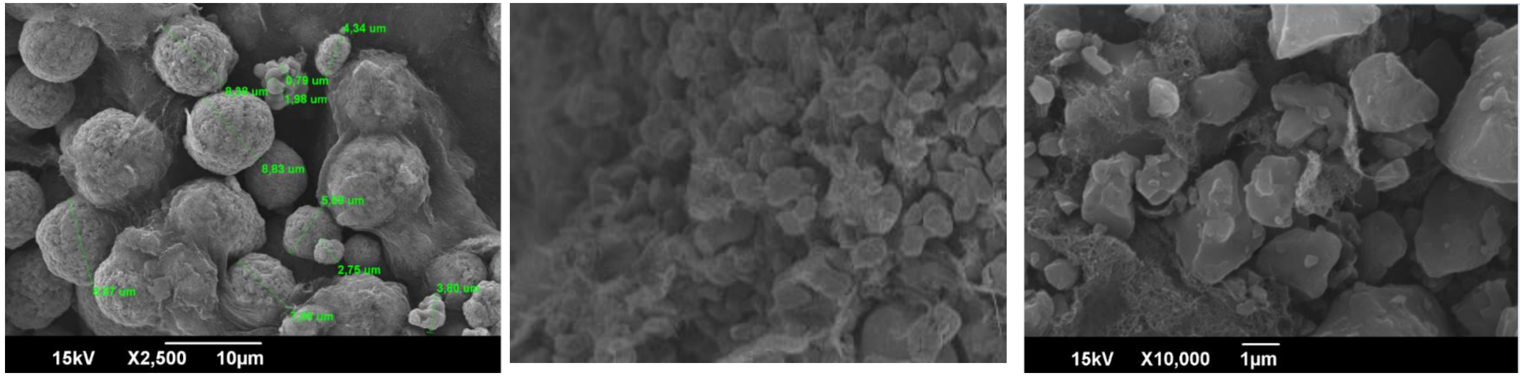


NANORAMIC BINDER FREE ELECTRODE PROCESS



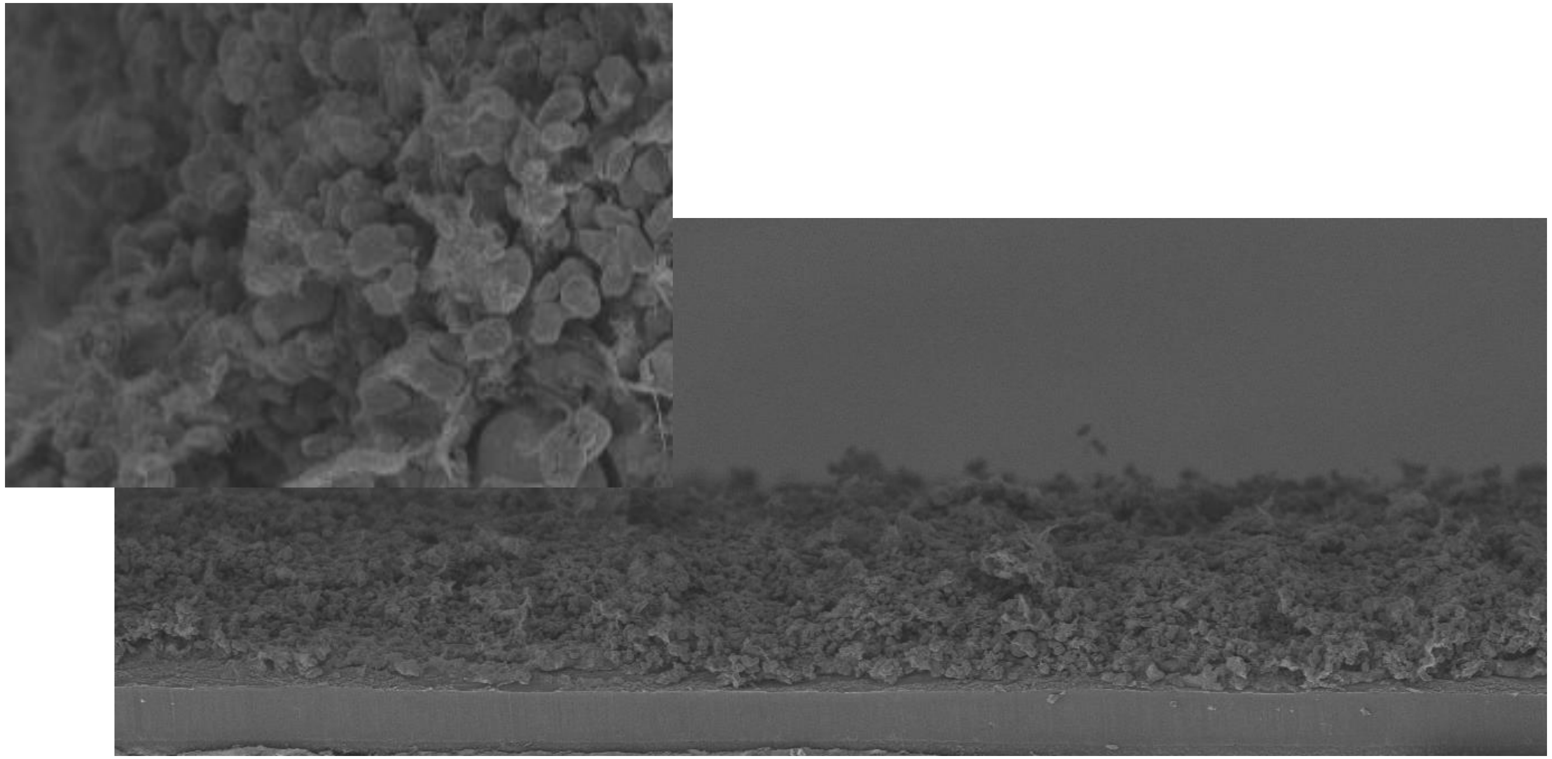
Advantages

1. Reduction in production cost, faster throughput
2. Dramatic improvement in C-rate capability
3. Superior low temperature performance
4. Superior high temperature performance
5. Dramatic improvement in cyclability
6. Increased energy density



COMPATIBLE WITH MOST CATHODE AND ANODE MATERIALS!!

NANORAMIC BINDER FREE – HIGH ENERGY DENSITY



Thick Electrodes

>100um per side possible

- High conductivity and good porosity allows for efficient use of electrode thickness
- Throughput not heavily affected because it faster to dry and UNIFORM

Ultra High Active Material Loading –

97~99.5% Possible

- Close to theoretical mAh/g limit performance

SECTION 02

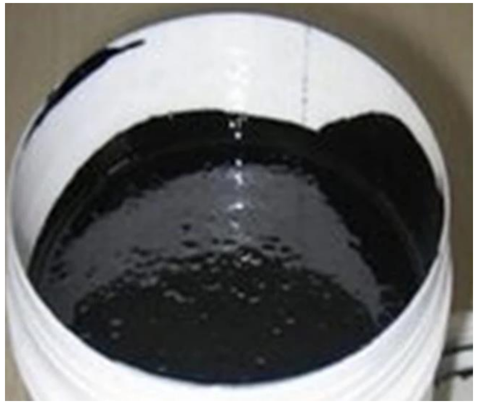
INTRODUCTION TO NANORAMIC CE PROCESS

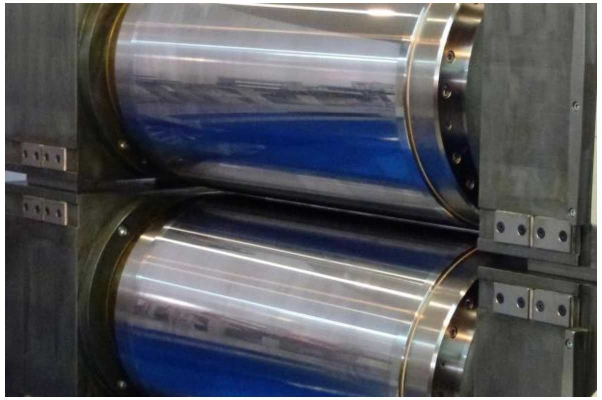
BINDER FREE ELECTRODE FABRICATION PROCESS

Slurry Preparation
Proprietary

Coating and Drying
Compatible with R2R coating machines

Calendering
Standard Process





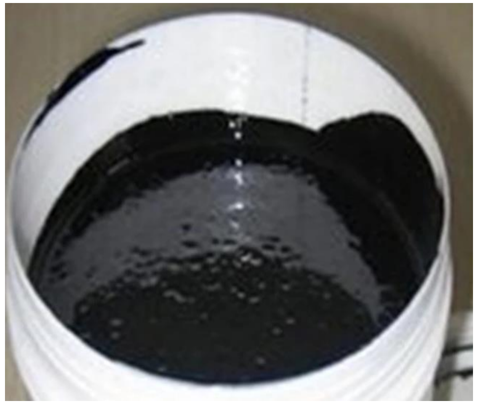
WHAT IS THE BOTTLENECK?

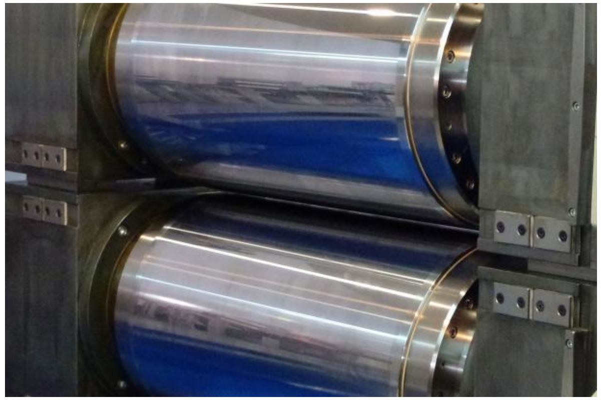
Slurry Preparation

Coating and Drying

Bottleneck!

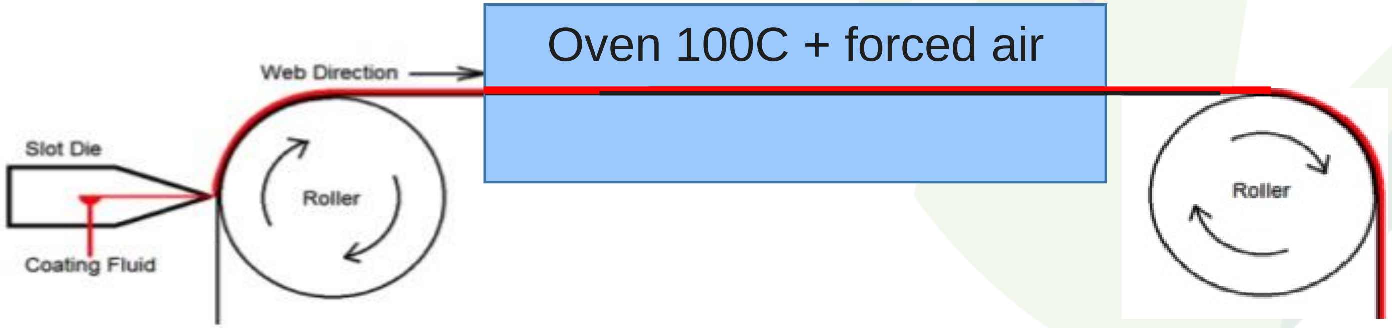
Calendering





THE DRYING STEP IS THE BOTTLENECK

Coating and Drying
Bottleneck!



- **It takes 3 – 6 min to dry the solvent after coating**
- **<u>The coating speed and therefore the throughput is determined by</u>**
  - **how fast the deposited layer can be dried**
  - **Oven length**

THE NANORAMIC CE ADVANTAGE

Solvent	Boiling Point	Vapor pressure at RT	Drying time at ~100C
N-Methyl-2-pyrrolidone - **NMP**	202 C	0.04 kPa	5 ~ 6 min
Water	100 C	3.2 kPa	2 ~ 3 min
Isopropyl – Alcohol - IPA	**82.5 C**	**4.4 kPa**	**1 ~ 2 min**
Acetone	**56.1 C**	**30 kPa**	**< 1min**
Mixtures with Water			**1~3 min**
Green Solvents / Non flammable			**1~3 min**

>2X HIGHER THROUGHPUT

Engineered structure that allows faster evaporation and no "polymer skin" formation

ELECTRODE TECHNOLOGIES COMPARISON

	Wet-coating method	Dry-coating method	**Nanoramic binder free**
Thick electrodes for high energy	☹	☺	☺
Manufacturing cost	☹	☺	☺
ESR / C-rate	☹	😐	☺
Temperature stability	☹	☹	☺
Compatibility with anodes/cathodes	😐	☹	☺

SECTION 03

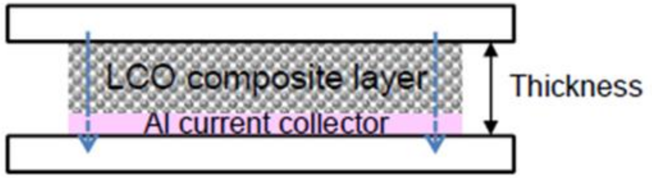
PERFORMANCE RESULTS

ELECTRODE CONDUCTIVITY – LCO CATHODE

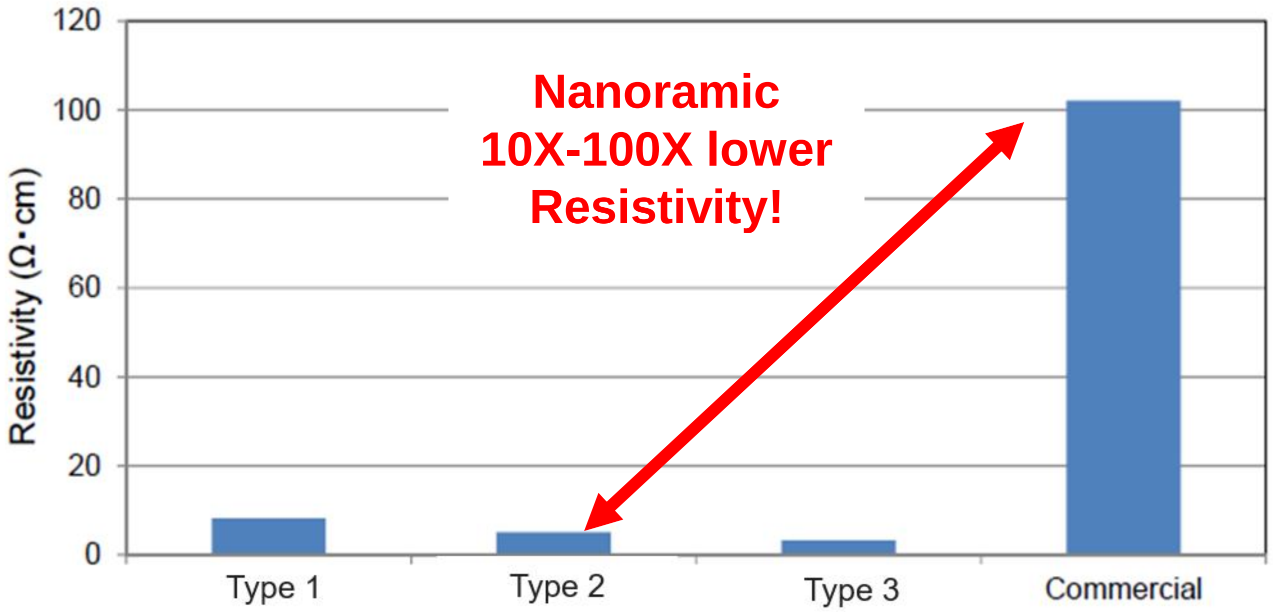
Measurement

- D.C. electrical resistivity measurement (vertical direction against electrode sheet)

Schematic experimental set-up

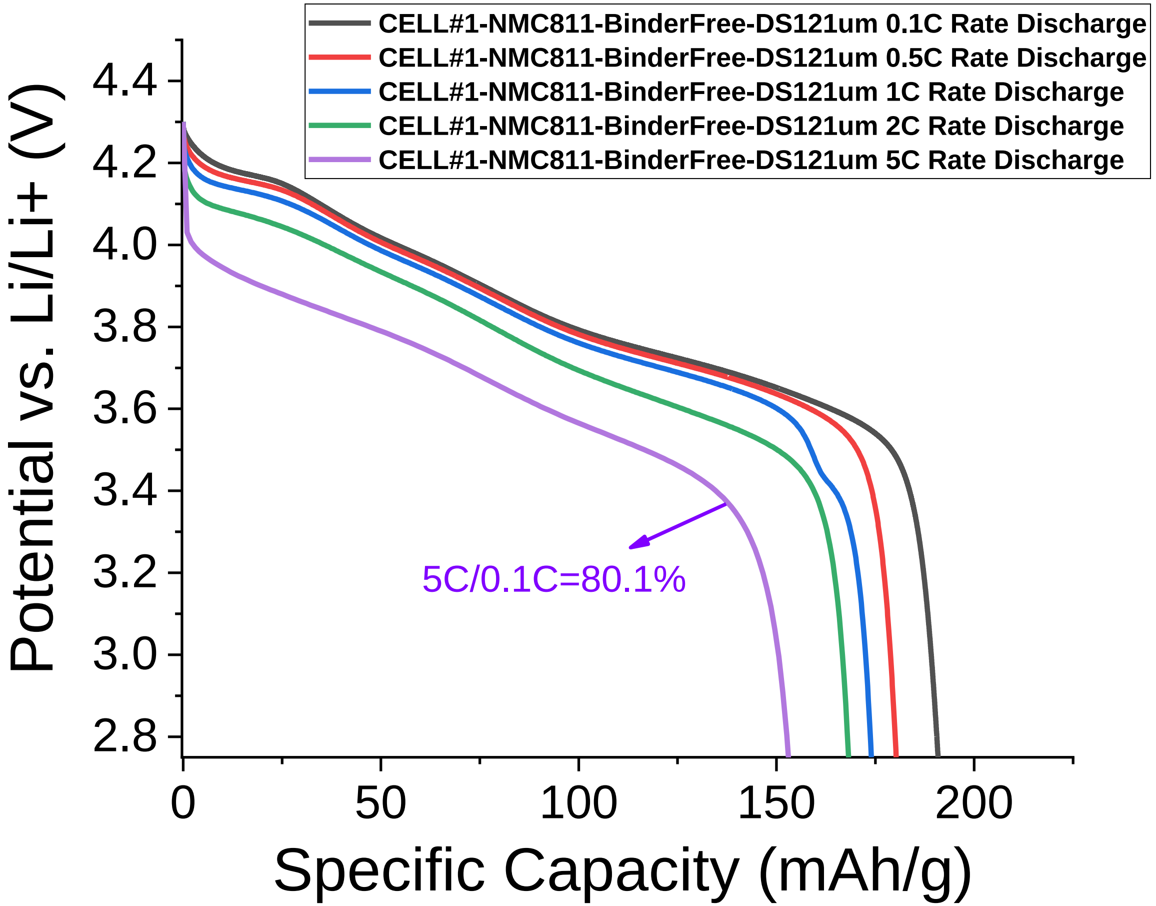


Results

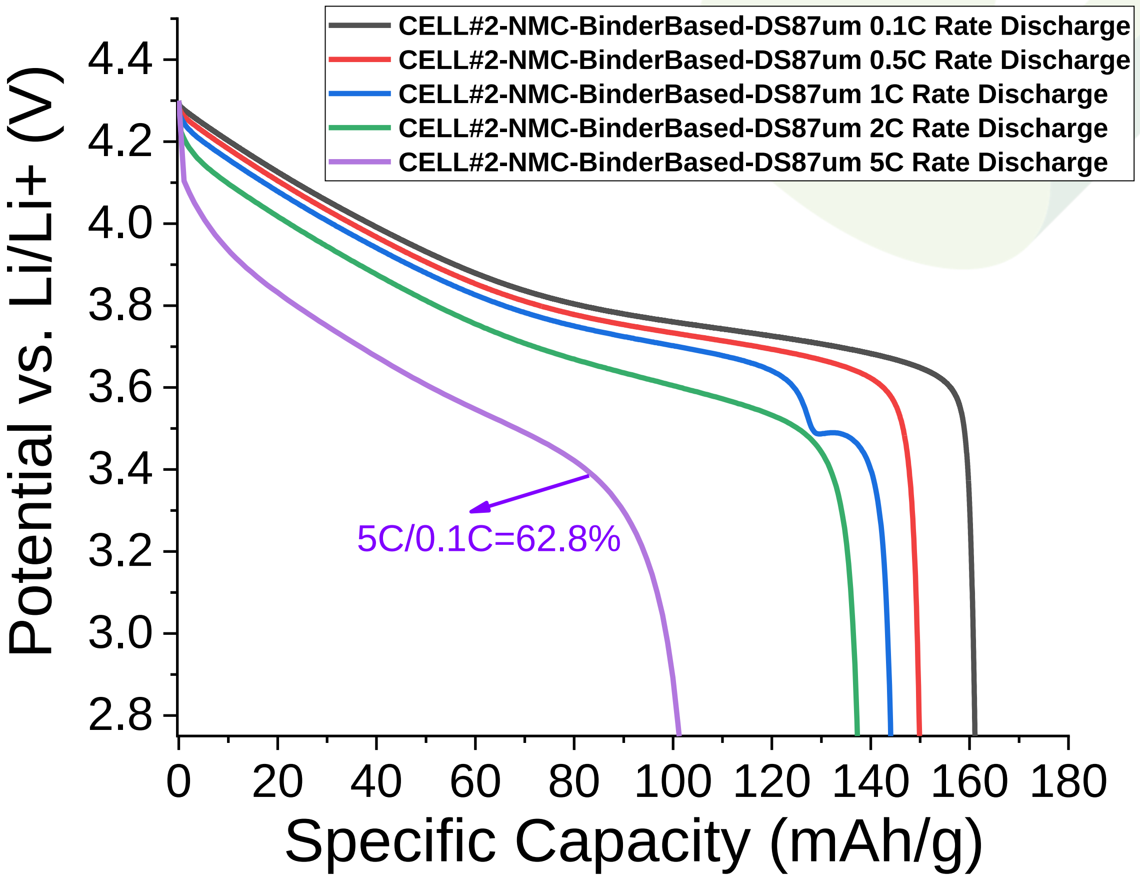


BINDER-FREE NMC811 VS. BINDER BASED NMC CONTROL ELECTRODE C-RATE DISCHARGE: 0.1C, 0.5C, 1C, 2C & 5C RATES

NANORAMIC BINDER-FREE 121um NMC



OFF-THE-SHELF BINDER-BASED 87um NMC



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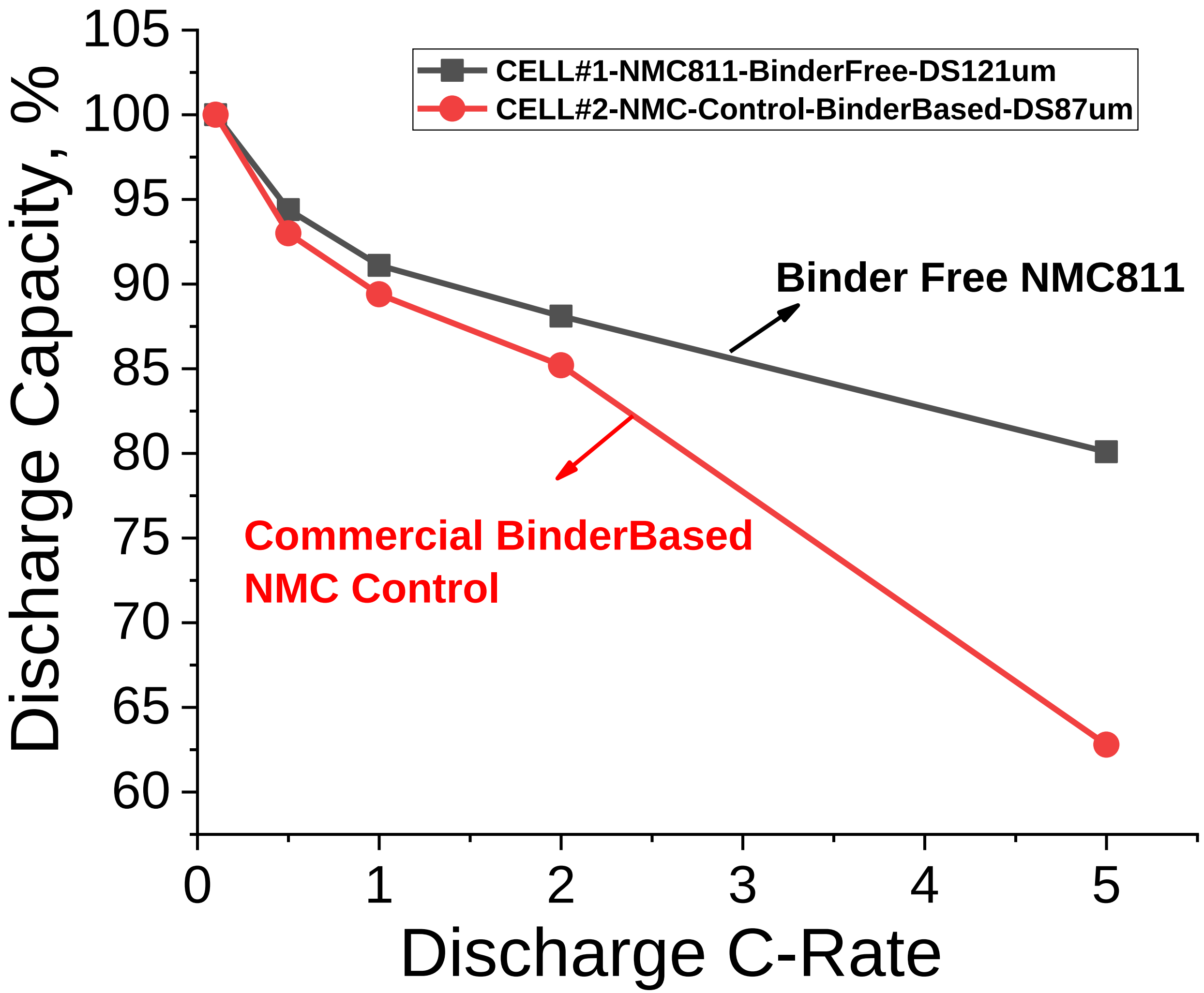
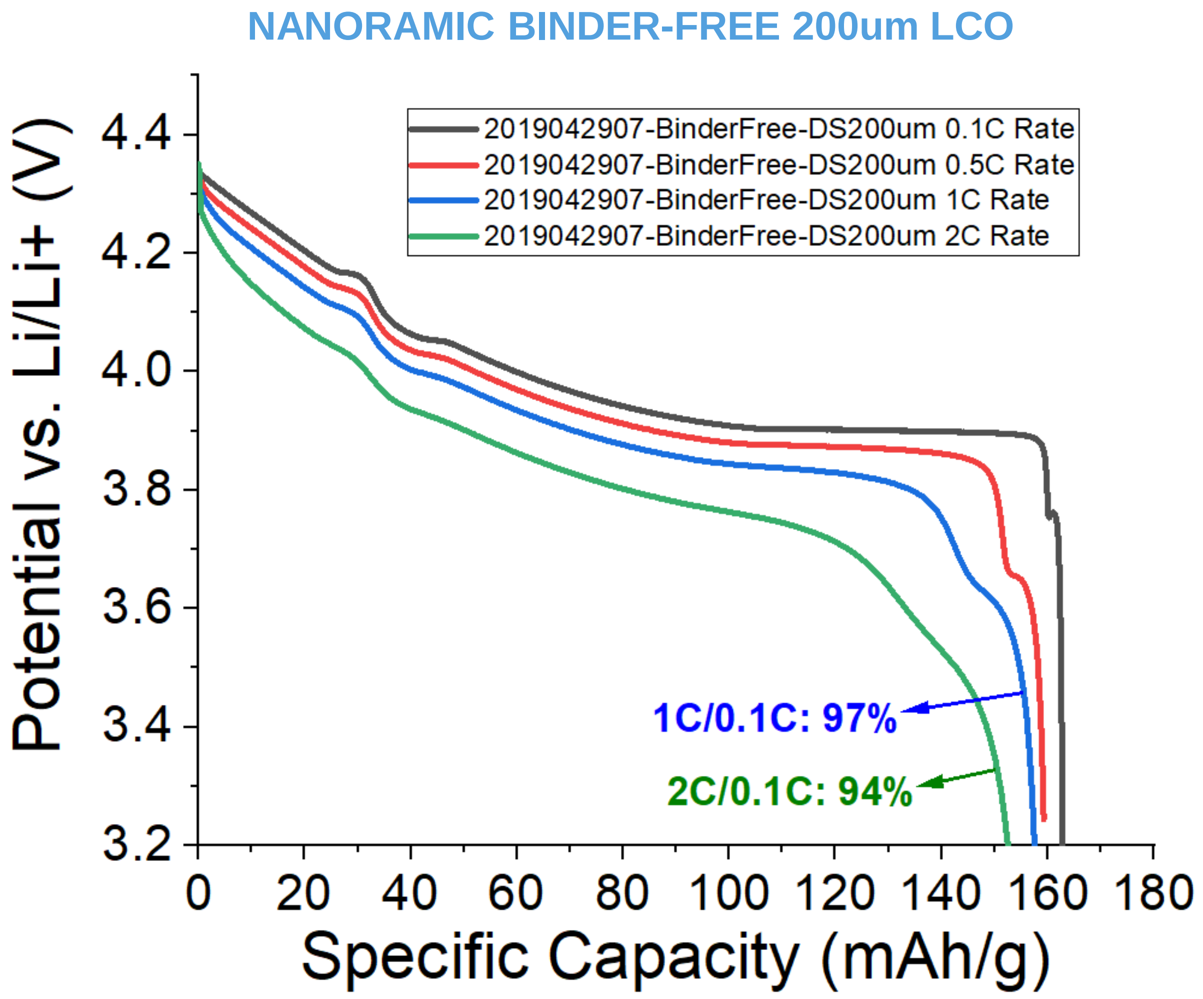
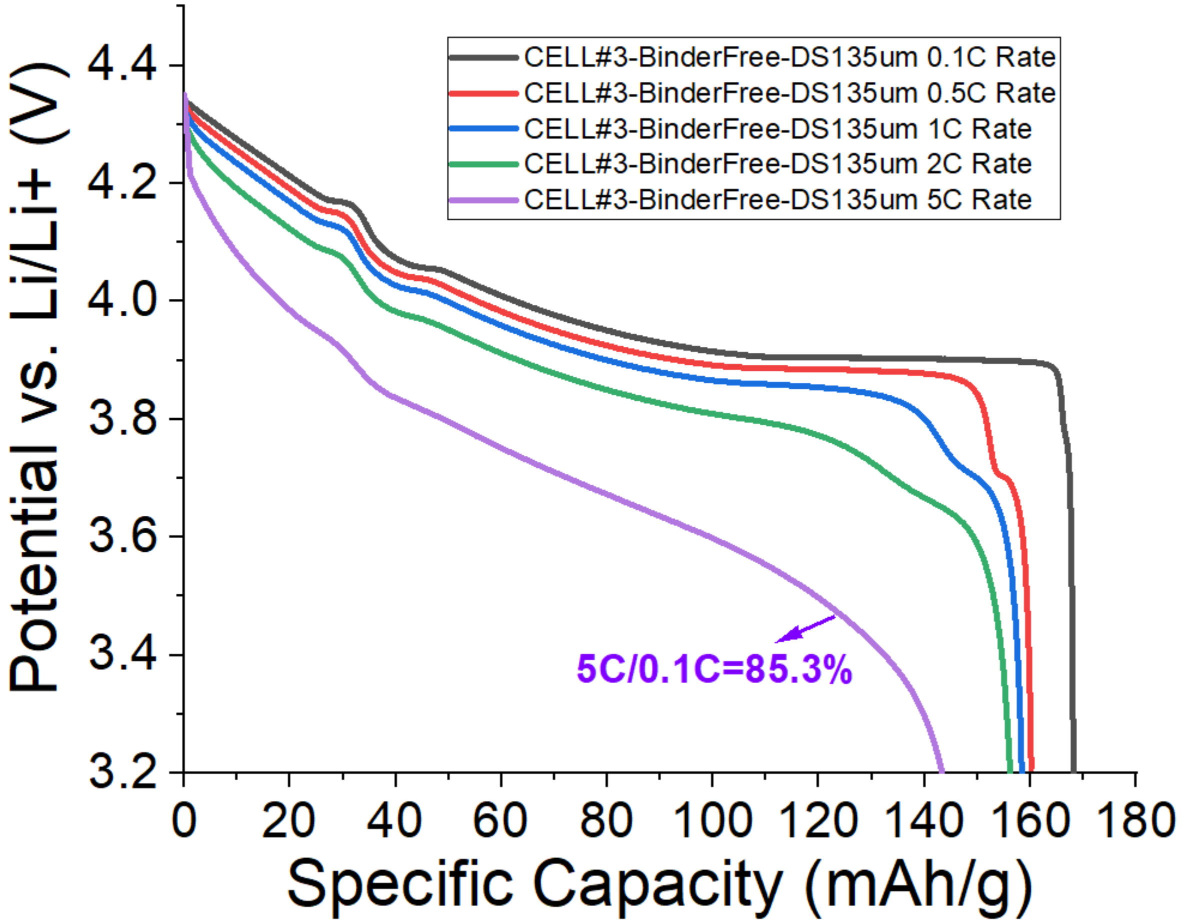


BINDER-FREE LCO CATHODE C-RATE DISCHARGE

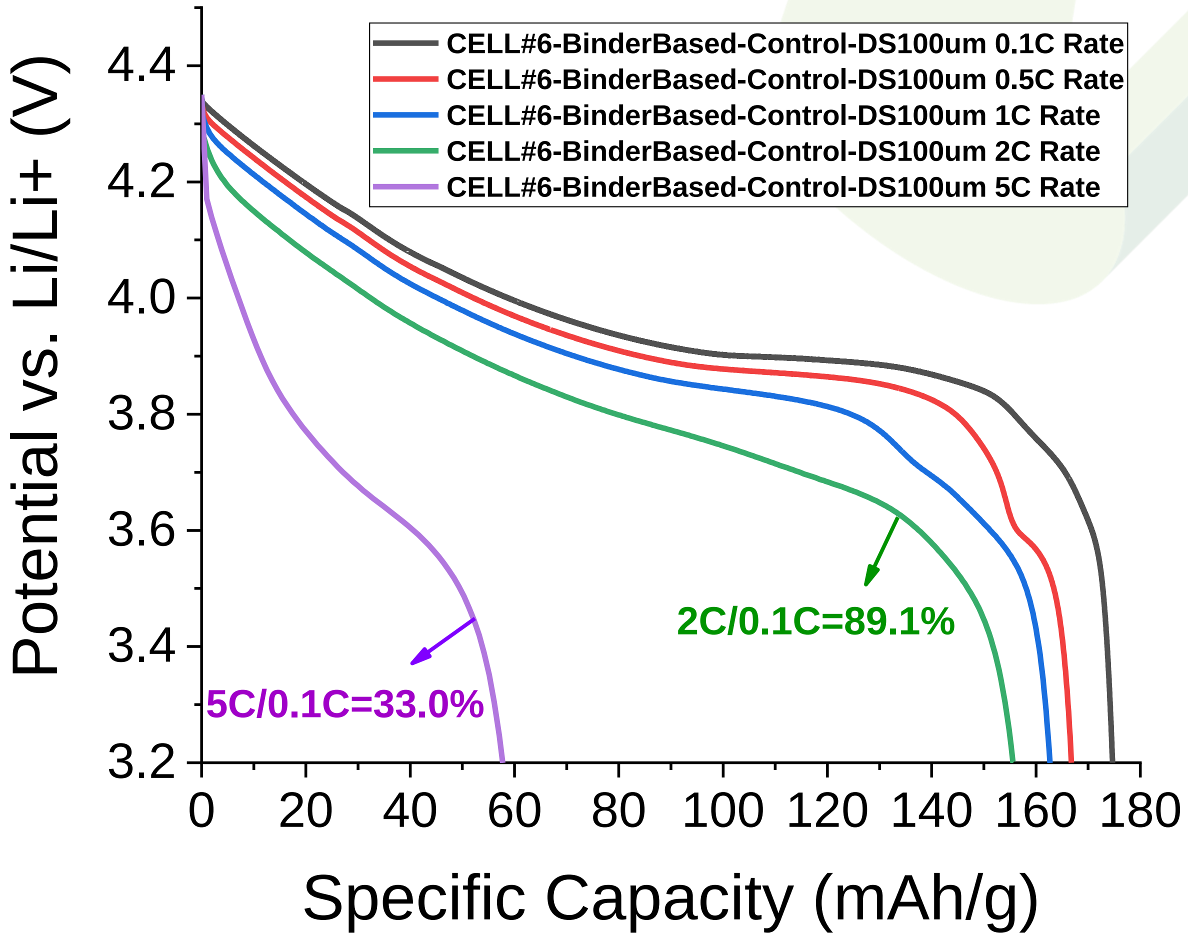


BINDER-FREE LCO CATHODE VS. CONVENTIONAL

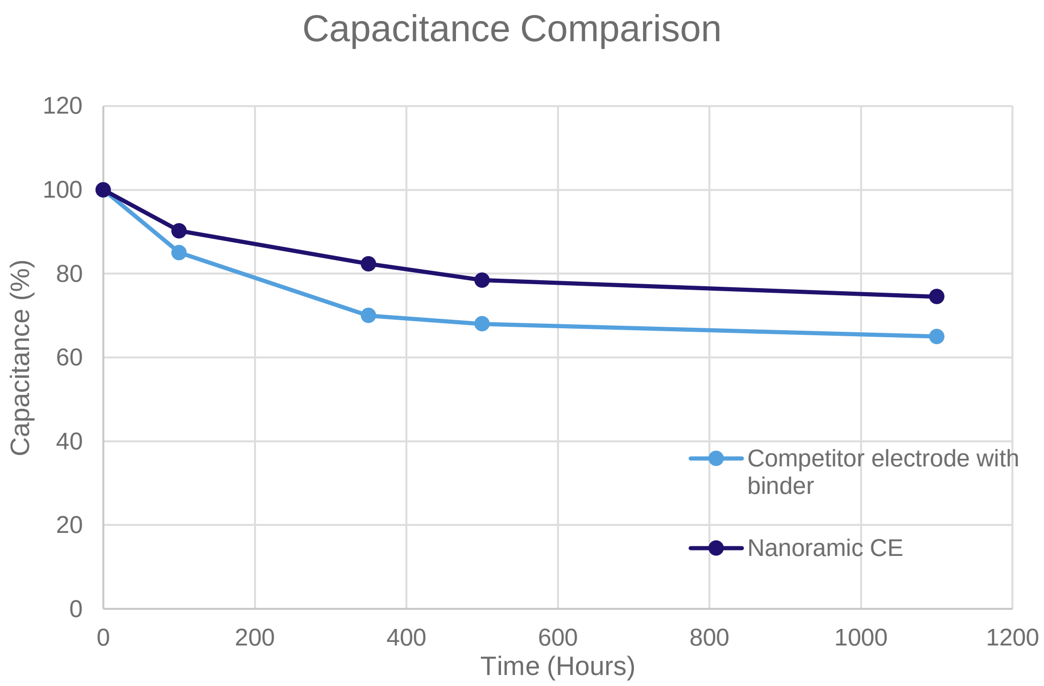
NANORAMIC BINDER-FREE 135um LCO

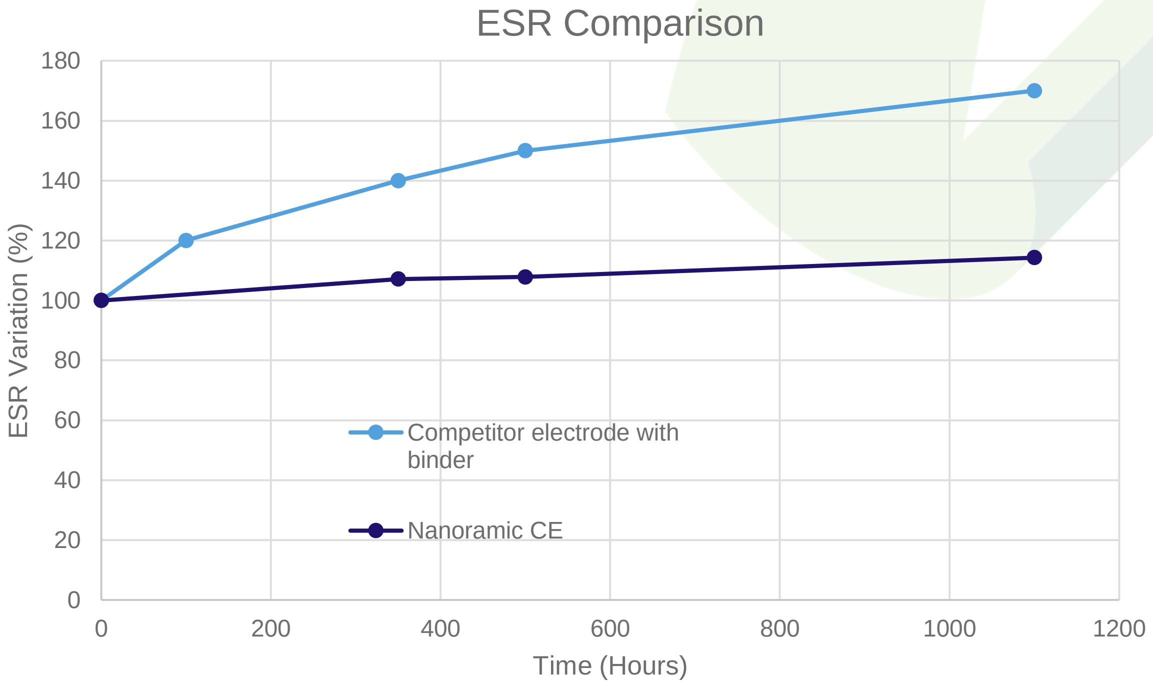


OFF-THE-SHELF BINDER-BASED 100um LCO



LIFETIME TEST IN EDLC – 2.3V, 85C, ACN ELECTROLYTE
LEAD-TYPE SMALL EDLC



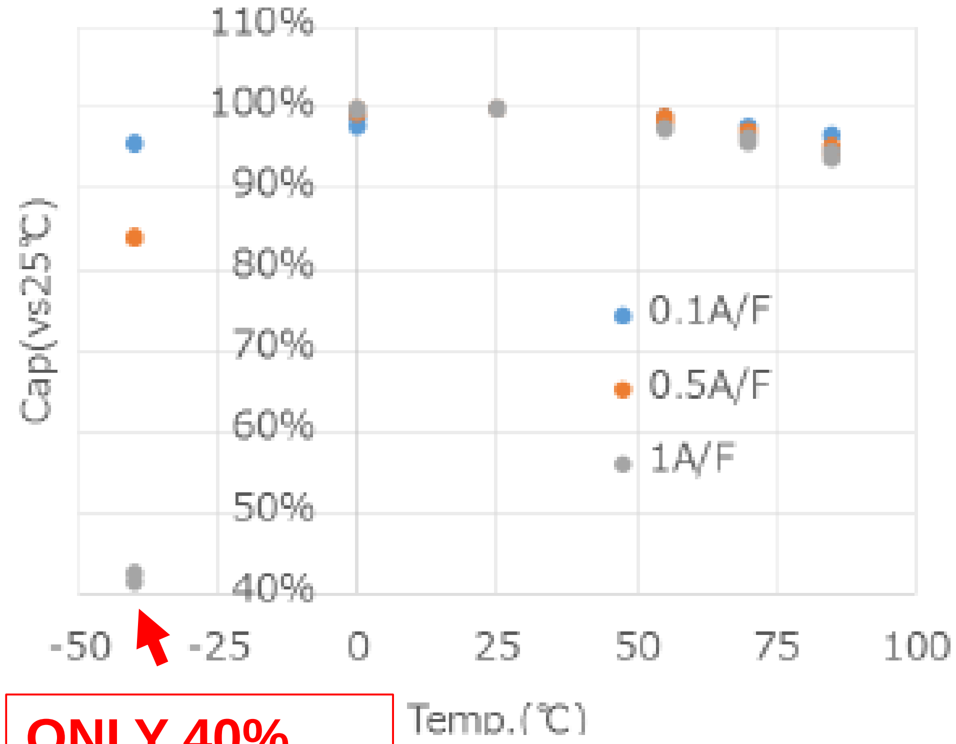


Lifetime is significantly improved in lead-type EDLC cell.
The ESR was 50% less when Nanoramic CE is utilized instead of conventional electrode
Capacitance is comparable

LOW TEMPERATURE PERFORMANCE IN EDLCs

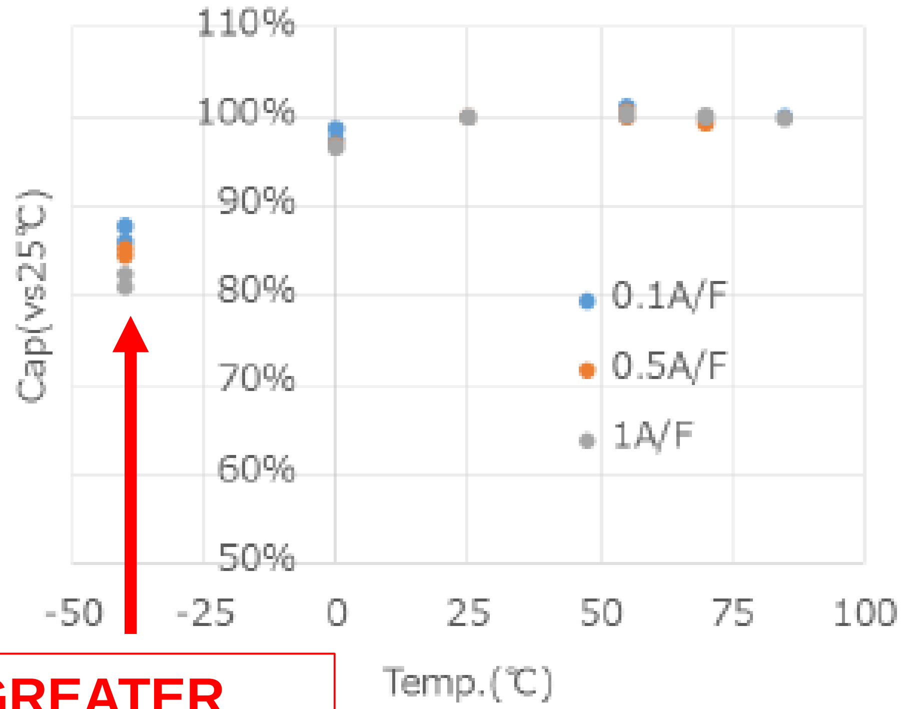
PC BASED ELECTROLYTE. DISCHARGE RATES VARYING FROM 0.1 TO 1 A/F. MIN TEMPERATURE -40C.

Standard Electrode



ONLY 40% RETENTION!

Nanoramic Binder Free



GREATER THAN 80% RETENTION!

BINDER-FREE ELECTRODE AVAILABILITY

LiC cathodes and ELDC electrodes

- Up to 50,000 m2/month total capacity
- Process licensing for high volume

LiB anodes and cathodes

- NRE (custom) → up to 50,000 m2/month → licensing

Nanoramic™
LABORATORIES

THANK YOU!

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