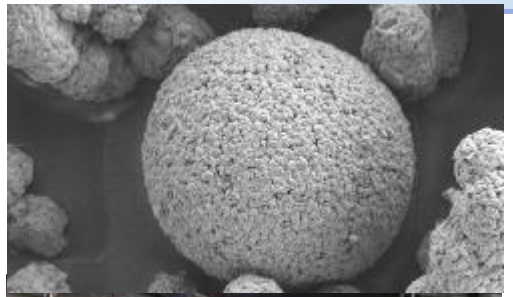


# AABC Europe (Virtual)
## Chemistry Symposium

# Crystallite Surface Engineering in Polycrystalline High Nickel Cathode Materials

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# Global EV and Battery Cathode Markets

**By 2030, ~2.5 million tons of annual cathode production will be required to support the global EV market.**

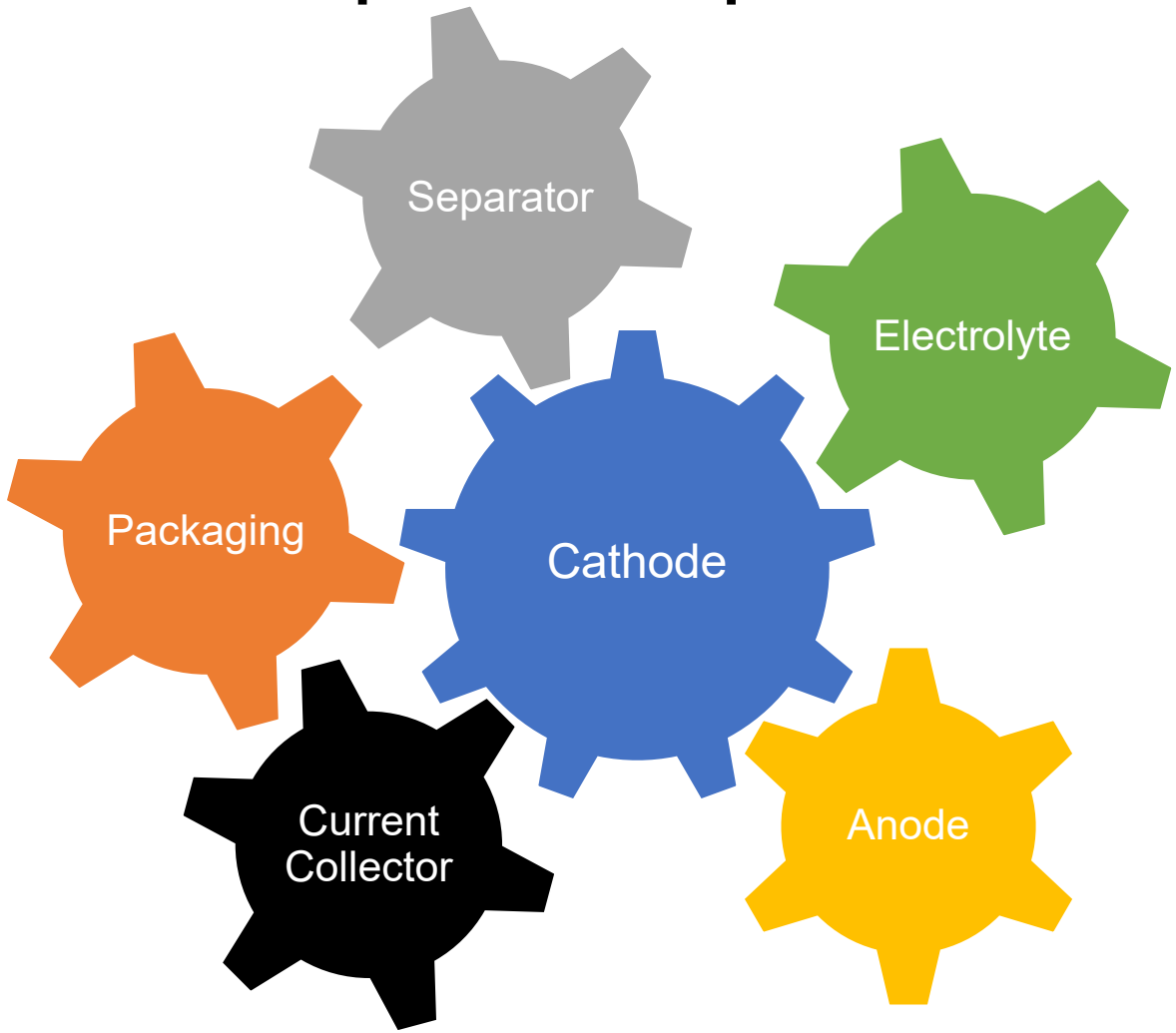
**By 2035, ~5 million tons of annual cathode production will be required.**

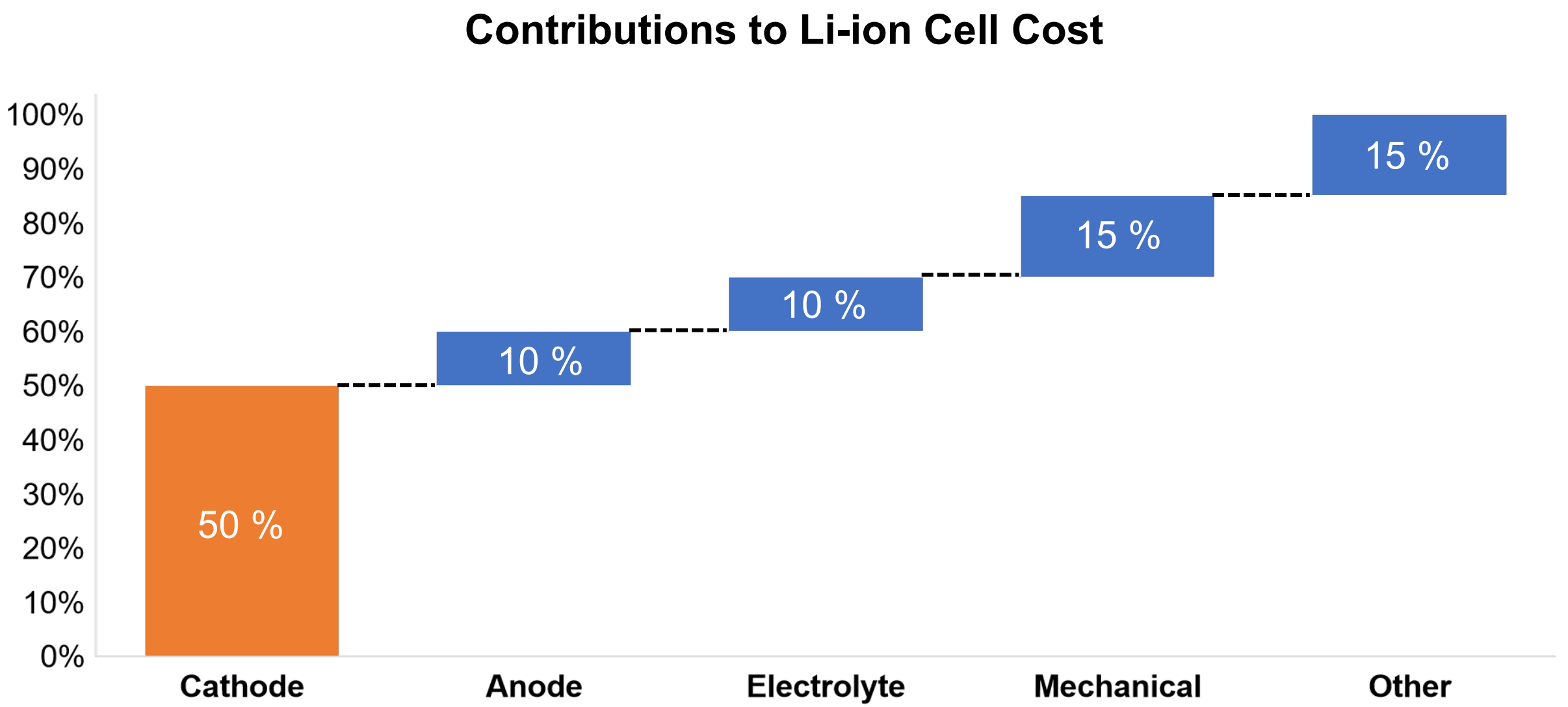
**Assuming 10,000 tons per plant, this will require 250 qualified cathode plants by 2030, and an additional 250 by 2035.**



Source: *Bloomberg New Energy Finance Electric Vehicle Outlook 2020*

# Compatibility Between Cathode and Cell Components is Required for Implementation





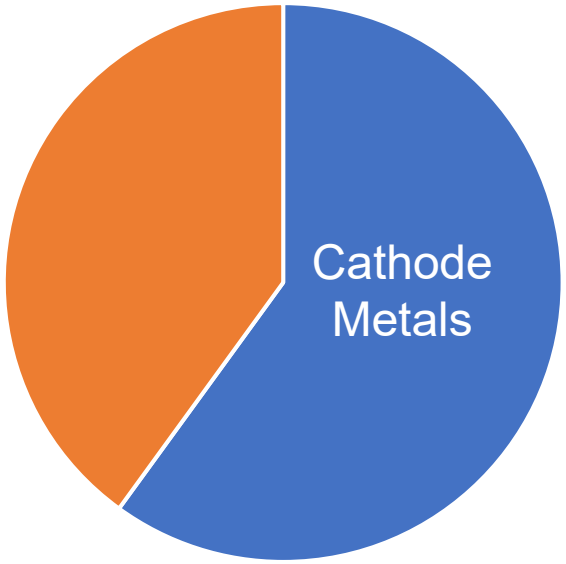



Source: *Benchmark Mineral Intelligence 2020*

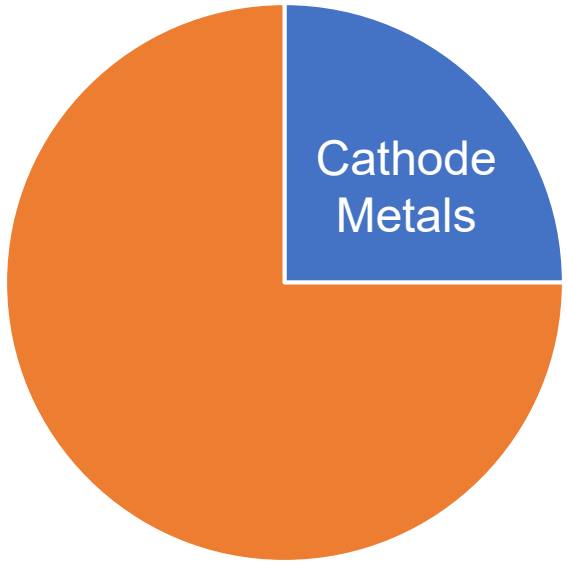
- 50-65% of cathode cost is metals cost, and metals costs assume ~ 25% of the total cell cost.

- Therefore, scale to achieve low-cost procurement of metals is very important which will favor big suppliers with long term purchase and supply agreements.

**Cathode Cost**




**Cell Cost**



- Currently, large suppliers are constructing plants and setting specifications.
- Already decided chemistry choices likely will not change during the next 10 years.
- **Improving these cathode chemistries without requiring significant modification to existing plants is critical.**
- Given the centrality of cathode chemistry and production, all the other cell components will have to match the cathode, meaning the cathode producers will also impact the other components**.**

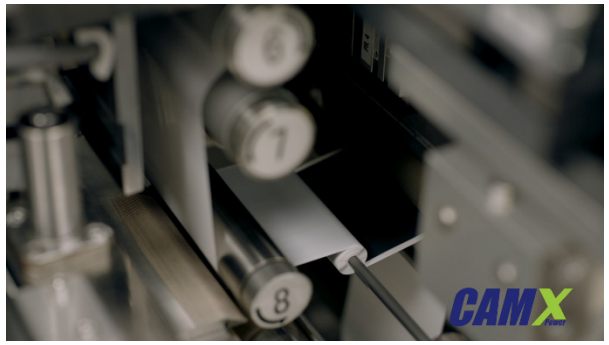
**Using vertical integration and incremental progress as key strategies for materials development,**

**Anticipating high nickel adoption in the market, we have focused on crystallite surface engineering in polycrystalline high nickel cathode materials (NMC, NCA, and LNO).**

**CAMX (previously a division of TIAX) has been engineering the interior of the secondary particles of high nickel cathode materials since 2002.**

## CAMX Power Vertically Integrated Development Facility Spanning the Li-ion Value Chain

Precursor Synthesis → Powder Calcination → Electrode Coating → Cell Fabrication → Battery Testing → Pilot Plant Scale Up




## Crystallite Surface Engineering in Polycrystalline High Nickel Cathode Materials

- Grain boundary engineering applies to the full range of nickel cathode materials and can enable lower cobalt concentrations with superior performance.
- Grain boundary engineering enhances existing, commercial cathode materials to be cheaper, safer, and better performing.
- CAMX's grain boundary enrichment technology, the GEMX™ cathode platform, was globally patented in the key jurisdictions.
- **The GEMX patents are independent of the synthetic route to place cobalt or its combination with additional elements (e.g., Al) in the grain boundary.**

# The GEMX Cathode Platform in the Market

- **RECENTLY SAMSUNG SDI ACQUIRED A NON-EXCLUSIVE, GLOBAL LICENSE TO THE GEMX CATHODE PLATFORM.**
- **Samsung SDI** is already selling cells with GEMX equivalent cathode material in the US and internationally.
- Samsung SDI and a Korean partner are adding a 150,000 ton capacity to an existing 30,000 ton plant in South Korea to be completed by 2023.

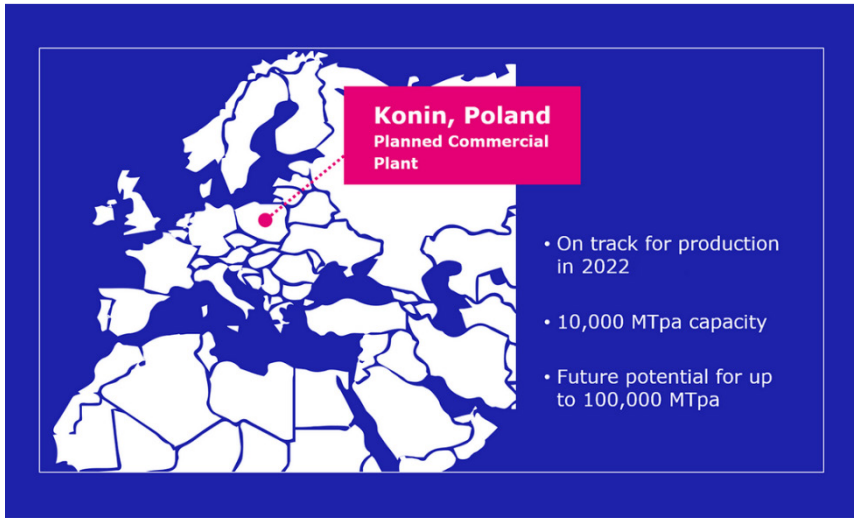
# The GEMX Cathode Platform in the Market

- In 2016, Johnson Matthey (JM) licensed a predecessor of the GEMX cathode platform and in less than a year after significant technology transfer from CAMX, built a pilot plant to produce eLNO® (JM's branding), which combines the GEMX cathode platform with JM processing technology.

- In 2018, JM licensed the full GEMX cathode platform.

"Given the huge amounts of capital being committed…[£550 million]…management must be far enough advanced in testing to have visibility on pricing and returns. **It's no longer possible to plausibly dismiss eLNO as a mere curiosity."**

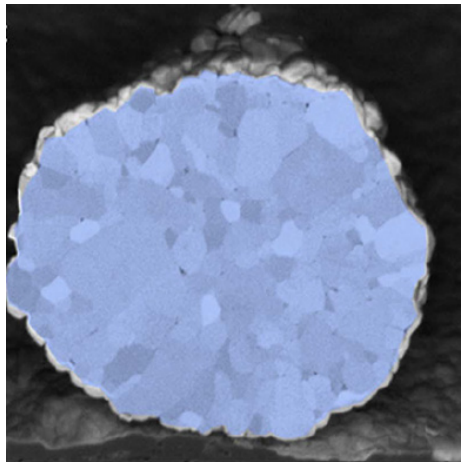
Bloomberg Article (Nov 2020)




Source: *Johnson Matthey*

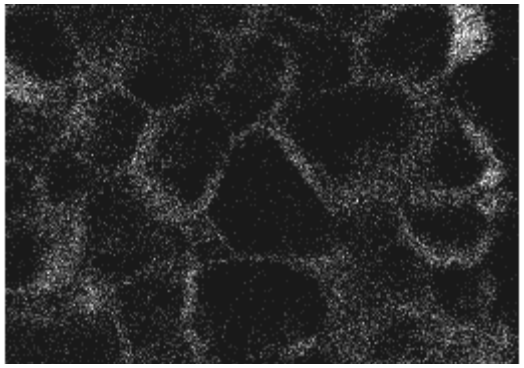
# Cobalt Grain Boundary Enrichment Benefits

**Uncycled High-Nickel Cathode Material (Conventional)**

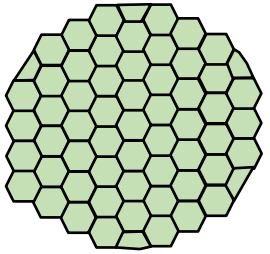


SEM micrograph*

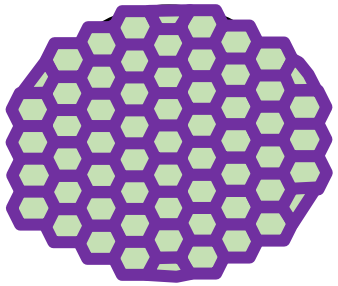
**Uncycled Grain Boundary-Enriched High-Nickel Cathode Material (GEMX)**



STEM with EDS map of cobalt



**Conventional High-Nickel**

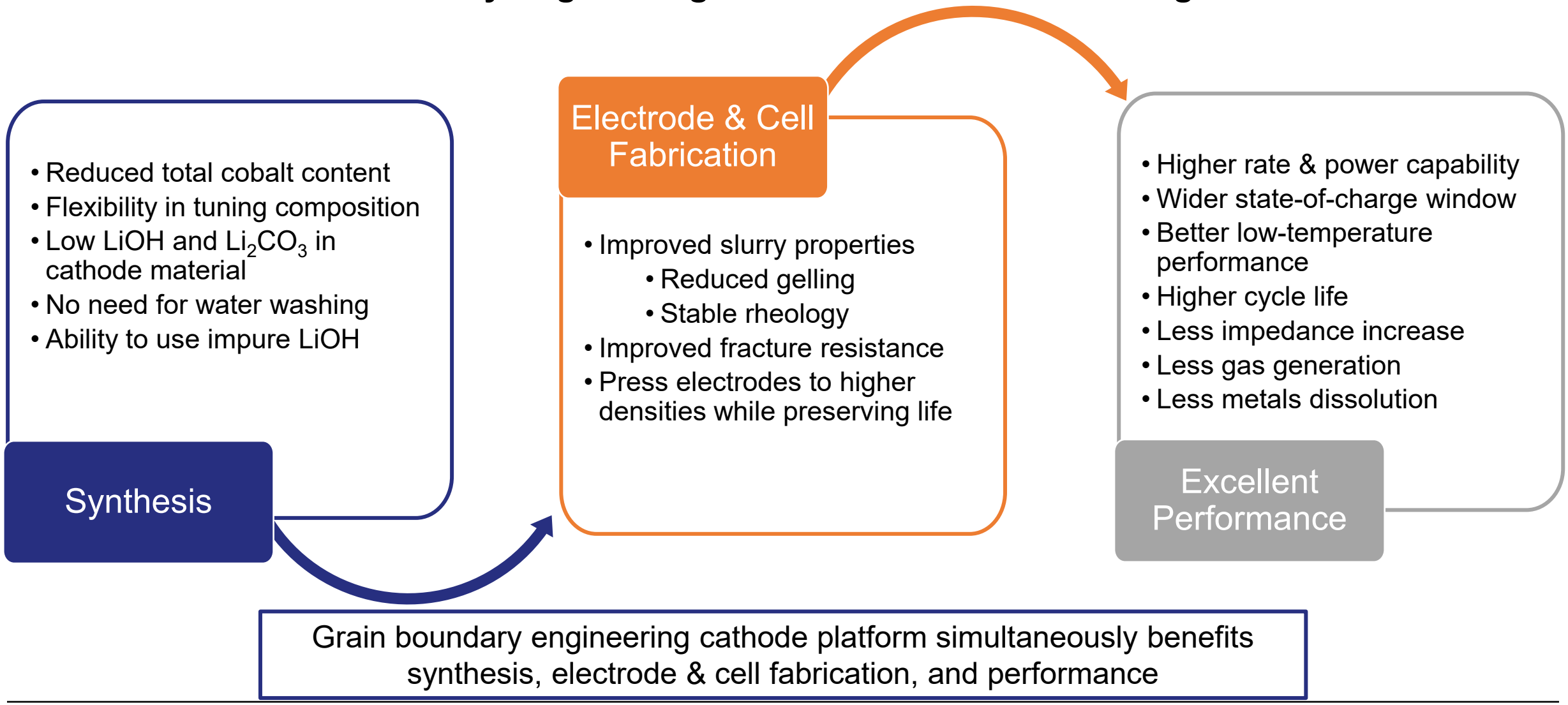


**GEMX™**

- **Reduced Total Cobalt**
- **Higher Power**
- **Higher Energy**
- **Better Extreme Temperature Performance**
- **Longer Cycle Life**
- **Lower Impedance Growth**
- **Flexible Synthesis with Minimal Processing Steps**
- **Improved Electrode & Cell Fabrication Properties**

**Chem. Mater.* 31.2 (2018): 491-501.

## Grain Boundary Engineering Enhances The Manufacturing Chain




Grain boundary engineering cathode platform simultaneously benefits synthesis, electrode & cell fabrication, and performance

## Previously Presented Applications at AABC US 2020 demonstrating the GEMX Cathode Platform:

**Application 1:** GEMX-enhanced NMC with 10 mol % total Co content

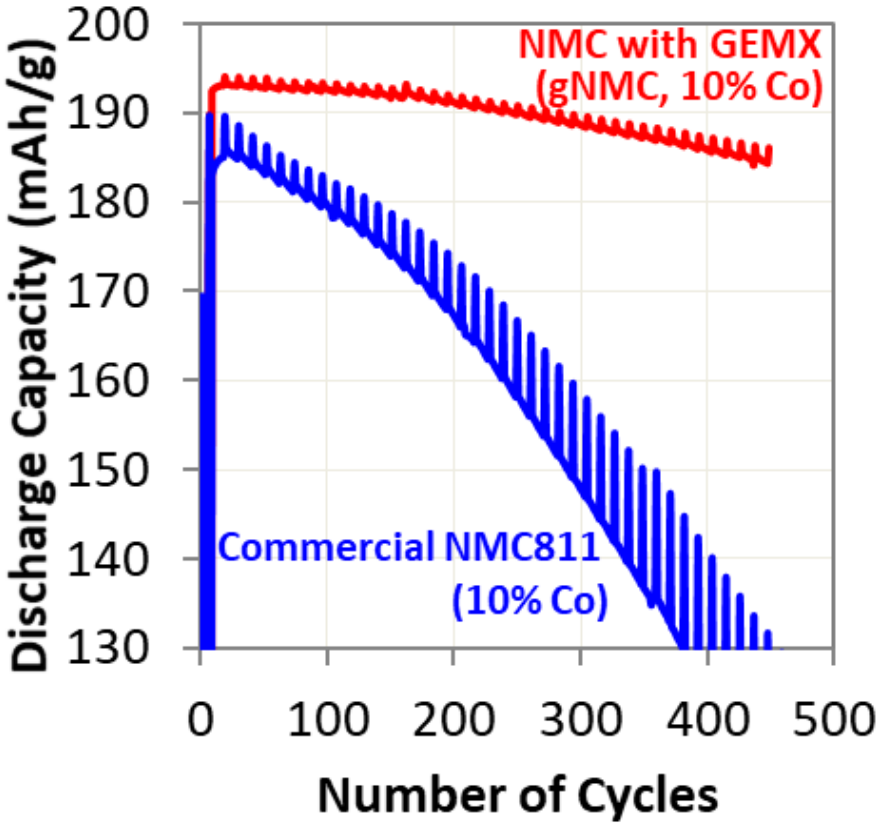
**Application 2:** GEMX-enhanced NCA with 9 mol % total Co content

**GEMX being a platform technology, many other high-nickel compositions can be synthesized with grain boundary enrichment.**

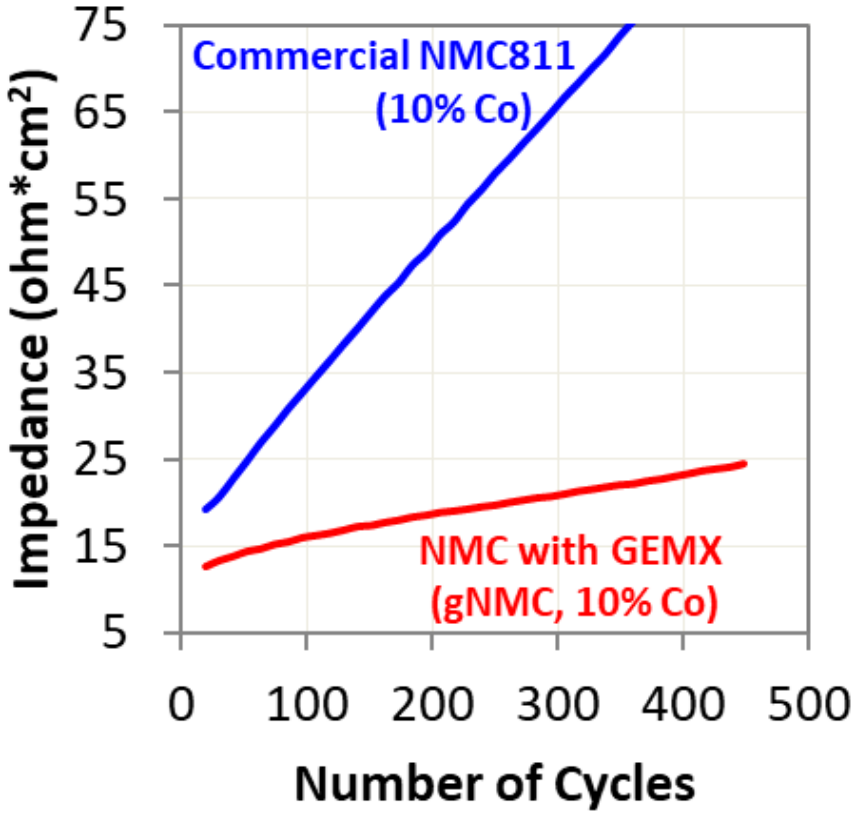
# Application 1: GEMX-enhanced NMC with 10 mol % total Co content

gNMC™ with 10 mol % Co exhibits superior performance compared to **commercial NMC811**

**Higher Capacity & Capacity Retention**




**Lower Impedance & Impedance Growth**

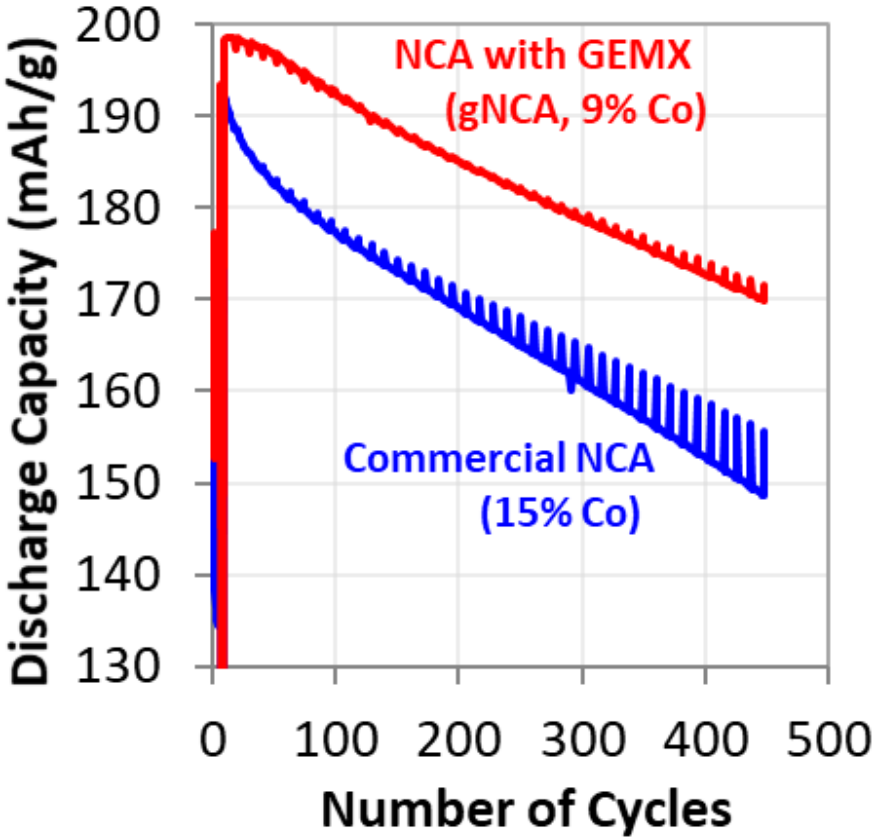



Data shown for full coin cells with graphite anode (~2 mAh/cm$^2$ cathode loading) cycled at 45°C from 2.7 – 4.2 V under a rapid aging test protocol with average C-rate > 1. Discharge capacity is normalized to mass of active cathode material.

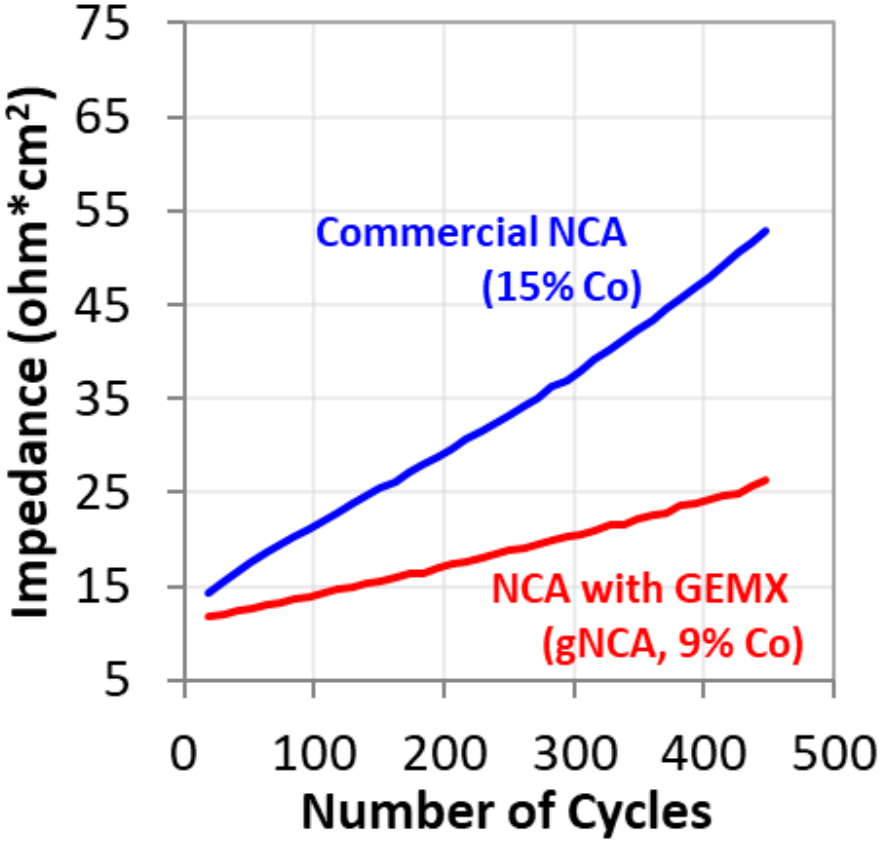
# Application 2: GEMX-enhanced NCA with 9 mol % total Co content

**gNCA™** with 9 mol % Co exhibits superior performance compared to **commercial NCA** with 15 mol % Co

**Higher Capacity & Capacity Retention**




**Lower Impedance & Impedance Growth**




Data shown for full coin cells with graphite anode (~2 mAh/cm$^2$ cathode loading) cycled at 45°C from 2.7 – 4.2 V under a rapid aging test protocol with average C-rate > 1. Discharge capacity is normalized to mass of active cathode material.

- During the past few years, CAMX power has extended its crystallite surface engineering to aluminum enrichment in the grain boundary alone or with cobalt enrichment.
- **Patents in the United States are granted** (global patents in other key jurisdictions are pending).

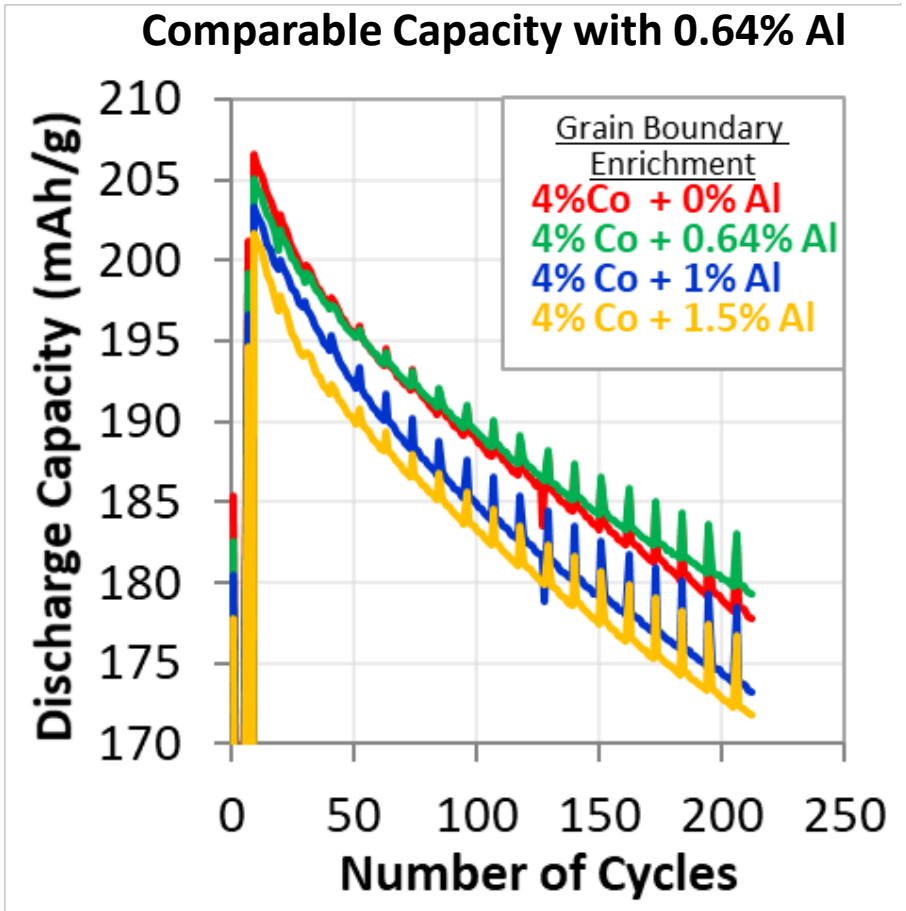
# Benefits of Aluminum and Cobalt in the Grain Boundary:

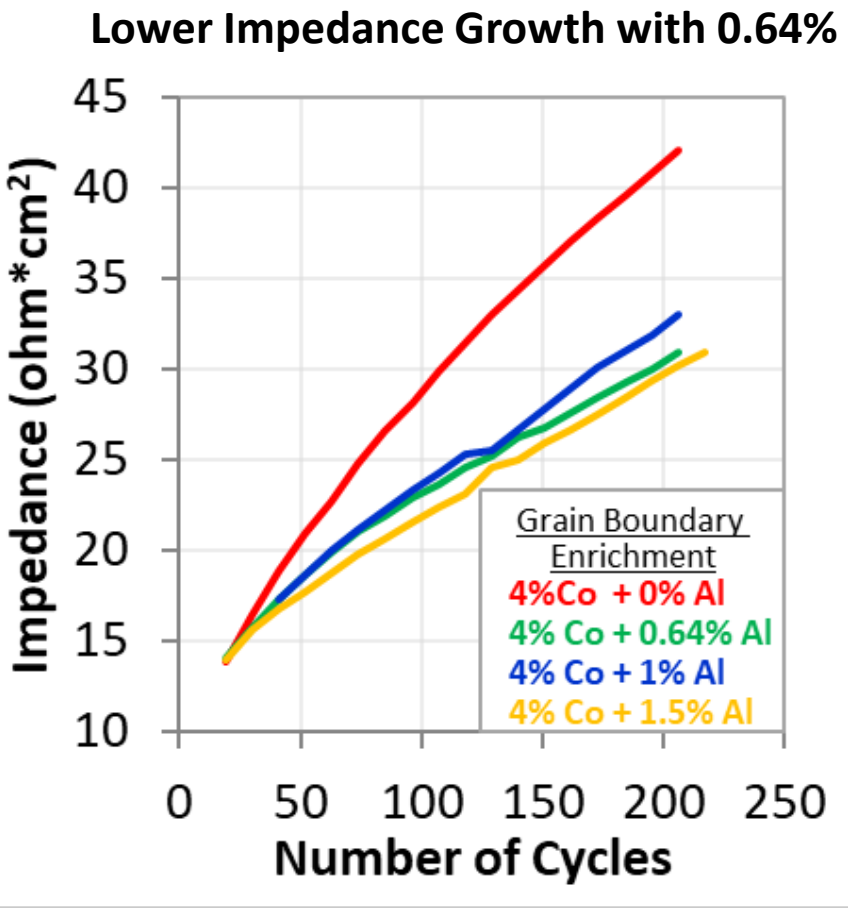
**Application 3:** GEMX-enhanced NCMA with 6.7 mol % total Co content

**Aluminum and Cobalt can be independently enriched in the grain boundary to tune performance and provide a pathway to further reducing Cobalt.**

# Application 3: GEMX-enhanced NMCA (gNMCA™) with 6.7 mol % total Co content

Enrichment of the grain boundaries with Cobalt and Aluminum improves impedance growth without sacrificing capacity



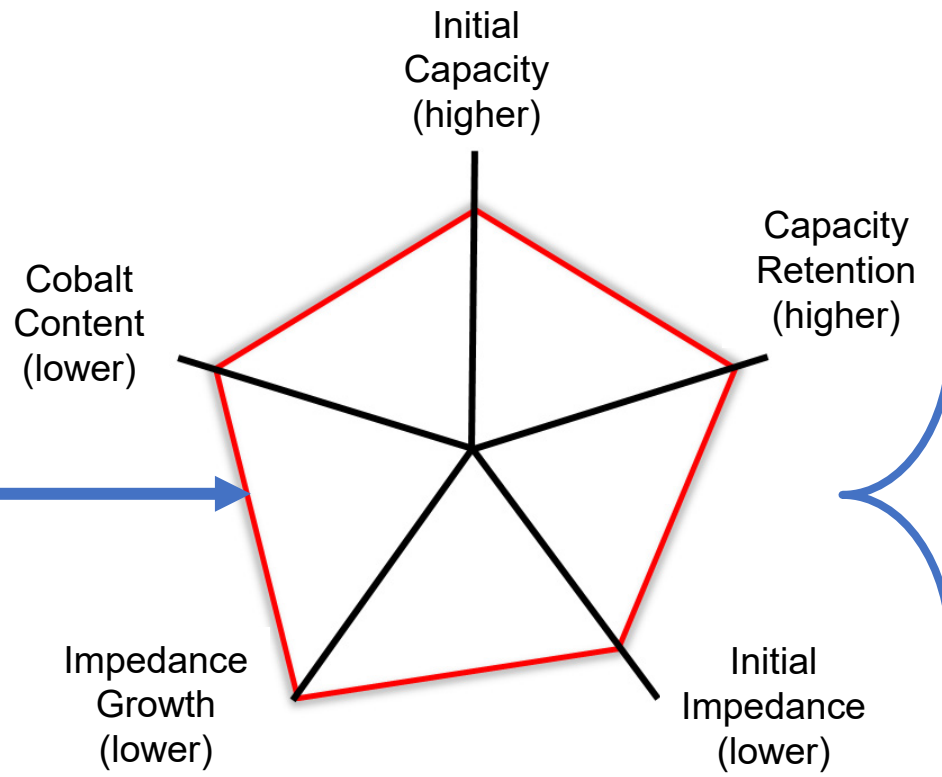




Data shown for full coin cells with graphite anode (~2 mAh/cm$^2$ cathode loading) cycled at 45°C from 2.7 – 4.2 V under a rapid aging test protocol with average C-rate > 1. Discharge capacity is normalized to mass of active cathode material.

# Objective: Meet Customer Requirements With Minimal Cost

## Customer Requirements

- **Energy Density**
- **Power Density**
  - **Fast Charging**
- **Cycle Life**
- **Calendar Life**
- **Operating Temperature Range**
- **Safety**
- … (Others)




## Tunable Parameters

- Elemental ratios (NCA, NMC, LNO)
- Processing cost and step reductions
- Feedstock cost (LiOH, $Li_2CO_3$, Ni, Co, etc)
- **Grain boundary structure and composition**
  - **Co grain boundary enrichment**
  - **Al grain boundary enrichment**
- … (Others)

- CAMX's vertically integrated development facility can serve as a **launching pad** for new entrants into cathode production or existing companies to extend their offers.
- CAMX can serve as a **pre-engineering facility** to develop specifications for grain boundary enriched cathode materials.
- With cathode chemistry at the center, CAMX can serve as an **assessment facility** for other cell components.

**Thank You for Your Attention!**

**For more information please visit camxpower.com**

**Please email info@camxpower.com with any questions**