Umicore at the Core Event in Poland

Wednesday, 8th November 2023

Short to mid-term battery trends: Umicore's CAM portfolio covering full spectrum of EV segments

Geon Seog Son
Senior Vice President R&D, Umicore Battery Materials

Hi, good afternoon everyone. I'm Geon Seog Son, but please call me G.S. I'm in charge of Umicore's global precursor and cathode active materials Research & Development.

Are you ready to embark with me on a journey into the world of high energy and powerful cathode powders? Anyone would like to join? I hope everyone, thanks.

As Frank and Geert mentioned, we have very structured innovation processes and systems which cover both the short term to long term time horizons. Today, I would like to focus on the short term and mid-term battery technology that will be used in the EV market, namely, the liquid lithium-ion battery. I would like to introduce to you various, key battery materials technologies that can be used in this battery and will bring significant value to our customers and to us.

So, Katharina, you did a good job in explaining this very complex slide. Actually, in my organization, we have a dedicated team that tracks customers' needs and consolidates market intelligence. This resulted in this very important slide that captures the customers' needs and the different battery materials that we have to develop to serve the upcoming EV models.

We can simplify the requirements of the market into 3 different segments. First, the premium EV segment, which will definitely require high nickel content battery materials from 80 up to 90 plus. These high nickel battery materials will also cover the high end of the mass EV segment.

But there is more for the mass segment. Katharina showed that many vehicle platforms will be introduced in the future in the mass segment. For these, we have also developed next generation battery materials focused on high voltage medium nickel. We call it next generation battery materials due to the high voltage capability, which I will explain to you later.

But that is not all. Some might think that we don't have any technology for the entry EV segment because of the existing LFP and LFMP battery materials technologies. However, we have high lithium and manganese battery materials, in which we made significant progress the last months.

And this is not the end of our product portfolio…

We have also zero cobalt cathode materials called NMx which will serve the needs of the entry as well as the mass EV segments.

As you can see, for each EV segment we have at least two different battery materials propositions. Why?

Cell makers, cell designers, they require freedom and flexibility to meet the needs of their car OEM customers. These needs can vary depending on the region, on driving patterns, on the regulation of the driving cycle. Yes, they need freedom. With only one cathode materials technology, they cannot meet all these different requirements. And we are providing them with these options.

Katharina showed you how many platforms will be launched in the EV mass segment...

That is why we are providing multiple solutions with Umicore's cathode materials portfolio for Li-ion batteries spanning ALL the short to mid-term performance needs of entry, mass and premium EVs .

Let me start with high-nickel NMC where Umicore has industry-leading technology and is further pushing the technology boundaries for premium
and mass EVs. I'd like to share with you more details of our high nickel development trajectory and what we have achieved with our excellent R&D team the last three years. I'm very proud of this team because they enjoy challenges, sometimes very tough challenges, and aim to be at the top in the battery materials technology field. Through a combined focus on both precursor to cathode materials research & development as well as detailed battery testing, they were capable of developing truly industry-leading battery materials. Let me share with you how we did this.

Before we go into the technical details, I would like to show you on this slide the customer recognition of our efforts. If you look at our order book for 2027, the vast majority concerns high nickel battery materials.

Now, let's focus on Umicore's high nickel technology capabilities which span the two major morphologies: the first one being poly-crystalline, the other one being mono-crystalline (also called single crystalline).
But before I'm diving into these details, I'd like to first go back to the basics and share what high nickel cathode materials are about.
What is the major priority for the premium EV segment? Longer driving range and fast charging. How can you make this happen? Yes, with high nickel content in the cathode materials. The higher the nickel content in the cathode, the higher the energy density. This seems relatively easy and straightforward, but from a technological perspective it's not easy at all. Why? When the nickel content in battery materials increases, more and more technological hurdles and drawbacks result from this.
Where are these drawbacks coming from? Well, cathode active materials are a layered structure. Transition metals are bonded with oxygen and make a salt with in between space for the lithium to go in and out. In a low nickel content environment, this process is very stable. Up to medium nickel, it's still okay and capable to achieve long cyclability. But when you go up to > 80% nickel content in your battery materials, issues start to arise. When lithium is going in and out, this salt thickness will expand and contract with a greater amplitude, which might result in cracks.
Specifically in a poly-crystalline structures, the prime particles which have a nano micro size are agglomerated to make a secondary particle shape. But if due to the high nickel content the expansion and contraction level increases, this poly-structure will result in even bigger cracks In this case, the lithium diffusion will become difficult and slow down. On top of this, the liquid electrolyte can get into these cracks and make a side reaction on the surface of the prime particle increasing the resistance on the surface of this particle. This results in a higher resistance meaning again lower diffusivity of lithium, but more importantly, it can be the source of a critical thermal event.
So one needs to be able to manage this kind of cracking of the polycrystalline structure that happens with higher nickel content, in order to be able to offer a high quality product to the customer.

And here Umicore can make the difference as a leader in mono-crystalline and poly-crystalline high nickel structures. Let me explain to you how our poly -and mono-crystalline cathode materials can solve these issues and how Umicore was able to develop them.

As you know, Umicore has an upstream organizational set-up meaning that we produce both the precursor materials as well as the cathode materials. This upstream set-up proved to be key in solving these kind of technical challenges brought on by higher nickel content, as you need to start already from the precursor development stage to be able to solve the issues. As **Geert** explained to you, we start in the precursor phase from a liquid to create solid particles. But if you can control during the build-up of the precursor the shape of the solid primary particle and its direction, you can avoid the high nickel risks. Well, I'm proud to say that Umicore has succeeded in making such one direction solid precursor particles, also called mono-crystalline structures.
Yes, We can make very structured precursor materials which makes a big difference in the end performance when it comes to high nickel content.

Let me just give you an example. You are driving a car in a city. To drive out of the city, you have to make quite some zigzag in the streets. And your drive takes a long time. The same thing happens in cathode materials. In the case of poly-crystalline structures, which do not have a microstructure of the primary particle, lithium diffusion has to zig and zag and will take more time.
But if you have a "one direction" structure, this would be like providing a highway for the lithium diffusion which will prevent any cracks from happening in the case of higher nickel content and the issue of other materials coming in these cracks. So here Umicore can make mono-crystalline structures to solve the issue seen in poly-crystalline morphologies.

But we can also improve the existing poly-crystalline structures to cope with the issues. For both the mono as well as poly-crystalline structures we perform several technological innovations:

- We perform doping of the materials meaning that we put additive materials in the precursor precipitation. This allows us to avoid an extra, external treatment in the cathode process, ultimately resulting in cost savings. So we already make a doping from precursor stage.
- But this is not all we need to do. The surface of the precursor after lithiation, can contain residual lithium which can generate a lot of side reactions. If there is humidity, if there is CO2, it can make a side reaction and then also generate gas. This means you need an optimized washing process to reduce such chemical reactions with the electrolyte and to promote lithium diffusion. This is done through a special coating that contains specific additives. And this is what Umicore's R&D team developed.
- But there is more… to make a reliable product, you need a **homogeneous** coating . If you don't have a homogeneous coating, this could actually result in more resistance or side effects because a metal particle or oxide particle could generate additional side reactions as a catalytic reaction. And here we can at Umicore, thanks to our R&D team, make homogenous coatings.

These innovations result in technology and product leadership in the in both the poly and mono crystal high nickel structures. However, for mono-crystalline structures, we are not simply among the industry leaders, we can truly state that we are in the top position.

Why is this? As you can imagine, mono crystalline structures have a much higher mechanical strength than poly because poly is as I explained an agglomerated shaping of the prime particles.

However, mono-structured particles are much bigger than the prime particles of poly structures. This means that one lithium ion has a much longer path the follow to diffuse to outside this particle
But Umicore also succeeded in solving this by manipulating the layered structure allowing aa shorter lithium ion diffusion path. We call this passive control: making a larger area for the lithium diffusion, to unlock faster diffusion and an equally faster charging rate.
We demonstrated these mono-crystalline performance achievements to our customers and noticed that they had a strong preference for our robust mono-crystalline structured high nickel cathode materials.
So that is the reason Umicore is in the top position in the mono high nickel.

To protect our products and to secure freedom to operate, we have almost 100 patents. And our customer, they love this. Our innovations for high nickel products, can be used on poly only or mono only, but we also have the far-reaching technological capabilities to make a blend between both mono and poly by putting the mono particles inside over the bigger poly particles, we can use space more efficiently and again provide higher energy density.
So we have actually two top market leading products. That's the reason we have long term contracts because customer they recognize our product is working.

Now let's move on to our next generation mid-nickel cathode materials. Of course we did not develop this exception technological capabilities to use this only for high nickel cathode materials. We applied what we learned from our high nickel innovations into current existing medium nickel. And as a next step, we developed on top next generation high voltage medium nickel product which can unlock higher energy density for mass EVs.

Why am I calling this next generation high-voltage medium nickel? Power is voltage multiplied with current. The current limit is for cathode active materials. This means that if we increase the voltage, we can unlock higher power and energy density. Seems easy, right? We can just increase the voltage and then we can have high energy density. But there are always trade-offs…

If you increase the voltage, this can result in a decomposed electrolyte or a reaction between the cathode active materials and the electrolyte. So if we can't succeed in managing these side-reactions, high voltage applications are not viable and cannot provide the necessary durability and cyclability.

We used what we learned from our high nickel innovations and developments to manage this. Currently we are in the joint development stages with key customers and the final stage of vehicle application. So far in our order book for 2027, there is only little amount of mid-nickel, but we anticipate the portion will increase driven by this new next generation high voltage mid-nickel that comes without any side-reactions.

So what exactly did we apply from our high nickel innovations to allow mid-nickel at high voltage?

- The surface coating. Surface coating means to avoid, to protect side reactions between the cathode materials and the electrolyte.

- But we also used our doping innovations. We dope the primary particle to enhance the spacing for the salts.
- Another high-nickel learning used for the next generation high-voltage mid-nickel is reshaping. As I mentioned, if we make a different gradient according to the radius of the particle, we can minimize side reactions. One example is if we reduce nickel content on the surface area, in that case we can reduce the high nickel side impact in the electrolyte. So we can generate a gradient of the transition metals in the particle and offer this as a solution to the customer.

Now what's the benefit of all this innovations to allow high voltage mid-nickel? We can go to lower nickel and cobalt content compared to high nickel cathode materials, while still providing similar energy density. That's the reason why next generation high voltage mid-nickel can cover not only the mass EV segment but also the bottom of the premium EV segment.
At 4.46 volt, we can provide very decent energy density that is comparable to the energy density of high nickel.
Actually I believe we could achieve an even higher voltage with our technology but we prioritize safety and customer design. So comparable energy density to high nickel while providing more safety as
mid-nickel content means that the contraction-expansion risk is lower than with high nickel. And to be very clear, next generation high-voltage mid-nickel provides much higher energy density compared to LFP. So to conclude: Umicore’s next-gen high-voltage mid-nickel NMC provides pCAM and CAM cycle and voltage stability when charged up to 4.46V unlocking energy density close to that of high-nickel for mass and premium EVs. We aim for mass market production of this technology as of 2027.

But is this is not all Umicore has in terms of cathode materials chemistries for the EV mass segment? No. There is another very special technology in our portfolio that we call high lithium, high manganese HLM which provides a superior range / cost proposition to future entry and mass EVs
You can already imagine from the name what the special characteristics of the high lithium, high manganese HLM cathode materials are.
Yes: low nickel and low cobalt,(even zero cobalt)asin HLM there is no cobalt. But very interestingly, despite this low nickel and low cobalt, we achieve an energy density of the medium nickel level. This is quite the achievement, right? However, as I previously mentioned, there is always a trade-off.

This HLM concept is not new. It has been researched for a long time. But why did it not materialize so far? Why did it remain so long only in a R&D level?
First reason is voltage fading. Next is manganese dissolution on the surface.
These major difficulties hindered the industrialization of HLM. But again, thanks to our combined precursor to cathode active material development, we were able to make huge progress.. In such a way that we are now anticipating the start of mass production soon. Which brings us in the position of being the first player capable of industrializing this excellent HLM technology.

Maybe someone will ask what's the big advantage compared to LFP? Because LFP is a good technology. It’s cheap raw materials and good safety. But maybe you heard this technology is primarily adopted in China.
Looking at this graph you will see on the right side the cost comparison between HLM and LF(M)P based on our internal forecast of the metal prices in 2027. Maybe you will

say that there is only 3% cost benefit to HLM. Well, I'd like to say that cost competitiveness is there.
But if you look at left side of the graph, you will see that energy density wise, there is big difference. HLM has around 30% better energy density than LF(M)P, and even more compared to LFP.

What is this so special? This high energy density, what's the meaning to us? Well, with high energy density, you can achieve the same driving range with a lighter and smaller battery.
You might remember from Katharina's presentation how important the smaller car segment is in size. If we can provide materials that allow a compact battery, what is the benefit in the car? They can use more space for the passengers, trunk… right? And they can have a better mileage because it's lighter. So this is the beauty of our HLM product: we are abme to bring a superior range / cost proposition for future entry and mass EVs.

If we are looking at all the benefits of HLM one by one:

- Frank already mentioned the importance of CO2. In particular in Europe and North America, CO2 is key. Why is electrification happening? Because of the CO2 of the internal combustion engine. So if we can provide a technology with cost competitiveness and better energy density and less CO2, we will have to do it. And up until now, there was no feasible, mass producible alternative technology to LFP. But now we have succeeded in developing this and are ready to target the market. This means that cell designers now have a choice, right? They have a different choice next to LFP.
- Another benefit of HLM is connected to my statement that LPF will have most of its momentum in China . A major ingredient of LFP is iron phosphate. That is actually a side product of local metallurgical activity. They are huge inventories of this iron phosphate in China. However, we cannot produce this iron phosphate in Europe or in North America at the same price or within applicable CO2 limits. That's one of the key reasons there will be limitated LFP-based EV applications in North America and Europe.

That's the reason Katharina and Ralph could say boldly that we expect to see a substantial portion of LFP-based EVs in China and perhaps also in the rest of the world, but not such a substantial presence in Europe and in North America. Don't get me wrong, there will be LFP-based EV in these markets. We are not saying it will be zero in Europe and North America. But the proportion will be much smaller than in China.

We have prepared a short video on HLM. Please enjoy. I will take a rest.

HLM video playing

G.S., Senior Vice President R&D, Umicore Battery Materials
Did you enjoy the movie? I hope so. Okay.
Why is HLM so special?
Normally, in an NMC structure, lithium is only located within the salt.
But in HLM, this lithium-ion can go into the transition metal area. That's the reason we can achieve a high lithium proportion in HLM. But what's the meaning of this to us?
If we have high lithium content, we can allow more electrons which means we obtain a high capacity.

And another big benefit of HLM is that we can use oxygen redox. Normal NMC can only do transition metal reduction. So, as you in the left bottom of the graph, in NMC only metal reduction is possible. Which means that we have a limitation in the capacity.
But if we can use oxygen redox in the charging and discharging, we can expand much higher the capacity. So, that's the reason why with very low nickel content in HLM, we can still keep the capacity associated to medium nickel.

But, as I mentioned, this creates a lot of technological issues such as voltage fading, manganese dissolution and gassing. Because if we use too much of oxygen redox, this can provide a source of thermal runaway.
So, how was Umicore capable of overcoming these technical hurdles of HLM?

- We used what we learned from our high voltage medium nickel and high nickel cathode materials innovations. Starting from the precursor, we performed modeling to make the right design of the precursor. With the help of modeling, we then made the right structure of the precursor in terms of pore porosity and pore size and the distribution of these inside the precursor. This provided to be the ideal solution for the chemistry design. This innovation even allows us to use and advantageous lithium source in HLM because the nickel content is lower. We can use lithium carbonate instead of lithium hydroxide. It means we can cut down costs further.
- Next to this, we did a study of electrolyte conformity to be operated in high voltage. Umicore's battery lab, which is capable of testing a large cell in a full pack mode, was comfirming with the customer which electrolyte would fit best our HLM cathode metals. This capability to joint test with the cell customer further accelerated our industrialization capabilities.
- We also needed an mechanism to achieve the right gassing during the activation stage. We developed a mechanism that keeps the right amount of oxygen in the product and minimizes the gas generation.

All these developments would not have been possible without advanced analytic tools. Two years ago, Umicore created a new R&D center in Korea with really top-notch analytical tools. These tools allow us to see microscopically inside our material, allowing us to achieve this significant progress in terms of technological innovations.

So, in a nutshell, we are now providing an alternative cathode materials technology to LFP for the entry EV segment. With HLM we are capable of providing a superior range – cost proposition for entry EVs and we believe there is also the potential to serve with this HLM technology the EV mass segment. Umicore is the first player to demonstrate mass-production capabilities of HLM and we anticipate market introduction as of 2026 in Europe and North-America.

So, last but not least. We also developed a zero-cobalt version of NMC, also called NMx. Yes, we removed the volatile cobalt content in the NMC. But as always, there is a trade-off. Cobalt has a major functionality in NMC. So if we fully eliminate cobalt, this can provide technical issues.

So, what's the function of cobalt in NMC? First, it provides structural stability of the NMC. Secondly it provides faster kinetics. Now, if we are not using cobalt, does it means that we are losing this functionalities. No? We can compensate this using our technological innovations from the high nickel NMC as well as innovations developed in the framework of HLM, more precisely the transition metal migration. So, we are able to compensate the drawbacks coming from zero cobalt with our new, own technological inhous Umicore developments, which are not yet achieved externally.

With the above-mentioned technological innovations, we can produce NMC with zero-cobalt. This means that we can lower the cost by saving on cobalt while still achieving the required stability and performance characteristics of the chemistry. We aim to position NMx as a lower cost technology for mass market vehicles with market introduction as of 2025/2026.

So, to close my presentation on Umicore's short to mid-term cathode chemistry portfolio, I'd like to ask you just one thing. Remember, when you get up from this room, or when you go into bed tonight, this picture. It shows that Umicore has a broad yet targeted portfolio consisting of multiple cathode material solutions that cater all EV car segments. We have not even one chemistry for each segment, we have at least two chemistry solutions per segment providing optionality and flexibility to our customers.

And finally, some might say that cathode active materials are a commodity. I hope that this presentation conveyed to you how important continued R&D is to bring new technologies and products to the market in order to provide toour customers cost competitiveness versus ICE, to increase the energy density and achieve customized performance characteristics per segment and to enable low CO2 mobility. Therefor I'd like to strongly say that cathode materials are not a commodity. To the contrary we are talking about ongoing and continuous R&D efforts.
I did not highlight process innovation yet, there will a deep dive on this topic in the presentations tomorrow. But I would like to highlight already that Umicore has a high efficiency. Why? We can produce all these chemistries on our existing production lines. We can launch all these innovative chemistries them without having to invest new CAPEX, as we can produce them in our existing plants.

Okay, that's it. I hope you enjoyed this long, quite technical presentation. Thank you.

Caroline Kerremans, Head of Investor Relations
Thank you, G.S., you said it all. The presentation of Stephane will further build on yours and provide further insights into our long-term technology roadmap. That is why we suggest to take a break now to process all these insightful ideas and information that we got from G.S..
And then we will go to Stephane after a break, and then we will provide the time to ask all your questions. So I think we have foreseen 15 minutes, but let's try to stick to 10 also, so the people online, we will be back soon for the next presentation after the break. Thank you.