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PRODUCTION OF LITHIUM-ION BATTERY CELL COMPONENTS

2nd edition, 2023



RWTHAACHEN
UNIVERSITY



Battery Production



Battery Production

The Chair of Production Engineering of E-Mobility Components (PEM) of RWTH Aachen University has been researching lithium-ion battery production for many years. The team's range of topics extends from the automotive sector to stationary applications. Through its participation in numerous national and international industrial projects with companies at all stages of the value chain and thanks to key positions in renowned research projects, PEM offers extensive expertise.

Overall, VDMA represents more than 3,700 German and European mechanical and plant engineering companies. The Battery Production Department acts as a contact for all questions relating to battery machinery and plant engineering. The specialist department researches technology and market information, organizes customer events and roadshows, offers platforms for exchange within the industry and is in constant dialogue with research and science.



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IBU | tec

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Preface

Production of lithium-ion battery cell components

- The volume of lithium-ion batteries (LIB) sold will increase significantly in the coming years due to the growing number of electric vehicles on the market, which means that the production of components that are installed in battery cells is attracting increasing attention for economic and ecological reasons.
- The production of battery components – such as the anode's and cathode's active material, the inactive components of the outer casing, or the separator – is responsible for a large part of the added value and CO₂ emissions.
- For the implementation of sustainable concepts in battery component production, a better understanding of existing processes is necessary.
- This guide summarizes the state of the art in the production of various battery components.

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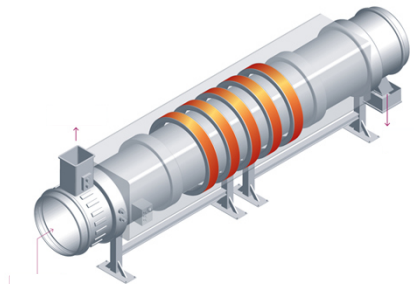
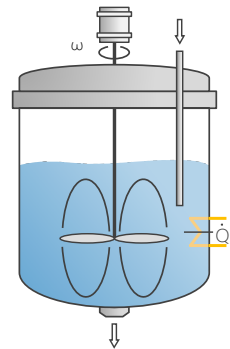
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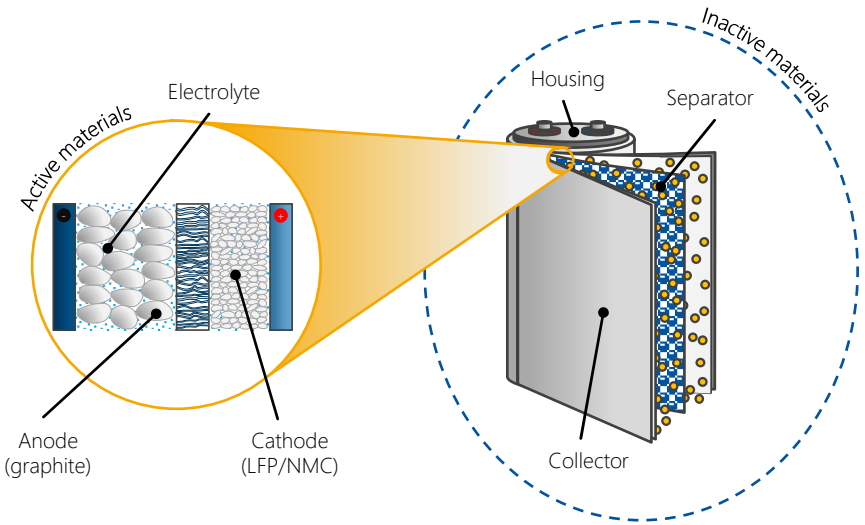
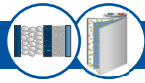
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- Electrode foil
- Separator
- Cell housing



Design of a Battery Cell

Fundamentals of battery components



Active materials			Inactive components		
Cathode NMC	Anode	Electrolyte	Collectors	Separator	Housing
Cathode LFP					

Description

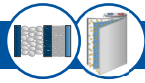
- A battery cell consists of a **positively and a negatively charged electrode**, a **separator** and an **electrolyte solution**.
- The **positive electrode (cathode)** consists of a **15 - 25 μm aluminum foil** as current collector, the **overlying active material** (e.g. nickel-manganese-cobalt-oxide – NMC or lithium-iron-phosphate – LFP), and additives.
- The **negative electrode (anode)** consists of an **8 - 18 μm copper foil** coated with active material (graphite) and additives.
- Both electrodes are **electrically insulated from each other by the separator**.
- The **electrolyte** saturates the inside of the cell and **enables the flow of ions**. It is injected into the battery cell after cell assembly and usually consists of **lithium hexafluorophosphate** and a **solvent such as DMC as well as additives** in various ratios. The production of these materials can basically be divided into the production of the **cathode materials**, the **anode active materials**, the **electrolyte** and the **inactive materials**.

Key Takeaways

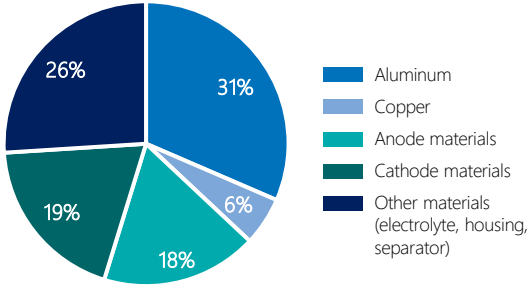
- The active material stores lithium ions and releases them during the charging or discharging process.
- The electrolyte solution saturates the inside of the cell and enables the flow of ions.
- The electrolyte is able to conduct lithium ions so that they can move.

Battery Cell Components

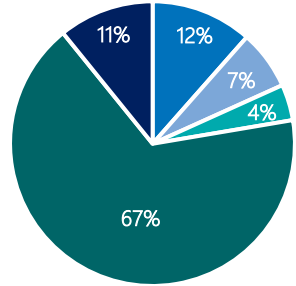
Fundamentals of battery components



Weight distribution¹



Value distribution^{1,2}



¹ Based on NMC622 cathode chemistry

² Based on material prices in 2023

Active materials			Inactive components		
Cathode NMC	Anode	Electrolyte	Collectors	Separator	Housing
Cathode LFP					

Description

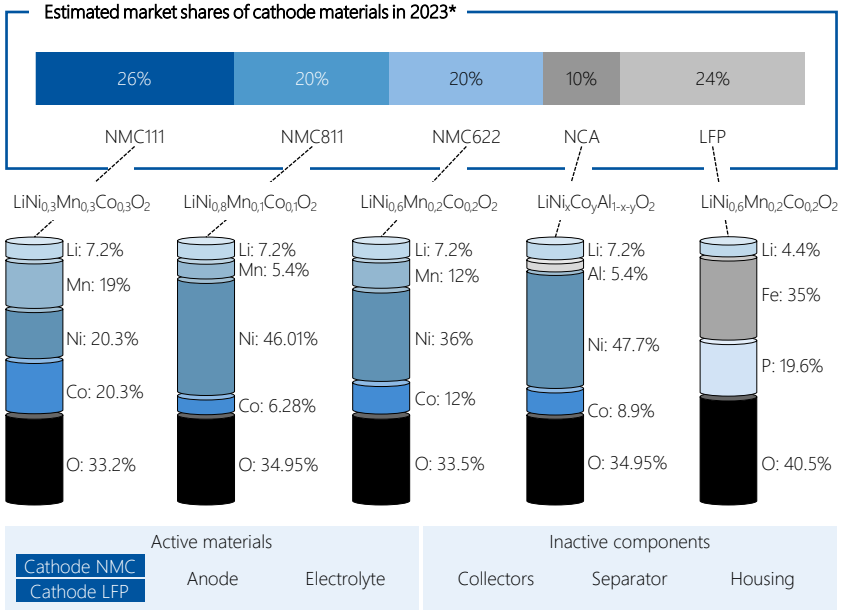
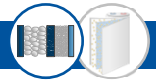
- The **main components** of a battery system are **aluminum, copper, anode material, cathode material,** and other components (electrolyte, plastic, steel, separator, etc.).
- **Aluminum and copper** are used as **current collectors**. Aluminum is also used for the **cell housings**.
- In more than 90% of cells, **graphite** is used as the **anode material**. The **cathode material's** composition varies greatly, but **lithium nickel manganese cobalt oxide (NMC)** or **lithium iron phosphate (LFP)** are usually used.
- While the **cathode materials** only account for just under 20% of the material weight, they are **responsible for almost 70% of the NMC cathodes' material value**.
- In order to keep **battery cell prices** low or to be able to offer electric mobility more cheaply, price challenges in the production of battery components such as cathode or anode active material must be solved.
- **As a growing market, battery component manufacturing** is enabling numerous European plant manufacturers and material producers as well as chemical companies to establish themselves in this market and drive forward **a long-term sustainable economy**.

Key Takeaways

- To enable economically viable processes, the active material must meet the highest standards to guarantee high quality of the battery cell, reduce reject rates in production, and ensure safety.
- As the market for battery materials and components as well as their requirements are extremely volatile, the information in this guide is intended as a snapshot.

Cathode Materials

Fundamentals of battery components



Description

- The chart above shows the mass percentages of the five most important cathode active materials in 2023.
- The proportion of high-nickel cathode materials (**NMC622 and NMC811**) has **increased significantly** in recent years compared to NMC111.
- LFP plays an important role, particularly in China.** The **LFMP** variant also exists there, in which low proportions of manganese (Mn) are integrated, which **increases** the cell material's **energy density**.
- NCA (nickel cobalt aluminum oxide)** was preferred by Tesla for a long time but is becoming less and **less important** as a cathode material.
- Strongly fluctuating raw material prices and limited extraction capacities of the elements contained in the cells are causing battery cell manufacturers to strive for raw material security, which can be achieved by switching to alternative cell chemistries or recycling.
- These fluctuations are also due to long supply chains, as raw material deposits are limited to certain countries.

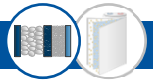
Key Takeaways

- There is currently a strong market concentration on NMC cathode materials, which contain expensive and emission-intensive base materials.
- LFP is gaining in importance due to its long service life and low material prices.
- The trend towards high nickel content appears to be continuing.

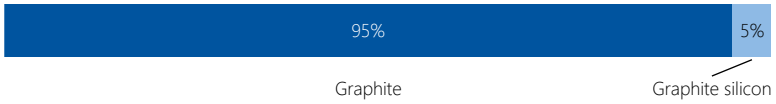
*Internal market analysis PEM, 2023; Friedrich et al., Recovery of Valuable Metals from E-Waste and Batteries by Smart Process Design, 2020; Mayyas et al., The case for recycling: Overview and challenges in the material supply chain for automotive li-ion batteries, 2018

Anode Materials

Fundamentals of battery components



Estimated market shares of anode materials in 2023



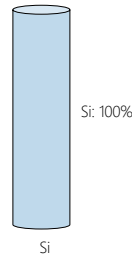
Graphite



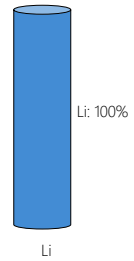
Graphite silicon



Silicon



Lithium



Active materials			Inactive components		
Cathode NMC	Anode	Electrolyte	Collectors	Separator	Housing
Cathode LFP					

Description

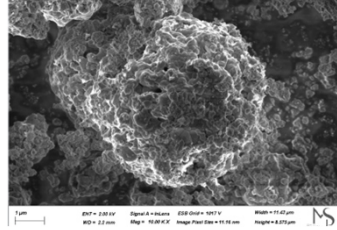
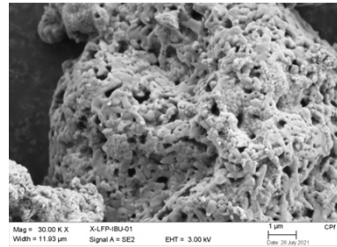
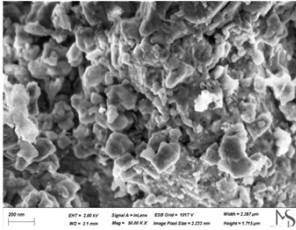
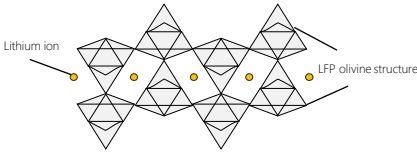
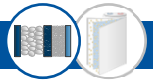
- The chart above shows the mass shares of the four most important anode active materials in 2023. **Graphite and graphite-silicon dominate the market**; silicon and lithium anodes are not currently produced on an industrial scale and are more likely to be a future alternative.
- Silicon is added to graphite anodes to increase energy density. **Mass fractions of less than 20%** are currently possible. However, this anode composition has not yet reached the mass market.
- Theoretically, **pure silicon anodes** can enable very high energy densities. The biggest challenge in their implementation is currently that the anode **changes its volume significantly (by up to 300%)** during the charging and discharging process. This is often accompanied by an extremely **short service life** of the battery cell. There are some companies with promising approaches to tackle this challenge, so that **pure silicon anodes should be possible in a few years' time**.
- Pure lithium anodes** theoretically enable an even **higher energy density** than silicon and graphite anodes. Their biggest challenge at present is that they are **not stable in combination with liquid electrolytes**. The implementation of **solid-state batteries** (all-solid-state batteries – ASSB) could therefore also be accompanied by an **anode revolution**. A disadvantage of lithium anodes is that the **raw material is expensive and scarce**.

Key Takeaways

- Graphite currently dominates the market as anode material and is unlikely to be replaced in the coming decade.
- There are promising alternatives that could significantly increase batteries' energy density and performance in the future.

LFP Overview

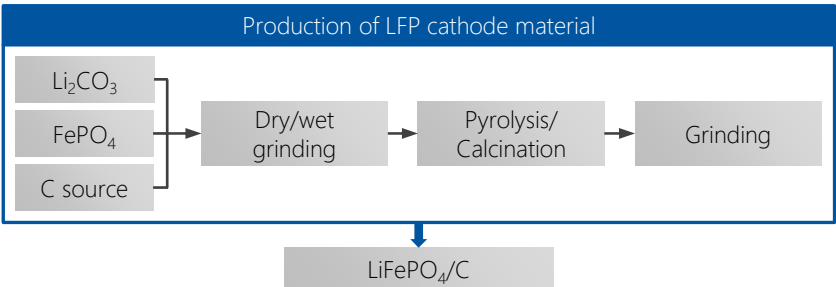
Active material production: LFP cathode material



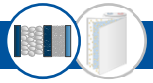
Description

The figure above shows the olivine-like arranged LFP with embedded lithium ions. The steps involved in producing the **lithium iron phosphate cathode material** are illustrated below. LFP is mainly produced industrially in a single-stage thermal process, which is divided into the sub-processes of grinding and calcination as well as the final application to the cathode. The precursor can be synthesized either via the carbonate or the hydroxide route. The decision is usually made in favor of the cheaper raw material. LFP can be produced using different processes. The following process is explained as an example.

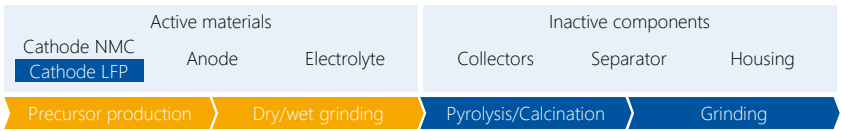
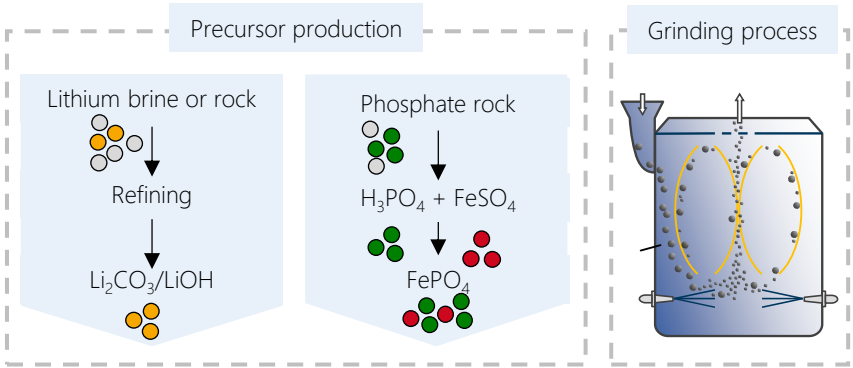
Lithium iron phosphate (LiFePO_4) generally has a lower energy density than NMC, but at the same time has higher thermal and chemical stability and a long service life. The product has a larger market share and is already favored over NMC in the Chinese mass market.



Precursor and Grinding



Active material production: LFP cathode material



Process steps

- Lithium usually originates from lithium-rich brines or lithium-rich rock or corresponding minerals and is further processed from there into lithium hydroxide or lithium carbonate, both of which can be used in LFP production.
- Phosphate is usually extracted from phosphate rock and processed into phosphoric acid before being reacted with water-soluble iron compounds to obtain iron phosphate. Scrap iron or other diverse sources can be used as a source of iron salts. Iron phosphate and lithium precursors for LFP batteries must be of battery quality, while the precursors of iron phosphate are not a separate battery product in this respect.
- The reactants – consisting of a lithium source, a metal phosphate, and sugar or a carbon source – are placed in a mill for mixing.
- The starting materials must have a **high degree of purity**, as impurities can form electrochemically inert phases and interfere with the transport of the lithium ions.
- The solutions are mixed according to the **desired ratio** of lithium and iron phosphate.

Process parameters

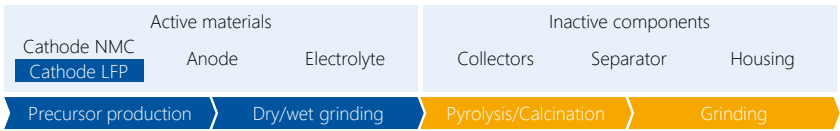
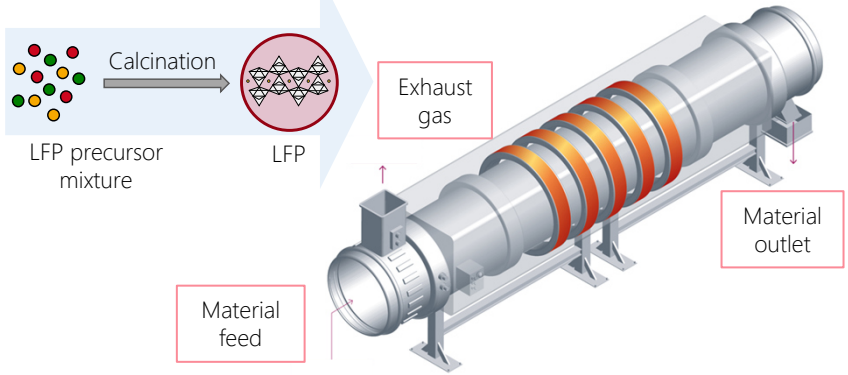
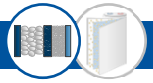
- Purity of the reactants
- Correct mass flows
- Favorable reactants (choice between LiOH and Li₂CO₃)
- Correct material quantity ratio

Quality criteria

- Homogeneity of the grain size
- Homogeneity of the product
- Correct material quantity ratio for the thermal process
- Particle size distribution

Calcination/Pyrolysis

Active material production: LFP cathode material



Process steps

- After dry or wet grinding, the LFP material is homogeneous, which ensures good reactivity.
- **Calcination** is particularly important for the overall process, as it creates the final chemical composition of the LFP.
- Calcination is a high-temperature process in which the LFP material is heated in an oven.
- The **calcination process** usually takes place at **more than 500°C for several hours**. The exact reaction conditions depend on the desired material parameters, but the treatment usually takes place in a **pure nitrogen atmosphere**.
- Calcination or pyrolysis ensures that other volatile components are removed from the LFP precursors. These include water or volatile organic compounds (VOCs) from the carbon source.
- After calcination, the material is **ground again** so that it leaves the production line **homogeneous and of consistent quality**.

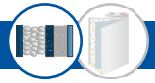
Process parameters

- Temperature: >500 °C
- Period: few hours
- Reactant mixture with correct homogeneity and correct ratio of materials
- Purity of the reactants
- Reaction atmosphere: oxygen-free

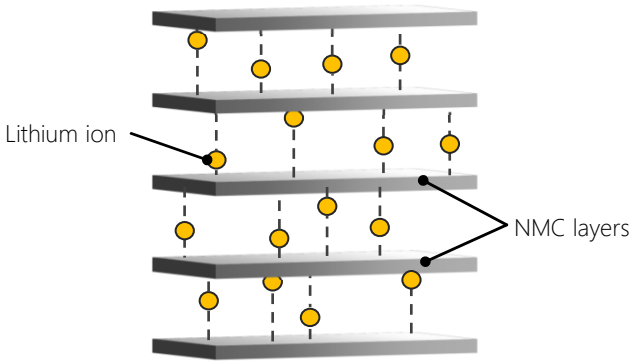
Quality criteria

- Particle size
- Homogeneity
- Crystal structure
- Side reaction
- Purity
- Amount of material ratio

NMC Overview



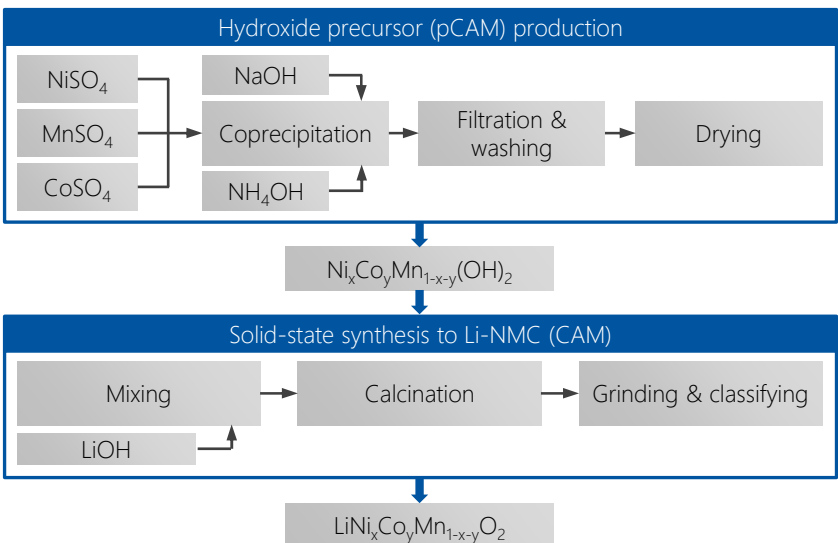
Active material production: NMC cathode material



Active materials			Inactive components		
Cathode NMC	Anode	Electrolyte	Collectors	Separator	Housing
Cathode LFP					

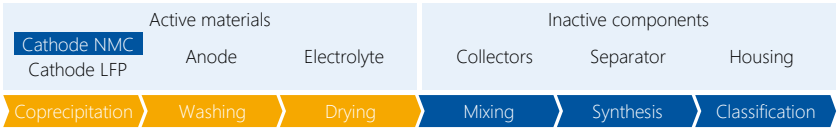
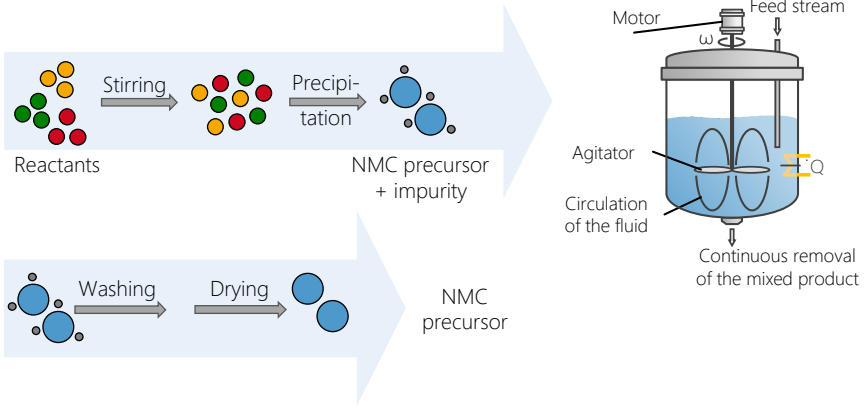
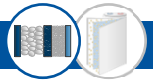
Description

The figure above shows the layered NMC with embedded lithium ions. The production steps for manufacturing the **nickel-manganese-cobalt cathode material** are illustrated below. NMC is mainly produced industrially in a two-stage process, which is divided into the process chains of the precursor cathode active material (pCAM) and CAM.



pCAM Production

Active material production: NMC cathode material



Process steps

- In **coprecipitation**, the three reactants nickel, manganese and cobalt sulphate are present in **separate solutions**.
- The starting materials must have a **high degree of purity**, as impurities can form electrochemically inert phases and disrupt the transport of the lithium ions. This reduces the battery cell's **reversible capacity**.
- With rapid stirring, a **precipitation reaction** takes place in the reactor. There is a risk of the metal hydroxides precipitating independently of each other.
- In order to be further processed into NMC material in solid-state synthesis, the material must be cleaned and dried after mixing.
- The material cleaned with detergent can either be dried using continuous drying or in a spray dryer.

Process parameters

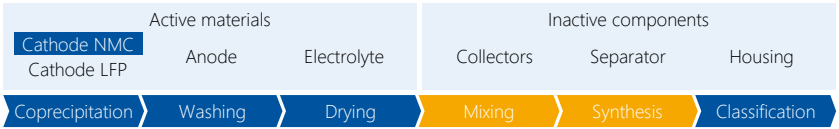
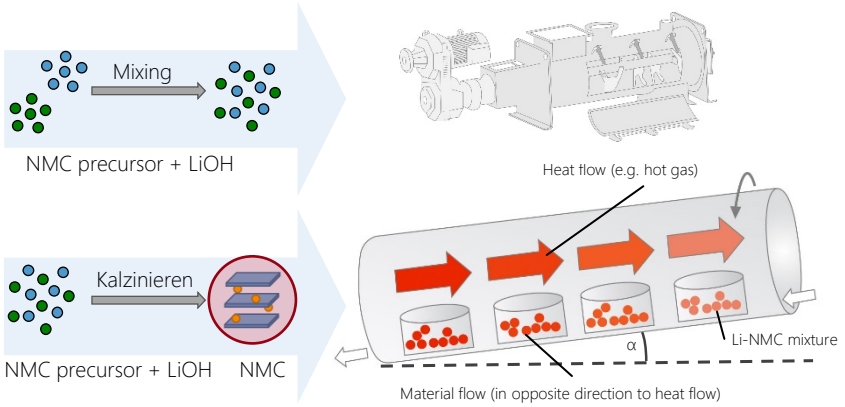
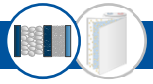
- Purity of the reactants
- pH value: 11 - 12
- Stirring speed: 1,000 min⁻¹
- Mixing temperature: 35°C - 80°C
- Drying temperature: 100°C - 110°C
- Stoichiometric ratio

Quality criteria

- Homogeneity
- Agglomerate formation
- Purity
- Residual moisture
- Viscosity
- pH value

CAM Production

Active material production: NMC cathode material



Process steps

- Some of the lithium evaporates in the next steps through temperature treatment and must be compensated for in the mixing process by a slight **lithium surplus** of 5% - 10%.
- During calcination, the finished NMC material is produced. The temperature largely determines particle size, mobility of free electrons, and crystal growth.
- Different temperature profiles, including lithiation and sintering, produce specific material properties in high-nickel cathode chemistries. The material passes through the furnace for **several hours**.
- Heat is absorbed during **evaporation**, resulting in the formation of temperature gradients. The **heating rate** of the oven is kept low to prevent uneven temperature distributions.
- The **reaction atmosphere** usually consists of pure **oxygen**, which serves to maintain the correct ratio of lithium to nickel.
- After calcination, the finished NMC material is ground to achieve the desired particle fineness. The material is ground into itself with a stream of air until it reaches the right fineness to pass through the sieve.

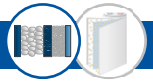
Process parameters

- Stoichiometry Li to NMC: 1,05 - 1,10
- Particle size: few micrometers
- Stirring speed
- Iron-free synthesis conditions
- Temperature: 500°C - 950°C
- Temperature profile
- Air mill speed: 300 m/sec
- Particles in mill: few micrometers

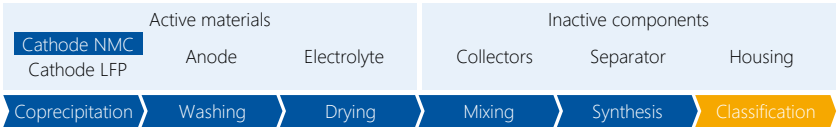
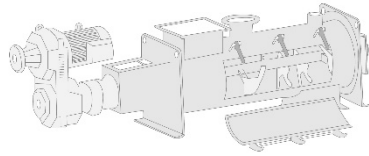
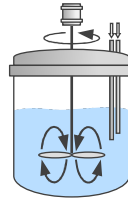
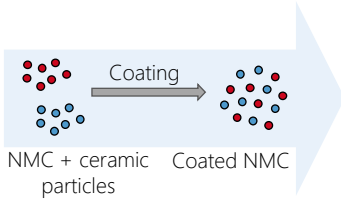
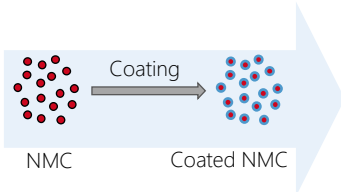
Quality criteria

- Particle size
- Uniformity of particle shape
- Purity
- Particle morphology
- Homogeneity
- Crystal structure
- Amount of material ratio

Post-Treatment



Active material production: NMC cathode material



Process steps

- After ultrafine grinding, the cathode material's cycle stability can be increased by **post-treatment** of the NMC particles.
- **Coatings** of NMC particles with **ceramic nano-particles** are suitable for this purpose.
- The coatings can be applied using **wet-chemical** or **chemical vapor deposition processes**.
- After the wet-chemical process, the coated NMC material must be **dried**.
- NMC batteries are characterized by extremely high energy densities, which are ideal for automotive applications.
- Compared to LFP batteries, NMC batteries have a higher energy density, but less cycle stability and less chemical and thermal stability.

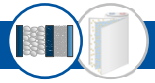
Process parameters

- Coating material
- Coating thickness
- Coating process
- Mixing speed

Quality criteria

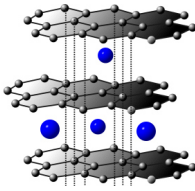
- Particle size
- Uniformity of particle shape
- Purity of the particle coating
- Particle morphology
- Homogeneity of the particle coating
- Thermal and chemical stability
- Longevity

Graphite Overview

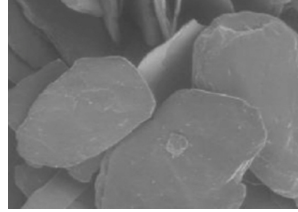


Active material production: Anode material

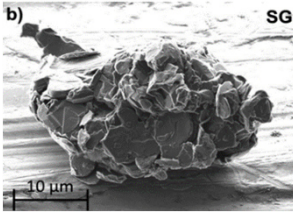
Structure of the graphite layers



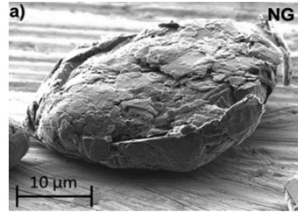
Flake graphite



Synthetic graphite



Natural graphite



Active materials			Inactive components		
Cathode NMC	Anode	Electrolyte	Collectors	Separator	Housing
Cathode LFP					

Description

Graphite is the most commonly used anode material in lithium-ion batteries. It is a natural form of the element carbon and crystallizes in a hexagonal crystal structure, as can be seen in the figure above left. The two-dimensional layers – called ‘graphene’ – are held together by van der Waals forces and thus form a three-dimensional structure. Lithium ions can be intercalated between the layers, which is known as ‘intercalation’. This molecular structure manifests itself in the fact that graphite is usually found in nature in flat flakes (‘flake graphite’), as shown in the figure above right.

Anode graphite can basically be obtained in two ways: Flake graphite can be processed into natural graphite (see below right), or synthetic graphite (see below left) can be obtained from various carbonaceous precursor materials in a thermal process.

Production of synthetic graphite

Pre-treatment

Graphitizing

Particle refinement

Production of natural graphite

Flotation

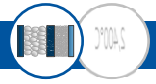
Spheronization

Purifying

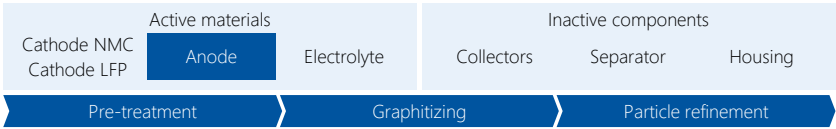
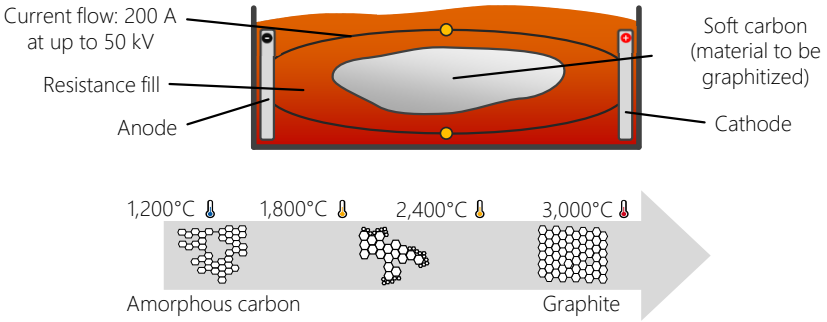
Coating

Synthetic Graphite

Active material production: Anode material



Graphitization:



Process steps

- First, coke and pitch are **mixed** together as starting materials at more than 200°C in an intensive mixer or kneader.
- In the next process step – **calcination** – the resulting molded body is fired at 800°C to 1,200°C in the absence of atmospheric oxygen. The aim is to carbonize the pitch and create amorphous carbon as a binding phase.
- In the Acheson furnace, the mixture is **graphitized** and receives its typical graphite structure through the arrangement of the **graphene layers**.
- The soft carbon is surrounded by a **resistive fill** (e.g. granular coke). When current is applied, great heat is generated due to the electrical resistance.
- High degrees of purity can be achieved by thermal or thermochemical modification of the process.
 - **Thermal**: Temperature and dwell time are increased so that all impurities can evaporate.
 - **Thermochemical**: Additives convert the impurities into volatile compounds and diffuse out of the graphite.

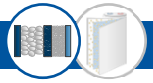
Process parameters

- Calcination at 800°C - 1,200°C
- Graphitizing at 1,800°C - 3,000°C
- Dwell time: few hours to several weeks (long cooling time, especially after graphitization)
- Voltage: e.g. 40 - 50 kV
- Current: e.g. 200 A

Quality criteria

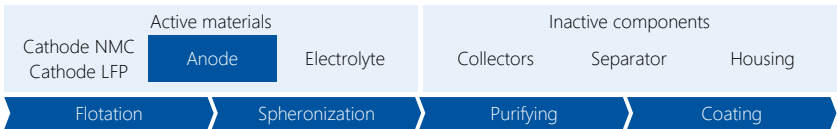
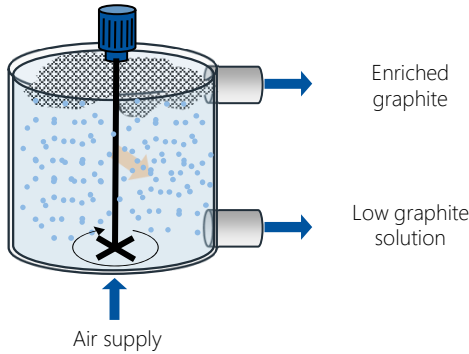
- Purity
- Particle shape
- Particle size
- Homogeneity
- Surface structure

Natural Graphite



Active material production: Anode material

Flotation:



Process steps

- Natural graphite is extracted by **conventional mining**.
- In the first process step, the graphite is separated from the surrounding rock. **Flotation** is easily possible due to the nature of graphite, as it is **hydrophobic** (not soluble in water), so that graphite rises with air bubbles and floats on the surface.
- Several mills arranged in a row ensure spherical particles with a high tapped density, low surface area and narrow particle size distribution through continuous **micronization** and subsequent **spheronization**.
- The spherical graphite obtained is then **purified**, increasing the carbon content to more than 99.95%.
- In the final process step (**coating and carbonization**), the properties of the rounded and cleaned particles are improved by applying special Hansen Solubility Parameters (HSP) pitch and treating them in inert continuous furnaces at temperatures of around 1,300°C in a time-consuming process.

Process parameters

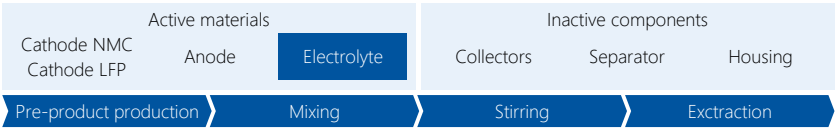
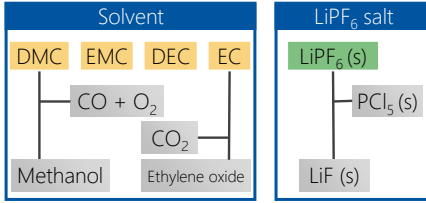
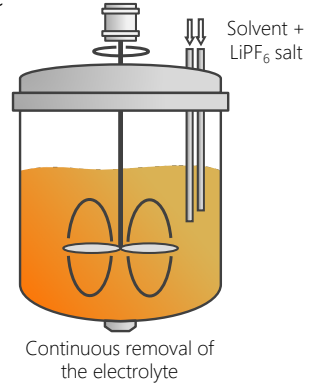
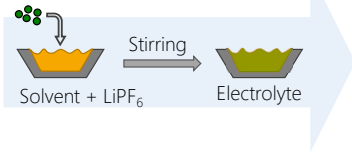
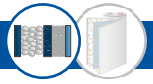
- Temperature: ~1.300°C
- Dwell time: several hours
- As little waste as possible during spheronization
- Low price

Quality criteria

- Purity
- Particle shape
- Particle size
- Homogeneity
- Surface structure
- High proportion of flake graphite
- High proportion of carbon in the final product

Electrolyte Production

Active material production: Electrolyte



Process steps

- The electrolyte consists of a conductive salt (e.g. lithium hexafluorophosphate – LiPF₆) and a solvent (e.g. dimethyl carbonate – DMC, ethylene carbonate – EC, diethyl carbonate – DEC, or ethyl methyl carbonate – EMC). Both are combined in the reactor.
- LiPF₆ is the most important electrolyte component as a conductive salt and accounts for the majority of the costs.
- Additives (e.g. vinylene carbonate – VC) improve the **long-term stability** of the battery.
- Contamination with water causes a **decomposition reaction** of LiPF₆, which is why residues and the formation of water must be avoided.

Properties

- The production and handling of electrolytes is critical due to the demand in production and the formation of hydrofluoric acid (HF) on contact with water or humidity.
- Electrolyte significantly determines the temperature stability and performance of a lithium-ion battery.
- Electrolytes make up around 10% of the cell weight, which is why both lighter electrolytes and electrolytes with better or different properties will become more important in the future.

Process parameters

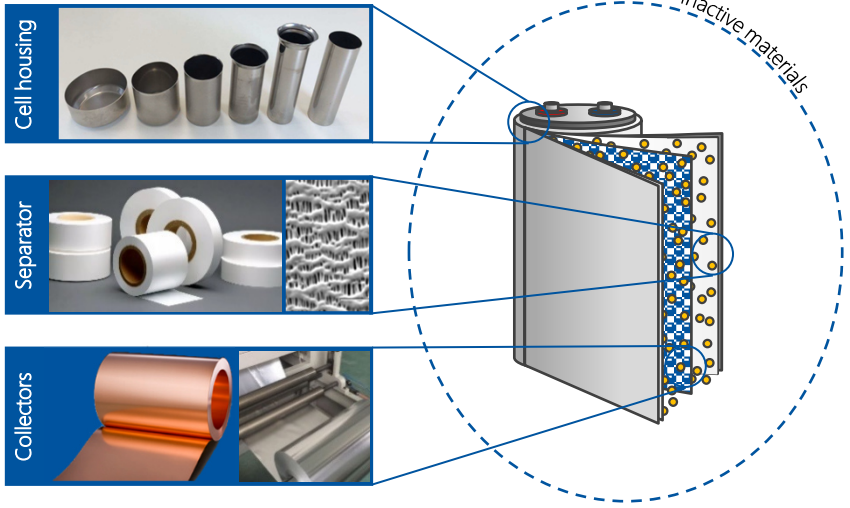
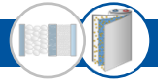
- Salt concentration: 0,8 - 2 mol/L
- Typical composition:
 - Salt: 12,6 wt%
 - Additives: 0 - 10 wt%
 - Solvent: approx. 85 wt%

Quality criteria

- Ionic conductivity
- Water content
- Temperature resistance
- Purity of the raw materials
- Purity of the final product

Overview

Inactive components



Active materials			Inactive components		
Cathode NMC	Anode	Electrolyte	Collectors	Separator	Housing
Cathode LFP					

Description

The production steps for manufacturing the **current collectors (electrode foils)**, the **separator**, and the **cell housing** of a round, prismatic and a pouch cell are explained below. The illustration above shows a cut-open round cell with a direct view of the cathode, anode, and separator.

The **electrode foils** fulfill the task of transporting the electrons from the active materials into the cathode and the anode to the cell collectors, which conduct the current out of the battery cell. They also play a major role in the cell's internal heat conduction.

The **separator** serves as an electrical insulator and transport medium for ions between the cathode and anode. To ensure ion conductivity, the micropores fill with electrolyte during cell production.

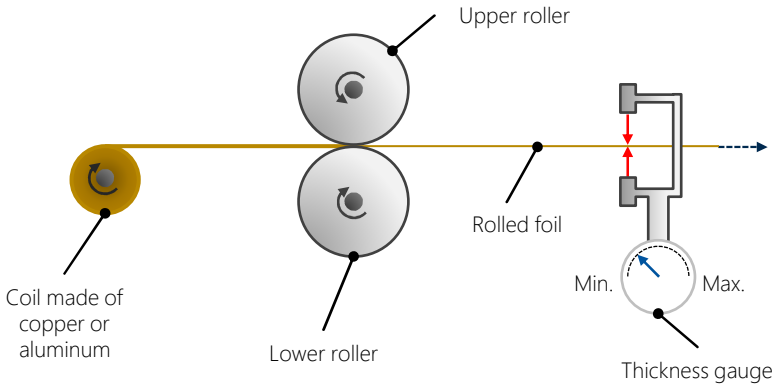
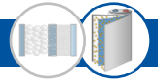
The **cell housing** provides mechanical protection against external influences and prevents electrolyte leakage as well as chemical reactions with the environment.

Key Takeaways

- The inactive components are not directly involved in the electrochemical processes for energy storage within the battery cell.
- These components contribute significantly to the durable and safe functioning of a battery cell and are key differentiating features in many respects.

Electrode Production

Inactive components: Electrode foil



Process steps

- The copper or aluminum foil is rolled to a defined thickness in a **continuous rolling process**.
- The upper and lower rollers are arranged opposite each other and compress the foil to the desired thickness with a **defined line pressure**.
- **Line pressure** and **feed speed** of the foil are kept **constant** throughout the rolling process in order to achieve uniform compaction.
- To increase accuracy and reproducibility, the foil's thickness is measured after rolling.
- The **cleanliness** of the rollers is crucial for the subsequent processing step, as foreign particles can lead to **surface damage**.
- The rollers and the foil can be cleaned by **suction** (in combination with compressed air) or by **brushing**.

Process parameters

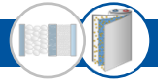
- Constant feed speed
- Constant line pressure
- Roller diameter

Quality criteria

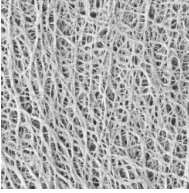
- Surface quality
- Impurities
- Uniform foil thickness
- Surface roughness of the rollers

Separator Overview

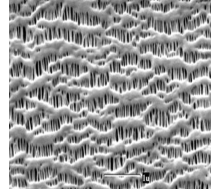
Inactive components: Separator



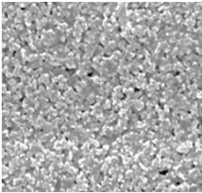
Close-up of polyethylene separator (wet process)



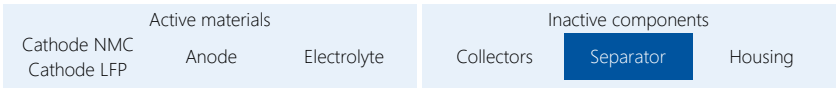
Close-up of polypropylene separator (drying process)



Close-up of ceramic-coated separator



Delivery form of the separator as a roll

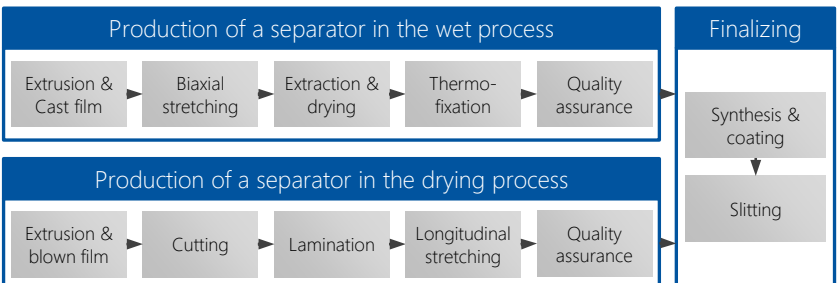


Description

Several technologies exist for the manufacture of microporous separators, which differ in terms of the **raw materials** used and **production**. The production processes are listed below and are primarily divided into a wet process based on PE and a dry process based on PE or PP. Eventually, a typically ceramic composite is applied to the separator with an engraving roller to meet the requirements of a lithium-ion battery.

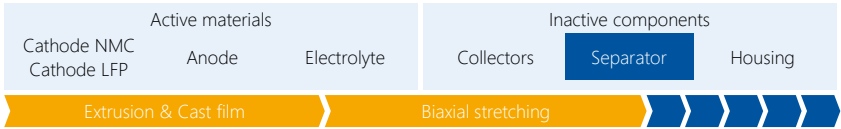
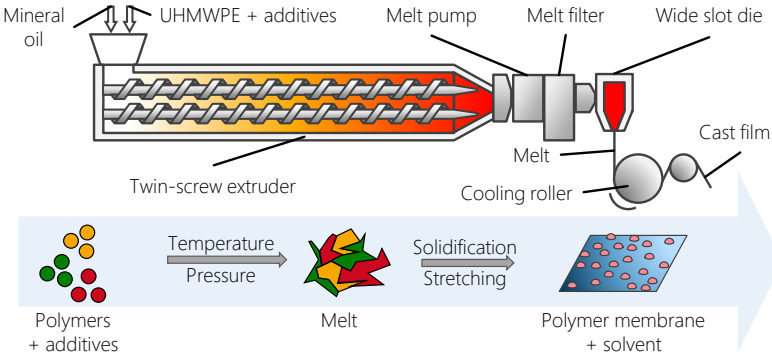
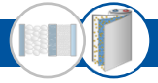
The **PE-based wet process** is the most widely used production method. The systems are up to 110 meters long and can produce the separator film with a working width of up to 5.50 meters. Although the wet process can vary, it basically consists of the process steps shown below.

In the **drying process**, the **semi-crystalline thermoplastics PP or PE** are used as starting materials. The process steps explained below can vary here as well.



Wet Process (I/III)

Inactive components: Separator



Extrusion

- As **starting materials** for the **wet process**, mixtures of HDPE (high-density polyethylene) or UHMWPE (ultra-high molecular weight polyethylene), mineral oils as plasticizers, and some additives are used.
- The mixture is metered into a co-rotating **twin-screw extruder** where it is **homogenized and melted** by adding heat and shearing. A **melt pump** generates a constant, high pressure with which the melt is conveyed to the **slot die**.

Cast film

- The **melt** emerging from the slot die **solidifies** into a cast film through contact with the cooling roller, whereby uniform cooling across the working width and circumference is important.

Biaxial stretching

- In **biaxial simultaneous stretching**, the edges of the film are held by clips, the distance between which increases both **in the running direction and transversely**.
- In **biaxial sequential stretching**, the material is first stretched **in the longitudinal direction** using rollers and then **in the transverse direction** using clips.

Process parameters

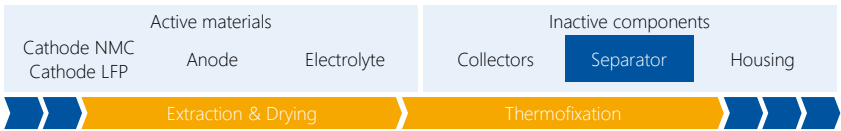
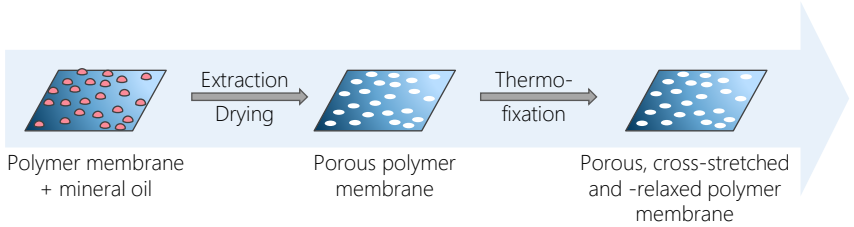
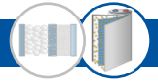
- Thickness control
- Temperature (melt, slot die, cooling roll)
- Web speed

Quality criteria

- Constant surface properties and thickness
- Homogeneity and purity of raw materials
- Constant temperature and web speed
- Cleanliness in the process environment

Wet Process (II/III)

Inactive components: Separator



Extraction

- The aim of **extraction** is to wash the mineral oil out of the extruded, stretched film. The extracted molecules leave behind pores, creating a **microporous structure**.
- Possible **solvents** are chlorinated and fluorinated hydrocarbons. The most widely used is **DCM** (dichloromethane), which is banned in the EU.
- Economical production requires extensive **recycling** of the DCM and mineral oil, which are then fed back into the process.

Drying

- Immediately after extraction, **drying** takes place to remove the DCM from the resulting pores by evaporation.

Thermofixation

- The film is fixed at the edges by using holding clips and passed through another **stretching oven** to perform cross-stretching and -relaxation in **different temperature zones**.

Process parameters

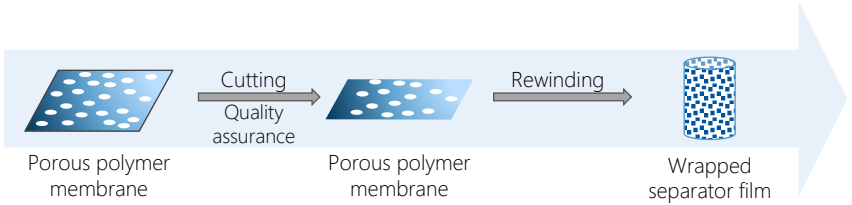
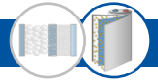
- Temperature control of the drying zones
- Solvent used
- Extraction speed
- Web speed

Quality criteria

- Recycling degree of the solvents
- Completeness of extraction without residues
- Technical cleanliness
- Homogeneity of the pores

Wet Process (III/III)

Inactive components: Separator



Take-off/Quality assurance

- After leaving the heat-setting process, the finished separator film is trimmed at the edges in a **take-off stand**, and an **inline quality check** (for thickness, optical defects, etc.) is carried out.
- The following test methods can be used for quality assurance:
 - Thickness, tensile test, puncture test, breakdown voltage
 - Hg porosimetry, scanning electron microscopy, air permeability test according to Gurley
 - Shrinkage measurement, DSC, TMA, hot-tip test
 - Ionic conductivity, electrolyte wetting
 - Optical inspection

Winding

- The final work step consists of **controlled winding**, which is usually carried out on a winder with a full working width of a 5.50-meter maximum.
- The wound rolls can be further assembled or packaged.

Process parameters

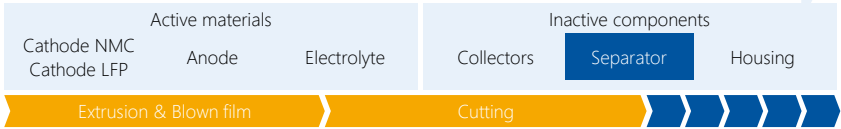
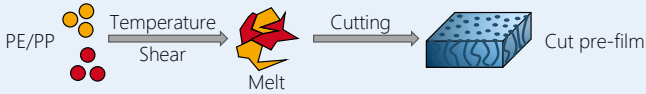
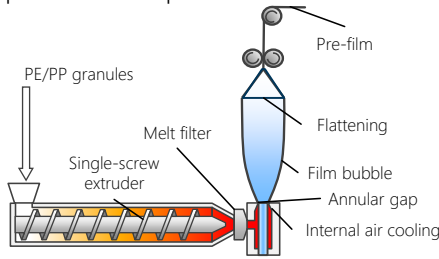
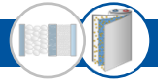
- Winding speed
- Test methods used
- Cut size
- Packaging size

Quality criteria

- Technical cleanliness
- Winding quality

Drying Process (I/II)

Inactive components: Separator



Extrusion

- The PE/PP granules are **melted** and homogenized in a single-screw extruder by applying heat and shearing.

Blown film

- In the drying process, apart from the **cast film process** there is also a **blown film process**.
- In the blown film process, the melt is pressed through an **annular gap**, creating a **tube** through which air flows from the inside and which is cooled from the inside and outside.

Cutting

- After winding, the pre-film is transferred batch by batch into narrower rolls on a **slitting machine**.

Process parameters

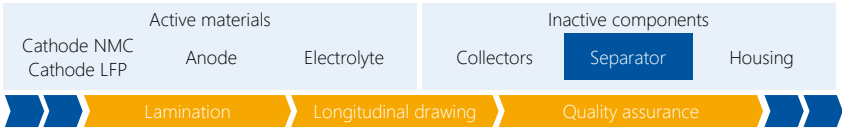
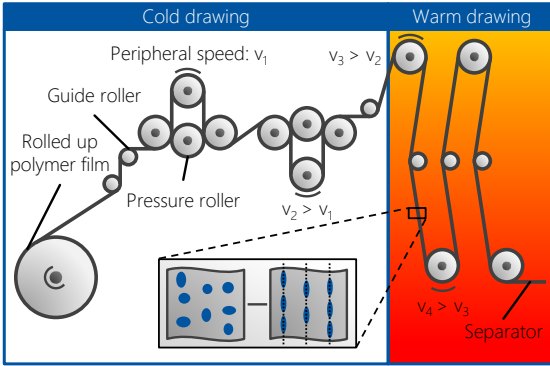
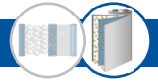
- Temperature and speed of the single-screw extruder
- Internal pressure of the blown film process
- Pressure and temperature of lamination

Quality criteria

- Homogeneity and purity of the raw materials
- Film thickness
- Distribution and size of the lamellas
- Technical cleanliness

Drying Process (II/II)

Inactive components: Separator



Lamination

- In a subsequent step, the roll material is laminated together with **several layers** under **pressure and temperature**. In this way, a PP/PE/PP trilayer structure can be produced.

Longitudinal drawing

- To create a pore structure, the **lamellas** must be arranged in a row, perpendicular to the machine direction. This structure is created by a drawing process.
- In **longitudinal drawing**, the drawing process is realized by different roller speeds at different temperatures.
 - **Cold drawing**: Initiation of pore growth
 - **Warm drawing**: Creation and enlargement of pores
- After drawing, the separator is heat-set using heated rollers to reduce shrinkage values.

Quality assurance/Rewinding

- The separator is **trimmed at the edges**, and inline quality assurance (with regard to thickness, optical defects, etc.) is carried out.
- Eventually, the separator is **rewound**.

Process parameters

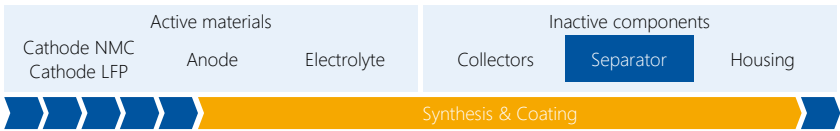
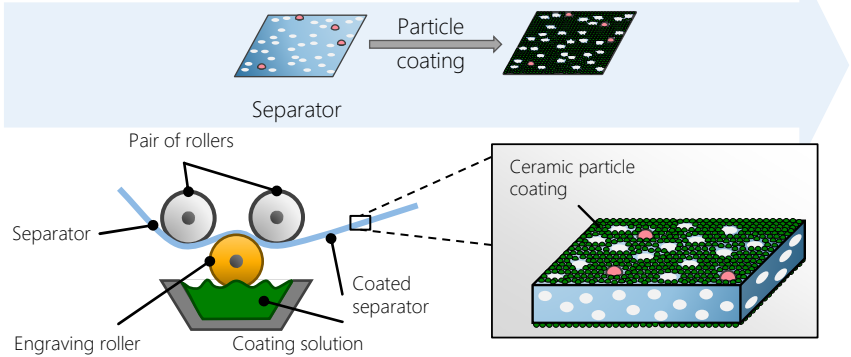
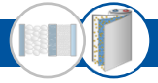
- Roller speeds in the drawing process
- Temperatures in the drawing process
- Belt speed of the film

Quality criteria

- Technical cleanliness
- Wrapping quality
- Homogeneity of the pores

Separator Coating

Inactive components: Separator



Process steps

- All PP and PE separators produced using the **wet or drying process** can be coated with functional materials to improve their thermal stability or laminability. A ceramic coating or impregnation of PET nonwovens is also used to produce separators that are resistant to high temperatures.
- Due to the system technology, coating takes place after the primary cutting process.
- The **ceramic particles** of aluminum oxide (Al_2O_3), aluminum oxide hydroxide (AlOOH), or SiO_2 are produced from the respective metal chloride using a **thermal process** at high temperatures.
- A suspension of ceramic particles and binder is applied to the separator film using an **engraving roller**.
- After coating, which can be applied to one or both sides, **drying** is required.

Process parameters

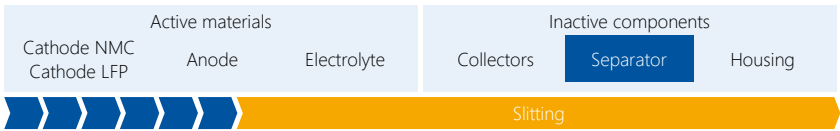
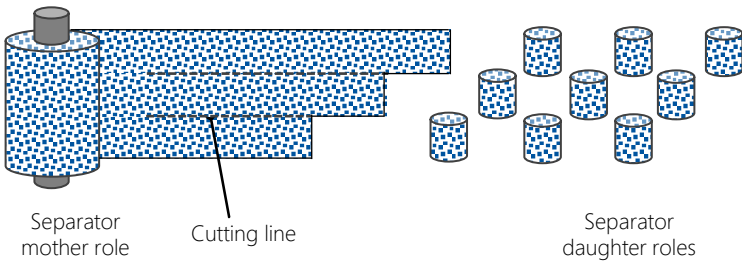
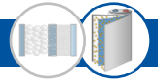
- Process duration for particle synthesis
- Choice of binder
- Hardness of the anilox roller
- Cleaning cycle of the anilox roller
- Drying temperature profile

Quality criteria

- Particle size distribution
- Particle shape
- Wettability
- Homogeneity of the coating
- Coating thickness

Slitting

Inactive components: Separator



Process steps

- After production or following coating, the separators are cut to the width required for cell production using cutting machines.
- Slitting involves cutting a wide separator belt (**mother roll**) into narrower separator belts (**daughter rolls**).
- During the cutting process, a **primary cutting process** is usually required to reduce the working width from 5.50 meters to 1.50 meters, for example. This is followed by the **secondary cutting process**, in which the width required for cell production is cut to size.
- Dust and foreign particles are then removed using special **cleaning devices**.
- Important quality criteria are the **cutting quality** of the resulting edges and the **cleanliness** of the separator web.

Process parameters

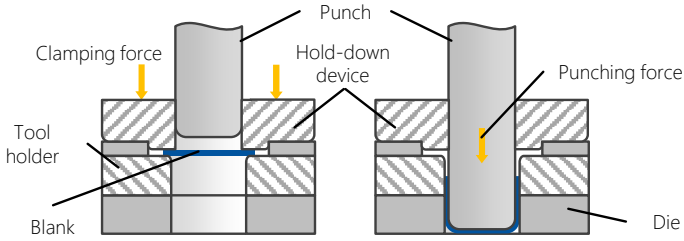
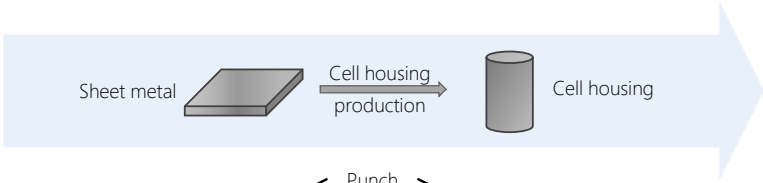
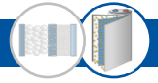
- Process duration for particle synthesis
- Choice of binder
- Hardness of the anilox roller
- Cleaning cycle of the anilox roller
- Drying temperature profile

Quality criteria

- Particle size distribution
- Particle shape
- Wettability
- Homogeneity of the coating
- Coating thickness

Cell Housing Production

Inactive components: Cell housing



Process steps

- **Deep drawing** is a tensile pressure forming process in which sheet metal blanks are pressed into a hollow body that is open on one side. Due to the good process control, this method is particularly suitable for mass production. Investments in machines and tools are high.
- The raw material is pressed through a die with a **punch** to create a round or prismatic housing. This procedure is repeated in several stations with different tool geometries (punch and die) until the desired shape of the housing is achieved.
- After the final deep-drawing step, the excess material at the top end is cut off cleanly.
- Finally, the housing is **washed, dried, and tested**.
- **Reverse extrusion** can be used as an alternative to cell housing production.

Process parameters

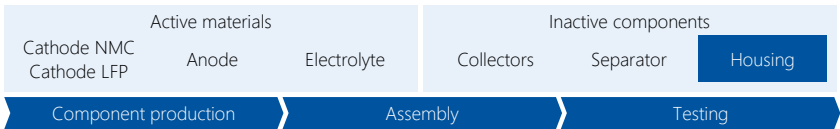
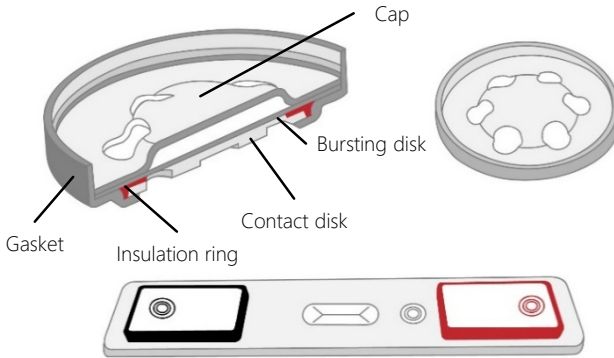
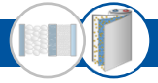
- Component format (round or prismatic)
- Component size (component height)
- Material
- Sheet thickness
- Forming force
- Drawing speed

Quality criteria

- Dimensional accuracy
- Uniformity of the wall thickness
- Edge quality
- Surface quality
- Cleanliness
- Residual particles
- Stresses in the material

Cell Lid Production

Inactive components: Cell housing



Process steps

- The individual parts of a lid assembly consist of **metallic components** and **plastic components**. The metal components are manufactured by stamping, fine blanking, cold forming, deep drawing, etching, or friction welding and are in some cases also subsequently electroplated. For plastic components, injection molding is used. Due to the sensitivity of components that have to perform safety-relevant tasks in the assembly, some parts are also provided in taped form or oriented in special component carriers for assembly.
- Some lid assemblies are put together in clean rooms with **fully automated systems**. In addition to handling the individual components of a lid assembly, processes such as laser welding, riveting, and dosing of sealants are used during assembly. Various components contain poka-yoke elements to guarantee error-free assembly.
- **Optical and electrical inspection** are carried out during and after assembly. Leak tests of laser-welded connections are also required.

Process parameters

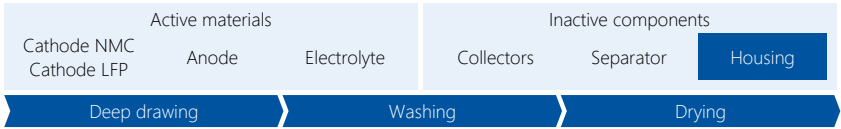
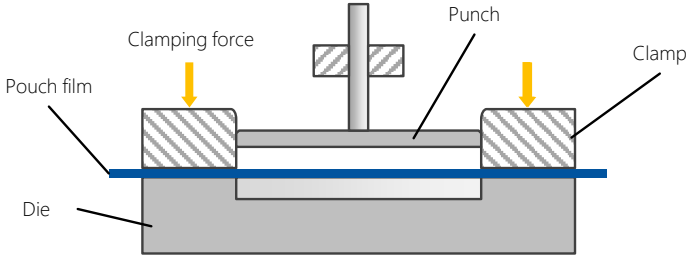
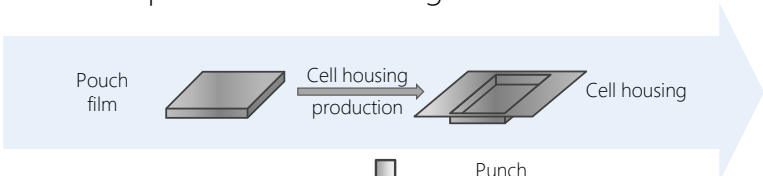
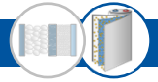
- Lid assembly size
- Components' accuracy of fit
- Number of components
- Assembly speed

Quality criteria

- Cleanliness
- Residual particles
- Geometric dimensional accuracy
- Tightness

Pouch Housing Production

Inactive components: Cell housing



Process steps

- The **pouch film** consists of a **plastic composite film**. The plastics used are **polyamides** and **polypropylene**. **Aluminum** serves as a diffusion barrier for water and the electrolyte.
- The pouch film is supplied via a **discontinuously** operating reel.
- The unwound film is held in the press by two clamps with a defined **clamping force**.
- The punch presses the film into the **die** to create the final shape. The excess material is cut off cleanly at the top end.
- **Punch force** and **punch speed** have a significant influence on the quality of the housing.

Process parameters

- Punch size
- Punch shape
- Die height
- Clamping force
- Compressive force
- Punch speed

Quality criteria

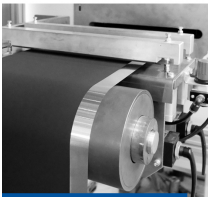
- Quality features
- Surface quality
- Impurities
- Uniformity of the wall thickness
- Cracks in the material
- Edge quality
- Film thickness

Guides

on electric mobility

In various battery-related publications, the Chair of Production Engineering of E-Mobility Components (PEM) of RWTH Aachen University, in collaboration with VDMA, presents the different process and recycling chains from cell to battery pack and goes into detail about the manufacturing methods of the numerous components.

Available online



PRODUCTION PROCESS
OF A LITHIUM-ION
BATTERY CELL

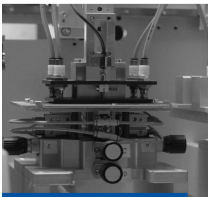


Production Process of a Lithium-Ion Battery Cell

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