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PRODUCTION PROCESS OF A LITHIUM-ION BATTERY CELL

Battery Production

The chair "Production Engineering of E-Mobility Components" (PEM) of RWTH Aachen University has been active in the field of lithium-ion battery production technology for many years. These activities cover both automotive and stationary applications. Through a multitude of national and international industrial projects with companies at every level of the value chain as well as key positions in renowned research projects, PEM offers extensive expertise.

Battery Production

The VDMA represents more than 3,500 German and European mechanical and plant engineering companies. The Battery Production specialist department is the point of contact for all questions relating to battery machinery and plant engineering. It researches technology and market information, organizes customer events and roadshows, offers platforms for exchange within the industry, and maintains a dialog with research and science.

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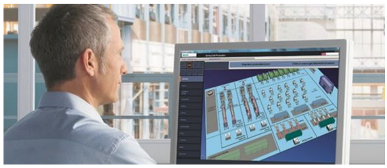

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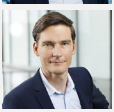

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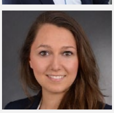

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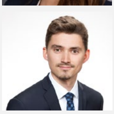

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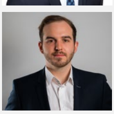

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Do you have any questions?

Contact us!

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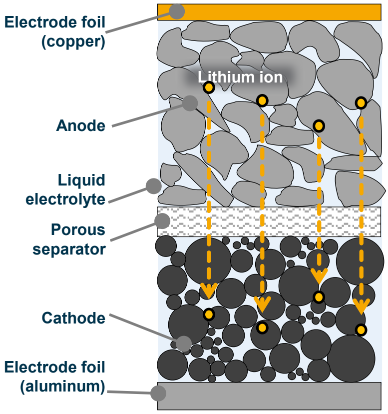
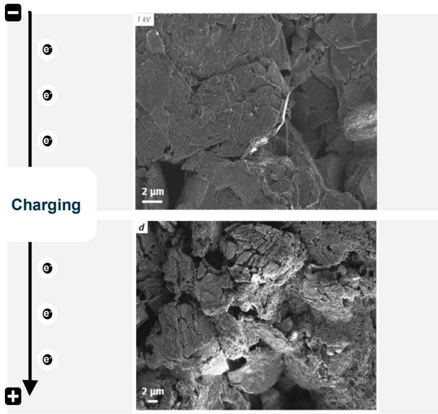
Operating Principle

of a lithium-ion battery cell





Electrode manufacturing | Cell assembly | Cell finishing

- The manufacture of the lithium-ion battery cell comprises the three main process steps of electrode manufacturing, cell assembly and cell finishing.
- The electrode manufacturing and cell finishing process steps are largely independent of the cell type, while cell assembly distinguishes between pouch and cylindrical cells as well as prismatic cells.
- Regardless of the cell type, the smallest unit of each lithium-ion cell consists of two electrodes and the separator which separates the electrodes from each other. Between them is the ion-conducting electrolyte.

Technology Development

of a lithium-ion battery cell

Product innovation [excerpt]

- Permutations
  - High-nickel batteries
  - Silicon graphite anodes (Si/C)
- Inactive components
  - Multilayer separator materials
  - Thinner and lighter packages
- Fourth technology generation
  - Large-format cells
  - Metallic lithium anodes

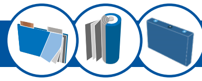
Process innovation [excerpt]

- Electrode manufacturing
  - Dry coating
  - Laser drying
- Cell assembly
  - Laser slitting and cutting
  - Innovative stacking process
- Cell finishing
  - Intelligent forming protocols
  - Early quality detection

- Technology developments already known today will reduce the material and manufacturing costs of the lithium-ion battery cell and further increase its performance characteristics.

* According to Zeiss, Li-Ion Battery Components – Cathode, Anode, Binder, Separator – Imaged at Low Accelerating Voltages (2016)

Dosing & Mixing



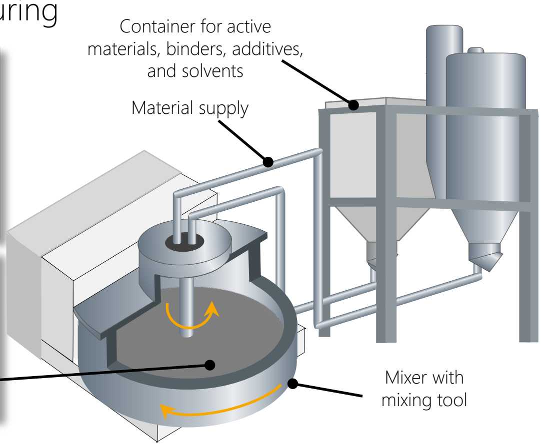
Electrode manufacturing

Anode recipe*

Active material: Graphite (95 wt.%)
Conductive carbon: nanomicroscopic carbon, e.g. carbon black (1 wt.%)
Solvent: Deionized water
Binder: CMC (2 wt.%)
Additive: SBR (2 wt.%)

Cathode recipe*

Active material: $Li(NiMnCo)O_2$ (95 wt.%)
Conductive carbon: nanomicroscopic carbon, e.g. Carbon Black® (1 wt.%)
Solvent: N-Methyl-2-pyrrolidon (NMP)
Binder: PVDF (4 wt.%)



Cell assembly | Cell finishing

Production process

- Active material and additives are dosed into the mixing vessel. Dry mixing takes place to break up heterogeneous phases. [Distributive mixing]
- Then the solvent is added partially or completely.
- The mixture is homogenized and deagglomerated. [Dispersive mixing]
- If not used as an additive, optionally a binder solution is added and incorporated.
- By applying vacuum, the previously bound and incorporated air is evacuated from the mixture.
- The final product is called “slurry”.
- Energy is applied in each case by one or more rotating tools.

Process parameters & requirements

- Mixing time: 20 min. - 6 hrs.
- Temperature control: 20 - 40°C
- Atmosphere (in the mixer): Inert gas or vacuum
- Atmosphere (installation site): Clean room or no requirement
- Different mixers for anode and cathode to avoid cross contamination

Quality parameters [excerpt]

- Homogeneity of the slurry
- Agglomerate size
- Bubble-free
- Purity (foreign matter content)
- Viscosity

Current technology alternatives

- Continuous mixing by a twin screw extruder
- Intensive mixing
- Inline dispersing

Innovations/Trends

- none

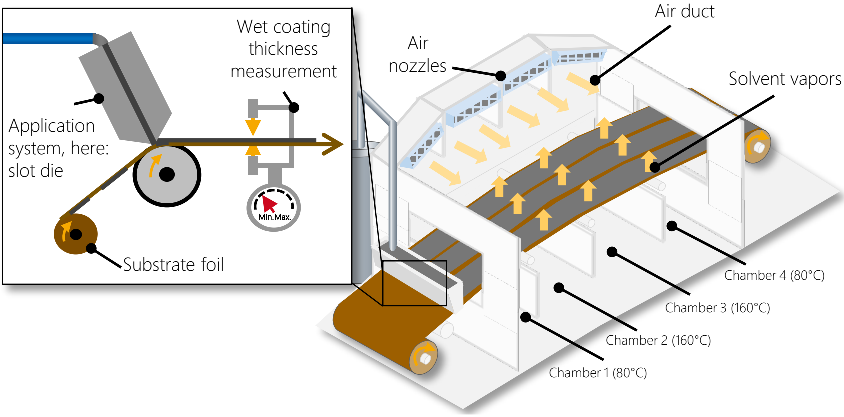
Production costs [excerpt]**

Investment for machinery and equipment: € 32 - 40 m
(Mixing)

* Sample electrode formulations
** Study by PEM of RWTH Aachen University: 10 GWh p.a., approx. 30,000,000 pouch cells p.a., cell capacity: 80 Ah

Coating & Drying

Electrode manufacturing



Cell assembly | Cell finishing

Production process

- The substrate foil is coated with the slurry using an application tool (e.g. slot die, doctor blade, anilox roller).
- Both continuous or intermittent coating of the substrate foil is possible. Coating of the top and bottom of the substrate foil can be done simultaneously or sequentially. Normally, a tandem coating process is used for sequential coating.
- After coating, the coated substrate foil passes through a drying channel. The web is transported either by roller or levitation systems. Heat is applied to remove the solvent from the coating.
- To realize an individual temperature profile, the channel is divided into different temperature zones. If toxic solvent has been used, it is recovered and processed or recycled.
- After passing through the dryer, the web is cooled down to room temperature and wound up.

Process parameters & requirements

- Drying speed: 35 - 80 m/min.
- Drying distance: up to 100 m
- Temperature profile in the drying zones: 50 - 160°C
- Solvent recovery
- Suitable film prestressing to avoid film cracking important

Quality parameters [excerpt]

Coating

- Coating thickness accuracy/homogeneity
- Surface quality (voids, particles)

Drying

- Adhesion between coating and substrate
- Residual moisture surface condition (cracks etc.)

Current technology alternatives

- Multilayer simultaneous application
- Additive manufacturing processes

Innovations/Trends

- Infrared drying: The convection dryers can be supplemented with infrared heating to make them more efficient.
- Laser drying: The use of a laser can shorten the dryer length and save energy costs.

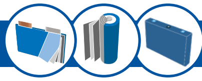
Production costs* [excerpt]

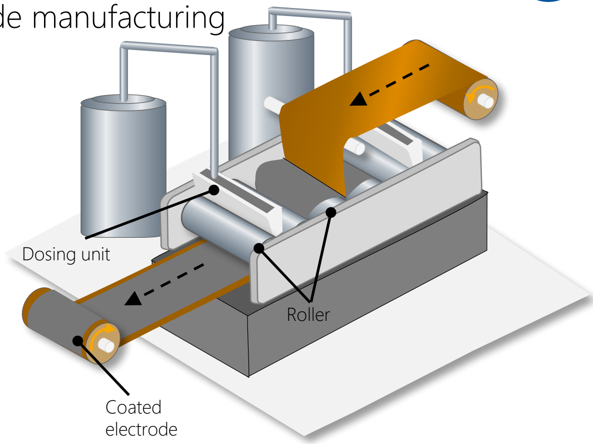
Investment for machinery and equipment: € 30 - 57 m
(Coating and drying)

* Study by PEM of RWTH Aachen University: 10 GWh p.a., approx. 30,000,000 pouch cells p.a., cell capacity: 80 Ah

Dry Coating

Electrode manufacturing



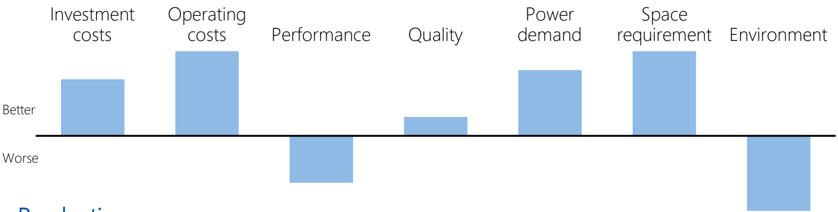


Compatibility with current process chain

Affected process step

Mixing → Coating & Drying → Calendering & Slitting → Vacuum drying

Qualitative evaluation: Dry coating versus conventional process



Production process

- The term Dry coating is used for several individual methods. All those methods are based on dry processing of materials to manufacture an active material layer. The absence of solvents is a significant difference to the conventional mixing process.
- Direct calendering and free-standing electrode production are the most promising technologies at present and have the highest potential for timely implementation in industry.
- The active material is homogenized and preconditioned in a mixing process.
- The active material is fed to a pair of rolls in the form of a powder or granules.
- The rolls rotate in opposite directions with optional differential circumferential speed.
- A dry film consisting of the active material forms on the faster rotating roll.
- Depending on the type of system, a dry film can first be generated and then applied to or calendered directly onto the substrate foil.
- Before the dry film is applied, it is usually cut to the desired width.

Technological Readiness Level

6 - 7 *Demonstration of the system prototype in the operating environment*

Advantages

- Elimination of solvents
- Reduction of plant and energy costs
- Reduction of space requirements

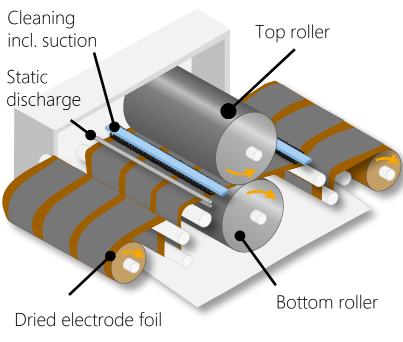
Challenges

- Increase of the web speed
- Adhesion of the layers
- Adjustment of porosity

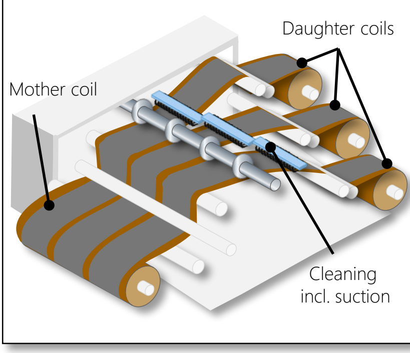
Calendering & Slitting

Electrode production

Calendering



Slitting



Cell assembly | Cell finishing

Production process

- In calendering, the copper or aluminum foil coated on both sides is compacted by a rotating pair of rolls.
- Before calendering, the electrode foil is statically discharged and cleaned by brushes or air streams.
- The material is compacted by the top and bottom rolls.
- The pair of rolls generates a line pressure that can be precisely defined.
- After calendering, the electrode web is cleaned and wound again (roll-to-roll process).
- The calendered mother coils are usually fed to the slitting line by a manual transport process.
- Slitting is a separation process in which a wide electrode web (mother coil) is divided into several smaller electrode webs (daughter coils).
- Usually, rolling knives are used for this purpose.
- The individual daughter coils are cleaned after the slitting process and wound up again (roll-to-roll process).

Process parameters & requirements

- Maintaining a constant line pressure of up to 2,500 N/mm
- Calendering speed: 60 - 100 m/min.
- Preheating sections and roll tempering optionally possible (approx. 50 - 250°C)
- Cutting speed (mechanical): 80 - 150 m/min.
- Suction for the cut edge strips

Quality parameters [excerpt]

Calendering
- Defined porosity and thickness
- Adhesion of the material to the film
- Surface cleanliness

Slitting
- Burr-free and positionally accurate cutting
- Dust extraction
- Cutting width tolerance: ±150 - ±250 µm

Current technology alternatives

- none

Innovations/Trends

- Integration of slitter into upstream process steps
- Laser slitter

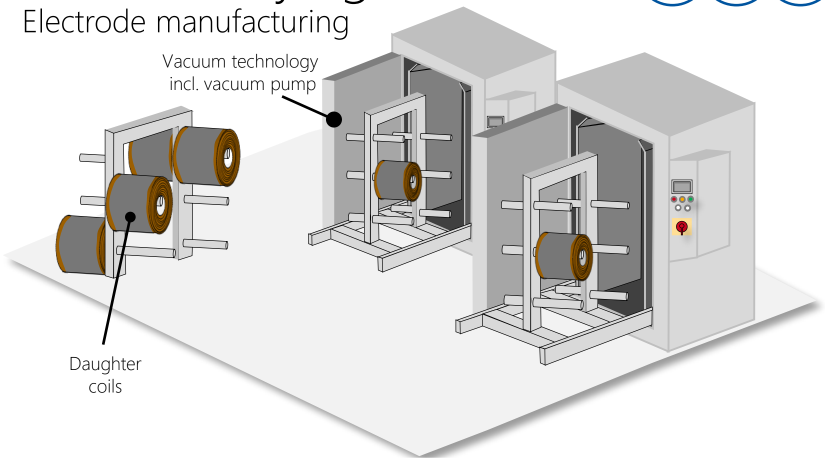
Production costs* [excerpt]

Investment for machinery and equipment: € 6 - 12 m
(Calendering and slitting)

* Study by PEM of RWTH Aachen University: 10 GWh p.a., approx. 30,000,000 pouch cells p.a., cell capacity: 80 Ah

Vacuum drying

Electrode manufacturing



Cell assembly | Cell finishing

Production process

- The coated daughter coils are brought onto a special goods carrier.
- The coils are then stored in a vacuum dryer.
- The drying time is approximately eight to 48 hours. During the drying process, residual moisture and solvents are removed from the coils.
- The reduction of residual moisture is realized by evaporation at low temperatures as a result of low total pressure.
- After completion of the vacuum drying process, the coils are transferred directly to the dry room or sealed under vacuum. The vacuum dryers are often used as a lock into the dry room.
- In addition, it is possible to operate the vacuum dryers with inert gas to prevent corrosion processes.

Process parameters & requirements

- Working pressure: 0.07 mbar < p < 1,000 mbar
- Drying time: 8 - 48 hrs./batch
- Drying temperature: 60 - 150°C
- Optional: Inert gas supply against copper corrosion

Quality parameters [excerpt]

- Constant heat supply and stable vacuum
- Residual moisture content (no residual moisture desired)
- Surface condition (cracking, etc.)

Current technology alternatives

- Continuous dryers: Daughter coils are transported through a drying system in the coiled or uncoiled state.
- Infrared dryer: Supplemented by an infrared heater

Innovations/ Trends

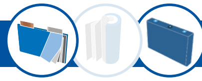
- Cell baking: Shifting the vacuum drying process directly before electrolyte filling in order to reduce the size of the drying chamber and optimize the process

Production costs* [excerpt]

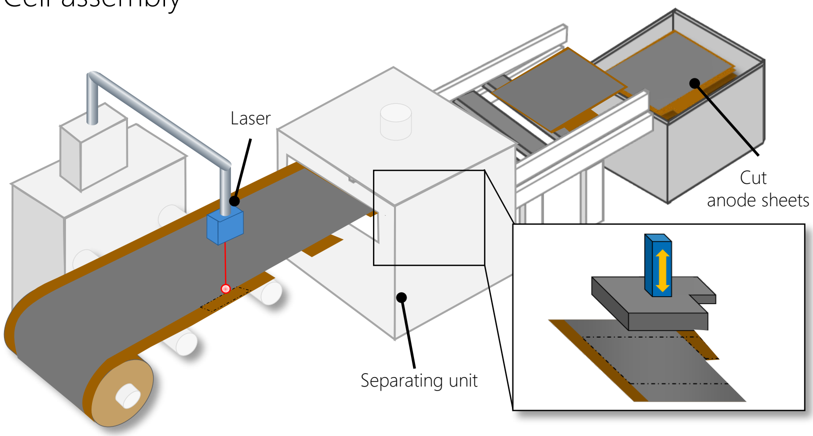
Investment for machinery and equipment: € 3 - 8 m
(Vacuum drying)

* Study by PEM of RWTH Aachen University: 10 GWh p.a., approx. 30,000,000 pouch cells p.a., cell capacity: 80 Ah

Separating



Cell assembly



Electrode manufacturing | Cell finishing

Production process

- Separating is the process of cutting electrode sheets from a continuous electrode web.
- Before the actual separation, a so-called notching process can be used.
- During notching, the dried electrode web is unwound and the contour of the electrodes is pre-formed in the web-like state.
- After notching, the electrode web can either be re-wound to a coil or fed directly to the separation process.
- Both notching and separation can be performed by laser or shear cutting.
- The electrode sheets are magazined and transported to the next process step.
- In the case of single sheet stacking, the separator foil is also cut to sheets.

Process parameters & requirements

- Separation time: 0.2 sec./sheet
- Separation tool: Very precise edge quality (in relation to wear resistance)

Quality parameters [excerpt]

- Edge geometry (e.g. minimization of burr formation during shear cutting and defect prevention by suitable radii in tab area)
- Minimization of thermal and mechanical influences during the separation process
- Minimization of the heat-affected zone and suction extraction of the vaporized material during the laser cutting process
- Tolerance requirements: approx. ±200 µm

Current technology alternatives

- Laser cutting: Instead of the conventional punching tool, the electrodes can also be cut (out) with a laser.

Innovations/Trends

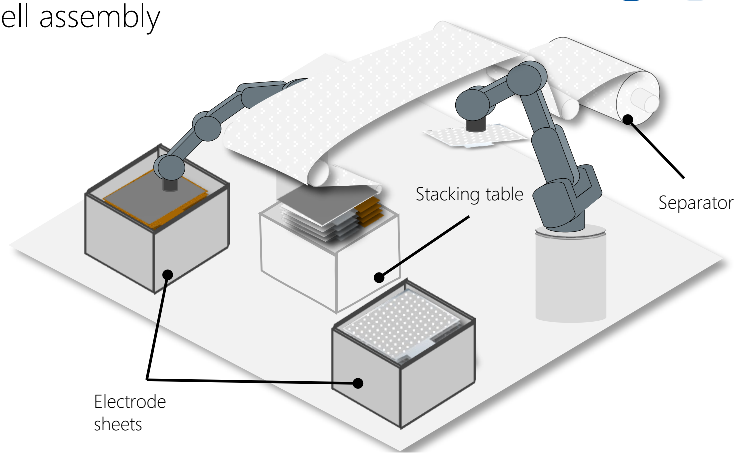
- Increase in tool utilization times (e.g. through coating)
- Increase in cutting/punching speed

Production costs* [excerpt]

Investment for machinery and equipment: € 20 - 30 m
(Separation)

* Study by PEM of RWTH Aachen University: 10 GWh p.a., approx. 30.000.000 Pouch cells p.a., cell capacity: 80 Ah

Stacking
Cell assembly



Production process

- During stacking, a cell stack is formed from an alternating arrangement of anode, separator, cathode, separator, etc.
- A cell stack can consist of up to 120 individual layers.
- Different stacking technologies can be used to produce the cell stack. Many stacking technologies are customized and patented by manufacturers.
- The electrode sheets are usually picked, transported and positioned by vacuum grippers.
- A common stacking variant used in the industry is the so-called Z-folding.
- In Z-folding, the anode and cathode are inserted into the web-shaped separator from both sides. The Z-shaped arrangement of the separator gives the process its name.
- After stacking, the cell stack is wrapped with separator, the separator is cut off and fixed with an adhesive tape.

Process parameters & requirements

- Stacking speed: <1 sec./sheet for Z-folding and single-sheet stacking
- Stacking accuracy: <200 - 300 µm

Quality parameters [excerpt]

- Positioning accuracy of the electrode sheets
- Mechanical separator preload
- Damage-free handling of the electrode sheets

Current technology alternatives

- Single-sheet stacking
- Lamination: Electrode sheets are laminated with the separator
- Pocket Stacking: Placement of the cathode sheets in a separator pocket and subsequent stacking with anode

Innovations/Trends

- Growth of stacking speed (sheets/sec.) while increase of stacking accuracy
- Development of new stacking technologies to reduce cycle times
- Handling of large-format electrode sheets

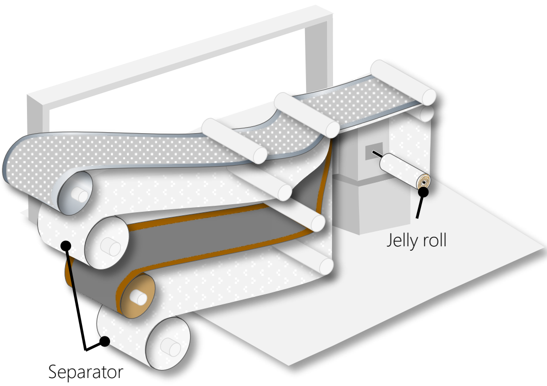
Production costs* [excerpt]

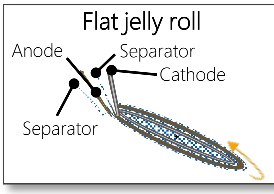
Investment for machinery and equipment: € 25 - 35 m
(Stacking)

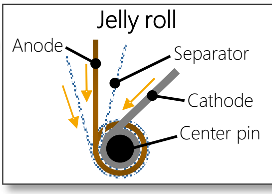
* Study by PEM of RWTH Aachen University: 10 GWh p.a., approx. 30.000.000 Pouch cells p.a., cell capacity: 80 Ah

Winding & Tab Welding

Cell assembly







Electrode manufacturing — Cell finishing

Production process

- Winding is used in the manufacturing of cylindrical cells. (Flat winding is still used occasionally in prismatic cells. In the meantime, however, stacking is used more frequently here.)
- In the production of the so-called jelly roll for a cylindrical cell, the electrode webs and two separator webs are fed into the process.
- Prior to winding, a tab is welded to the anode.
- Winding takes place around a center pin (cylindrical cell) or winding mandrel (prismatic cell). The web sequence is identical to that of the stacking process.
- The jelly roll is then fixed by an adhesive tape.
- The center pin can either be removed or remain in the cell housing.

Process parameters & requirements

- Machine throughput: up to 30 cells/min. (round cell)
- Integration of the tab welding process in the winding machine for cylindrical cells
- Machine throughput up to 6 cells/min. (prismatic cell)

Quality parameters [excerpt]

- Exact positioning and alignment of the electrode and separator webs
- Web tension of the electrode and separator webs
- Avoidance of electrostatic charging

Current technology alternatives

- none

Innovations/Trends

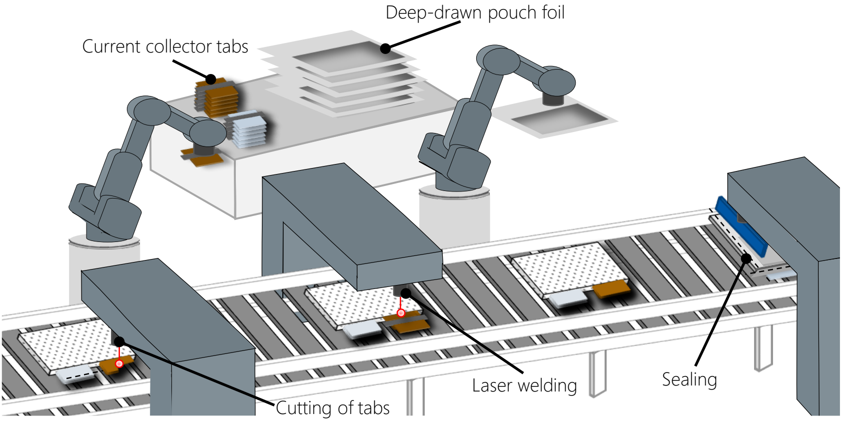
- Increase of the machine throughput
- Increase of the winding diameter
- Functional integration of the center pin (e.g. for heat dissipation)

Production costs* [excerpt]

Investment for machinery and equipment: € 20 - 30 m
(Winding)

* Study by PEM of RWTH Aachen University: 10 GWh p.a., approx. 550,000,000 cylindrical cells p.a., cell capacity: 5 Ah

Packaging
Cell assembly



Electrode manufacturing | Cell finishing

Production process

- The uncoated flags of the cell stack are cut to a defined length.
- The shortened flags of the cell stack are each welded to an anode or cathode current collector tab. The contact is usually made by means of an ultrasonic welding process.
- The pouch foil (aluminum composite foil) is un-wound and deep-drawn.
- The cell stack is positioned in the deep-drawn pouch foil so that the tabs extend beyond the edge of the pouch foil.
- The top of the cell stack is also covered with pouch foil and sealed gas-tight on three sides of the foil. The resulting pouch pocket has an open side, which is used in the next step to fill the cell with electrolyte.
- The sides where tabs extend from the pouch are usually sealed.

Process parameters & requirements

- Material compatibility at joint areas
- Parameter set for ultrasonic welding: frequency, amplitude, pressure, time
- Flexible beam guidance and shaping for laser welding
- Deep-drawing of pouch foil up to 10 mm
- Sealing temperature and pressure

Quality parameters [excerpt]

- Low mechanical and thermal stress during the welding processes
- Low contact resistance of the welds for electrical contacting
- Strength and tightness of the sealing
- Rule of thumb: "1 mm seal seam width corresponds to approximately one year of calendrical service life."

Current technology alternatives

- Sealing by means of impulse/contact sealing
- Joining of the tabs to the cell flags by means of laser welding process
- Use of two single foils or a folded pouch foil (bookfolding)

Innovations/Trends

- Reduction of mechanical and thermal stress
- Increase of the deep-drawing depth for thicker cell stacks
- Positioning of tabs on opposite sides instead of on one side

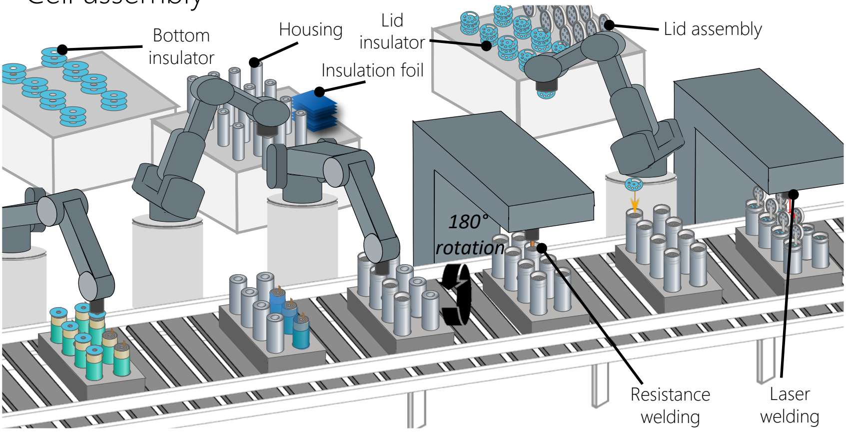
Production costs* [excerpt]

Investment for machinery and equipment: € 20 - 35 m
(Packaging pouch cells)

* Study by PEM of RWTH Aachen University: 10 GWh p.a., approx. 30,000,000 Pouch cells p.a., cell capacity: 80 Ah

Packaging

Cell assembly



Electrode manufacturing | Cell finishing

Production process

- An insulator ring is placed on the top of the jelly roll (side of the anode tab).
- The cell can is pushed over the jelly roll so that the insulator ring now rests on the bottom of the cell can. The anode tab is joined to the bottom of the cell can by resistance welding.
- Another insulator ring is placed on the top of the jelly roll (side of the cathode tab).
- If the cell can has a conical opening, the opening angle can be reduced to 90 degrees by swaging. A bead is imprinted on the housing.
- The lid assembly is welded to the cathode tab.
- After electrolyte filling, the lid assembly is crimped onto the beaded cell cup, thus closing the cylindrical cell.

Process parameters & requirements

- Material compatibility at joint areas
- Parameter set for ultrasonic welding: frequency, amplitude, pressure, time
- Flexible beam guidance and shaping for laser welding

Quality parameters [excerpt]

- Low mechanical and thermal stress during the welding processes
- Low contact resistance of the welds for electrical contacting
- Tightness of the cell
- Low mechanical stress on the jelly roll during handling (e.g. avoidance of shifting of the layers due to friction during in-sertion into the housing)

Current technology alternatives

- Welding of the cover assembly by means of ultrasonic or laser beam welding

Innovations/Trends

- Reduction of mechanical and thermal stress during welding operations
- Avoidance of the use of tabs (e.g. tabless design from Tesla)

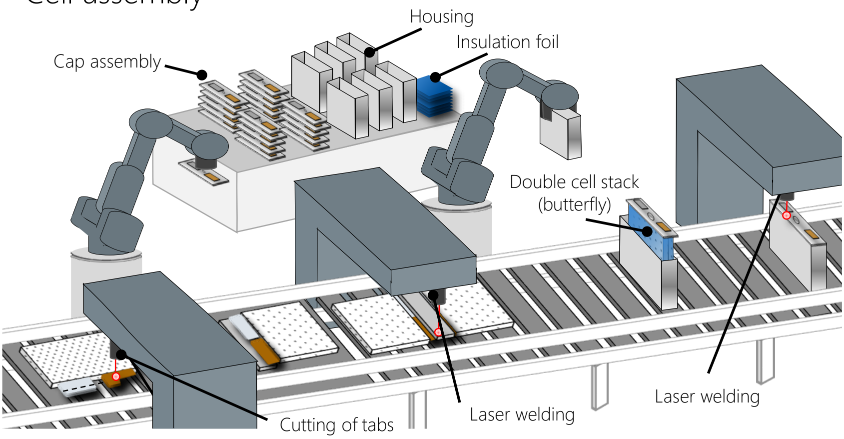
Production costs* [excerpt]

Investment for machinery and equipment: € 35 - 45 m
(Packaging cylindrical cells)

* Study by PEM of RWTH Aachen University: 10 GWh p.a., approx. 550,000,000 cylindrical cells p.a., cell capacity: 5 Ah

Packaging

Cell assembly



Electrodde manufacturing → Cell finishing

Production process

- The uncoated flags of the cell stack are shortened to a defined length.
- The shortened flags of the cell stack (or the uncoated edges of the flat jelly roll) are each welded to an anode or cathode tab.
- Subsequently, the tabs are welded to the cap assembly.
- The joining between the cell stack and the cap assembly is usually made by ultrasonic welding.
- Often the cell stack is wrapped in an additional insulation foil to protect it from contact influences with the housing. The cell housing may include other insulation components.
- The cell stack is inserted into the housing until the cap assembly rests on the edge of the housing. The housing and lid are joined together using a laser welding process.
- Typically, the lid assembly includes a fill opening, which is the cell housing's only opening after the cap assembly is welded.

Process parameters & requirements

- Material compatibility at joint areas
- Parameter set for ultrasonic welding: frequency, amplitude, pressure, time
- Flexible beam guidance and shaping for laser welding
- Possible subsequent cleaning in case of welding spatter
- Laser protection during laser welding

Quality parameters [excerpt]

- Low mechanical and thermal stress during the welding processes
- Low contact resistance of the welds for electrical contacting
- Tightness of the weld seam between housing and cap assembly

Current technology alternatives

- Laser welding can be used as an alternative to the ultrasonic welding process for contacting between the cell stack and the cap assembly

Innovations/Trends

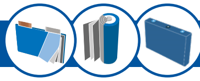
- Reduction of mechanical and thermal stress during welding operations
- Connecting multiple cell stacks within one housing

Production costs* [excerpt]

Investment for machinery and equipment: € 45 - 60 m
(Packaging prismatic cells)

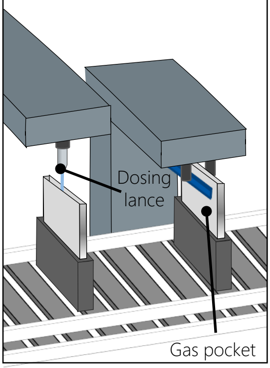
* Study by PEM of RWTH Aachen University: 10 GWh p.a., approx. 22,000,000 prismatic cells p.a., cell capacity: 130 Ah

Electrolyte filling

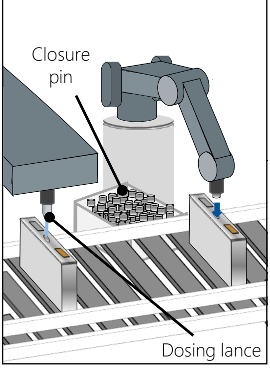


Cell assembly

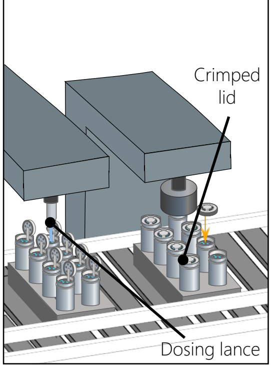
Pouch



Prismatic



Cylindrical



Electrode manufacturing → Cell finishing

Production process

- Electrolyte filling takes place after the electrode stack, or the electrode winding has been placed in the packaging (housing or pouch foil).
- A dosing lance is positioned at the opening of the packaging. The precision of the positioning during filling significantly determines possible electrolyte contamination on the packaging.
- Filling: The electrolyte is filled into the packaging of the cell with the dosing lance. The accuracy of the dosing is a critical process parameter.
- Wetting: A dynamic (under-)pressure profile is applied to the cell during and after the filling process. This activates the capillary activities, and the cavities of the porous cell components are filled with electrolyte.
- (Partial) Filling and wetting can be repeated several times to ensure optimal electrolyte distribution.
- After electrolyte filling, the opening of the cell packaging is closed.

Process parameters & requirements

- Working pressure: approx. 150 mbar
- Particularly dry/inert environment
- Tightened safety measures due to use of electrolytes
- Gravimetric measurement of the electrolyte quantity
- Continuous or cyclic filling and wetting

Quality parameters [excerpt]

- Dosing accuracy precision
- Positioning accuracy of the dosing lance
- No electrolyte residues on the packaging
- Homogeneous electrolyte distribution in the cell

Current technology alternatives

- Various dispensing methods (e.g. pump technologies)
- Final closing (pouch cell): Sealing of the fourth side
- Final closing (prismatic cell): Laser welding of the filling opening

Innovations/Trends

- Risk reduction of electrolyte reactions with moisture by, e.g., inert gas supply, lower dew points or lower pressures during the process

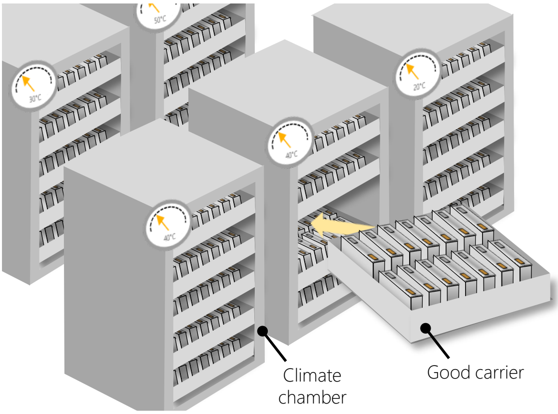
Production costs* [excerpt]

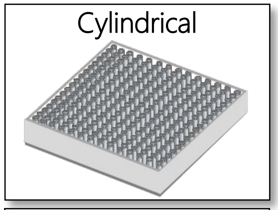
Investment for machinery and equipment: € 35 - 45 m
(Electrolyte filling)

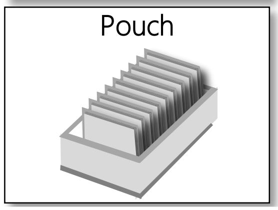
* Study by PEM of RWTH Aachen University: 10 GWh p.a., approx. 30,000,000 pouch cells p.a., cell capacity: 80 Ah

Pretreatment

Cell finishing







Electrode manufacturing | Cell assembly

Production process

- After electrolyte filling, various optional technologies can be used with the aim of improving electrode wetting and thus avoiding inactive areas during formation. These technologies include high-temperature soaking.
- In this process, the environment of the cells is raised to a temperature between 30°C and 50°C in a rack or chamber system.
- The higher temperature reduces the viscosity of the electrolyte and leads to an improvement of the contact of the liquid electrolyte and the access of the electrolyte to the mesopores of the electrode.
- This ensures faster penetration of the electrolyte into the pores of the electrode and the separator.

Process parameters & requirements

- Homogeneous temperature application in a temperture window of 30 - 50°C
- Soaking time

Quality parameters [excerpt]

- Electrolyte distribution within the cell

Current technology alternatives

- Roll pressing [pouch cells]
- Vibrating table [prismatic/cylindrical cells]
- Pre-charging [all formats]

Innovations/Trends

- Inline measurement technology for wetting degree measurement

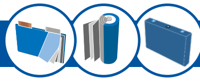
Production costs* [excerpt]

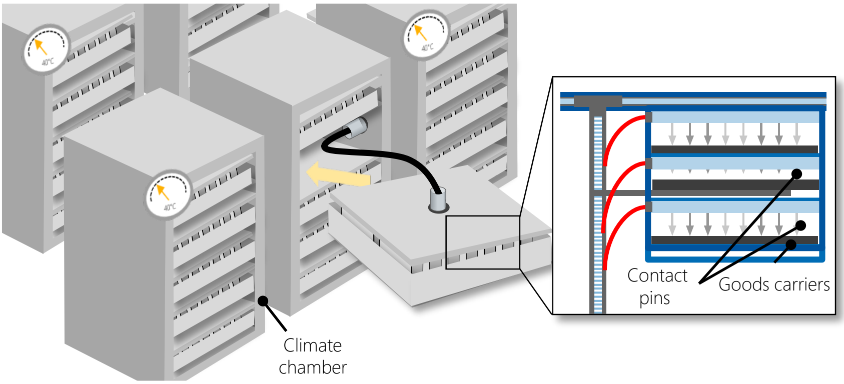
Investment for machinery and equipment: € 10 - 20 m
(HT soaking)

* Study by PEM of RWTH Aachen University: 10 GWh p.a., approx. 30,000,000 pouch cells p.a., cell capacity: 80 Ah

Formation

Cell finishing





Electrode manufacturing | Cell assembly

Production process

- "Formation" refers to the initial charging and discharging processes of the battery cell.
- For formation, the cells are placed into formation racks in special product carriers and are contacted by contact pins.
- The cells are then charged or discharged according to precisely defined current and voltage profiles.
- During formation, lithium ions are deposited in the crystal structure of the graphite on the anode side. This forms the Solid Electrolyte Interface (SEI), which is a boundary layer between the electrolyte and the electrode.
- The parameters during formation vary depending on the cell manufacturer and have a great impact on the cell performance. The formation depends on the cell concept as well as the cell chemistry and represents the core knowledge of a cell manufacturer.
- Pouch cells are usually pressurized during the forming process by special product carriers.

Process parameters & requirements

- First charging cycle: approx. 0.1 - 0.5 C;
- Successive increase of C rates with each charging and discharging cycle
- Duration of forming process: up to 15 hrs.
- Low contact resistance at the contact pins

Quality parameters [excerpt]

- Formation of the SEI layer
- Stability and composition of the SEI layer
- Internal resistance of the cell
- Cell capacity after formation

Current technology alternatives

- There are different procedures for the formation depending on the cell manufacturer and the cell chemistry.

Innovations/Trends

- Inline measurement technology for early quality detection

Production costs* [excerpt]

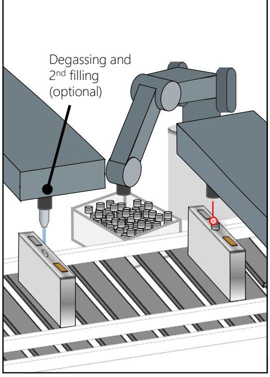
Investment for machinery and equipment: € 65 - 85 m
(Formation)

* Study by PEM of RWTH Aachen University: 10 GWh p.a., approx. 30,000,000 pouch cells p.a., cell capacity: 80 Ah

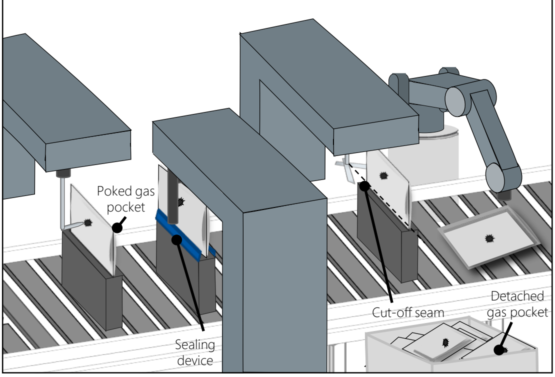
Degassing

Cell finishing

Prismatic



Pouch



Electrode manufacturing | Cell assembly

Production process

- During the first charging process (especially with larger cells), a large amount of gas is generated.
- In the pouch cell, these gases formed during formation are collected into a dead space (also described as a "gas pocket"). During the degassing process, the gas pocket is pierced, and vacuum is applied. The escaping gases are extracted. Then the area between the gas pocket and the cell is sealed under vacuum. The gas pocket is separated and disposed as a hazardous waste. A final folding and, if necessary, gluing of the sealing edges to reduce the outer dimensions of the pouch cell can optionally be carried out.
- In the case of the prismatic cell, the temporary stopper is removed and the cell is also degassed under applying of vacuum. If necessary, a second filling can also take place in this process step. Eventually, the cell is sealed.
- Depending on occupational health and safety as well as environmental protection regulations, the extracted gases must be aftertreated (e.g. RTO) before they are fed into the exhaust air system.
- Particularly in case of smaller cells with lower gas generation and depending on the manufacturer, the gas ash is not separated after degassing.

Process parameters & requirements

- Pouch cells: Folding and gluing of seal seams to increase volumetric energy density.
- Particularly dry (or even inert) environment required
- Sealing against moisture and oxygen

Quality parameters [excerpt]

- Residual gas inside the cell
- Damage-free cell handling (different characteristics of the gas bubbles)

Current technology alternatives

- Pressing of the cells for degassing
- Sealing and folding technology

Innovations/Trends

- Integration of degassing steps for ever larger cylindrical formats

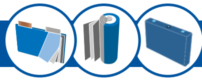
Production costs* [excerpt]

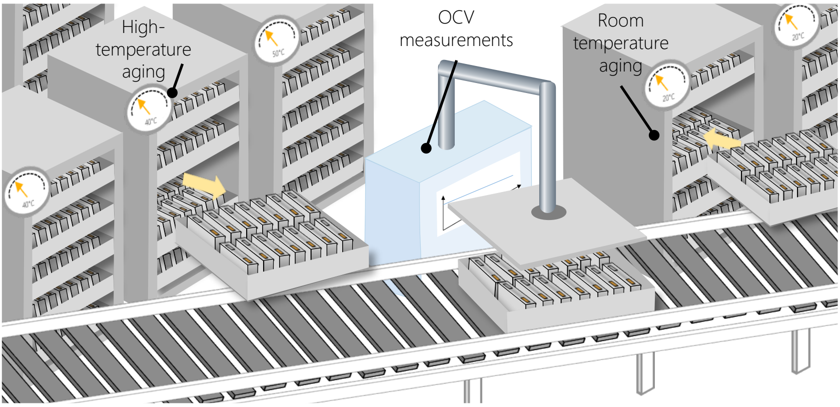
Investment for machinery and equipment: € 10 - 15 m
(Degassing)

* Study by PEM of RWTH Aachen University: 10 GWh p.a., approx. 30,000,000 pouch cells p.a., cell capacity: 80 Ah

Aging

Cell finishing





Electrode manufacturing | Cell assembly

Production process

- Aging is one of the cell quality determination steps and part of the End-of-Line (EoL) test.
- For this purpose, the cells are stored in so-called aging racks and/or towers.
- A distinction is made between high-temperature (HT) and room temperature (RT) aging.
- Cell properties are monitored by regular open circuit voltage measurements over a certain period of time (up to three weeks).
- If there does not occur significant change in cell properties during the entire period, this means that the cell is okay and can be shipped.
- The duration of the aging process depends heavily on the particular cell manufacturer and the cell chemistry used.
- In contrast to formation, pouch cells are not pressurized in this process step.

Process parameters & requirements

- State of charge (SOC) of the cell at the beginning of the aging: 30 - 80%
- Aging time: up to 3 weeks
- Room temperature: approx. 20 - 25°C, high-temperature: approx. 30 - 50°C

Quality parameters [excerpt]

- Self-discharge rate (Increased loss rate: >5 mV/week may indicate, e.g., cell-internal short circuits)

Current technology alternatives

- A wide variety of procedures exist for the sequence and duration of HT and RT aging depending on the cell manufacturer and the cell chemistry.

Innovations/Trends

- Measurement technology for early quality detection

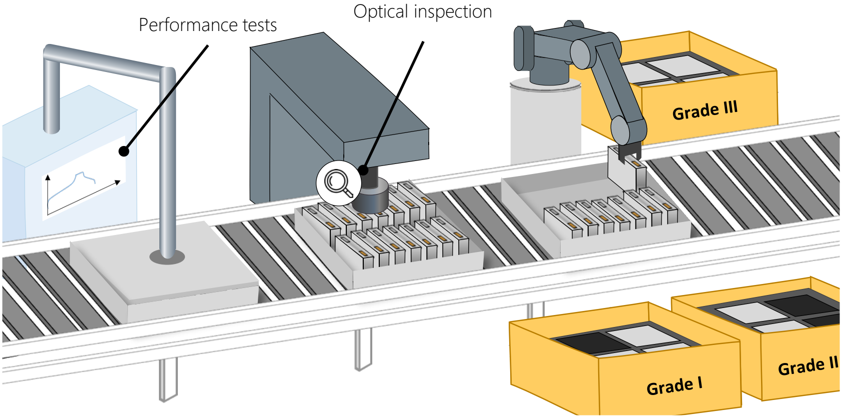
Production costs* [excerpt]

Investment for machinery and equipment: € 15 - 30 m
(Aging)

* Study by PEM of RWTH Aachen University: 10 GWh p.a., approx. 30,000,000 pouch cells p.a., cell capacity: 80 Ah

EoL Testing

Cell finishing



Electrode manufacturing | Cell assembly

Production process

- Before the cells leave the plant, they are tested in an End-of-Life (EoL) test stand.
- The cells are removed from the product carriers in the aging racks and fed to the test station.
- Depending on the manufacturer various tests are performed e.g. pulse tests, internal resistance measurements (DC), optical in-spections, OCV tests, capacity tests and leak tests. After that, the cells are discharged to the shipping state of charge.
- Following testing, many cell manufacturers grade the cells according to performance data (grading).
- Once testing is complete and all tests have been successfully passed, the cells can be packaged and shipped.
- For transport, the cells are usually covered with a plastic cover and stacked in a cardboard box.

Process parameters & requirements

- Allowable loss rate: <5 mV/week

Quality parameters [excerpt]

- Low self discharge
- Low internal resistance
- Constant capacity

Current technology alternatives

- Depending on the cell manufacturer, different test sequences and test durations exist.

Innovations/Trends

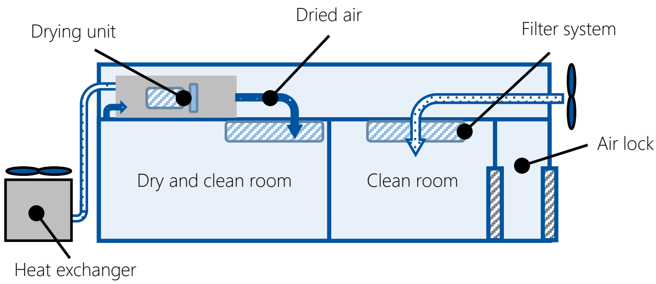
- Reduction or integration of the EoL test in upstream process steps

Production costs* [excerpt]

Investment for machinery and equipment: € 5 - 15 m
(EoL test)

* Study by PEM of RWTH Aachen University: 10 GWh p.a., approx. 30,000,000 pouch cells p.a., cell capacity: 80 Ah

Process Environment



	Clean room classes	Dry room (dew point)	Temperature	Comments
Mixing	ISO 7-8	**Water-based electrodes:** Controlled process conditions Semi-dry (5°C to -5°C) **NMP-based electrodes:** Dry (0°C to -30°C) to very dry (-40°C to -60°C)	22 ±2°C	Electrode production takes place under clean room conditions, since foreign particles in the coating cannot be removed by cleaning methods (e.g. suction) later in the process.
Coating				
Drying				
Calendering				
Slitting				
Vacuum drying		Encapsulated process [Vacuum or Inert]		
Cutting	min. ISO 7	Very dry (-30°C to -60°C)	22 ±2°C	Cell assembly must be carried out under dry conditions, as water inside the cell leads to severe quality losses (service life) and a safety risk (formation of hydrofluoric acid).
Stacking/ Winding				
Packaging				
EL filling				
Soaking	/	/	20°C to 50°C	Cell finishing takes place in a normal environment. Since the cell is already sealed and degassing takes place in a vacuum chamber, there are lower requirements for the particle environment and humidity.
Formation				
Degassing	min. ISO 7	Very dry (-40°C to -60°C)	22 ±2°C	
Aging	/	/	20 °C to 50 °C	
EoL testing			22 ±2°C	

Online Industry Guide

Key to battery production

Available online

Are you looking for strong solutions in battery production? Do you want to set up an entire production line or are you searching for a process development partner?

The new comprehensive overview by the VDMA Battery Production department about what companies offer which kind of technology along the process chain will help you find the right partners.

https://vdma-industryguide.com/batteryproduction

Directly contact the companies' battery experts. Search the divisions within the production chain according to your needs and find the right corporation.

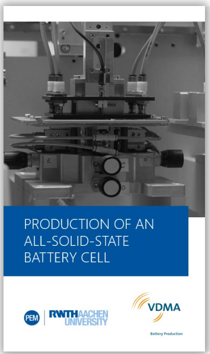
You can then send your contact request via a bookmark function.

Guideline

to electric mobility

Available online

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



Production Process of an All-Solid-State Battery Cell

The publication “Production Process of an All-Solid-State Battery Cell” presents manufacturing technologies and chains for the three electrolyte classes of the all-solid-state battery cell. In addition, the transferability of competencies from the production of lithium-ion battery cells is discussed.

2nd edition
ISBN 978-3-947920-29-7

Publisher
PEM of RWTH Aachen University & VDMA

Battery Module and Pack Assembly Process

The publication “Battery Module and Pack Assembly Process” provides a comprehensive process overview for the production of battery modules and packs. The effects of different design variants on production are also explained.

3rd edition
ISBN 978-3-947920-05-1

Publisher
PEM of RWTH Aachen University & VDMA

Component Manufacturing of a Lithium-Ion Battery Cell

1st edition
ISBN 978-3-947920-06-8

Recycling of Lithium-Ion Batteries

1st edition
ISBN 978-3-947920-11-2

Guideline

to electric mobility

Available online

In its series of "Guide to E-Motor Production and Fuel Cell Production" articles, the chair "Production Engineering of E-Mobility Components" (PEM) of RWTH Aachen University presents further components for electric mobility.

Production Process of a Hairpin Stator

The guide "Production Process of a Hairpin Stator" covers the processes involved in manufacturing hairpin stators as the predominant construction method for automotive traction applications, from straightening the wire to hairpin production, assembly and interconnection, to impregnation and testing.

3rd edition
ISBN 978-3-947920-19-8

Publisher
PEM of RWTH Aachen University

Production Process of a Continuous Hairpin Stator

1st edition
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Rotor Production Processes

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