Ten technical trends of lithium-ion battery industry

Strategy realized

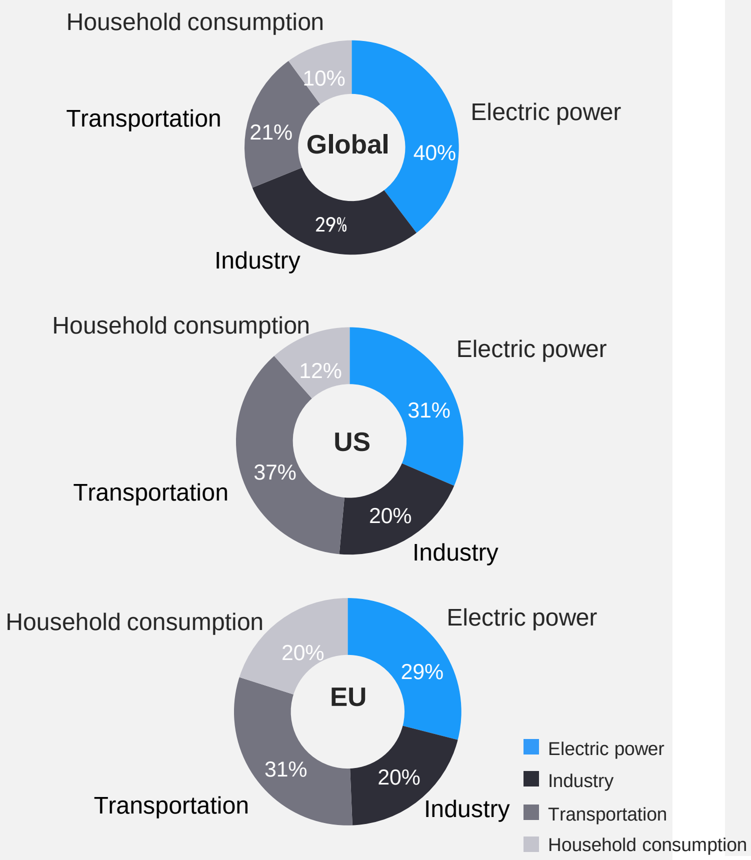
The better the question. The better the answer.
The better the world works.

EY 安永
Parthenon 博智隆

1.1 Global new energy policy

Transportation industry ranks among top three in carbon emissions

2021 Carbon emissions by industry



Global new energy policy guides carbon reduction in transportation industry

We will move faster to develop green and low-carbon modes of transportation to keep the growth of carbon emissions in the transportation domain within an appropriate range. We will promote low-carbon transformation of transportation vehicles and equipment, vigorously promote new-energy vehicles, while gradually reducing the proportion of cars that run on traditional oil-based fuels in new car sales and car ownership, promote the replacement of public service vehicles with electric vehicles...

China's Action Plan for Carbon Dioxide Peaking Before 2030

Ensure the US achieves a 100% clean energy economy and reaches net-zero emissions no later than 2050. Use the federal government procurement system in the short run to achieve zero-emission vehicles, and develop rigorous new fuel economy standards aimed at ensuring 100% of new sales for light- and medium-duty vehicles will be zero emissions. Speed up the promotion of electric vehicles in medium and long run, and deploy more than 500,000 new public charging outlets before the end of 2030...

US Plan for a Clean Energy Revolution and Environmental Justice

Speed up the process of vehicle electrification, increase high-speed rail traffic, promote automated transport equipment at large scale, drive the entry of zero-emission vessels into market, deploy more shared bicycle infrastructures, among others, to ultimately build a clean multimodal transport network system. It aims to deliver a 90% reduction in the transport sector's emissions by 2050 compared with 2020 level…

EU Sustainable and Smart Mobility Strategy

Development of lithium-ion batteries is highly related to national energy security

To vigorously promote the development of important technologies and basic equipment in the field of new energy, such as lithium-ion batteries, electrochemical energy storage and electric vehicles, gradually reduce our reliance on oil and explore a sustainable energy security path is an important strategic direction for many countries around the world

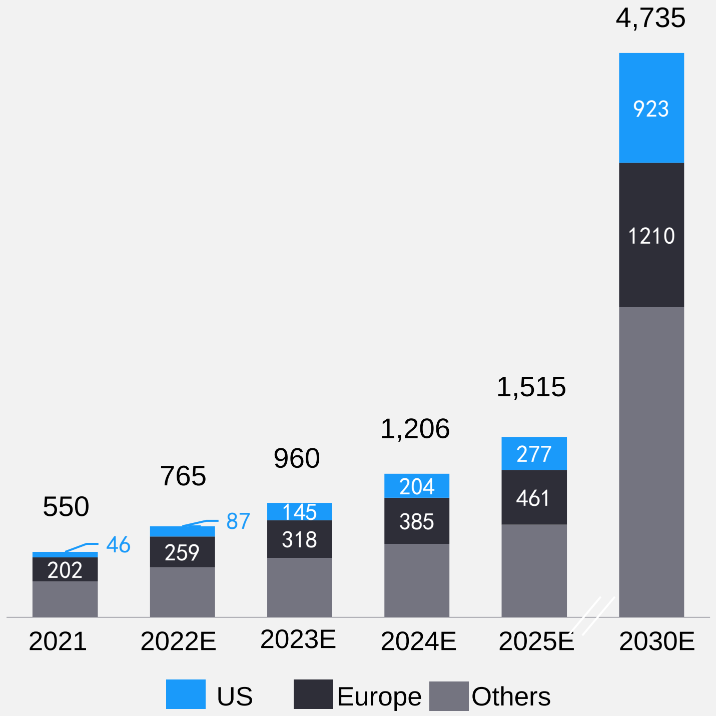
	2012	2021	Increase
Global installed capacity of electrochemical energy storage (GW)	<1	20	x20
Global market shipment of lithium-ion batteries (GWh)	<40	562	x14
Global sales volume of new energy vehicles (10 thousand units)	<15	653	x44

Source: Carbon Monitor, EVTank, Founder Securities, Guosen Securities, Public data, Da Dong Times Database (TD), EY Analysis

1.2 Global lithium-ion battery market size

Global and European and American lithium-ion battery market size forecast

Global and European and American lithium-ion battery market demand (unit: GWh)

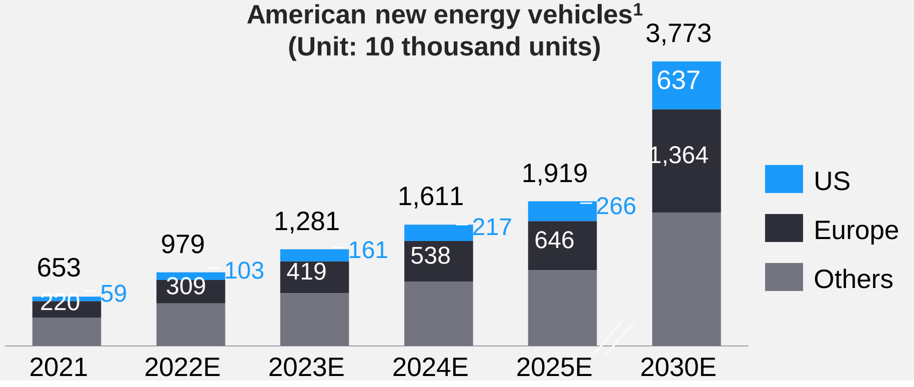


Growth of lithium-ion batteries is driven by the new energy vehicles and energy storage which are gaining pace

Driving force 1: New energy vehicles

Many countries have announced their aim to achieve carbon neutrality by 2050/2060, and new energy vehicles are deemed as an important part of carbon reduction. Therefore, many countries have released relevant policies to promote the development of zero-emission new energy vehicles. The industry embraces a window period of vigorous development

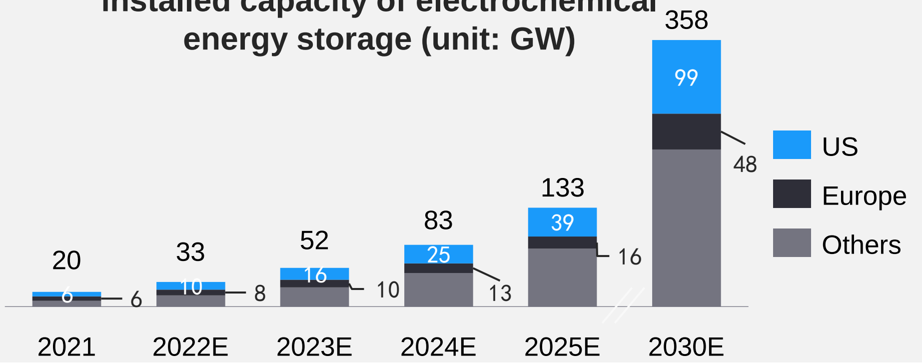
Sales volume of global and European and American new energy vehicles[1] (Unit: 10 thousand units)



Driving force 2: Energy storage

The carbon peak and neutrality goals have underlined the strategic position of renewable energy. As the key technology to support the development of renewable energy, energy storage is heralding the dawn. In future, the energy storage battery market is expected to see an explosive growth

Global and European and American installed capacity of electrochemical energy storage (unit: GW)



Note: 1. The sales volume of new energy vehicles herein only includes those of BEVs, PHEVs and EREVs.

Source: LMC Automotive, EVTank, Zheshang Securities, Bloomberg New Energy Finance, Intelligence Research Group, Public data, Da Dong Times Database (TD), EY Analysis

1.3 Challenges and bottlenecks to install lithium-ion battery capacity faced by countries and regions outside China, Japan and South Korea

Most countries and regions show an unbalanced growth in installed capacity of lithium-ion battery

Rankings and proportions of global power batteries by installed capacity

GWh, %, 2021

Country	Manufac-turer	Installed capacity	Proportion
China	Company A		32.6%
South Korea	Company B		20.3%
Japan	Company C		12.2%
China	Company D		8.8%
South Korea	Company E		5.6%
South Korea	Company F		4.5%
China	Company G		2.7%
China	Company H		2.1%
China	Company I		1.4%
China	Company J		1.0%
	Others		8.8%
	Total	296.8	100%

Major four challenges: lack of technological base, industrial chain support, core talents and construction experience

Challenge 1: Lack of technological base

Case 1: Europe is years behind Asia in technological reserves of the main components of cells, such as anode and cathode materials, electrolyte and separators
Case 2: India, Southeast Asia and other countries lack local large leading enterprises and relevant technology accumulation
…

Challenge 2: Lack of industrial chain support

Case 1: For battery anode and cathode materials, electrolyte, battery separators and other raw materials, US totally relies on overseas processing and import
Case 2: Due to the limited mineral resources in Europe, its electrolyte and separators are mainly supplied by manufacturers in Asia
…

Challenge 3: Lack of core talents

Case 1: North America lacks skilled engineers in manufacturing industry. Therefore, technical talents need to be introduced at high costs
Case 2: Europe, which as a whole has a labor shortage, needs to introduce talents from Asia. However, the application process for labor visas is complicated
…

Challenge 4: Lack of construction experience

Case 1: The hollowing-out problem of the manufacturing industry in the US has resulted in high manufacturing costs. A123 had tried to bring production line back but suffered from serious losses, being eventually acquired by a Chinese company.
Case 2: Europe lacks systematic methodologies as a support in integration, adjustment, calibration, cost control and other aspects
…

Source: Desk research, Da Dong Times Database (TD), EY Analysis

2.1 Pain points and challenges in the manufacturing process of pole pieces

Pole pieces

	Pain points of mixing	Pain points of coating	Pain points of rolling and slitting
Key pain points	1. Non-uniform mixing 2. Lack of online data on particles, impurities, dust and ingredients 3. Impurities mixed in the mixing process	1. High energy consumption 2. Lack of online data on viscosity, solid content and impurities of incoming slurry 3. Hard to control the online feedback on full characteristics of output quality	1. Inconsistent extension between separator area and foil area 2. Hard to keep the same thickness
Issue raised	1. Non-uniform mixing → Abnormal distribution of materials inside the batteries → Reduction in battery capacity, increase in battery internal resistance and reduction in battery cycle life → Safety issues emerged 2. The lack of online data on particles, impurities, dust and ingredients results in inability to improve quality 3. Impurities mixed in the mixing process→ Impurities pierce through the separators → Short circuit inside batteries, abnormal self discharge, and reduction in battery life → Safety issues	1. Current unit energy consumption of coaters: 2.3~3KWh/Wh 2. Non-uniform coating as a result of unavailability of online data on viscosity, solid content and impurities of incoming slurry, which influences the quality of coating 3. Full characteristics of output quality: Hard to control the online feedback on dryness, voidage of pole pieces and coating scale, which results in high defective percentage	1. Inconsistent extension between separator area and foil area may result in cambers/rippled edge, which may cause strip breakage 2. Poor consistency in thickness. Inconsistent electric current density tends to cause precipitation of lithium dendrite, which is unfavorable for the performance of cells. The severe polarization of batteries influences the capacity of cells

Source: *Analysis on lithium-ion battery Manufacturing Process Control and Potential Problems*, *Research on lithium-ion battery Intelligent Manufacturing Equipment Standard System*, Patent retrieval, Da Dong Times Database (TD), EY Analysis

EY Parthenon

2.2 Pain points and difficulties in the assembly process

Assembly

	Pain points of vacuum drying	Pain points of cell making	Pain points of assembly
Key pain points	**1. Excessive water content** **2. Efficient humidity control and corresponding quantitative management of battery performance**	**1. Dust and burrs occurred** **2. Online detection of accuracy, burrs and defects.**	**1. Machine damage caused by excessive handling** **2. Damage to cells in transit** **3. Online control of assembly process parameters, optimization of manufacturing models**
Issue raised	1. Excessive water content may cause product scrapped, quality decline and even product explosion 2. High air humidity may cause the lithium-ion battery to absorb moisture from the air, and its internal humidity may also increase accordingly. After charging, the moisture breaks down and the pressure inside the battery is high. Meanwhile, it's easy to cause bulge in the process of electrolyte injection, which may influence the thickness and SEI films, or incomplete formation, etc.	1. Slicing causes burrs and dust → Battery short circuit → Hidden safety troubles of battery 2. Inadequate detection on accuracy, burrs and defects of cells may influence the quality of chips	1. Excessive handling of assembly equipment tends to cause damage to machine 2. lithium-ion batteries after assembly need to be picked up inside the assembly unit → Damage to the assembly unit, and easy to damage the cells, resulting in high costs 3. For online control of assembly process parameters and optimization of manufacturing models, improper management may influence the efficiency and quality of assembly

Source: *Analysis on lithium-ion battery Manufacturing Process Control and Potential Problems, Research on lithium-ion battery Intelligent Manufacturing Equipment Standard System*, Patent retrieval, Da Dong Times Database (TD), EY Analysis

2.3 Pain points and difficulties in capacity grading and formation

Capacity grading and formation

	Pain points of formation	Pain points of capacity grading	Pain points of stereoscopic warehouse
Key pain points	**1. Energy consumption control** **2. Effectiveness test**	**1. Not quite satisfying heat dissipation effect, with high power consumption** **2. Inaccurate measurement of electric capacity**	**1. Long turnaround time and low efficiency** **2. Machine damage caused by excessive handling**
Issue raised	1. The drying process of electrodes and the running cost of drying unit in the drying room during the production of batteries consume more energy 2. Due to its various types and great difference in models, the cell has higher requirements for the effectiveness and compatibility of formation and capacity grading testing equipment. Poor effectiveness will make the formation a time-consuming and laborious process.	1. Cells charge and discharge → Massive thermal loss arising from the charging and discharging panel, which results in overtemperature → Damage to electronic components → Use air conditioner and a large number of fans to blow the charging and discharging panel, which is far away from the air conditioner and fans → Not quite satisfying heat dissipation effect, with high power consumption of air conditioner and fans. 2. During the testing of electric capacity of lithium-ion batteries, it is found that heat is different due to different current or voltage of these lithium-ion batteries → Uneven and non-constant environmental temperatures of lithium-ion batteries → Inaccurate measurement of electric capacity	1. In case of delivery of goods from the stereoscopic warehouse, all the pallets of the same layer need to be taken out in order, which is long in length → Very long turnaround time of pallets of the same layer, with low working efficiency → Unsmooth logistics and low efficiency of inbound and outbound logistics 2. The handling process is complicated and frequent. Excessive handling tends to cause damage to machine. There may be frequent downtime during the assembly process with high failure rate

Source: *Analysis on lithium-ion battery Manufacturing Process Control and Potential Problems, Research on lithium-ion battery Intelligent Manufacturing Equipment Standard System*, Patent retrieval, Da Dong Times Database (TD), EY Analysis

2.4 Pain points and difficulties in the manufacturing process of module/pack

Module/pack

	Pain points of module assembly	Pain points of packing
Key pain points	**1. Single cell, complicated software logical processing, gluing** **2. Great difficulty in laser welding, side seam welding and busbar welding, difficulty in testing**	**1. Low automation rate, less than 50%** **2. Frequent change and fast iteration in models with uncertain battery technologies** **3. Lack of standard technologies/products**
Issue raised	1. The software logical processing of single cell is complicated, which may spend a lot of time and costs; serious sinking of cells may cause insufficient gluing areas, resulting in failure of cell fixing and cracking of modules after long-term driving of vehicles, which may cause driving safety risk; serious bulge of cells may cause excessive glue, polluting the equipment and consuming manpower to clean the glue, and residual glue may cause breakage of blue film, and even failure of insulation. 2. There is great difficulty in laser welding, side seam welding and busbar welding. Especially, in module busbar welding, it's necessary to check whether there is any blow holes, excess weld metal of welding slag and the length of welding seam after the welding, and measure whether the length and width of the welding seam meet the specifications. Otherwise, they may seriously impact the quality of welding seam.	1. Low automation rate, less diversified product, low capacity, manual switch of products, long delivery cycle, less intelligent production lines and unstable product quality 2. Frequent battery technology iteration causes frequent change in models and difficulty in determining technologies, resulting in increase of packing costs 3. Non-unified downstream lithium-ion battery manufacturing processes and diversified specifications and models of lithium-ion batteries in the market cause difficulty in standardization in the equipment industry.

Source: *Analysis on lithium-ion battery Manufacturing Process Control and Potential Problems, Research on lithium-ion battery Intelligent Manufacturing Equipment Standard System*, Patent retrieval, Da Dong Times Database (TD), EY Analysis

2.5 Key points of lithium-ion battery production

Mixing
- Non-uniform mixing
- Unavailability of online data on particles, impurities, dust and ingredients results in inability to improve quality
- Impurities mixed in the mixing process

Coating
- Hard to control energy consumption
- Unavailability of online data on viscosity, solid content and impurities of incoming slurry
- Full characteristics of output quality: Hard to control the online feedback on dryness, voidage of pole pieces and coating scale

Rolling and slitting
- Inconsistent extension between separator area and foil area
- Roll surface flatness control

Vacuum drying
- Excessive water content
- Efficient humidity control and corresponding quantitative management of battery performance

Cell making
- Online detection of accuracy, burrs and defects.
- Dust and burrs occurred

Assembly
- Machine damage caused by excessive handling
- Online control of assembly process parameters, optimization of manufacturing models
- Damage to cells in transit

Formation
- Effectiveness test
- Energy consumption control

Capacity grading
- Not quite satisfying heat dissipation effect, with high power consumption
- Inaccurate measurement of electric capacity

Stereoscopic warehouse
- Long turnaround time and low efficiency
- Machine damage caused by excessive handling

Module assembly
- Single cell, complicated software logical processing, gluing
- Great difficulty in laser welding, side seam welding and busbar welding, difficulty in testing

Pack
- Low automation rate, less than 50%
- Frequent change and fast iteration in models with uncertain battery technologies
- Lack of standard technologies/ products

Source: *Analysis on lithium-ion battery Manufacturing Process Control and Potential Problems*, Da Dong Times Database (TD), EY Analysis

3.1 Simulation technology in lithium-ion battery production

Comprehensive multi-layer lithium-ion battery simulation solution – Production process

Major steps

Mixing

1. Modeling of mixing tank
2. Three-dimensional simulation on two-phase mixing of solid and liquid for the flow field distribution inside the mixing tank
3. Analysis of the speed of flow field, solid phase volume concentration and other distributions
4. Mixing experiment on cathode slurry of lithium-ion batteries, and explore the impact of different process parameters on viscosity, solid content of the mixed slurry and surface appearance of pole pieces

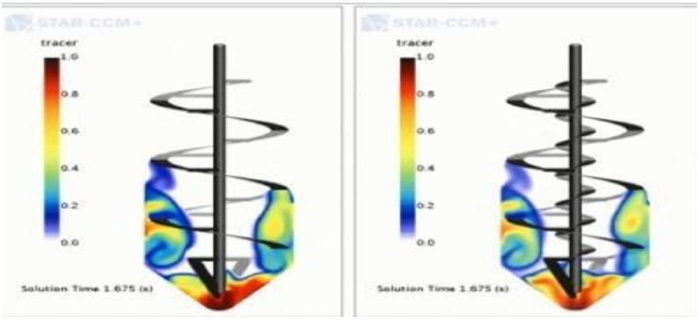
Coating

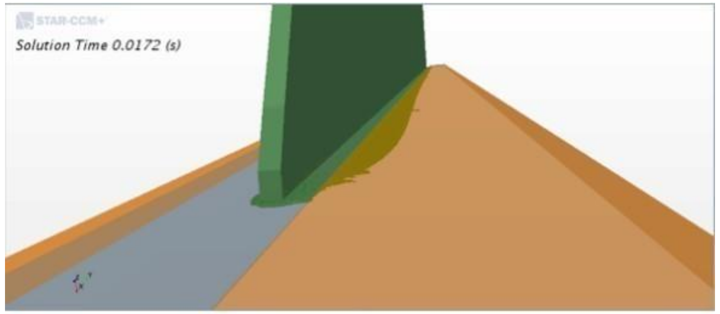
1. Set-up of base material components of coaters and assembly of geometric modeling
2. Set-up of properties of slurry for coating
3. Set-up of analysis division and output results
4. Creation of contact characteristics and referential constraints
5. Mesh splitting
6. Creation of load and boundary conditions
7. Creation of analysis tasks, submitting and post-processing.

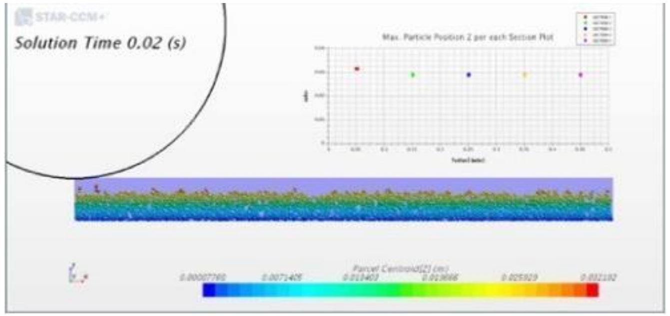
Rolling

1. Modeling of coarsely granulated particle of rolling and coating materials and battery pole pieces from the microscopic to the mesoscopic scale
2. Modeling of coarsely granulated particle based on rolling and coating materials and battery pole pieces according to pre-set rolling parameters
3. Molecular dynamics simulation for rolling of battery pole pieces, obtaining rolling simulation results of battery pole pieces

Application scenarios







Source: Siemens, *Comprehensive Multi-layer lithium-ion battery Simulation Solution*, *Research on Extrusion Coating of Lithium-ion Batteries*, Da Dong Times Database (TD), EY Analysis

3.1 Simulation technology in lithium-ion battery production

Comprehensive multi-layer lithium-ion battery simulation solution – Production process

Major steps

Drying

1. Fully automated drying of lithium-ion batteries based on the motion simulation technology of industrial robots
2. Intelligent feeding by six-axis robots combined with flexible modules before drying lithium batter cells
3. Intelligent monitoring and control of the drying process by the closed-loop temperature control system
4. Intelligent blanking by six-axis robots combined with flexible modules after drying, achieving completely unmanned drying process

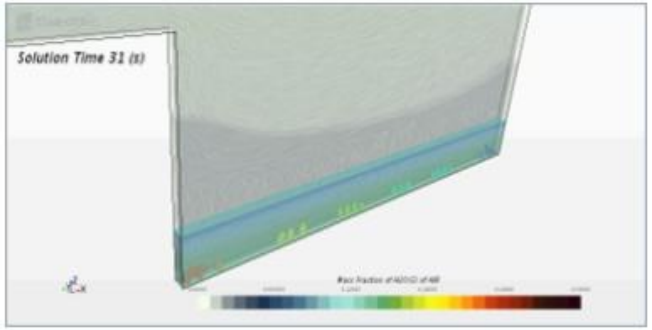
Electrolyte injection

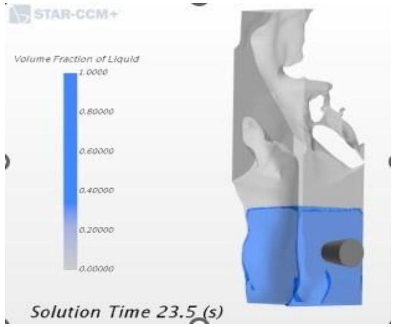
1. Set-up of injection system related parameters
2. Modeling of injection activation system
3. Extraction of fluid domain, mesh split of models with ICEM
4. Simulation of injection activation system

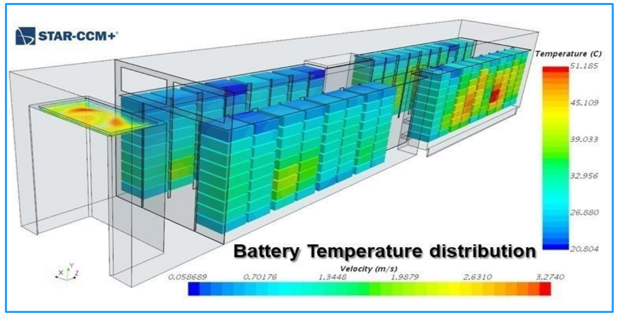
Formation

1. Simulation of formation process
2. Simulation of formation process based on the actual technical requirements for the formation workshop
3. After running the models, export statistical data based on analysis requirements, collect statistics on running status of each equipment (e.g., stackers) to find out bottlenecks in system and improve efficiency of production line

Application scenarios







Source: *Advanced Simulation Technologies Speed Up the Development of Power Batteries of Electric Vehicles*, *Comprehensive Multi-layer lithium-ion battery Simulation Solution*, Patent retrieval, Da Dong Times Database (TD), EY Analysis

3.2 Integration of lithium-ion battery production equipment

Current status

- Coating, rolling and slitting integrated machine
- Rolling and slitting integrated machine
- Laser cutting and winding/stacking integrated machine

Integration of lithium-ion battery production equipment

Coating, rolling and slitting integrated machine

Single sided surface density <±1.2%, double sided surface density <±1.0% , CPK>1.67; resolving 100% of the crack phenomenon on pole piece edge, achieving 24-hour non-stop. It can reduce shrinking and unwinding devices and the input to connection of AGV, reduce labor costs by 70% after employing fewer labors, and reduce space energy consumption by 75%. It can also reduce wears and tears of materials for repeated winding and unwinding by more than 50% at most.

Rolling and slitting integrated machine

Width: 950-1400mm, maximum roll pressure: 500T, roll gap: 0-1.5mm, minimum slitting width: 80mm, accuracy of slitting width: ±0.1mm, maximum rolling and slitting speed: 120m/min, slitting method: All-in-one cut with slitting by circle cutter.

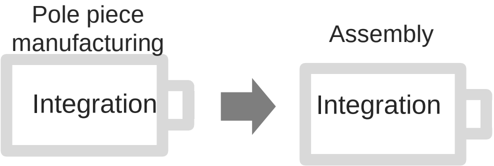
Laser cutting and winding/stacking integrated machine

Capacity≥100m/min, and the accuracy is greatly improved compared with traditional die cutting. 1 set of laser cutting and winding integrated machine= 2 sets of die cutting machine + 1 set of traditional winder, saving space and labor costs and the handling process from die cutting to winding, improving the safety in production.

Future

- Mixing, coating, rolling and slitting integrated machine (pole piece integrated machine)
- Rolling, cutting, laser slitting and winding/stacking integrated machine
- Assembly integrated machine

Simplified lithium-ion battery production process



1. The “blade battery” plan has simplified battery pack structure by reducing the dimension of cells
2. Tesla’s solvent-free dry battery plan has simplified the manufacturing process of cell and electrodes

New trend in technology

1. The series connection formation technology has been maturely applied; there is a trend of controllable formation interface and predictable capacity in future; capacity grading may be cancelled when the uniformity of battery is above CPK2.0
2. The front end process is controllable, and the capacity inspection step can be cancelled
3. Through the lithium refilling technology, cells can be initially charged, and the capacity grading inspection may be cancelled

- In the future, by simplifying the production process, the manufacturing cycle of lithium-ion batteries may be greatly shortened to reduce costs
- The future will embrace a trend and possibility of using mixing, coating, rolling and slitting integrated machine (pole piece integrated machine), rolling, cutting, laser slitting and winding/stacking integrated machine and assembly integrated machine

Source: Website of leading lithium-ion battery production equipment enterprise, *Simplified Processes in the lithium-ion battery Industry – lithium-ion battery Process*, Da Dong Times Database (TD), EY Analysis

3.3 Extensive application of laser technologies in various workshop sections

	Cutting and forming of tabs	Cutting of pole pieces	Cutting of separators
Cutting object	▸ The tab is the metallic conductor drawn from the anode and cathode of the battery, contacting with the outside when charging and discharging	▸ Upon slurry coating, drying and rolling, the pole piece of lithium-ion batteries forms a three-layer composite structure comprised of current collector and coating on both sides	▸ The separator is made of PP/PE film, responsible for blocking the current conduction in the battery in case of short circuit and overheating
Cutting process	▸ Cutting tabs of the anode and cathode out of pole pieces by laser ▸ Inconsistent alignment and dimensions as well as dust and burrs of tabs will cause self discharge or short circuit	▸ Expose the pole pieces of batteries under laser beam to form holes on the pole pieces rapidly. As the beam moves, the holes may be connected to form cutting seam	▸ The coil stocks of separator is cut into coil stocks that meet the requirements of specifications, sizes and quality through the cutting process
Advantage of laser cutting	▸ No consumables, high speed and stable cutting quality ▸ High flexibility in design, applicable to batteries of different types and specifications	▸ Laser cutting has the characteristics of high production efficiency and good process stability	▸ The separator is composed of organic compounds, which will be well cut by laser cutting
Future prospect	▸ The continuous improvement of power battery performance conversely forces intelligent manufacturing upgrade of lithium-ion battery production equipment, which has set higher requirements in photoelectric conversion efficiency and energy conservation and consumption reduction of laser devices.		▸ Overall, the cutting technology of tabs currently is embracing a trend of faster and faster cutting speed, with higher and higher requirements on cutting quality. In addition, the changes in coating material ingredients and density of anode, the sandwich structure of non-metallic materials and other new designs have set higher and higher requirements on cutting process.

Application of laser cutting in power battery field

Source: *Research on Application of High Speed Laser Micromachining on New Energy lithium-ion batteries*, SWS Research, Da Dong Times Database (TD), EY Analysis

3.3 Extensive application of laser technologies in various workshop sections

Application of laser welding in the industry of auto lithium-ion batteries with aluminum cans

- Material of welding position
  - Aluminum alloy
    - **Function:** Light, good toughness and high strength. Using aluminum alloy can improve its processing speed and significantly reduce heat input to improve the production efficiency and welding quality.
    - **Application:** Achieved by pulse or continuous laser beam.
  - Red copper
    - **Function:** Excellent plasticity, electrical conductivity, thermal conductivity, corrosion resistance and good process performance.
    - **Application:** Welding for red copper mainly includes brazing, gas welding, manual arc welding and TIG welding.
- Shape of batteries
  - Square
    - Welding position
      - Burst vent
      - Post
      - Flexible connection
      - Can sealing
      - Filling port
      - Module
- Welding method
  - Butt welding
  - Stitch welding

Source: *Research on Application of High Speed Laser Micromachining on New Energy lithium-ion batteries*, SWS Research, Da Dong Times Database (TD), EY Analysis

3.3 Extensive application of laser technologies in various workshop sections

Laser equipment is mainly used in pole piece making in the front section, welding in the middle section and module packing in the back section

Working procedure	Step	Equipment
1st working procedure (Pole piece manufacturing)	Slurry mixing	Blender
	Pole piece coating	Coater
	Pole piece rolling	Rolling machine
	Pole piece cutting	Slitting machine
	Pole piece making	Full-automatic tab welding and pole piece making machine, laser-based tab forming and pole piece making machine
2nd working procedure (Cell assembly)	Burst vent welding	Continuous laser welding, hybrid welding
	Winding/stacking	Winder, stacking machine
	Transition piece welding	Laser welding machine for transition pieces
	Assemble cell into the can	Pre-welding machine for being assembled into cans
	Can-cap welding	Cap welding machine (full-length welding)
	Electrolyte injection	Electrolyte injection machine
	Formation	Formation system
	Injection hole sealing	Sealing nail welding machine
3rd working procedure (Post-processing)	Capacity grading	Grading system
	Testing & grading	Battery testing equipment and grading machine
	Module packing	Transition piece welding machine (post welding)

Current status

Future applications

- Three-dimensional galvanometer flight welding
- Side welding of cap
- Cleaning of thinning zone of cathode

Source: *Research on Application of High Speed Laser Micromachining on New Energy lithium-ion batteries,* SWS Research, Da Dong Times Database (TD), EY Analysis

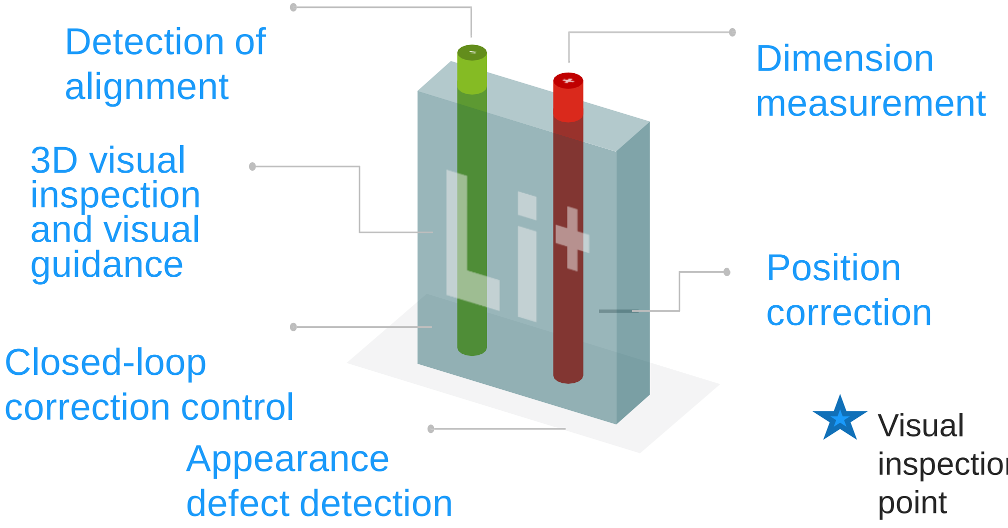
3.4 Extensive application of vision technologies in various workshop sections

Current status

Pole piece making: Mixing → Coating ★ → Rolling ★ → Cutting ★ → Metal cutting / Laser cutting ■

Cell making: Stacking / Winding ■ → Can welding → Drying → Electrolyte injection → Sealing and cleaning

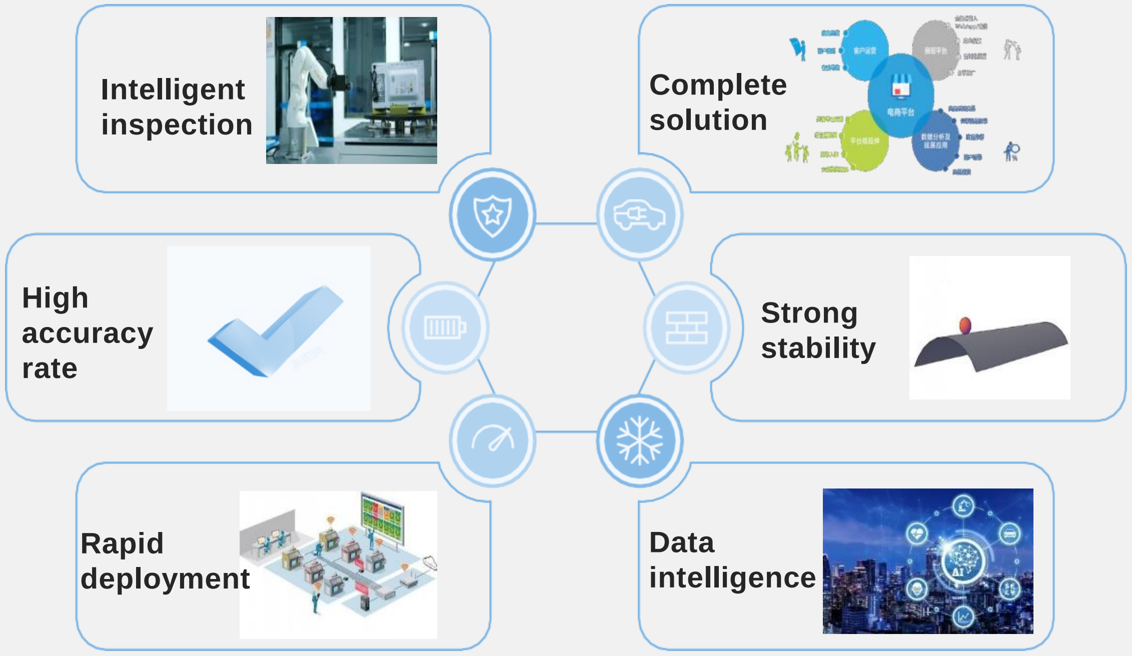
Assembly: Post-processing (formation, capacity grading test, etc.) → Module packing ★



★ Visual inspection point

Future

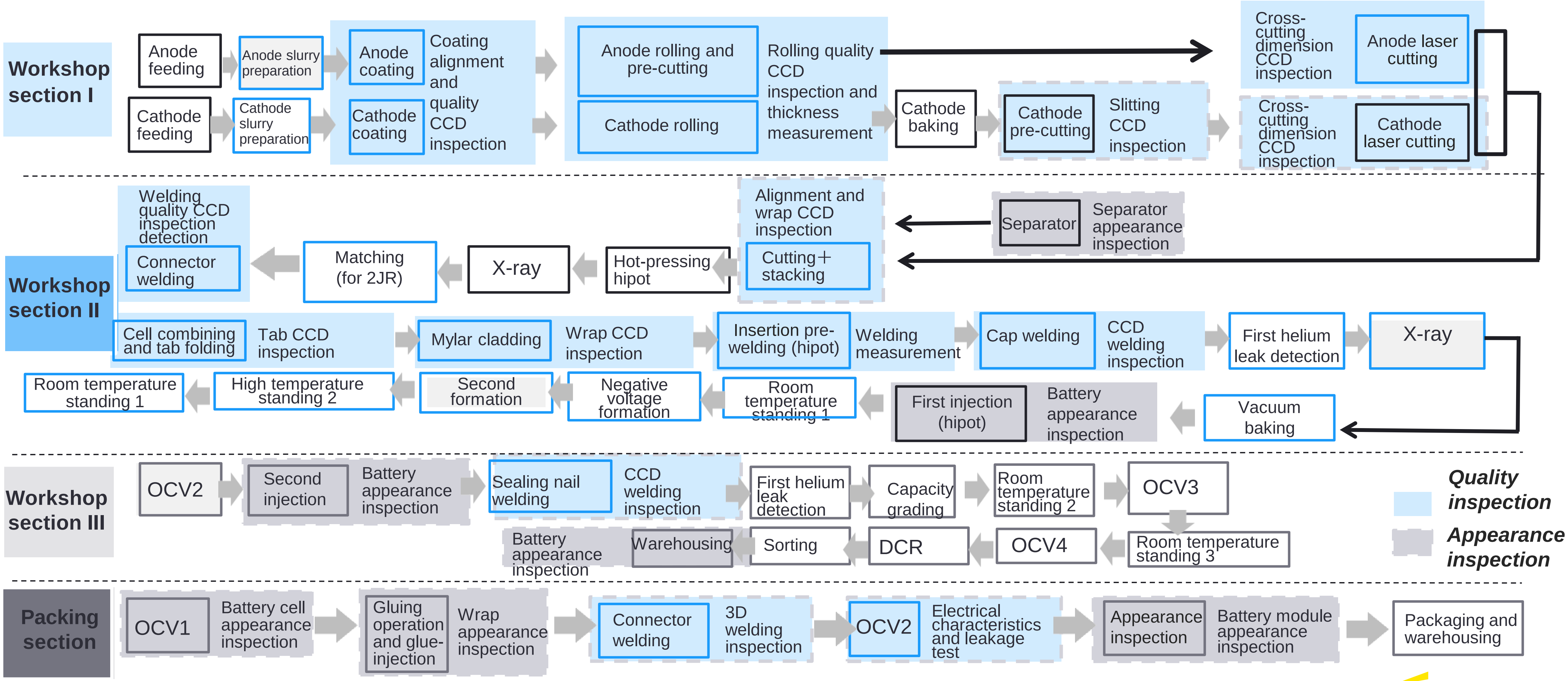
Visual inspection solution of whole production line for coating, rolling, cutting, metal die cutting/laser cutting, stacking/winding, can welding, packing and other parts



Source: ZVIT, Da Dong Times Database (TD), EY Analysis

3.4 Extensive application of vision technologies in various workshop sections

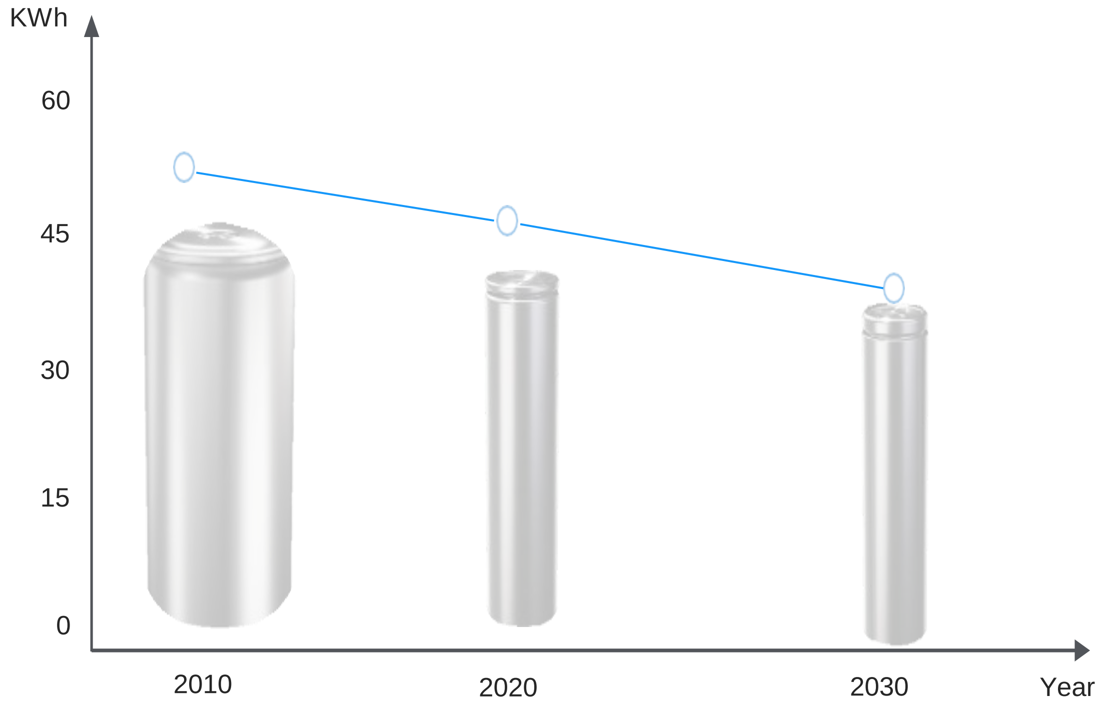
Future: 3D+AI Visual + AMR (Autonomous Mobile Robot)



Source: ZVIT, Da Dong Times Database (TD), EY Analysis

3.5 Application of environmental protection and energy saving

Current status: Energy consumption trend for production of 1Wh lithium-ion battery in 2010-2030: steady decline



Estimated trend of lithium-ion battery energy consumption: the energy consumption required to produce 1KWh lithium-ion battery will drop steadily from 50KWh in 2010 to less than 30kWh in 2030. With the application of energy-saving technology, the energy consumption required for future lithium-ion battery production will be significantly reduced.

Future energy-saving technologies

Production tends to be low pollution and low energy consumption

Mixing and coating stage

1. The solid content ratio is increased in the mixing stage, while waste heat utilization, circulating air supply and dry electrode technology are used in the coating stage.

The battery slurry contains binders and solvents, which are toxic to a certain extent. Improper control will cause pollution.
The coater generates high-temperature NMP waste gas, so the mixing and coating stages are major pollution steps in lithium-ion battery production. In the future, process improvements will be made in these two stages to achieve low pollution and low energy consumption.

Desiccant air-conditioning system

2. In the future, the development direction of single-rotor low-dew-point desiccant air conditioners will iteratively progress from two aspects: the optimization of refrigeration systems and the innovation of new dehumidification rotors in dehumidification materials.

The desiccant air-conditioning system for lithium-ion battery production will be updated along with the large-scale production of lithium-ion batteries, which will bring about a series of industrial changes and industrial upgrading.

High-frequency PWM bidirectional switching power supply mode

3. High frequency switching power works at high frequency, and the switching frequency is generally controlled within the range of 50-100kHz to achieve high efficiency

With high-frequency PWM bidirectional switching power supply mode, the battery discharge energy will be fed back to the power grid. The automatic detection power supply of grid-fed battery formation and grading, charging and discharging was successfully developed at the earliest in China.

Source: *Discussion on Energy Saving and Emission Reduction Application of Iron Lithium Ion Batteries*, *Research on Integrated Control Technology for Low Energy Consumption and Low Pollution Production of Lithium-ion Power Batteries*, Da Dong Times Database (TD), EY Analysis

3.6 High-speed production

Efficiency comparison of each production link

Production link	Efficiency	
	Current status	Future (within five years)
Slurry preparation	Annual production capacity of 6-9GWh/one production line for each positive and negative electrodes Solid content: 80% Time-consuming: 0.5-1.5H	Annual production capacity of 8-10GWh/one production line for each positive and negative electrodes Solid content: 85% Time-consuming: 0.4-1.2H
Coating	Bottom coating speed: 200-300m/min Effective coating width: 700mm-900mm-1200mm	Bottom coating speed: 220-350m/min Effective coating width: 800mm-1000mm-1400mm
Rolling	Speed: 100m/min Roller heat difference: ±1.5℃	Speed: 120m/min Roller heat difference: ±1.2℃
Winding	Speed: 3-3.5m/s	Speed: 3.5-4m/s
Baking	Baking time: 60min	Baking time: 30min
Capacity grading formation	Heating speed: 35 min (25℃-90℃, first cold start) Voltage accuracy: 0.5%F.S.	Heating speed: 30 min (25℃-90℃, first cold start) Voltage accuracy: 0.3%F.S.

High-speed production of lithium-ion battery **will be the future development trend**

The global lithium-ion battery industry is undergoing disruptive changes. The upgrade of power battery performance and quality competition accelerates the iteration of new equipment and new process.

In the slurry preparation process, the cyclic high-efficiency slurry preparation process and the twin-screw slurry preparation process have started to replace the traditional double-planetary slurry preparation process. The new-generation slurry preparation process both greatly improves the slurry preparation efficiency and solves the problems of unstable slurry preparation, high energy consumption, pollution, large area and other problems in the traditional slurry preparation system.

In the coating process, the double-sided coating and double-sided simultaneous drying process are also gradually replacing the traditional fold-back double-layer coater structure design. The advantage of the former is that it can significantly improve battery cycling, capacity, self discharge, internal resistance and other performance, improve drying quality, save equipment costs and operating costs and save installation space.

In the rolling procedure, the rolling and cutting integrated machine has both the functions of rolling and cutting of battery pole piece, which is replacing the traditional production method that the original rolling and cutting procedures are completed by two independent equipment. On the basis of high precision and high consistency in rolling and cutting of battery pole pieces, the production efficiency of battery pole pieces is significantly improved.

In the winding procedure, the winding machine process is evolving toward more efficient, compatible with a wide range of cell sizes, and higher precision. The application fields of laser die-cutting and winding integrated machine are also expanding.

In the process of cell baking, contact-type top-speed and high-vacuum baking equipment has also begun to be increasingly favored by battery companies. Its advantages are that it can greatly shorten the baking time, improve baking efficiency and reduce production energy consumption.

In the formation and capacity grading procedure, the new technology of high-voltage series formation and capacity grading also emerged. Using this technology, multiple batteries can be connected in series, using one current channel to detect multiple batteries. Compared with parallel devices, it can improve the consistency of formation or capacity grading products and significantly improve energy efficiency.

Source: Official websites of lithium-ion battery production equipment enterprises, Shenwan Hongyuan--*lithium-ion battery Equipment Industry Tracking Comment*, Da Dong Times Database (TD), EY Analysis

3.7 Application of sensor technology

- Blue: Used in the whole line of lithium-ion battery process
- Grey: Used in the lithium-ion battery process section

Material handling

Temperature sensor: Temperature control for battery production in material handling.

Humidity sensor: The ambient humidity must be controlled within a certain range to ensure their normal operation and improve work efficiency and reliability.

Mixing

Coating

Displacement sensor: Coating thickness is calculated immediately after rapid coating. Adjustments can be made prior to the drying process to minimize rejects.

Trough-type sensor: The motion mechanism of the equipment is complex, and the trough-type sensors with various appearances such as F/T/R/L/K are widely used in multiple stations of the equipment for position control such as positioning and position limit of the motion mechanism module.

Rolling and slitting

Color mark sensor: The tabs or pre-set color marks are accurately detected by the color mark sensor, so that the pole pieces can be cut or counted accurately.

Welding

Temperature sensor: Through the temperature sensor, the cooling start temperature point, power limit temperature point, output stop temperature point and the extreme thermal event temperature point circuit of the lithium-ion power battery are obtained.

Winding

Fiber optical sensor: In the pole piece and separator, the fiber optical sensor detects whether the pole piece is normally fed; the corresponding cylindrical, regional matrix, flat bracket and other types of optical fibers can be matched according to the on-site installation conditions and mechanical operation requirements to formulate application plans.

Photoelectric sensor: After the positive and negative electrode materials and the separator are wound into a small cell unit, tape should be attached to prevent the cell from loosening or offset, and the square photoelectricity detects that the cell coil stock is in place, so as to send a signal for the next step of gluing.

Vacuum drying – **Cell making** – **Formation and capacity grading**

Deviation sensor

Temperature sensor

Humidity sensor

Module and pack

Magnetic sensor: Applied to the upper limit of the cylinder module. The magnetic sensor detects the position of the cylinder, so as to control its position.

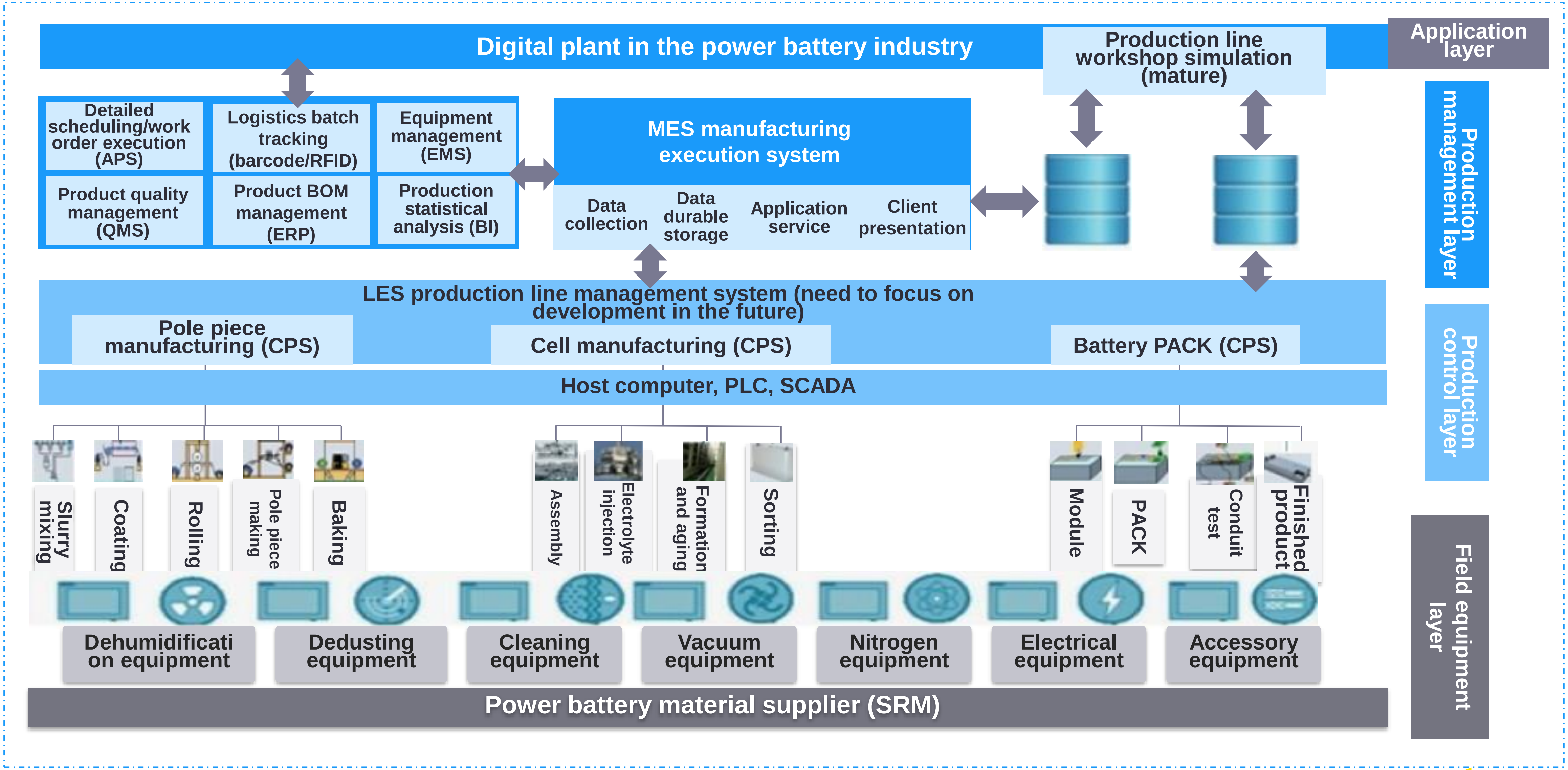
Stereoscopic warehouse

Deviation sensor: Deviation sensor detects the process of pole piece feeding, and feeds the result of the detection position back to the deviation controller for timely deviation, which has extremely high requirements on the stability and accuracy of the sensor.

PID photoionization sensor: An instrument for the detection of organic volatile components, which is used for detecting trace VOC volatilization.

Source: Stock Analysis Report, official website of lithium-ion battery production equipment, Da Dong Times Database (TD), EY Analysis

3.8 Digitalization of the whole process of production



Source: *Blueprint for Digital Workshop of Power Battery*, Da Dong Times Database (TD), EY Analysis

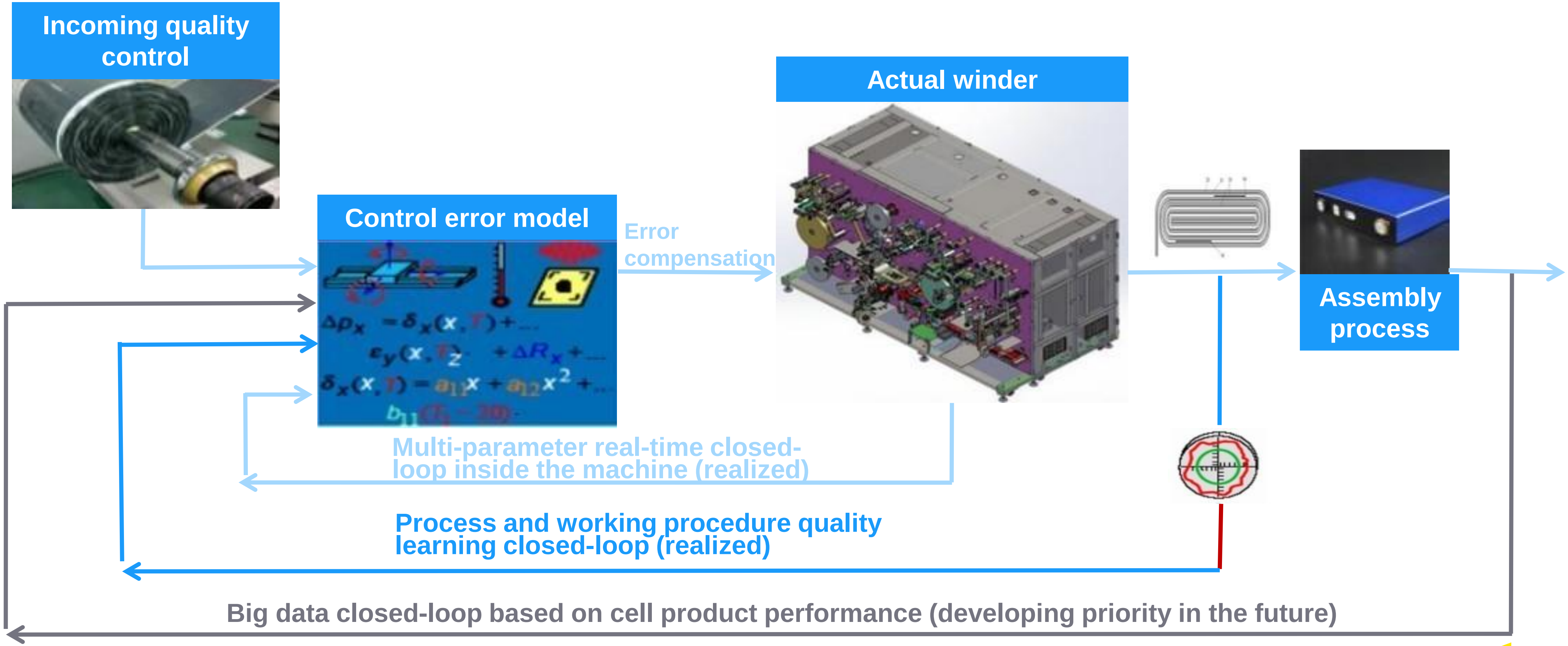
3.8 Digitalization of the whole process of production

Unmanned plant level for lithium-ion battery production	L0	L1	L2 (realized)	L3 (Breakthrough within three years)	L4 (Breakthrough within 10 years)）
	Planning-level single machine automation	**Specification-level working procedure automation**	**Integration-level information integration**	**Optimization-level manufacturing intelligence**	**Leading-level dark plant**
Information transfer (PDM)	Manual input of fixed program	Material delivery information program modularity	**One-click release control verbalization**	One-click release program self-adapting	One-click release transparent plant
Machine operation	Machine monitoring by manual operation	Manual machine start	**Centralized control of unit regulatory operation**	Centralized control of unit autonomous operation	One button start for standby mode
Quality monitoring	Manual quality monitoring	Automatic quality detection	**Automatic judge of quality**	Full quality closed-loop	Quality exemption
Equipment operation and maintenance	Breakdown maintenance	Predictive maintenance	**Health management**	Machine learning operation and maintenance	Healthy operation and maintenance
Manufacturing safety control	Manual quality monitoring	Safely self-diagnosis	**Security monitoring**	Security early warning closed loop	Full safety closed-loop
Material handling	Manual loading and unloading of materials Manual handling of auxiliary materials Manual handling of waste materials	Automatic material handling Manual handling of auxiliary materials Waste collected by a single machine	**Material with information flow** **Manual recovery of auxiliary materials** **Centralized disposal of waste**	Manual recovery of auxiliary materials Automatic waste handling	In-and-out of material dark box

Source: *Blueprint for Digital Workshop of Power Battery*, Da Dong Times Database (TD), EY Analysis

3.9 Application of AI data analysis

Providing machine optical optimization, mechanical precision optimization and comprehensive correction schemes in the equipment development process by calculating and simulating the laws of material, pole piece deformation, tension, friction and damping in the process of machine production, **so as to improve the manufacturing qualification rate and production efficiency.**



Source: *Blueprint for Digital Workshop of Power Battery*, Da Dong Times Database (TD), EY Analysis

3.9 Application of AI data analysis

The closed-loop idea of lithium-ion battery manufacturing industry - data, learning, modeling, closed-loop and optimization

Equipment, materials and systems are interconnected, with more than 3,500 quality data monitoring points (developing priority in the future)

Two-way traceability system based on QR code ID (Barcode) (realized)

IQC
- Dimension
- Composition
- Impurities
- Particle
- Particle size of material

Pole piece manufacturing
- Viscosity
- Solid content
- Thickness
- Dimension
- Humidity

- Thickness
- Dimension
- Humidity

Cell manufacturing
- Tension
- Alignment
- J/R dimension
- Humidity
- Joint strength

- Current
- Voltage
- Capacity
- Internal resistance
- Temperature

Battery pack
- Dimension
- Current
- Voltage
- Internal resistance
- Self discharge

OQC
- Voltage
- Internal resistance
- Discharge
- Reliability
- Safety

Pole piece FMEA

Cell FMEA

Battery pack FMEA

Big data analysis and closed-loop of battery manufacturing

Source: *Blueprint for Digital Workshop of Power Battery*, Da Dong Times Database (TD), EY Analysis

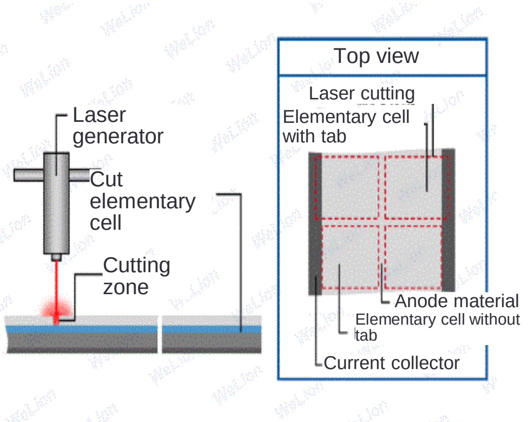
3.10 Polymer solid state/semi-solid state battery process

Polymer solid-state battery preparation process: Germany RWTH PEM preparation process

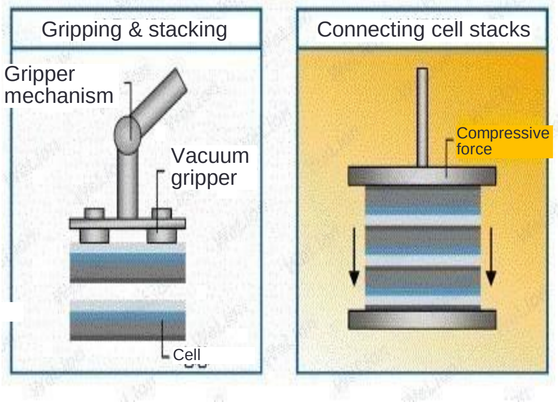
Production flow chart

- Assembly process: Cutting → Stacking → Contacting & packaging
- Formation process: Formation → Aging → Testing & grading
- Sealed cell

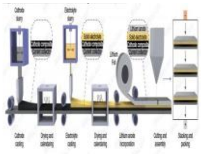
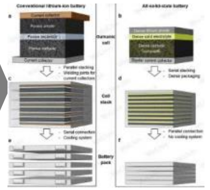
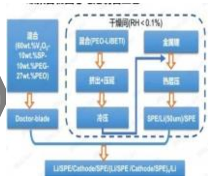
Cutting process of electrode-laser cutting



Connection process of single cell-extrusion molding



Preparation process of solid-state lithium-ion battery

Preparation method		Preparation characteristics	Process differences with liquid battery
Traditional coating process		✓ Make solid electrolyte interlayer by coating ✓ The electrode is prepared in a similar way to existing liquid batteries and is compatible with existing production lines	‣ The difference is small ‣ The main difference is the preparation of the electrolyte interlayer
Bipolar battery process		✓ The elementary cells composed of multi-layer positive electrode-electrolyte-negative electrode are stacked and connected in series to manufacture a high-voltage single battery pack	‣ Higher requirements for stacking and series connection process
Ah-grade preparation process		✓ It is required to control the material mixing ratio and the dryness of the preparation, and the requirements for the drying room are high	‣ Differences between mixed material systems and drying methods
Preparation process of Bollore extrusion method		✓ The extruded solid electrolyte is directly hot-pressed on the surface of the anode ✓ Single battery packs are prepared by winding method and assembled into modules	‣ The voltage, temperature and speed of extruder need to be strictly controlled ‣ Parameters (e.g., particle size of the feed) need to be strictly screened

Future development trends of semi-solid/solid-state batteries: dry electrode technique, hot metal cladding technique, intelligent manufacturing

Source: *Analysis of the Preparation Process of Solid-state lithium-ion batteries*, Sealand Securities, Da Dong Times Database (TD), EY Analysis

By virtue of unique professional capabilities related to lithium-ion battery technology and production process, we provide enterprises with integrated consulting services

EY provides "traditional consulting + business/organization empowerment + resource integration/importing + investment"

Traditional consulting	VS	EY Consulting services
Only providing standardized consulting services without participating in the subsequent implementation stage results in a disconnect between planning and implementation		By virtue of the strong internal service system and resources, EY provides you with one-stop services accompanying customers in every step of their growth

EY Parthenon

Market insight

Conduct in-depth analysis and research on the **macro environment, industry trends, customers and competitors,** among others, and analyze and summarize factors that may affect **business models, business layout, market access**, etc., to conduct **feasibility studies** and provide **solutions** for customers' **investment in the lithium-ion battery industry**

Production and capacity expansion service

From a technical point of view, assist customers in the **diagnosis and optimization of** lithium-ion battery **materials and design systems, plant site selection and construction planning,** and provide a series of planning and management services required for **plant operation**, and comprehensively help customers **make production and capacity expansion decisions and production process optimization**

Mergers and acquisitions consulting

Considering the strategic development needs of customers, we provide customers with one-stop services from the initial **M&A strategy** development to **target selection,** providing **financial advisory services, transaction execution**, and **M&A integration services** after the transaction is completed, to ensure that M&A integration **achieves the expected value**

Human resource planning

Design blueprints for enterprise talent development planning through **talent status review, demand analysis, gap identification**, etc., and conduct **training activities** such as giving lectures and conducting field investigations on talent training to assist enterprises to complete **the construction of talent team**, as well as meet the needs of enterprise strategic development

Remarks: The "one-stop service" here focuses on integrated services centered on production line investment, and the marketing and supply chain services around lithium-ion batteries can be added in a timely manner according to customer needs

Production and capacity expansion services, especially the unique services of EY Consulting, provide seven dimensions of technical services

Technical services

Diagnosis and optimization	Site selection for new plant	Construction of new plant	Warehousing logistics planning	Production process planning	Materials and equipment supply	Project management
Design and optimization of material systems	Determine a long list of sites	Determine the layout & design guidelines of the whole plant and workshops	System simplification	Prospective design of the process	Supply market analysis	Project time management
Failure analysis	Establish screening criteria and evaluation system	Determine the general plan of the whole plant and workshops	Separation of logistics and information flow	Process simulation	Find out potential suppliers	Project cost management
BMS design analysis	Perform detailed analysis on the shortlist of sites	Determine the detailed plan of the whole plant and workshops	Flexible design	Standard operating procedure (SOP) design	Supplier survey and evaluation	Project quality management
		Prepare construction plans, conduct construction and installation	Cost-benefit balance		Business negotiation support	Human resource management
						Project risk management

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- Professional background
  - Ms. Zhao has nearly 20 years of management consulting experience
  - Ms. Zhao has been deeply committed to the fields of strategic planning, operations and investment, focusing on providing domestic and foreign enterprises with consulting services in industry research, market access, investment strategy, growth strategy, business due diligence, mergers and acquisitions integration, among others
  - Ms. Zhao specializes in providing one-stop consulting services for new energy, high-end manufacturing and other customers
  - Ms. Zhao has rich experience in serving large listed private enterprises and large state-owned enterprises, and has provided consulting services for many well-known foreign enterprises
  - Ms. Zhao has led and been engaged in dozens of major projects, which have been well received by customers
  - Before joining EY, Ms. Zhao worked for a global risk management consulting firm and a leading domestic accounting firm
- Education background
  - Master's degree from Central University of Finance and Economics
  - Bachelor's degree from University of International Business and Economics

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