Fabbricazione di batterie per il settore trasporti: analisi di un processo manifatturiero in uno stabilimento industriale italiano

a cura di Carlo Novarese - FAAM

Success
It's not always what you see

Agenda

- Introduction:
    - The Lithium-ion cell market
- Production Environment and Safety
- Li-ion cell production process (pouch cell):
    - Electrode preparation
    - Cell Assembly
    - Cell Formation and Ageing
- Conclusions and Q&A

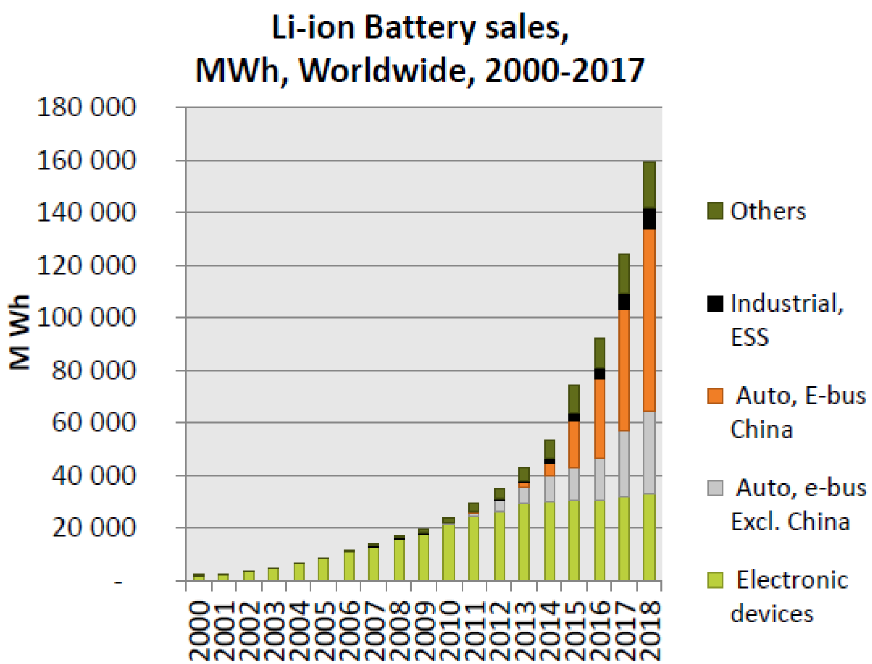
Introduzione:
Il mercato delle celle
litio-ione

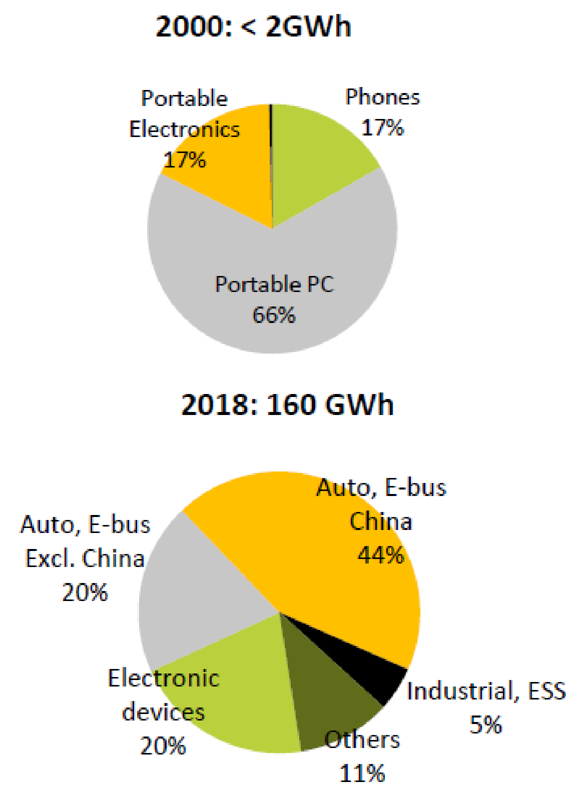
A huge fast growing market

LI-ION IN 2018 - MAIN APPLICATIONS

>160 000 MWh - 31 B$ (1)

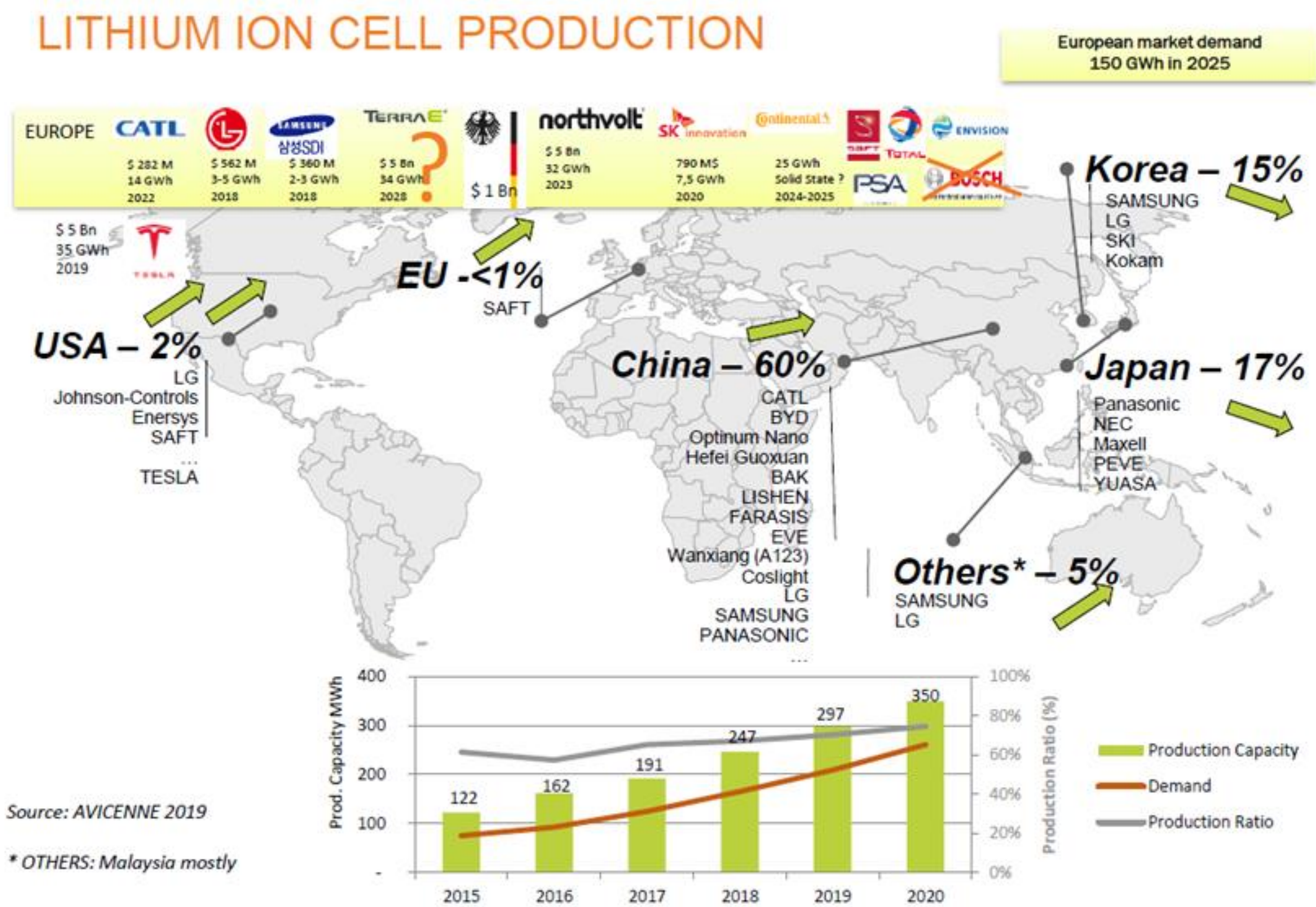
CAGR 2008/2018
+24 % per year in Volume



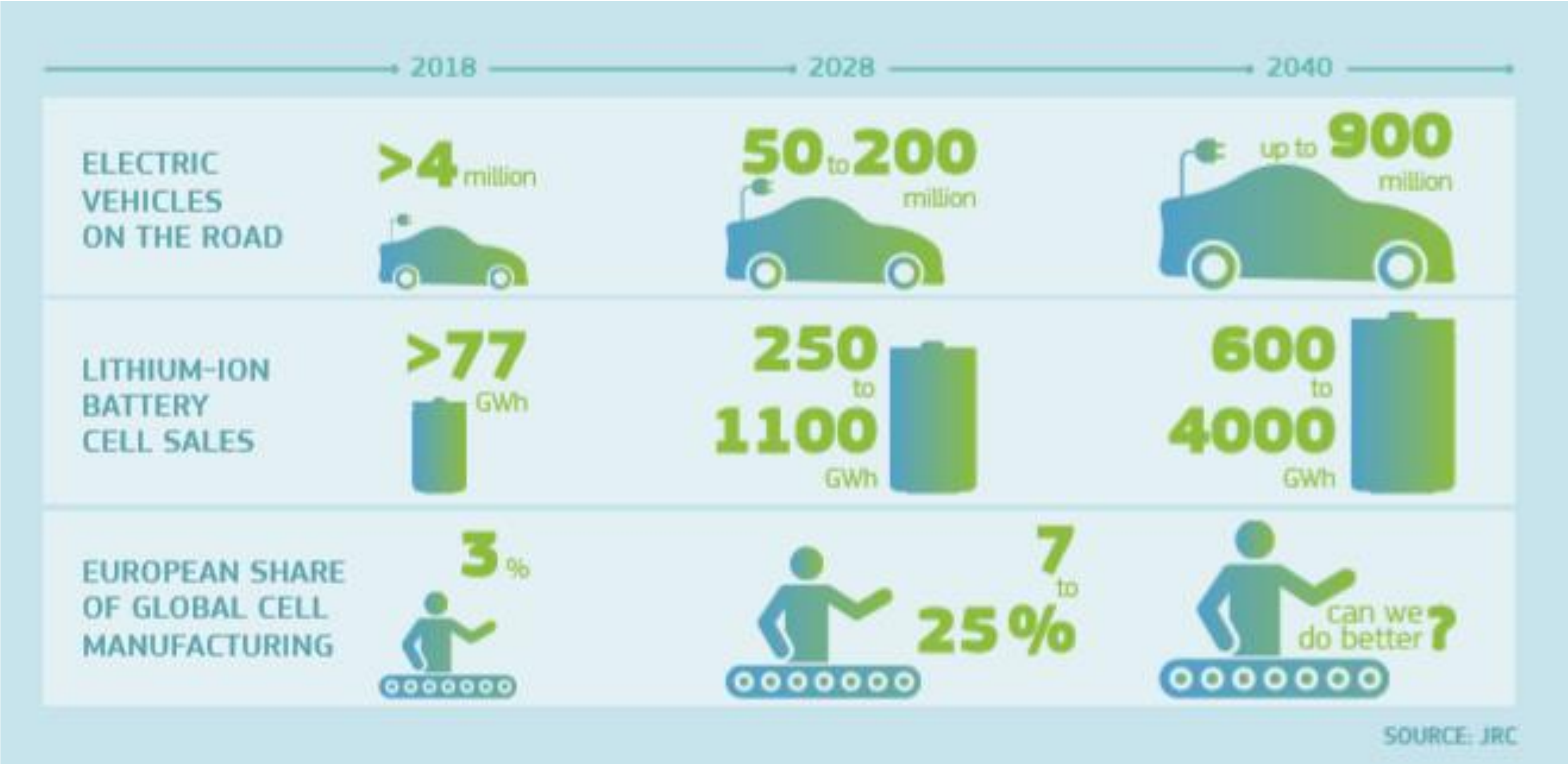


(1) Cell level
Others: medical devices, power tools, gardening tools, e-bikes…
Source: AVICENNE Energy 2019

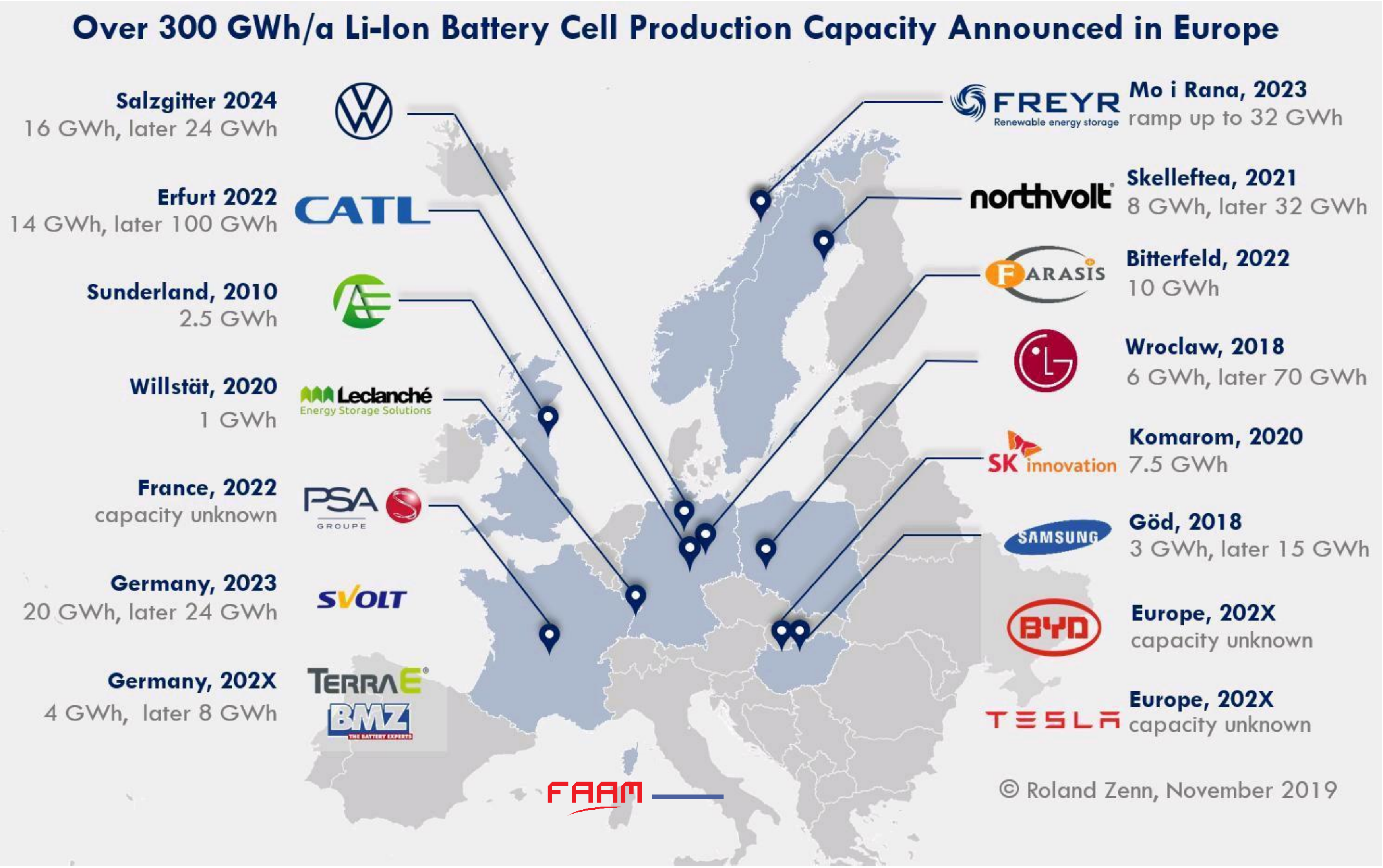
Far-east producers market leaders



Future expansion driven by the automotive industry

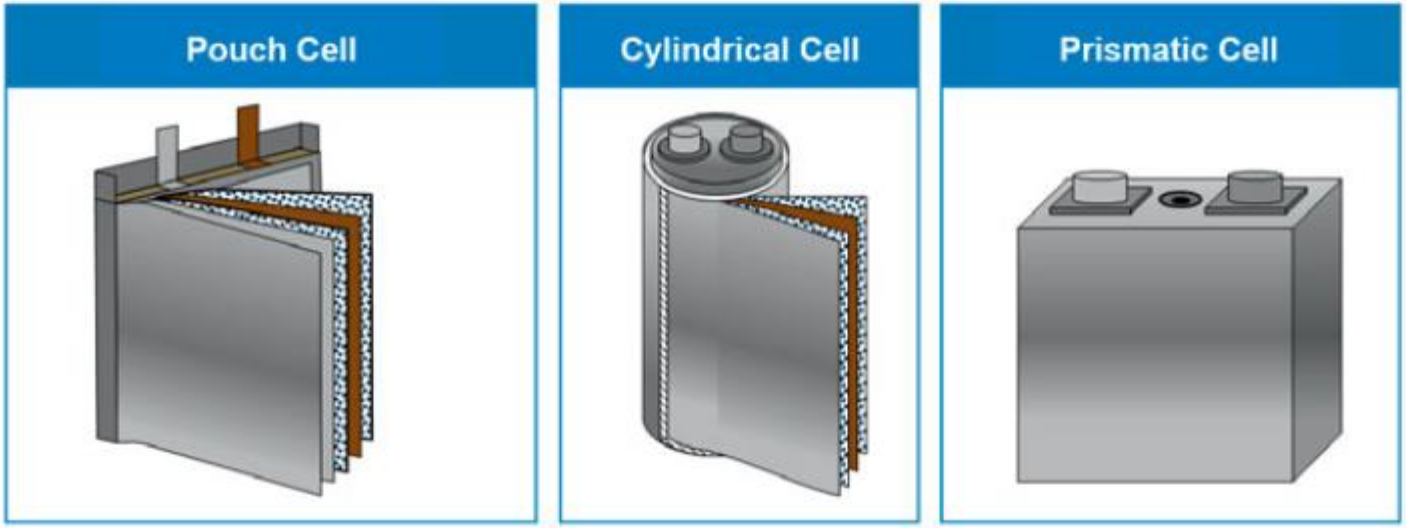


EU production plants announced



Li-ion cell production process

Li-ion cell formats



Overview of cell formats

Source: PEM, RWTH Aachen University

- There are three main li-ion cell formats: **pouch**, **cylindrical** and **prismatic**
- All these cell formats undergo similar process step in production: **electrode** production, cell **assembly** and **formation/ageing**
- However, certain parts of the assembly process have to be tailored on the cell formats (i.e. winding is used in the cylindrical cell opposed to stacking in the pouch cell)

Li-ion cell formats pros and cons

Category	Pouch Cell	Cylindrical Cell	Prismatic Cell
Volumetric energy density on cell level	Currently highest energy density with cylindrical cell	Currently highest energy density with pouch cell	Currently lowest energy density of the three cell formats
Volumetric energy density on module level	High energy density similar to cylindrical cell	High energy density similar to pouch cell	Currently lowest energy density of the three cell formats
Lifetime	Good	Good	Good
Housing	Aluminium compound foil	Mainly nickel-plated steel	Mainly aluminium
Dimensions	▪ Variable Design ▪ Efficient use of space ▪ High packing density	▪ Less flexibility to the pouch cell ▪ Inefficient use of space ▪ Low packing density	▪ Less flexibility to the pouch cell ▪ Efficient use of installations ▪ High packing density
Strength	▪ Unstable housing ▪ Expands during pressure build-up	▪ High tightness ▪ High stiffness ▪ Mechanically robust ▪ Withstands a certain internal pressure without deformation	▪ High tightness ▪ High stiffness ▪ Lower mechanical stability than the round cell
Thermal regulation	▪ Good surface to volume ratio ▪ Efficient temperature control	▪ High-energy cells: low heat dissipation	▪ Lots of volume compared to the surface

Comparison of cell formats

Source: PEM, RWTH Aachen University

Key processes

1) Electrode Manufacture

Electrode manufacturing equal for all cell formats

Mixing → Coating → Drying → Calandering → Slitting

2) Cell Assembly

Separation → Winding → Jelly Roll Isolation → Cell Top Assembly → Tab & Collector Welding → Insertion

Mounting Cell Top → Cell Closing / (Laser welding) → Electrolyte Filling & Sealing → Internal transport

Notching → Folding → Tab & Collector Welding → Assembly → Electrolyte Filling & Sealing → Internal Transport

3) Formation & Aging

Formation & Aging similar for pouch and prismatic cells

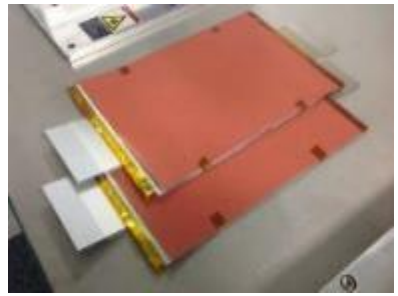
Voltage Measure → Formation → High temp. Aging → Aging → EOL-Test → Sorting & Packaging

Formation & Aging similar for pouch and prismatic cells

Voltage Measure → Formation → High temp. Aging → Degassing & Closing → Edge Folding → Aging → EOL-Test → Sorting & Packaging

Source: P3, UBS Evidence Lab

Li-ion cell (pouch) main components

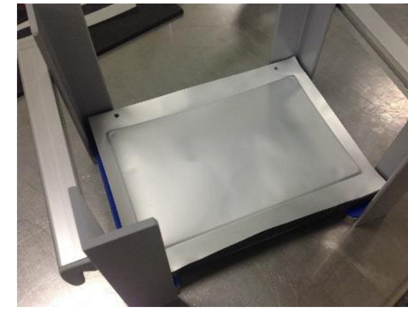


Stack

+

Electrolyte

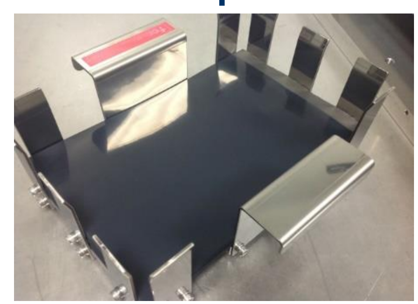
+



Pouch

Anode

Separator



Cathode

Working ambientes

- From the raw material warehouse to the final product one, all working ambientes have to be temperature and humidity controlled, air cleanliness too
- Ambientes could be classified depending on the air cleanliness (ISO classification, clean room) →
- Also, ambientes could be defined by the humidity control expressed in T of Dew Point
- The term grey room is used for spatially separate areas whose air purity is better than that of the surrounding spaces, but which do not necessarily offer clean room quality

Classification of air cleanliness by particle concentration

ISO classification number (N)	Maximum value of the admissible concentration (particles/m³) equal to or greater than the examined quantities listed in the following [a]					
	0.1 µm	0.2 µm	0.3 µm	0.5 µm	1 µm	5 µm
1	10 [b]	[d]	[d]	[d]	[d]	[e]
2	100	24 [b]	10 [b]	[d]	[d]	[e]
3	1 000	237	102	35 [b]	[d]	[e]
4	10 000	2 370	1 020	352	83 [b]	[e]
5	100 000	23 700	10 200	3 520	832	[d, e, f]
6	1 000 000	237 000	120 000	35 200	8 320	293
7	[c]	[c]	[c]	352 000	83 200	2 930
8	[c]	[c]	[c]	3 520 000	832 000	29 300
9 [g]	[c]	[c]	[c]	35 200 000	8 320 000	293 000

a All of the particle concentrations listed in the table are cumulative frequency-related, e.g., the 10 200 particles with 0.3 µm include for ISO class 5 all particles which are equal or greater than this particle size.

b These particle concentrations result for the classification in large air sample volumes. The procedure for sequential sampling may be used, see appendix D.

c Due to a very high particle concentration, information regarding the concentration limits is not appropriate in this section of the table.

d Sampling and statistical limitations for particles in low concentrations are not suited for classification.

e Limitations of collected samplings both for particles in low concentration and for particles larger than 1 µm are not suited for classification due to possible particle losses in the sampling process.

f In order to determine this particle size in connection with ISO class 5, the M descriptor may be adjusted for macro particles and used together with at least one other particle size. (see C.7.)

g This class can only be applied to the "production" operating state.

Warehouses

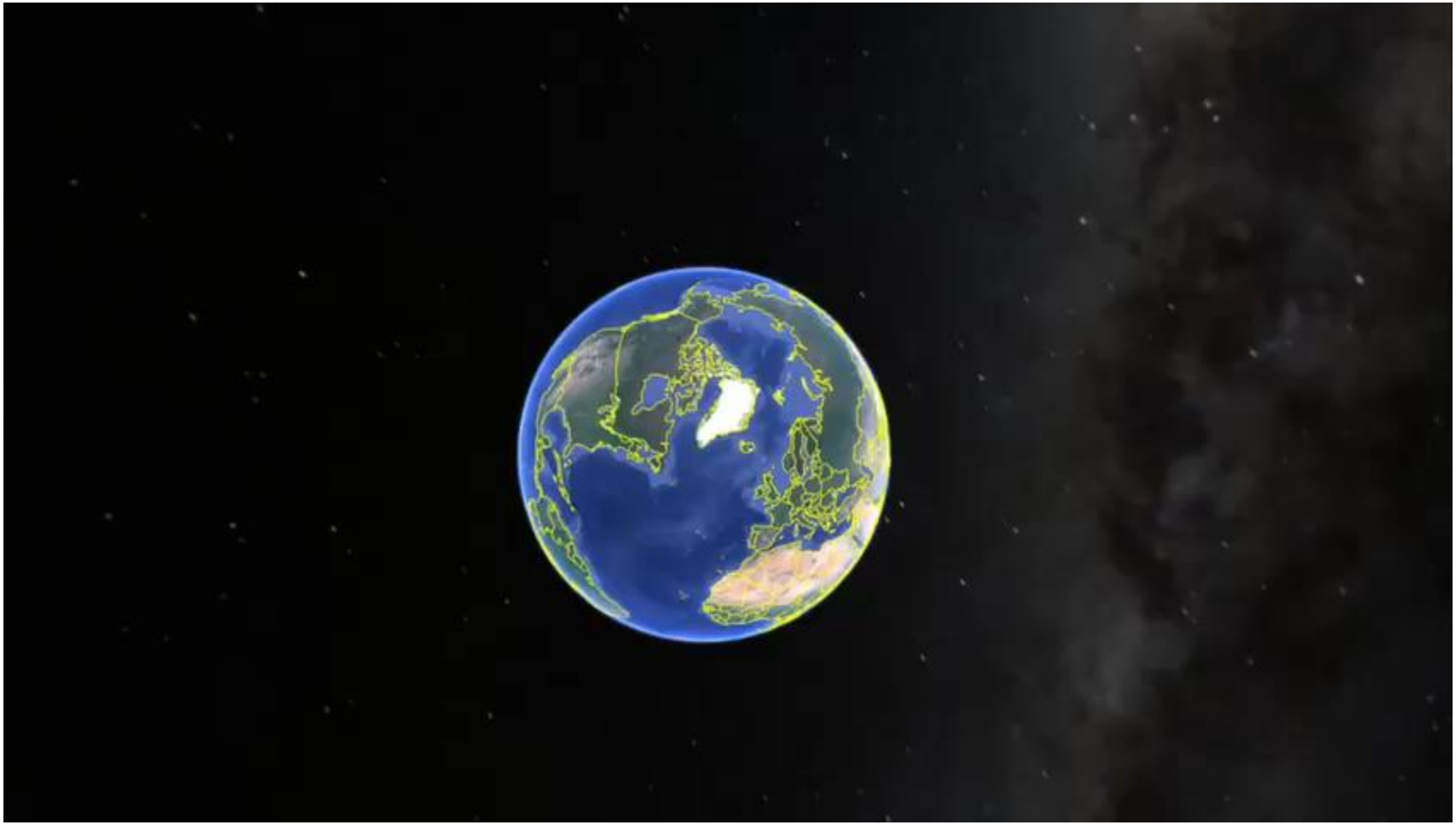
- Incoming raw materials have to be stored properly and safely in a specific designed warehouse

- Raw material warehouses is generally a grey room where temperature and humidity are controlled: several materials are sensible to ambient conditions and their shelf life could be severely affected

- Electrolyte and solvent have to be stored separately as they are highly flammable

- Final product warehouse is also temperature and humidity controlled: li-ion cell calendar life is affected by ambient conditions

How does a production line looks like



Electrode Manufacturing

Electrode manufacturing

- Four main processes:

  - Mixing
  - Coating & Drying
  - Calendaring
  - Slitting

- Electrodes are produced starting from powders (active materials, binders, etc) and current collectors (typically, thin aluminum and copper foils)




- Li-metal electrodes undergoes a slightly different production process (not covered)

- Depending on the materials and solvent used (if any), the electrode manufacturing required ambient that could vary from a grey room to a clean ISO 6 dry room

Mixing

Mixing – Anode example

Graphite (natural or artificial)

Binder 1

Binder 2

Slurry

Additive (carbon black)

Safety equipment during mixing

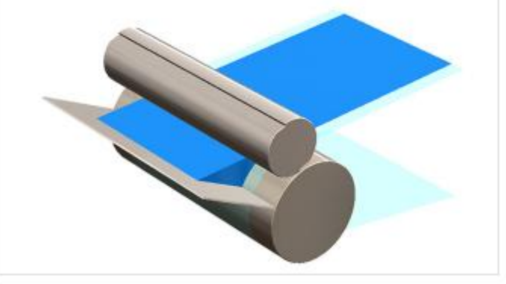
- Safety glass
- Respirator (with anti-powder filter)
- Safety shoes
- Nitrile (or similar) gloves
- Overall
- Hair cap

Coating

Coating

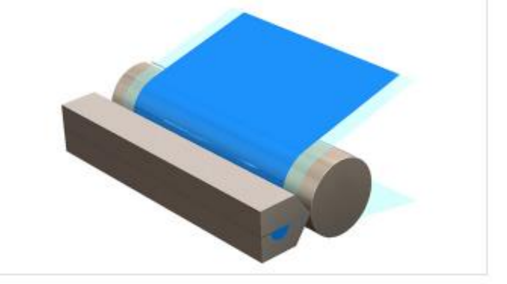
- During the coating phase, the slurry is deposited on the current collector to form a thin film that is dried and re-winded into a coil

- Coating equipment could use different techniques and technology to make the slurry deposition on the coating head, such as slot die, comma roll, gravure, etc



Comma Coater®

Closed Type Coater

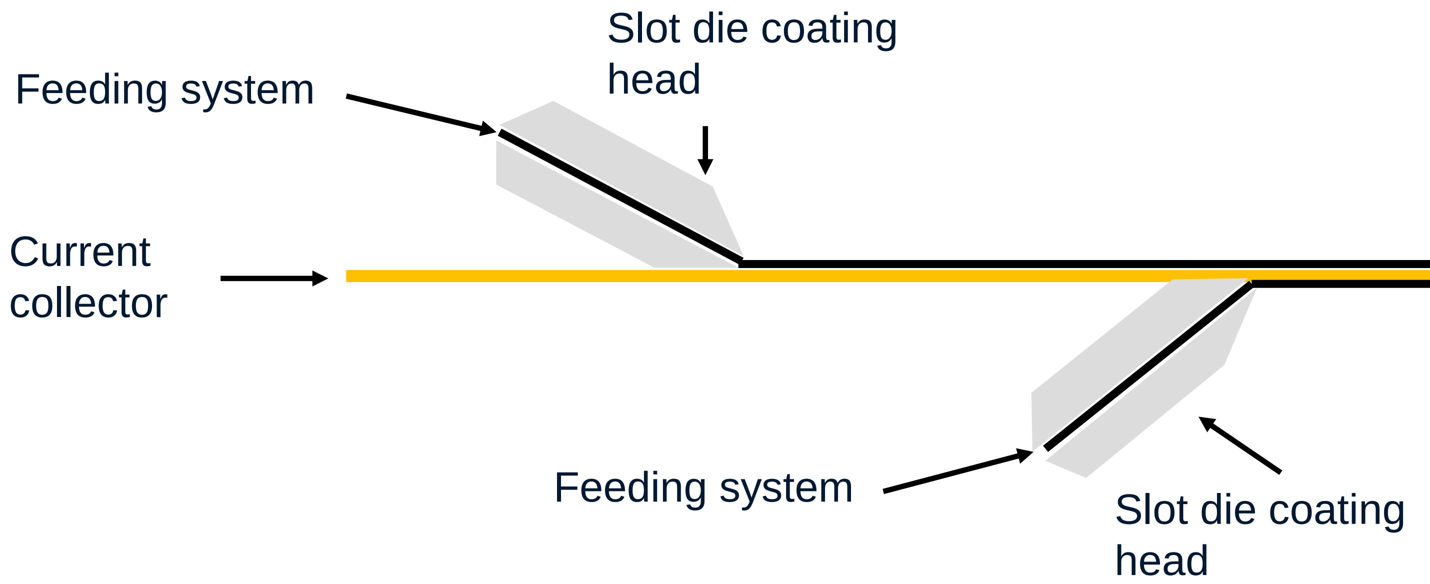


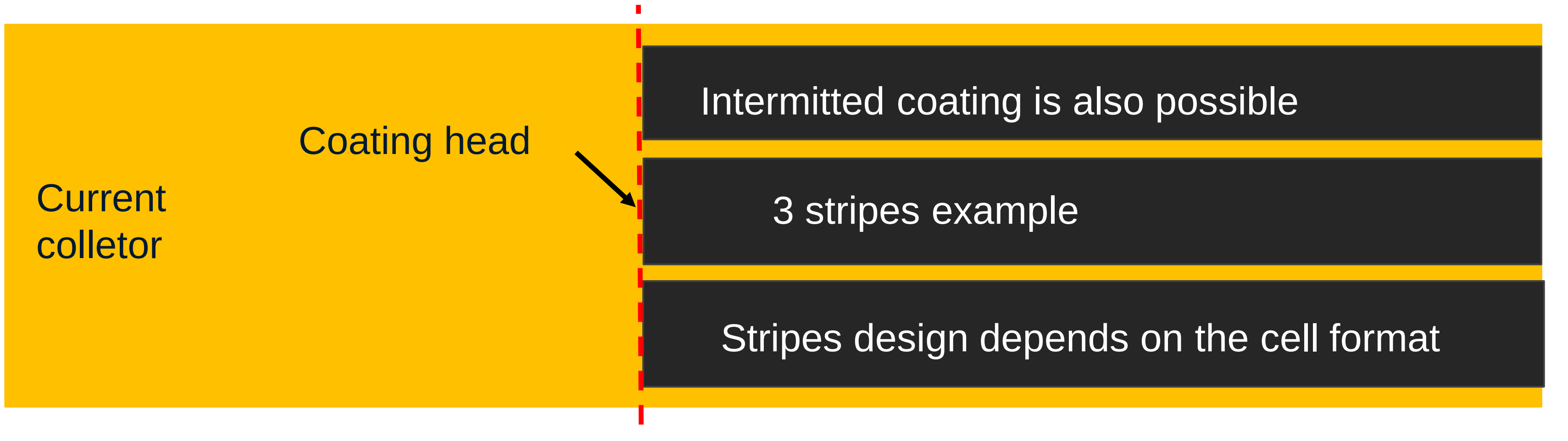
Die Coater

- Both sides of the current collector are coated (depending on the equipment the two sides could be coated simultaneously o separately)

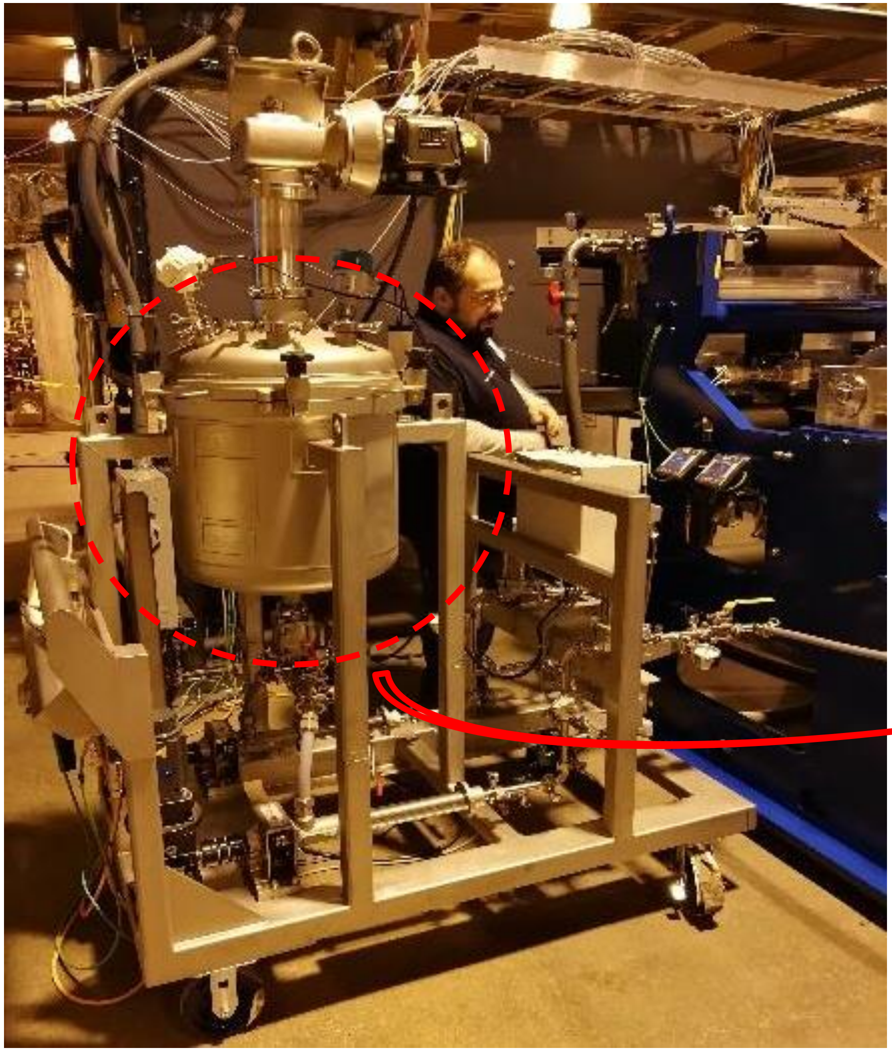
- Film thickness vary depending on the active material used and on the cell type (power vs energy), typically from 50 to 150 microns per side after drying

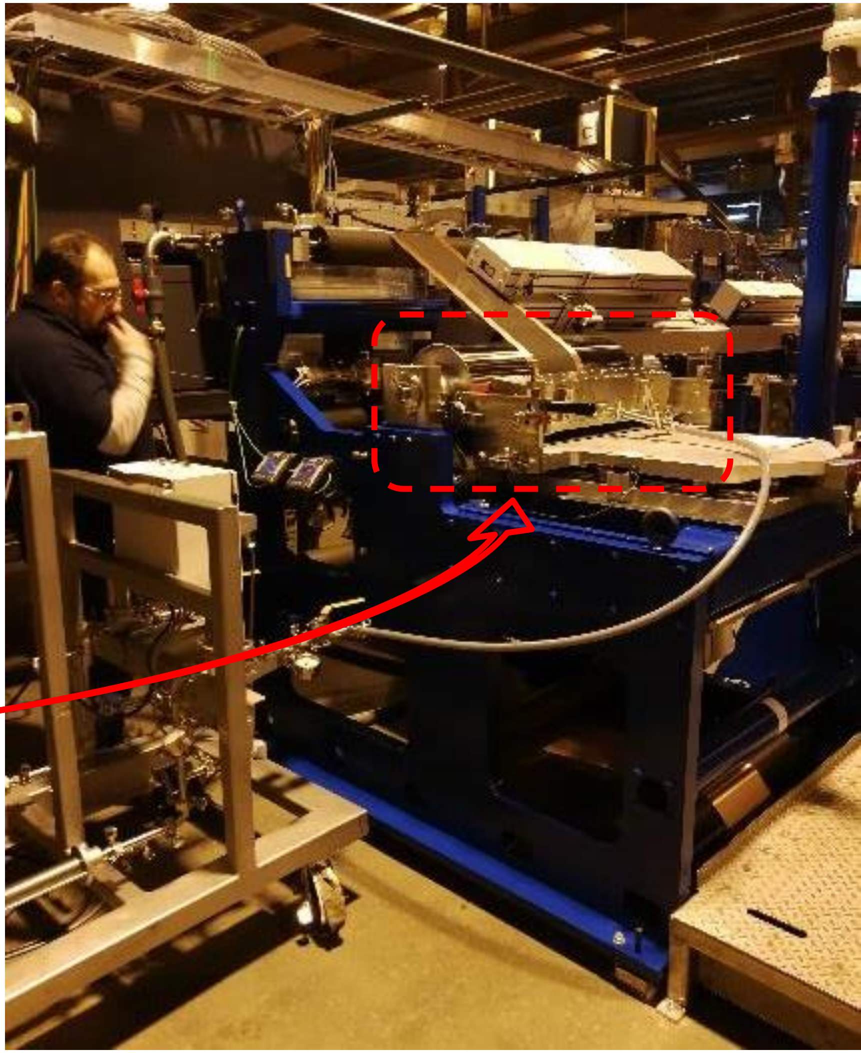
Two-side simultaneously die coating



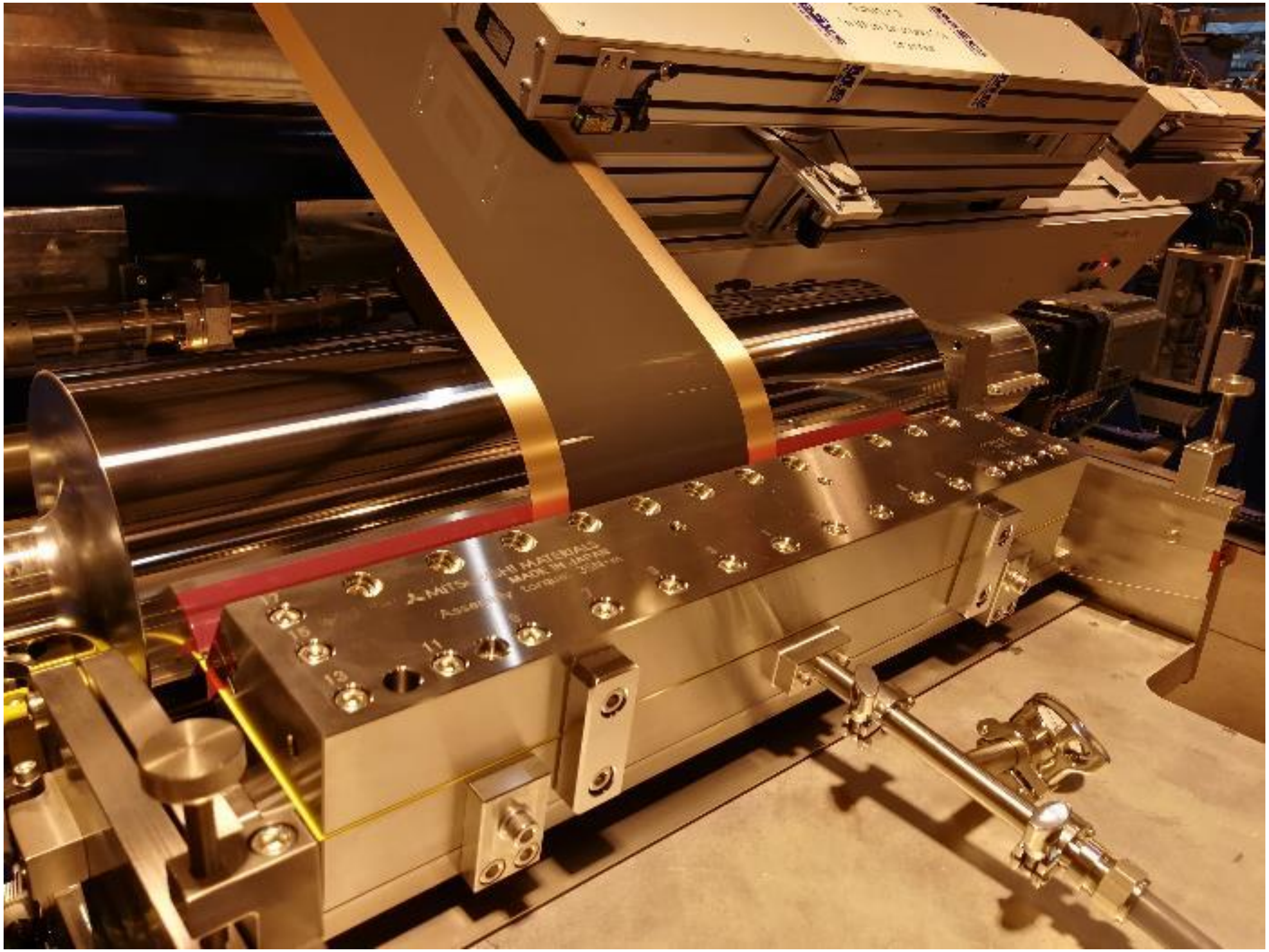


Coating feeding system and head (die)





Coating feeding system and head (die)

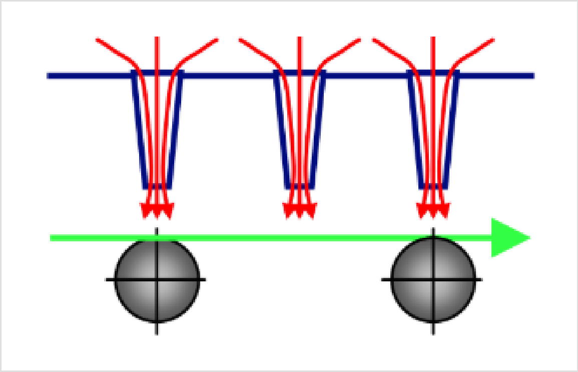


Drying

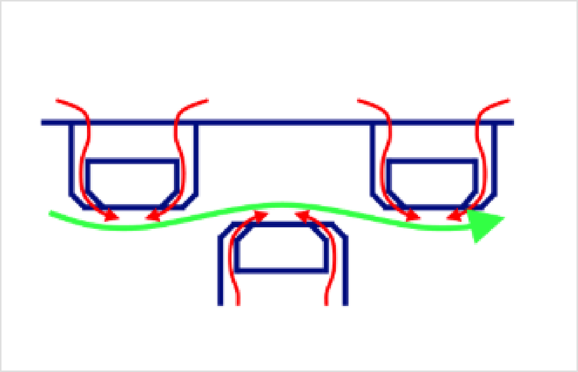
- During the drying phase, the coated electrode film goes through several drying zones (part of the coating machine) where solvents and water content are evaporated

- Evaporated solvents are collected and treated (if the mixing was a dry one, no solvents are present)

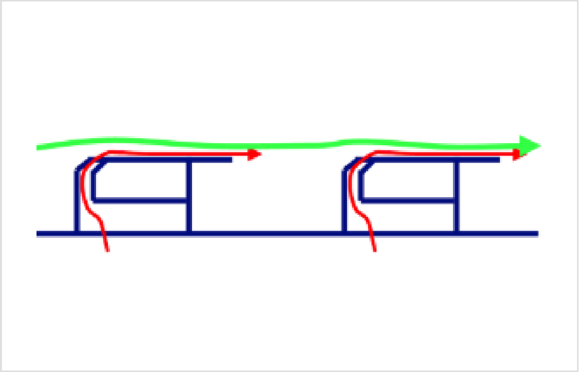
- Inside the dry chambers, different nozzle could be used to inject hot air on the electrode film surface, for example:



Jet nozzle



Floating nozzle



Airfoil nozzle

Drying

Safety equipment during coating, calendaring and slitting

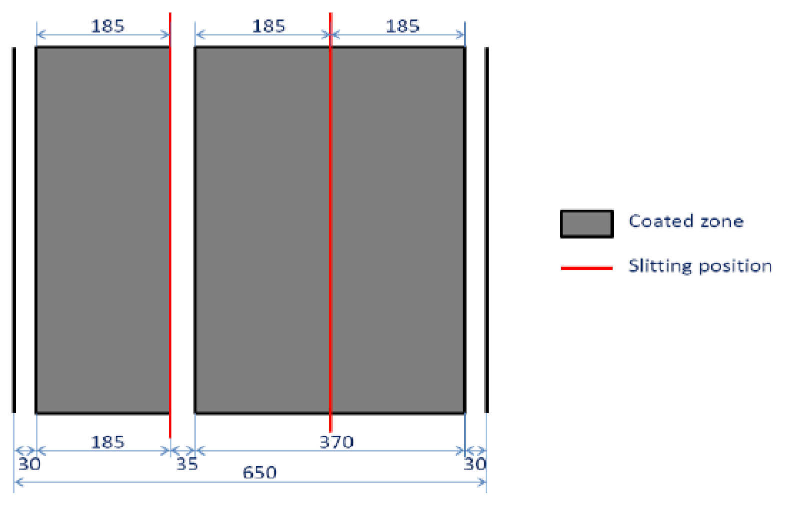
- Safety glass
- Respirator (with anti-powder filter)
- Safety shoes
- Nitrile (or similar) gloves
- Working gloves (anti-cut)
- Overall
- Hair cap

Calendaring (roll pressing) and slittering

Calendaring and slitting

- During the calendaring, the electrode coil is passed through a roll press to compress the active material

- Depending on the cell size and format, the electrode coil is then cut into smaller coils during the slitting process, for example starting from a two lanes coated coil three coils are obtained:

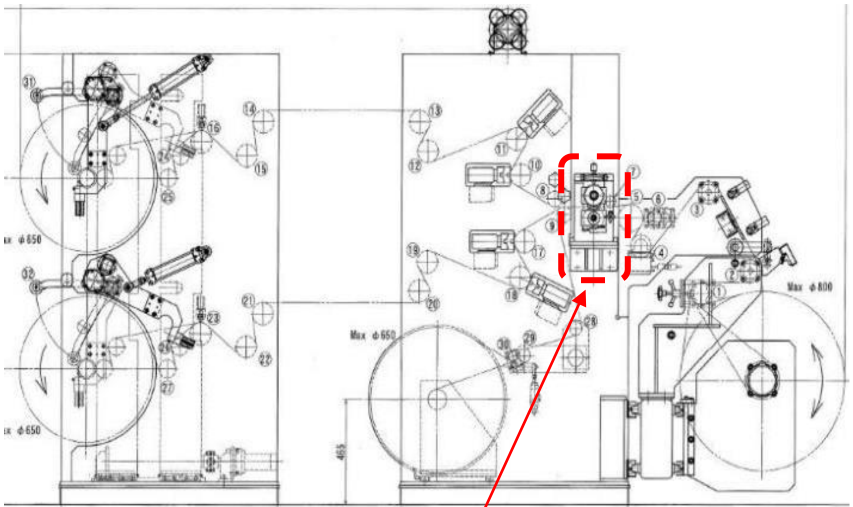


- The roll press unit could be connected “in line” with the coating equipment, the coating re-winding unit could be avoided.

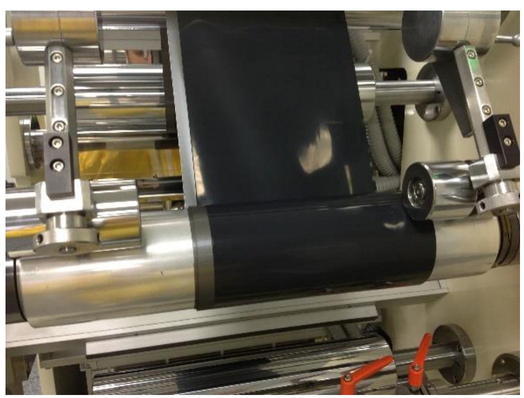
Calendaring

- In the calendaring process, the electrode is compressed.
- The main goal is to reduce the electrode volume to increase the volumetric density and to flatten its surface
- Compressing too much the electrode could result in reducing its porosity to a level which electrolyte cannot penetrate in its structure
- Electrode rolls could measure more than 2-3 kms and weight several hundreds of kgs

Slitting



REWINDER (2 levels) Slitter unit UNWINDER



- Starting from a main roll (also referred as jumbo roll), several smaller rolls are obtained by slitting it
- Aluminum and copper dust could be formed, it is mandatory to aspire them and avoid any contamination on the electrode surface
- Slit electrodes are normally stored in a temporary warehouse, ready to be assembled in the cell

Pouch cell Assembly

Cell assembly

- A laminated pouch cell with tabs (contacts) on the same side assembly process is presented
- Five main steps:
    - Notching and Drying
    - Stacking
    - Tab Welding
    - Pouch forming and stack insertion
    - Electrolyte filling and sealing

- Cell assembly process varies depending not only on the cell format (cylindrical, prismatic or pouch) but also on the cell design: electrodes could be for example laminated with the separator or just folded together with the it.
- After drying, the assembly process takes place in a dry room

Safety equipment during cell assembly

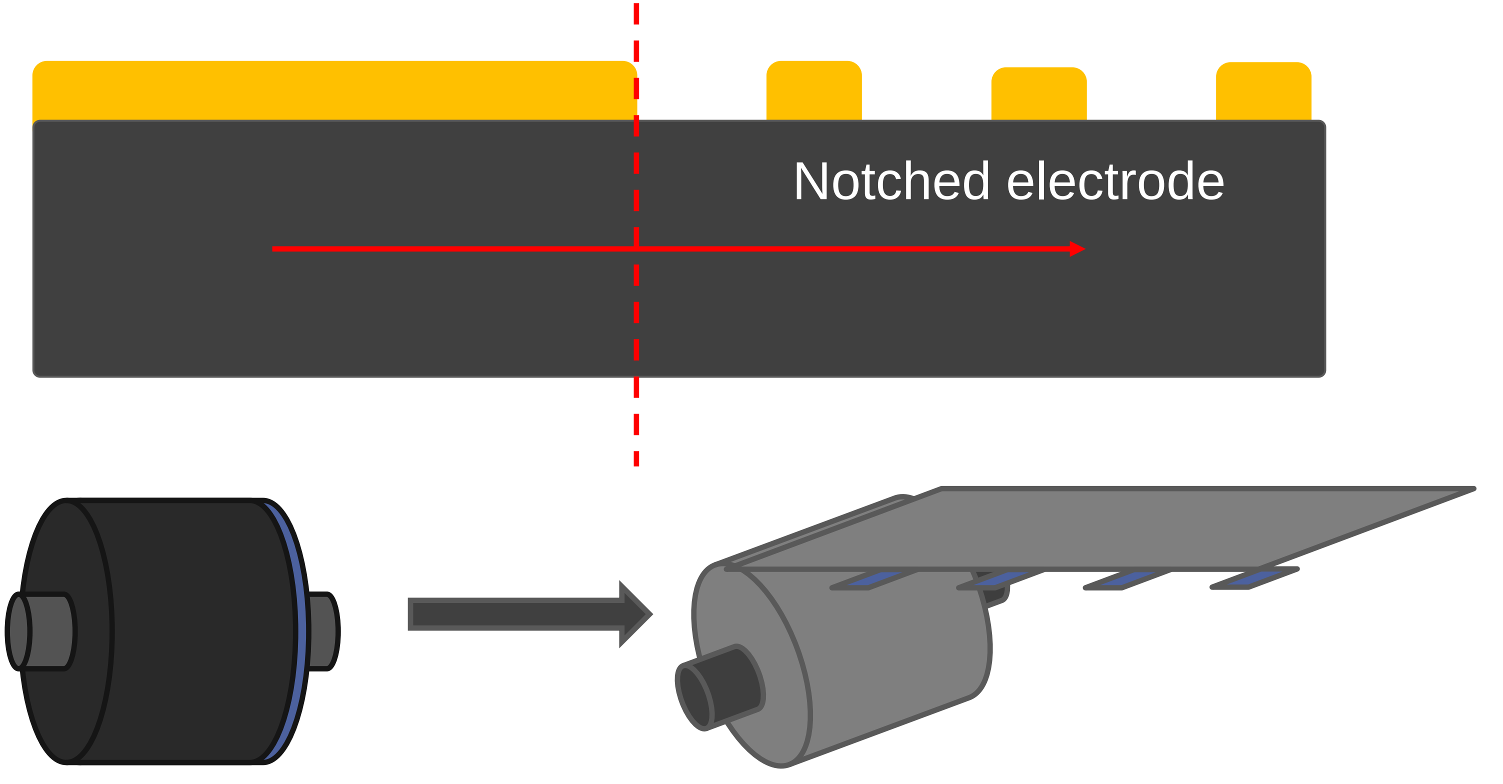
- Safety glass
- Respirator (with anti-powder filter)
- Safety shoes
- Nitrile (or similar) gloves
- Working gloves (anti-cut)
- Overall
- Hair cap

Notching and drying

Notching

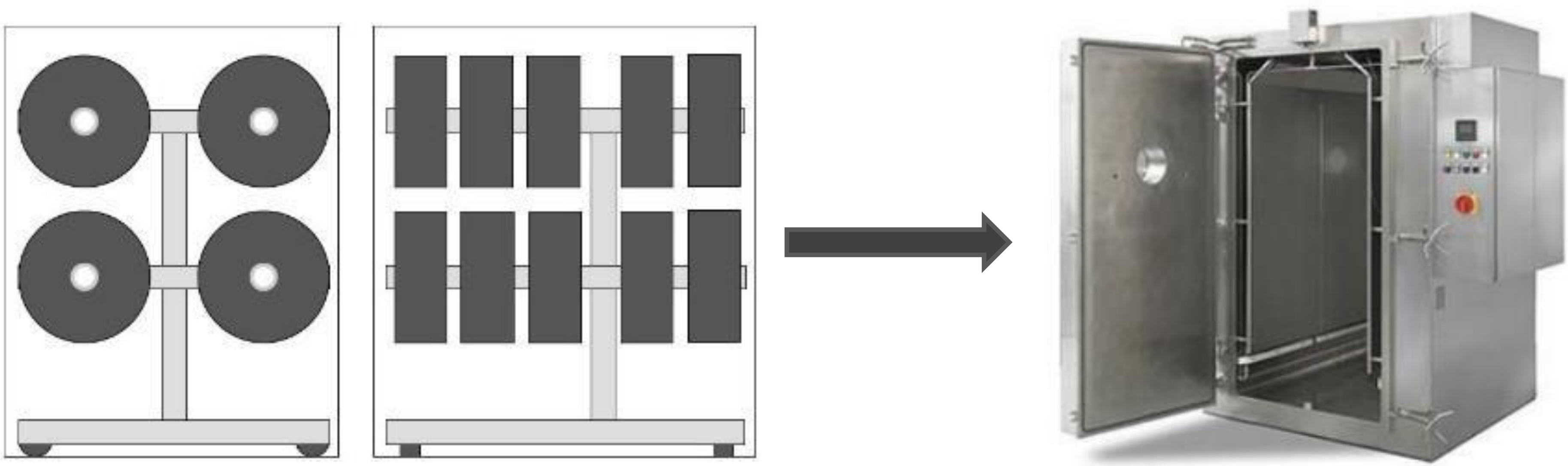
- During notching, the slit electrode is shaped depending on the contact position and the material in excess is exported

- Notching is preferably done before drying the electrodes and outside the dry room as it produce metallic dust



Drying

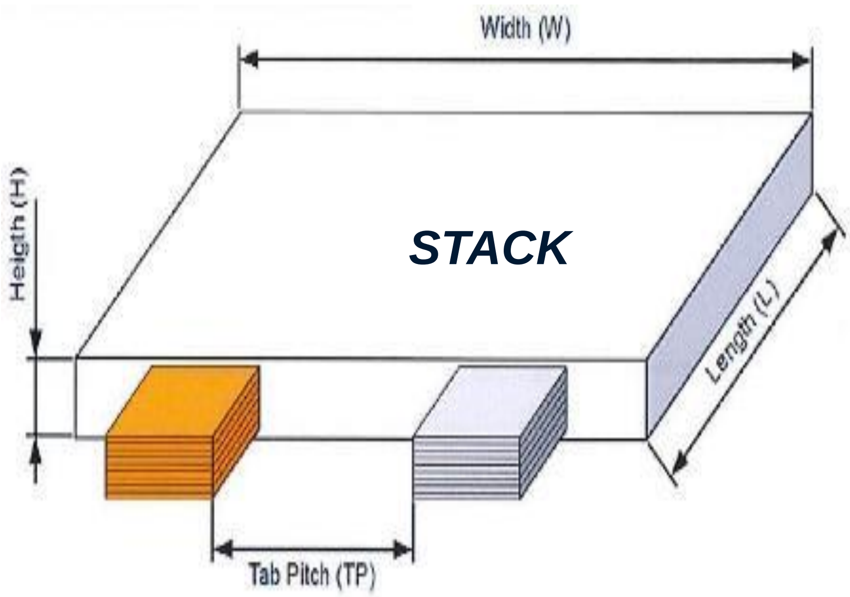
- Drying the electrodes is necessary to extract all the remaining water from inside their structure
- The presence of water inside a sealed cell could cause malfunctioning and reduce its life
- Drying could be performed in different ways, using ovens or other system, and could take up to 24 hrs

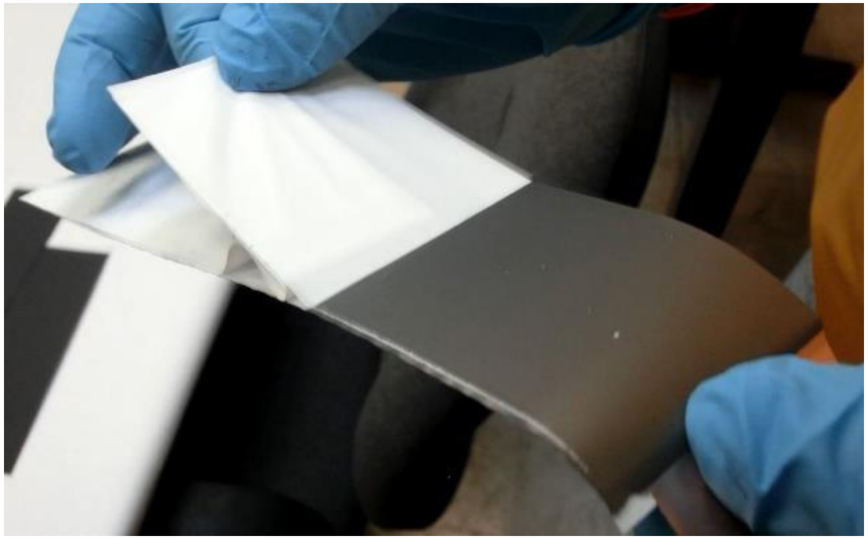


Stacking

Stacking

- Notched and dried electrodes (cathode and anode) are cut and then assembled alternately together with the separator to form a stack



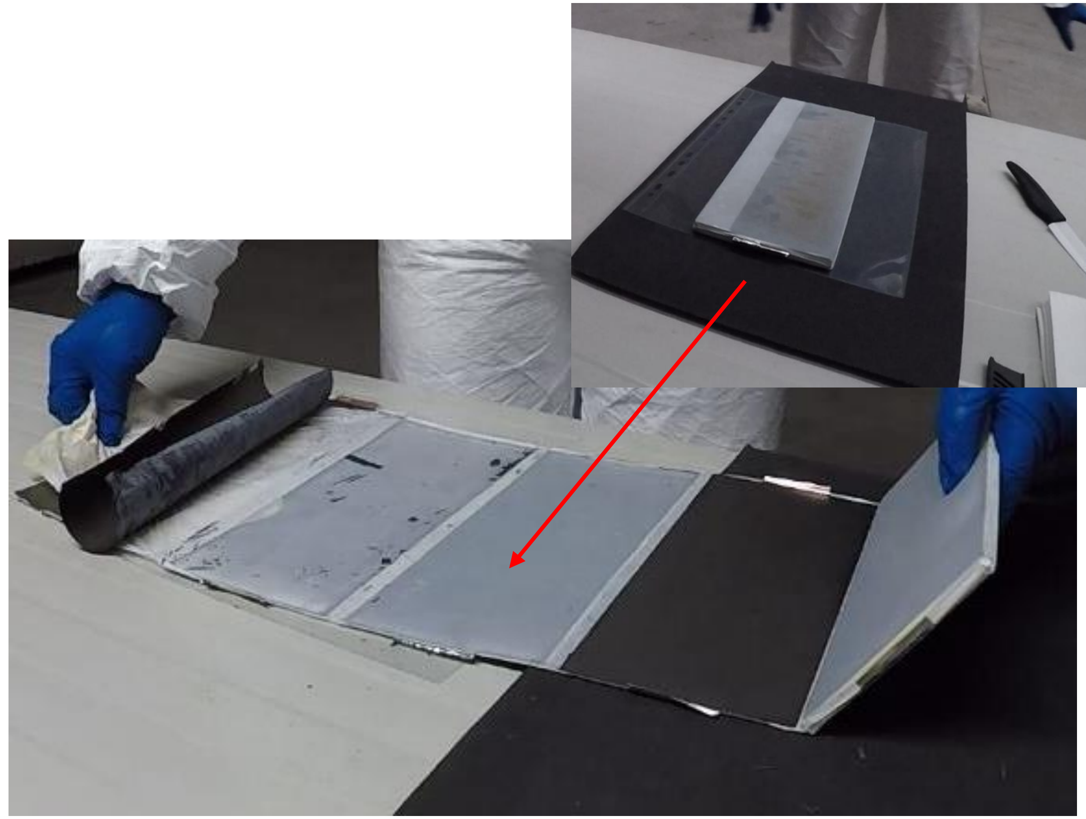


- During stacking the separator could be inserted in multiple ways, from a z-folding to a lamination system, greatly modifying the process layout and machine

- Depending on the cell design, electrodes prismatic cell could also be assembled using a stacking process. However, winding is generally more common.

Stacking example

- In this example several mono-cells (couples of cathodes and anodes sheets with a separator laminated in the middle) are laminated on a central long separator sheets and then wrapped



Bottom side: a laminated mono cell composed by one cathode, one anode and one separator sheet is laminated to the central seperator

Anode
Cathode

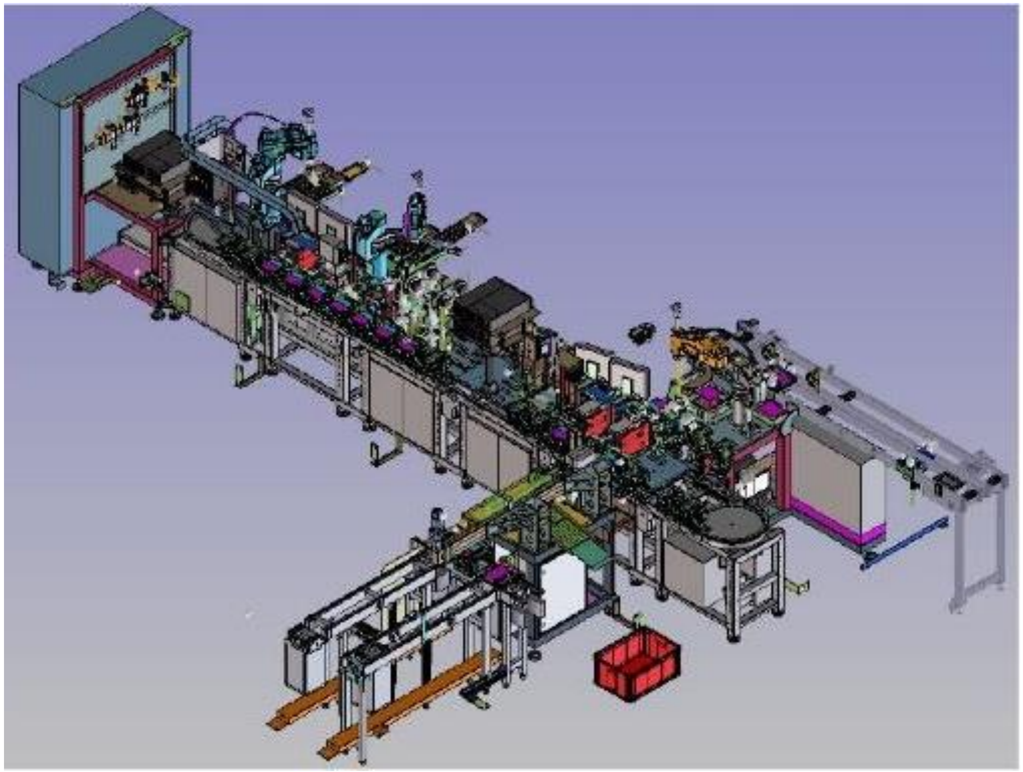
Tab welding

Tab welding

- The cell stack is taped and transferred to the tab welding station, where the positive and negative contacts are welded to form the cell terminals

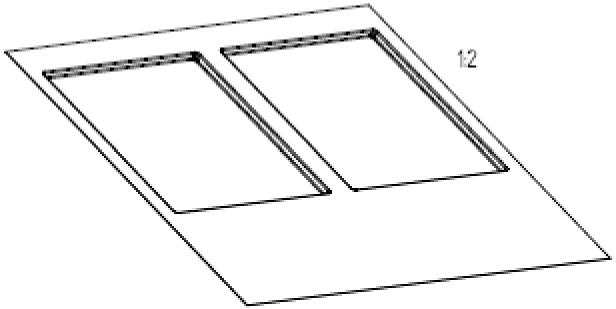
- Tabs are normally made of Al-Ni alloy for the cathode and Cu-Ni for the anode

- Tabs are welded via ultrasound on the stack notched current collector



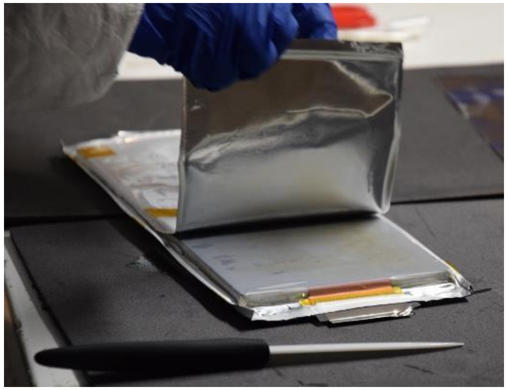
Pouch forming and stack insertion

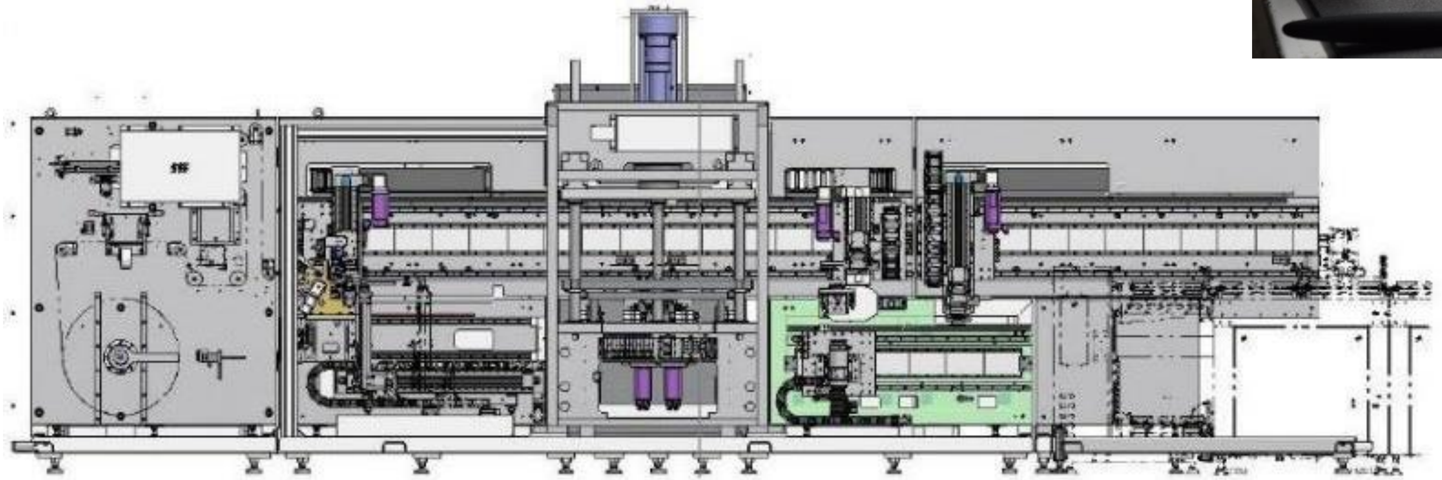
Pouch forming and stack insertion



- The pouch foil is stamped to form a upper and lower cavity to host the cell stack

- After the cell stack is inserted in the lower cavity, the foil is folded and the cell is sealed on three sides via heat: a special polymer on the pouch foil and tabs surface is melted sealing the cell.





Electrolyte filling and sealing

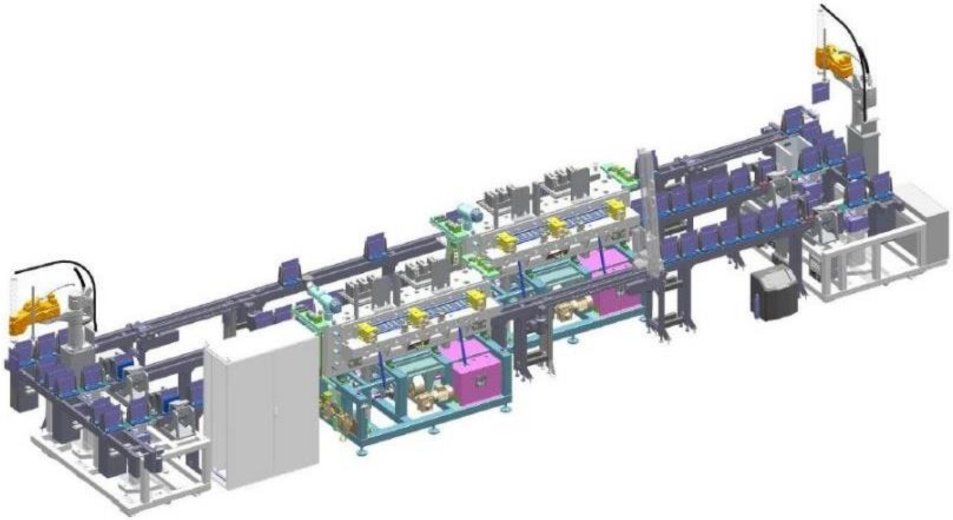
Electrolyte filling and sealing

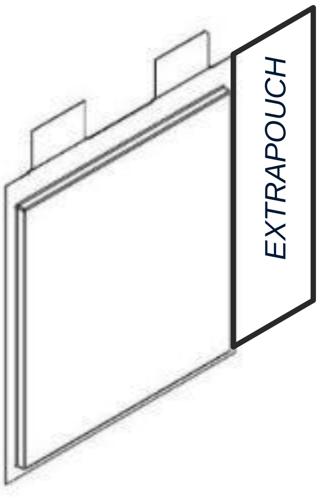
- Cells (only open on one side) are moved to the filling station

- Electrolyte is pumped (normally after vacuum has been achieved) inside the cells

- Cells are finally sealed and ready to be formed

- An extra-pouch is leaved: during formation, several gas are going to be formed. Before cells are ready to be used, they will have to be degassed by reopening them on the extra-pouch section and re-sealed afterwards under vacuum where the extra-pouch is cut.





Formation

Cell formation and aging

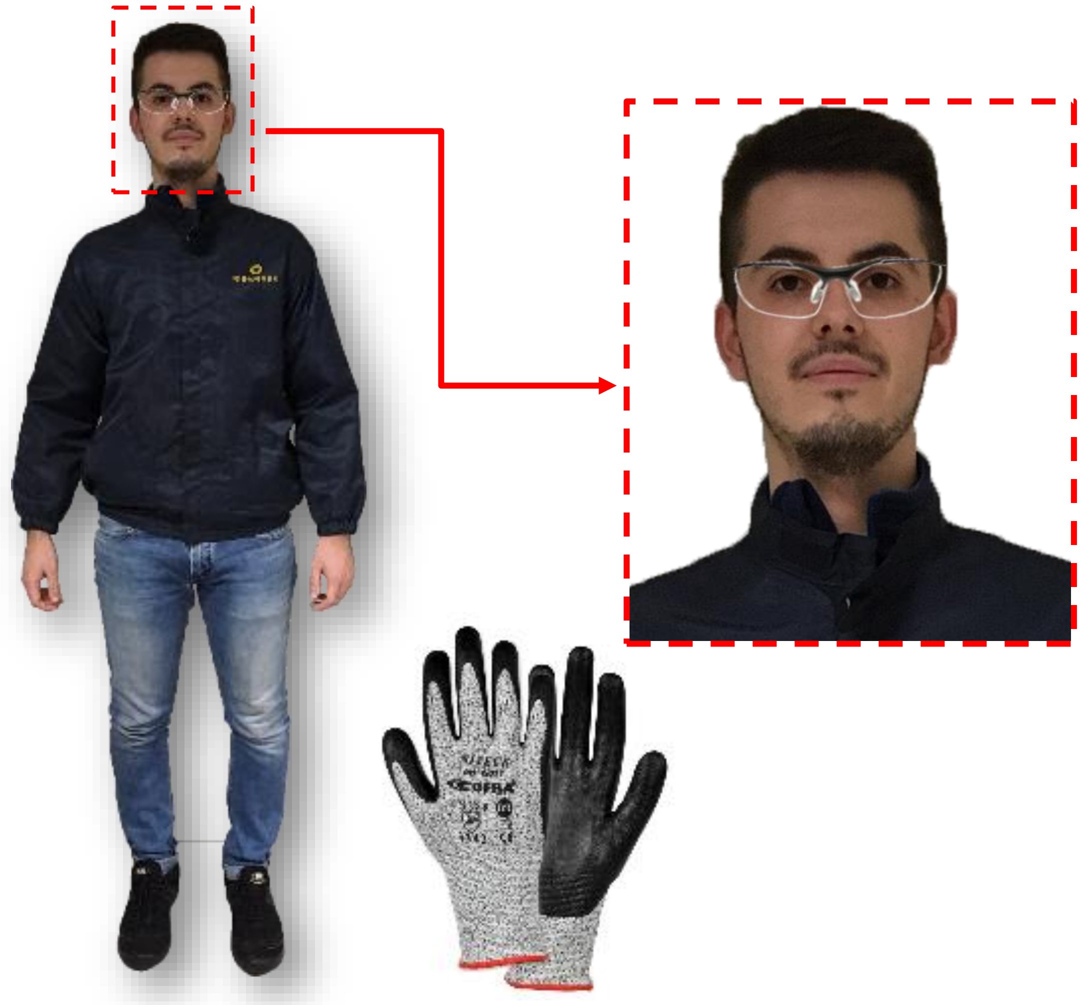
- During the last macro-phase of a cell manufacturing process, li-ion cells are
  - pre-charged
  - Formed (charge and discharge cycles)
  - degassed (if needed)
  - aged
  - tested
  - sorted and stored

- The order and duration of each process highly depends on the material used, cell type and manufacturer know-how.

- The whole process could last up to 10-15 days and requires a high level of automatization to be cost efficient

- Cells are moved on trays from one station to another

Safety equipment during formation

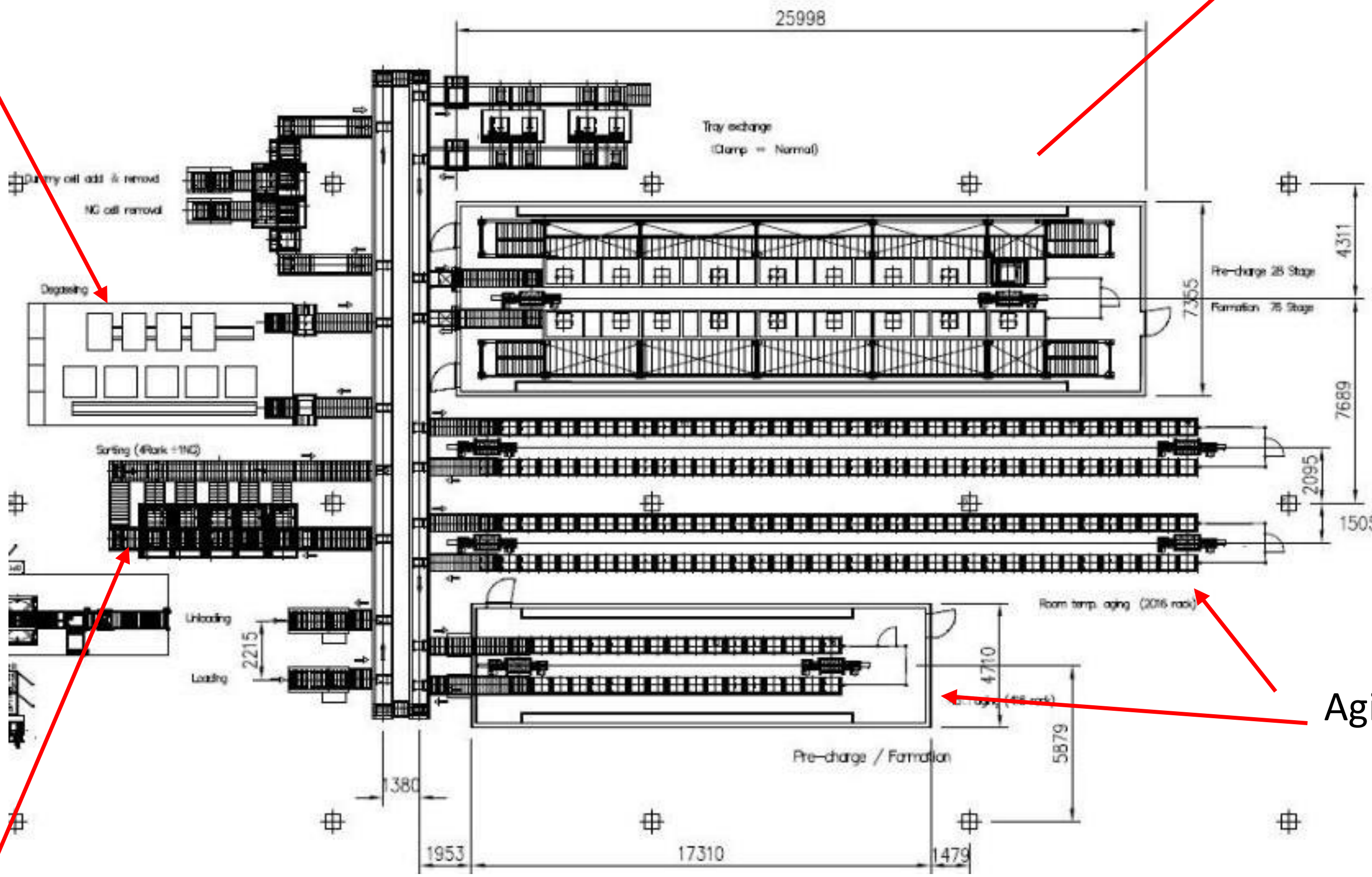


- Safety glass
- Safety shoes
- Working gloves (anti-cut)

Cell formation and aging

Degassing

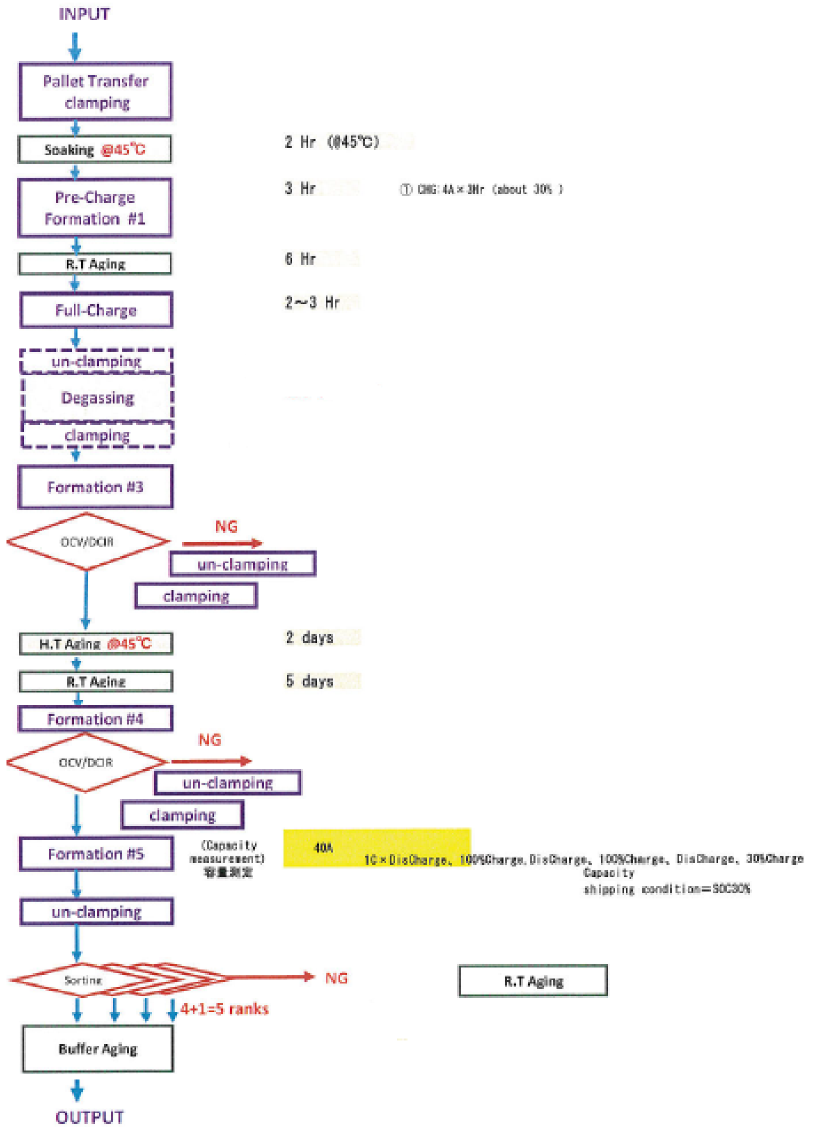
Pre-charge and
formation stations



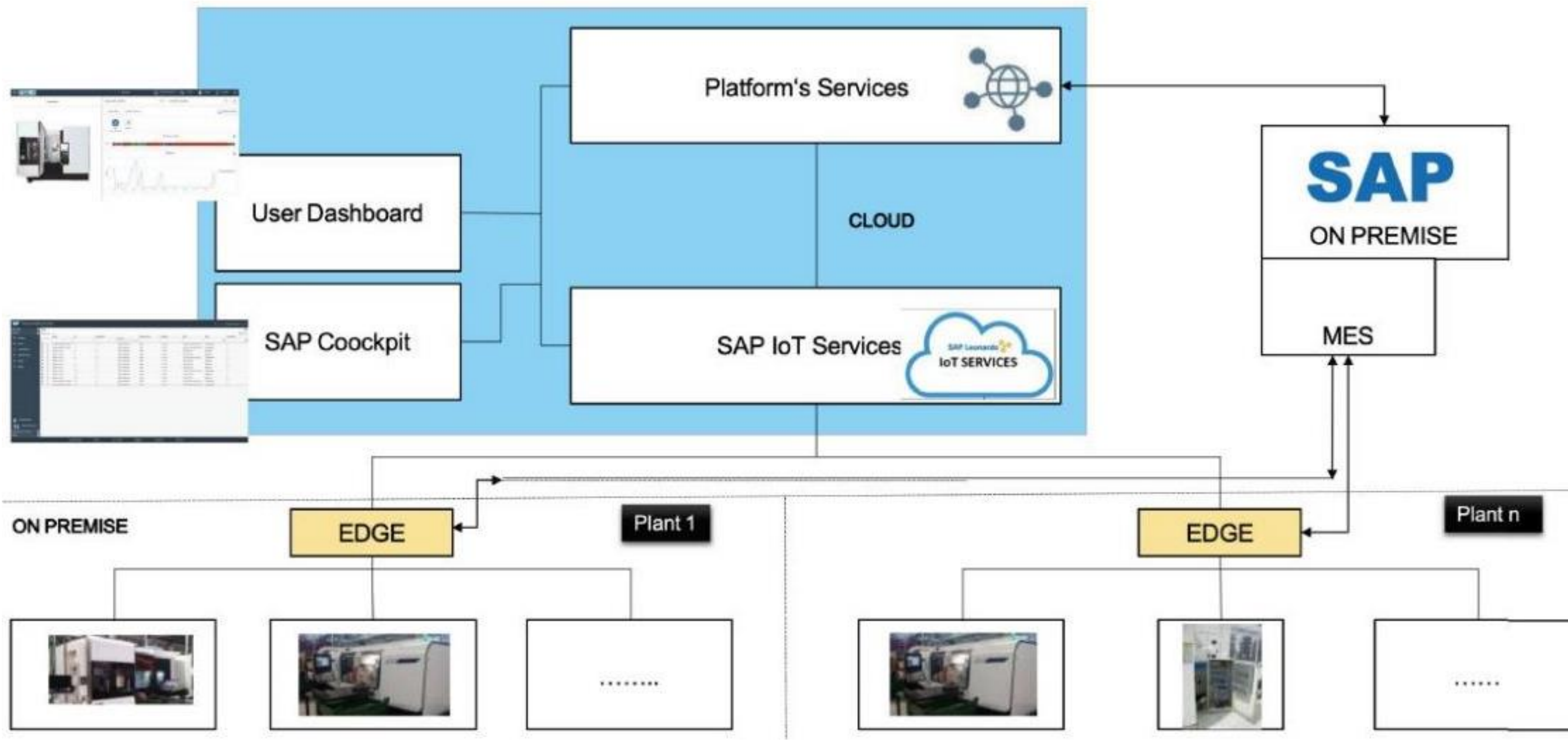
Aging

Sorting

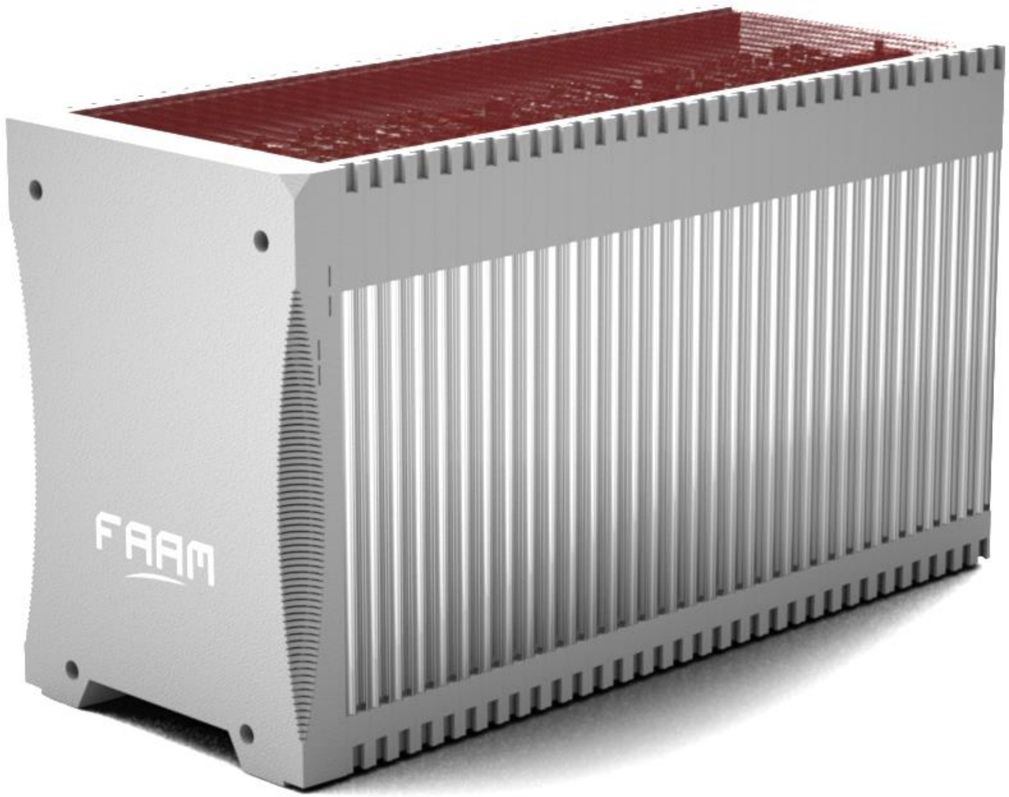
Formation process example



Data collection (example using SAP technology)



FAAM Lithium Technology
KOMBI



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