State of the art in AI modelling for battery cell production and current research progress

INSIGHT

Intelligent Data Models for Battery Cell Production and Recycling

28.3.2025. | Croatian Academy of Sciences and Arts

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Production process in short

Battery cell production process

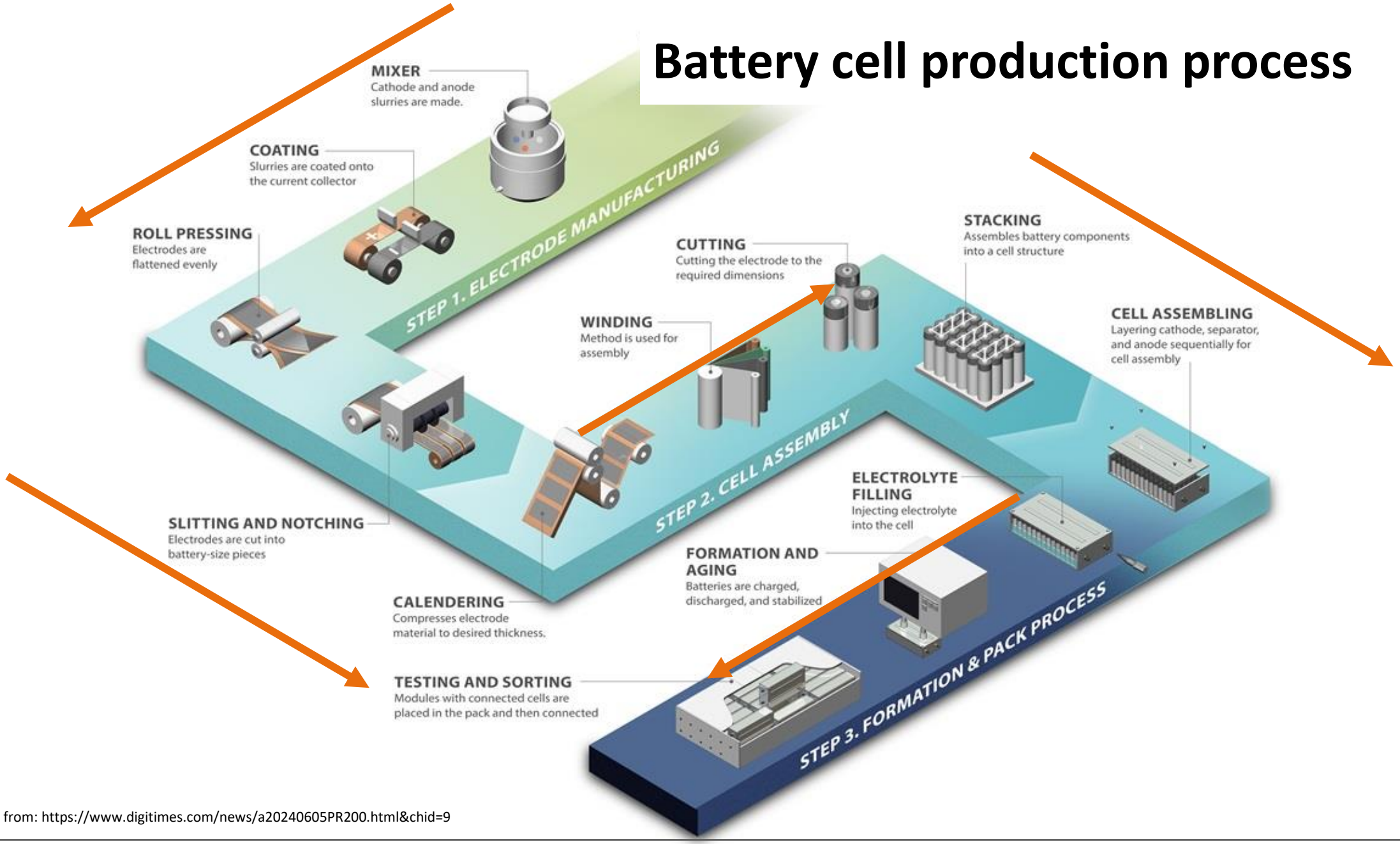


Image from: https://www.digitimes.com/news/a20240605PR200.html&chid=9

Battery cell production process
1. electrode manufacturing

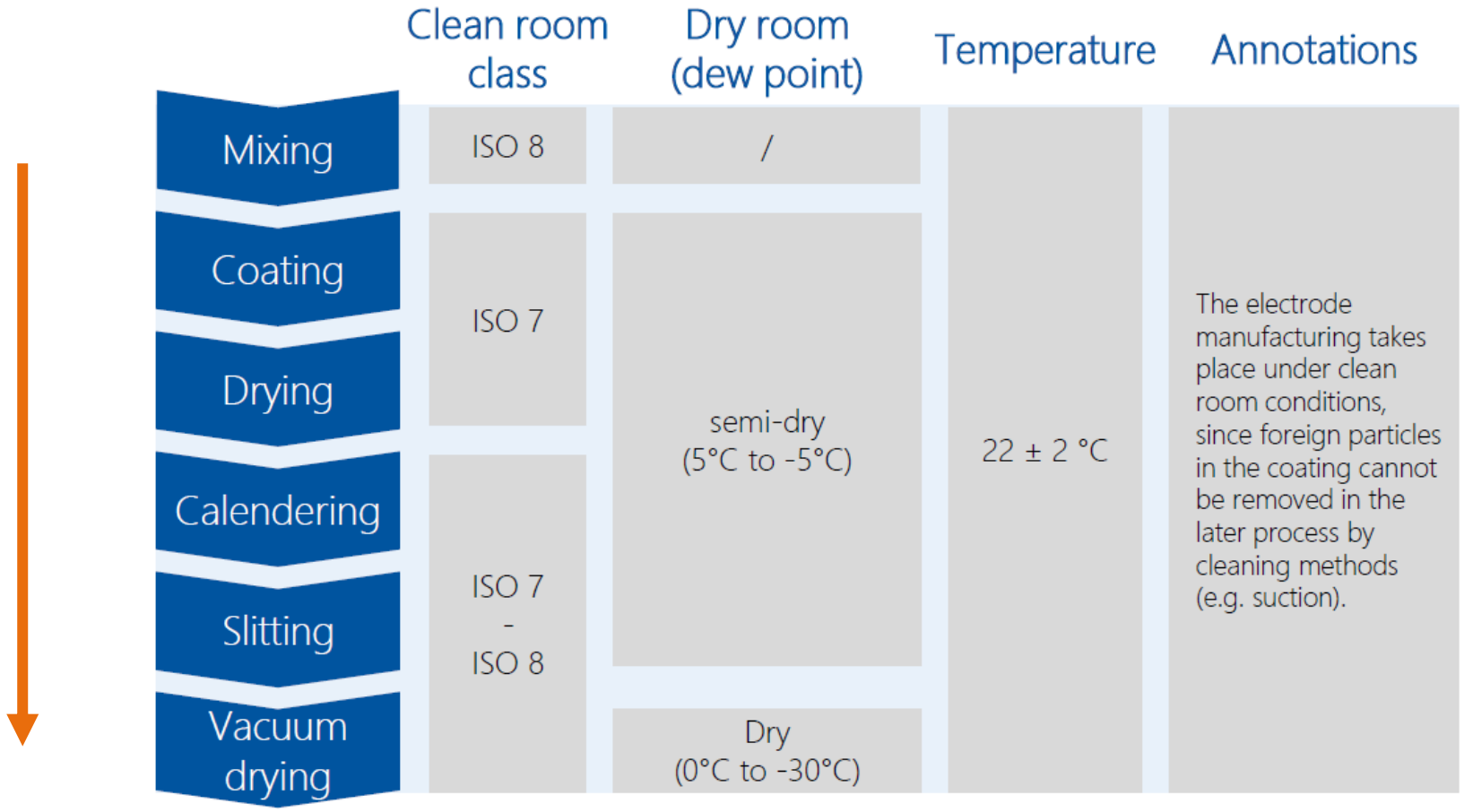
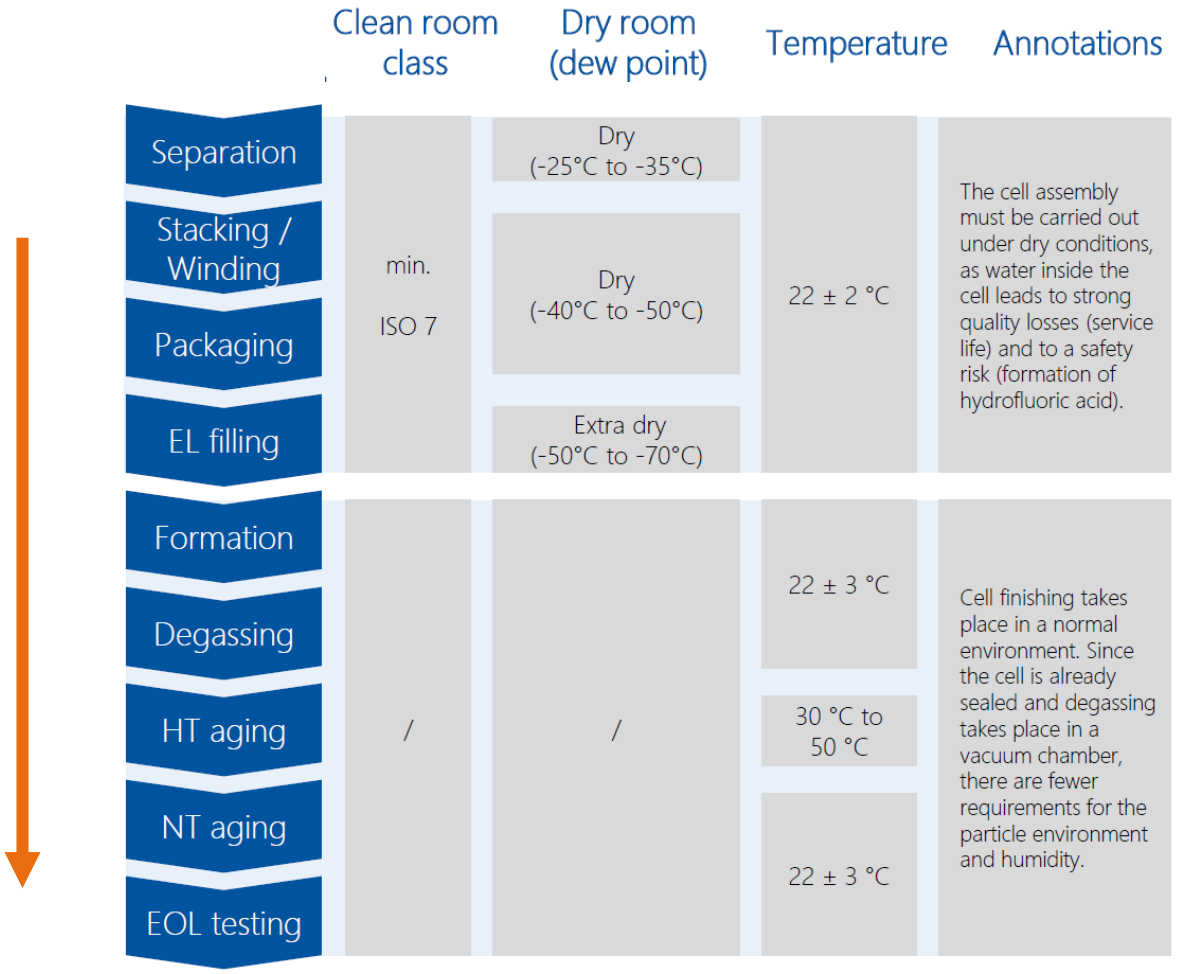


Image from: Lithium-ion Battery Cell Production Process, 2019, VDMA Battery Production,ISBN: 978-3-947920-03-7, https://www.researchgate.net/publication/330902286_Lithium-ion_Battery_Cell_Production_Process

Battery cell production process
2. cell assembly, 3. formation



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Motivation for AI modelling in battery cell production

High costs

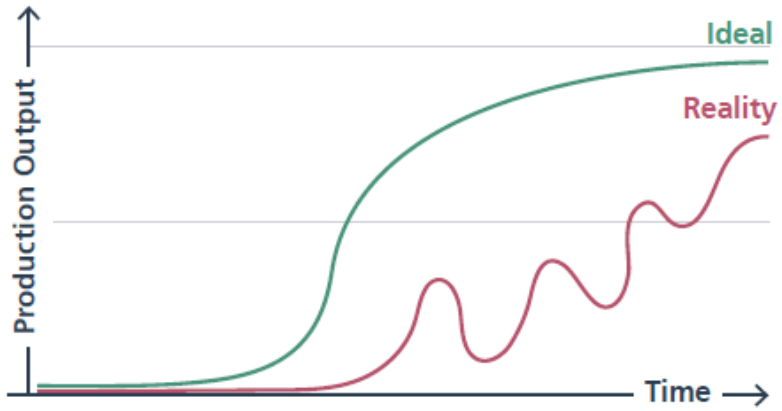
- For a giga factory of capacity 40GWh/year → scrap costs per year are around **10M€** after the process is stabilized [Dahmen et al. 2024]
- Goal: Optimize production process parameters in order to minimize scrap costs.
- Challenge: Several thousand process parameters.

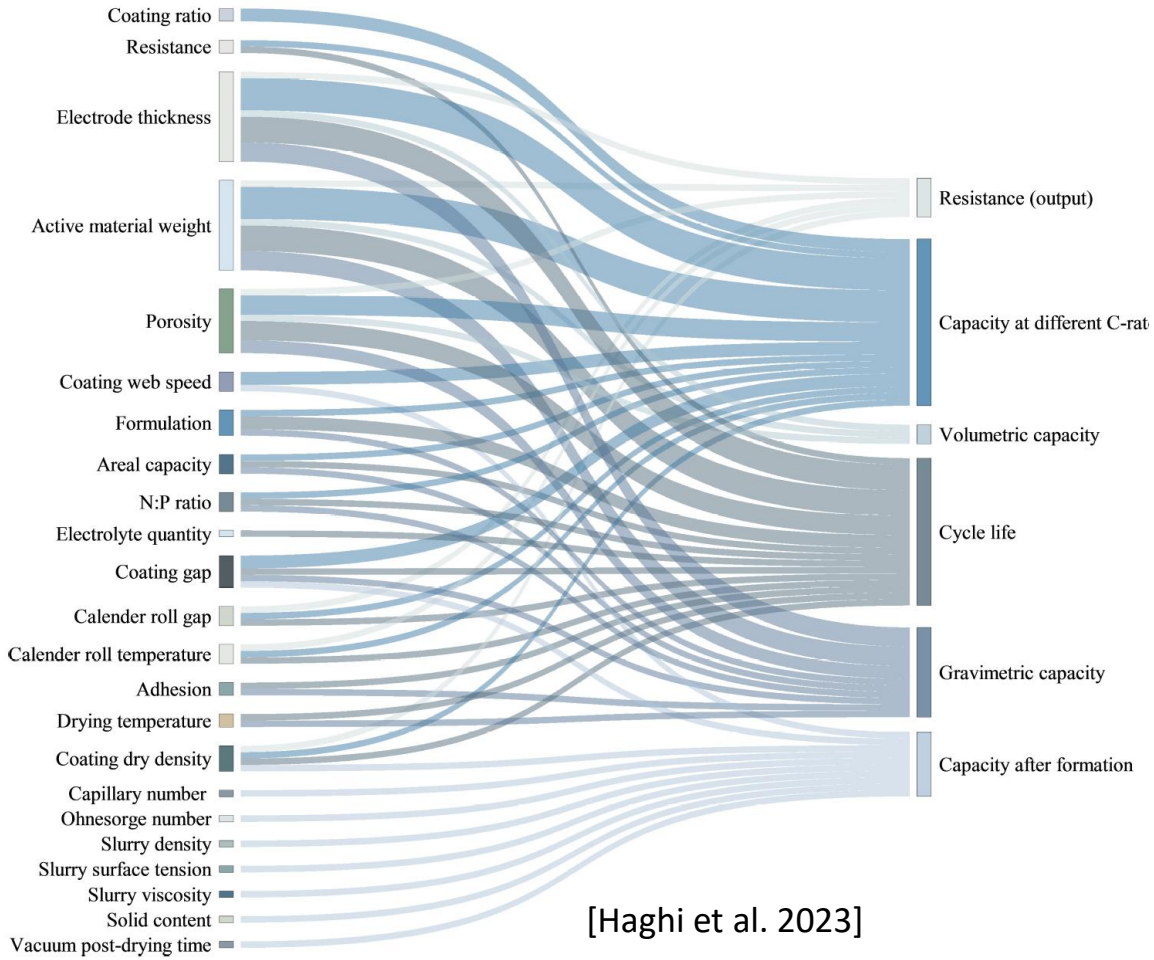
Image from: Dahmen C, Degen F, Eckstein MC, et al. Mastering Ramp-up of Battery Production. Published online October 16, 2024. doi:10.24406/PUBLICA-3727

Complexity

Most important production steps

- Mixing and coating are considered to be the processes of highest importance for the quality of battery cells. [Dahmen et al. 2024]
- Coating process → due to its high relevance regarding the final cell quality as well as the many challenges during ramp-up.



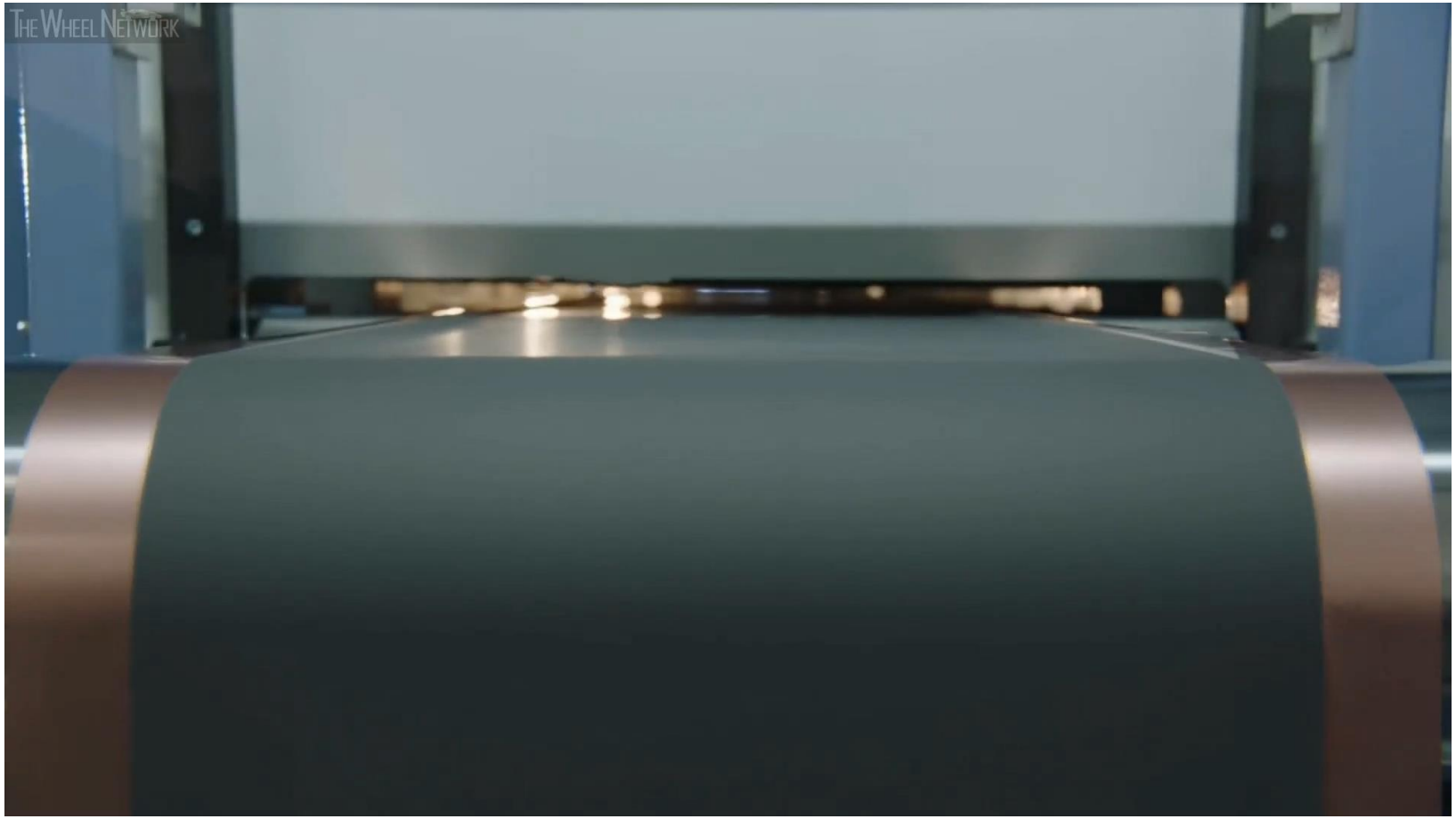


[Haghi et al. 2023]

Image from: Dahmen C, Degen F, Eckstein MC, et al. Mastering Ramp-up of Battery Production. Published online October 16, 2024. doi:10.24406/PUBLICA-3727
Haghi S, Hidalgo MFV, Niri MF, Daub R, Marco J. Machine Learning in Lithium-Ion Battery Cell Production: A Comprehensive Mapping Study. *Batteries & Supercaps*. 2023;6(7):e202300046. doi:10.1002/batt.202300046

The coating process

https://www.youtube.com/watch?v=OtHkkZEQDpg&ab_channel=TheWheelNetwork

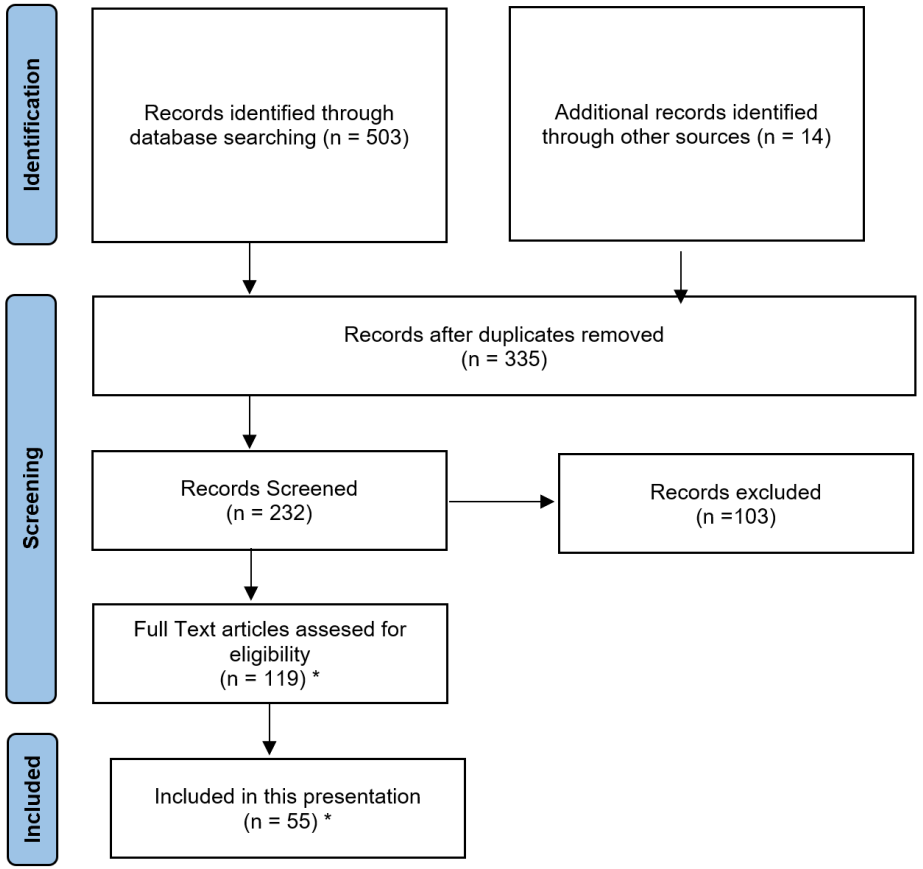


https://www.youtube.com/watch?v=OtHkkZEQDpg&ab_channel=TheWheelNetwork

We have made an extrensive literature survey

Literature survey

- An extensive literature survey was done on WoS and Scopus (+IEEE) with the following search terms in various combinations:
  - Battery Production
  - Battery Manufacturing
  - Battery Cell Production
  - Machine Learning
  - Neural Networks
  - Deep Learning
  - Data Mining
  - Predictive Modeling
  - Prediction
  - Process Parameters
  - Production Optimization
  - Quality Control



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Cell design from reviewed papers:

- pouch: 14 (24,6 %)
- Battery pack/module: 11 (19,3 %)
- electrodes: 10 (17,5 %)
- all: 7 (11.7%)
- not specified: 8 (14 %)
- coin: 5 (8,8 %)
- prismatic: 5 (8,8 %)
- ASSB: 2 (3, 5 %)
- materials: 2 (3,5 %)

Main (pre)conclusion – there is a minor number of papers dealing with cylindrical cells

Predictive models for production of cylindrical battery cells

Development of an initial prediction model

- Given the extensive review of the field and inhouse know-how (BMW Group and UNIZG FSB team), a model for prediction of surface loading in electrode manufacturing (coating) has been developed.
- The coating process is crucial for high quality battery cells → minor defects can affect subsequent production stages.
- To optimize throughput and yield, careful control of parameters like slurry viscosity and coating speed is essential.
- A thorough understanding of the underlying cause-effect relations is needed.
- Coating and drying processes need to be coordinated effectively.

Importance of predictive models → coating

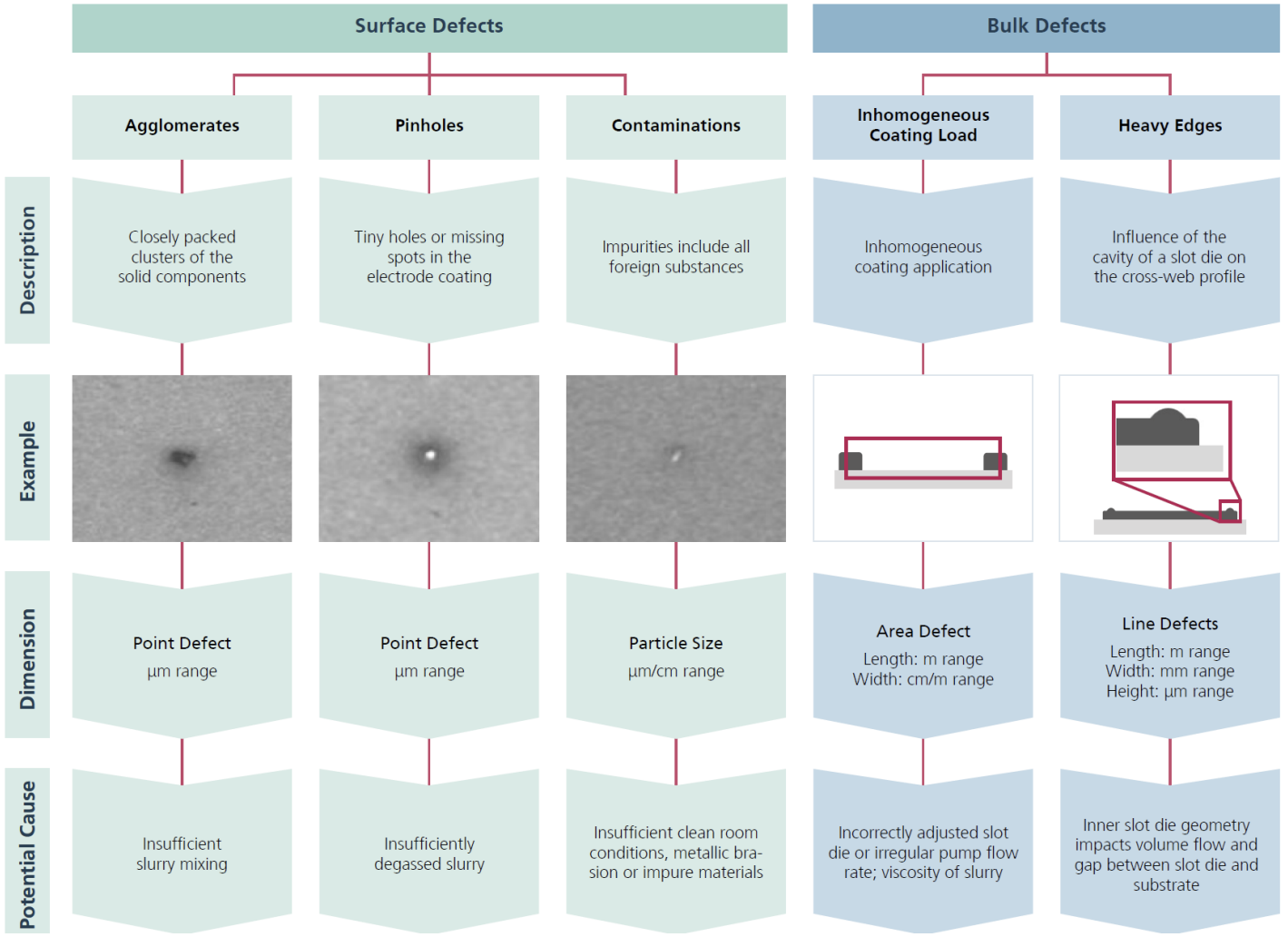
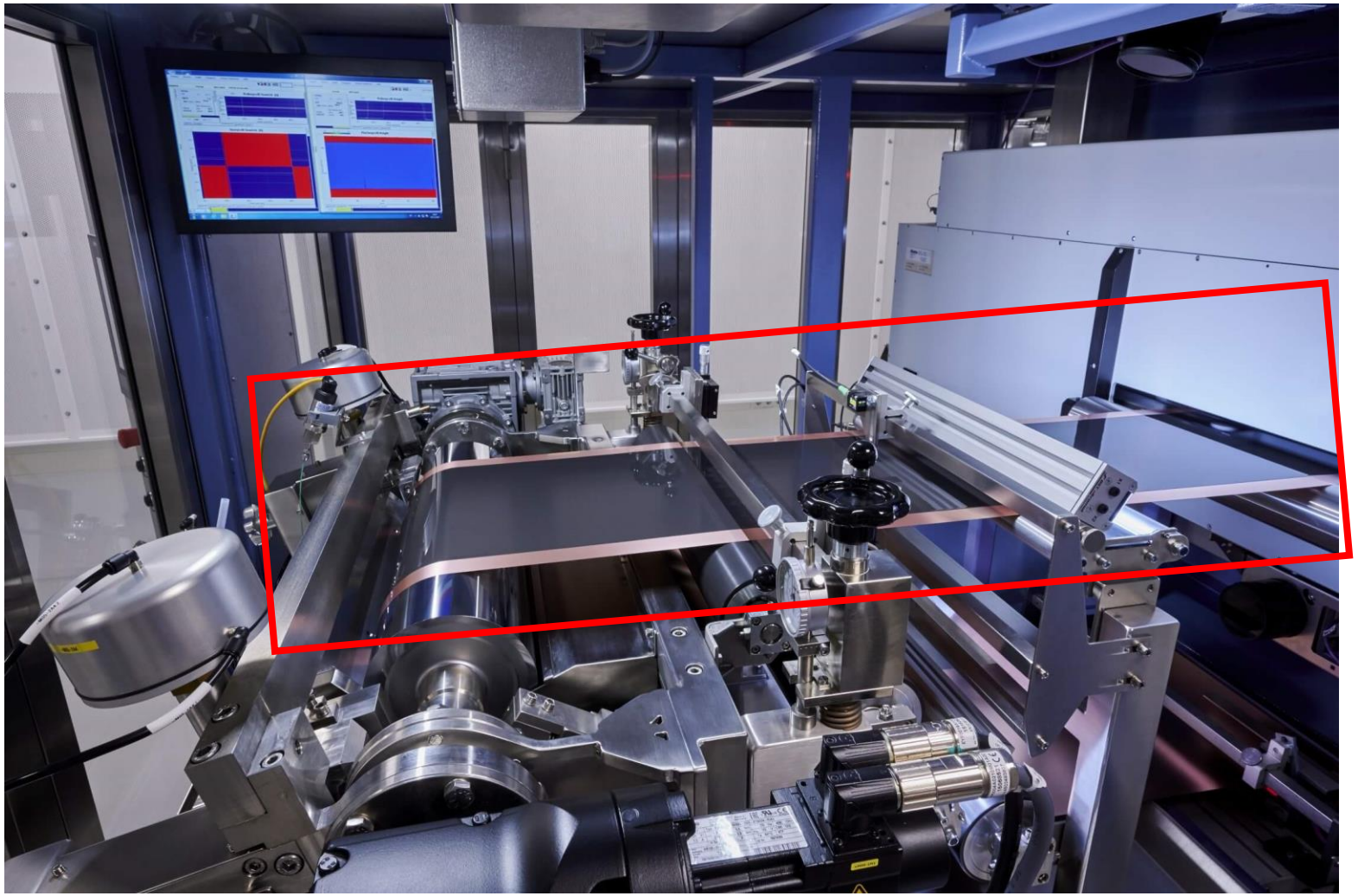
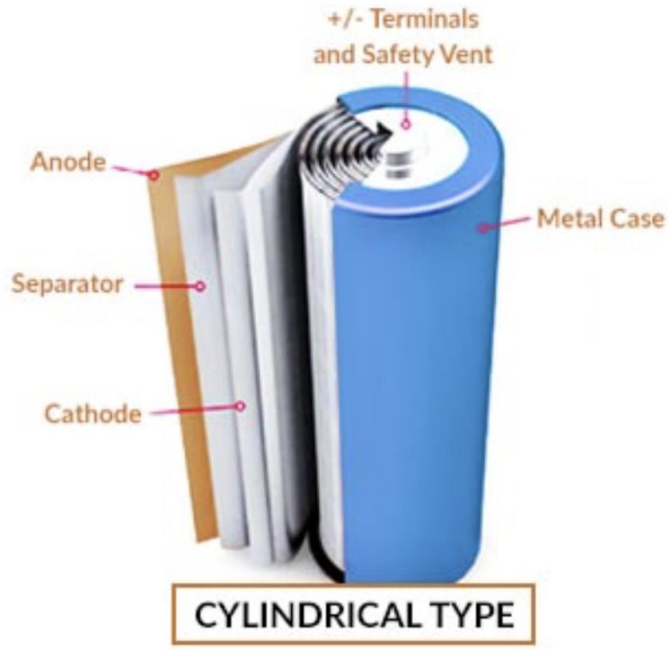


Image from: Dahmen C, Degen F, Eckstein MC, et al. Mastering Ramp-up of Battery Production. Published online October 16, 2024. doi:10.24406/PUBLICA-3727

Electrode coating process in battery cell production



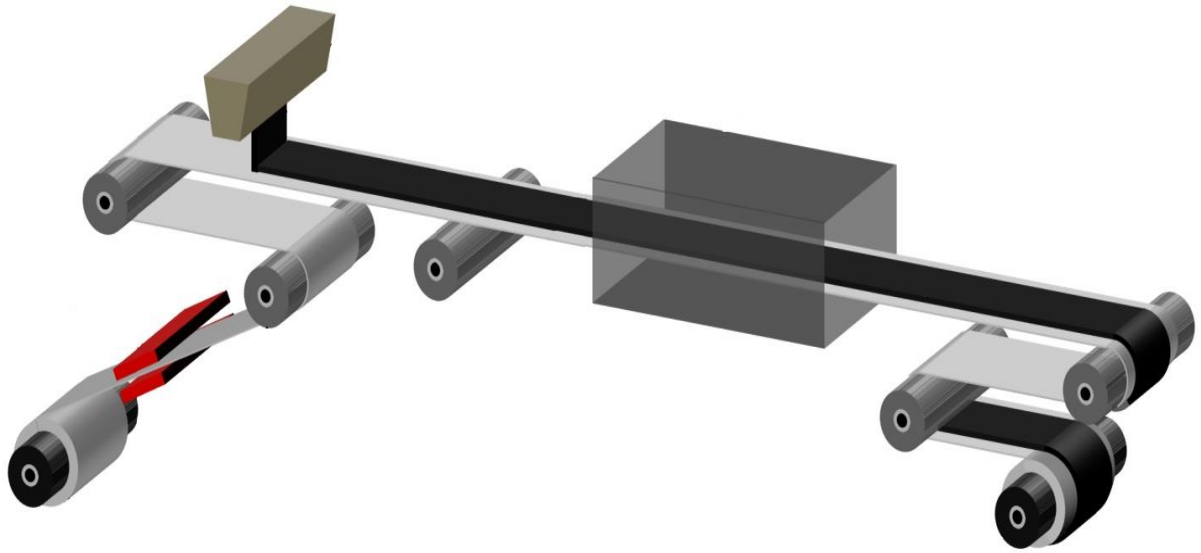


Images from: https://autotech.news/dry-manufacturing-process-offers-path-to-cleaner-more-affordable-high-energy-ev-batteries/ https://www.advancedcopperfoil.com/battery_materials.php

Intermediate „product”

Images from: https://www.greencarcongress.com/2019/06/20190607-iws.html
https://www.ise.fraunhofer.de/en/business-areas/electrical-energy-storage/production-technology-for-batteries/wet-and-dry-electrode-manufacturing-and-thin-film-technology.html

Coating and drying process



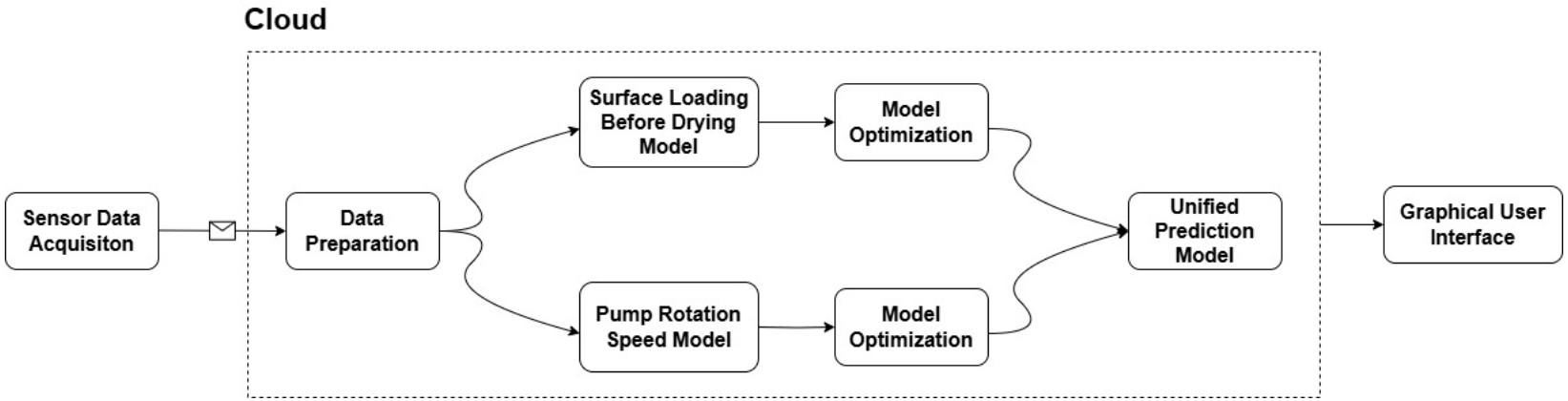


Image from: Samardžić Tin, Development of a prediction model for the electrode coating process in battery cell production, University of Zagreb, FSB, Master thesis, 2025.

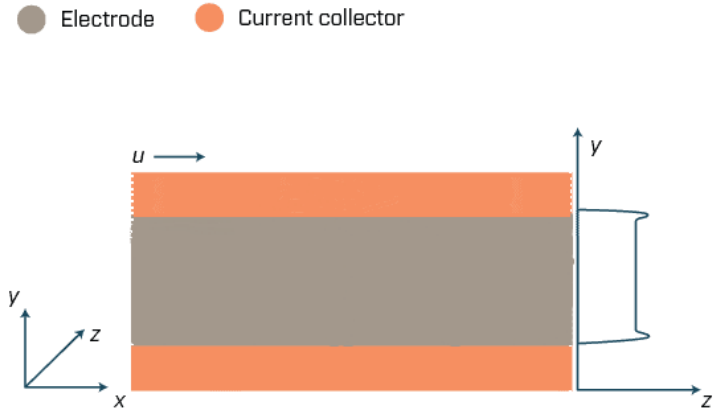
MACHINE PARAMETERS:

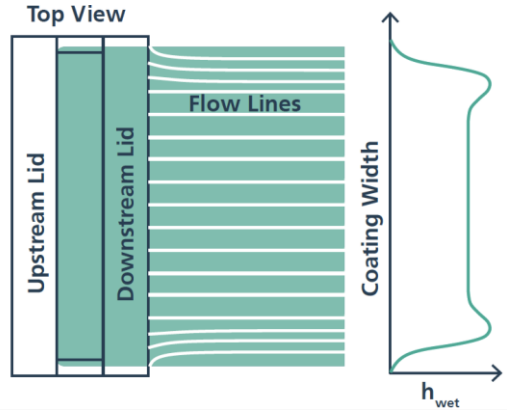
- Coating speed
- Nozzle width
- Distance between the nozzle and the current collector (copper foil)
- Bottom side temperature
- Top side temperature
- Bottom fan speed
- Top fan speed

INPUT PRODUCT PARAMETERS:

- Slurry density
- Slurry viscosity
- Slurry solids content

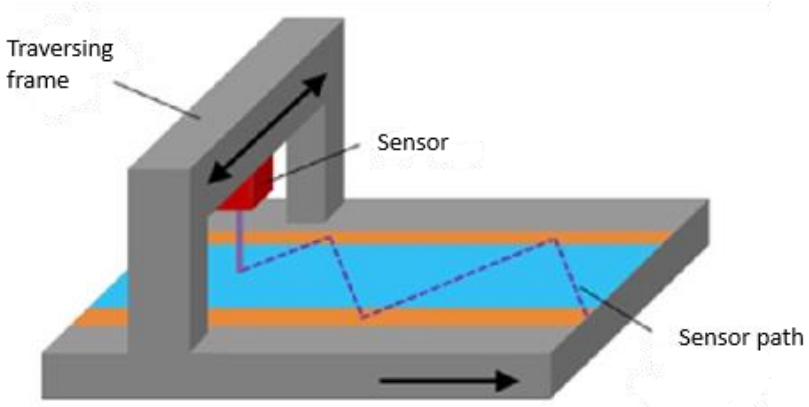
Surface loading measurements

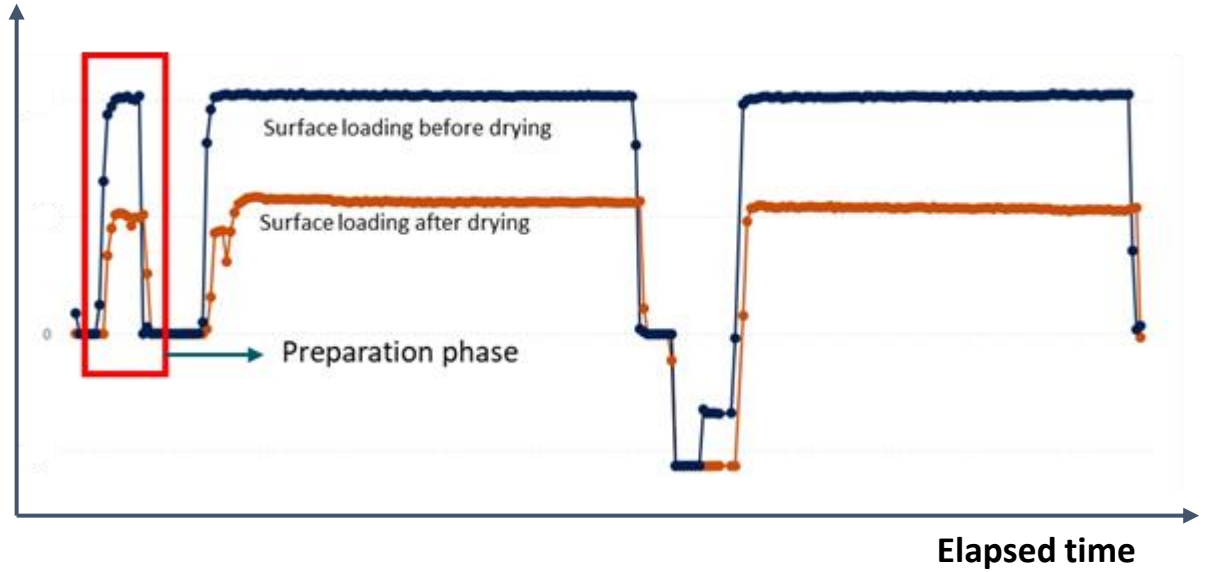




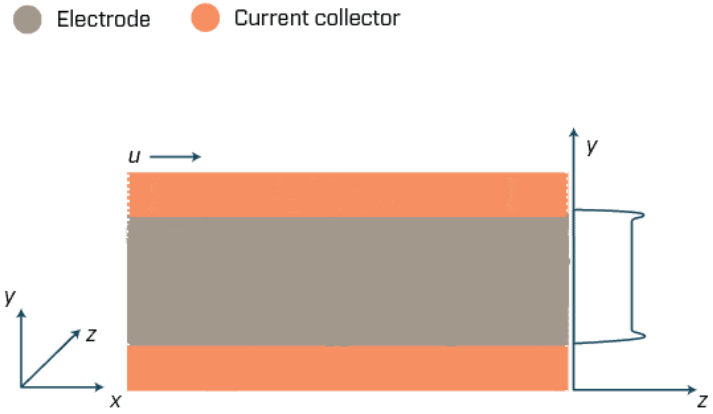
Dahmen C, Degen F, Eckstein MC, et al. Mastering Ramp-up of Battery Production. Published online October 16, 2024. doi:10.24406/PUBLICA-3727

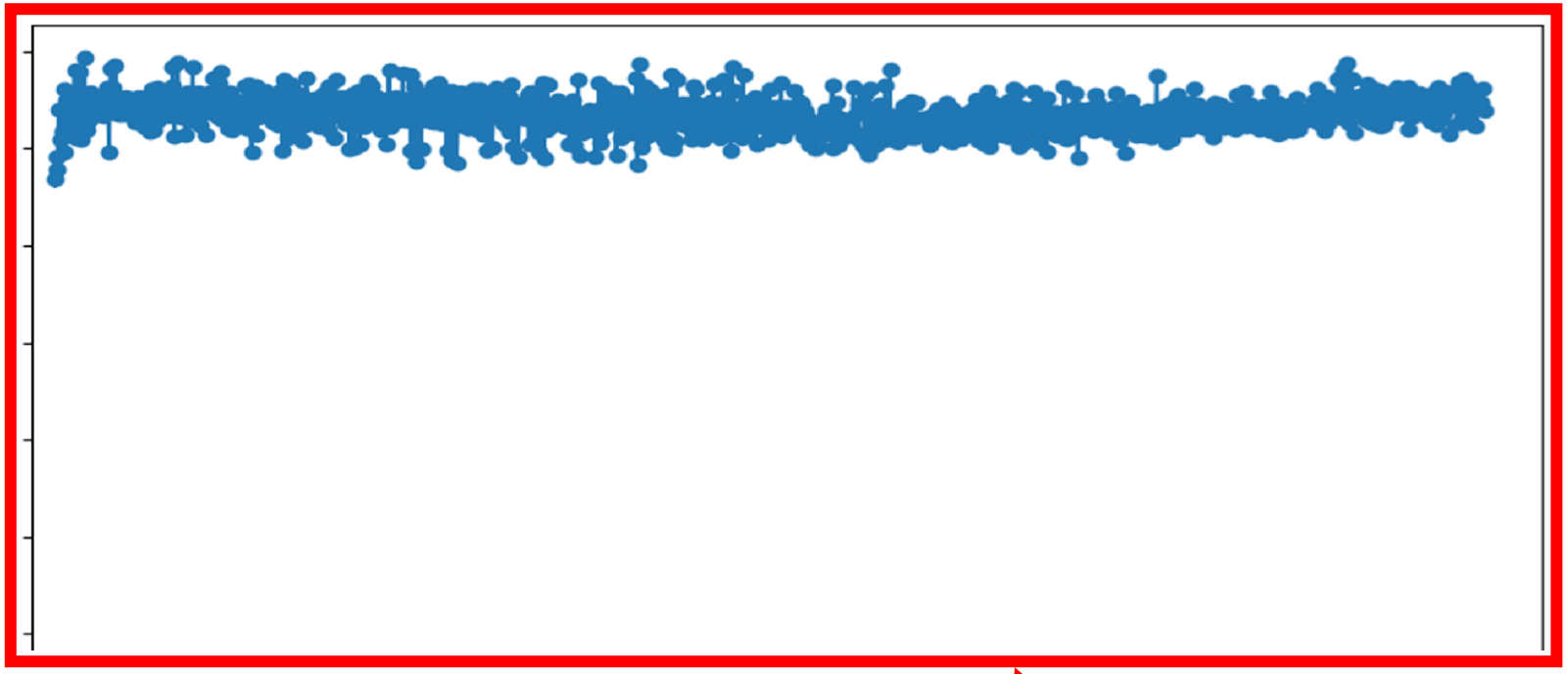
„Surface loading of the electrodes may vary according to the application, for graphite electrodes 6-9 mg/cm².” [Dammala et al. 2023]

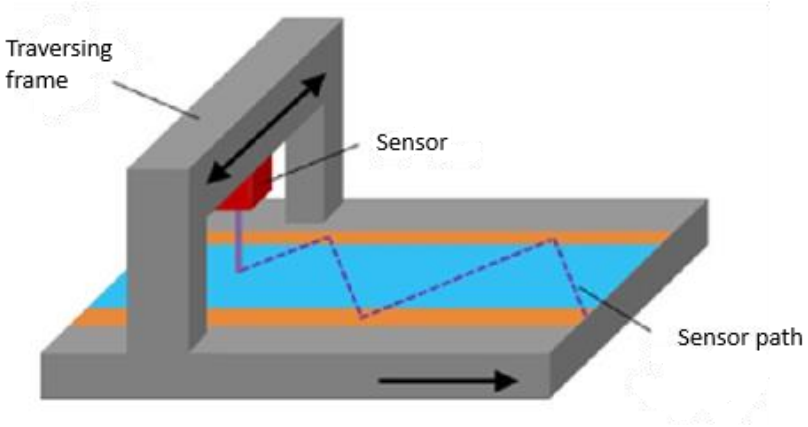


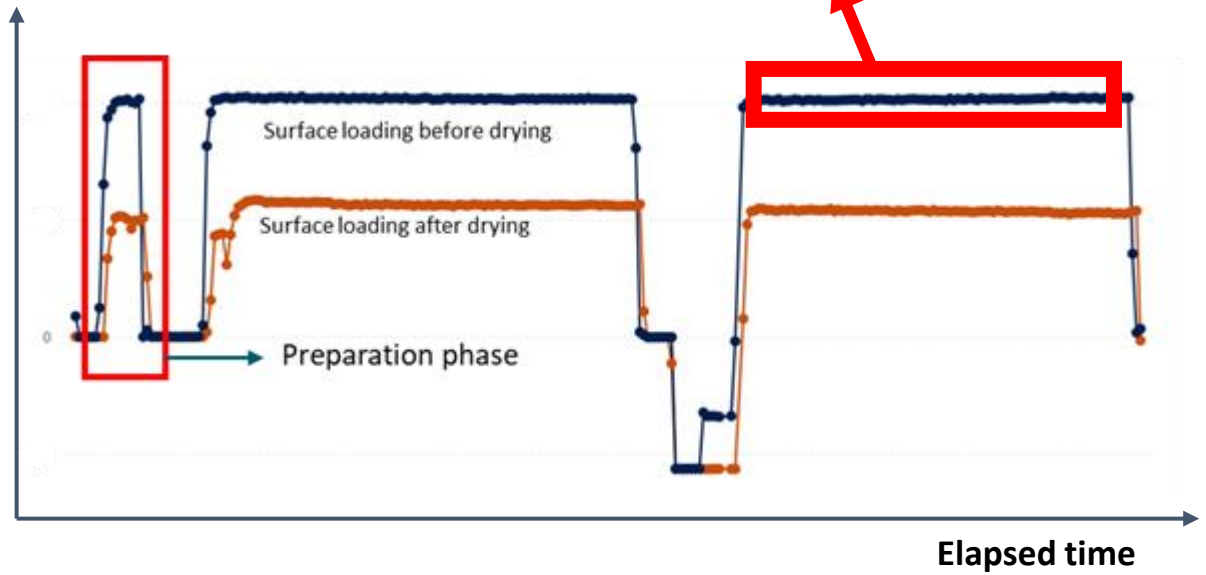


Surface loading







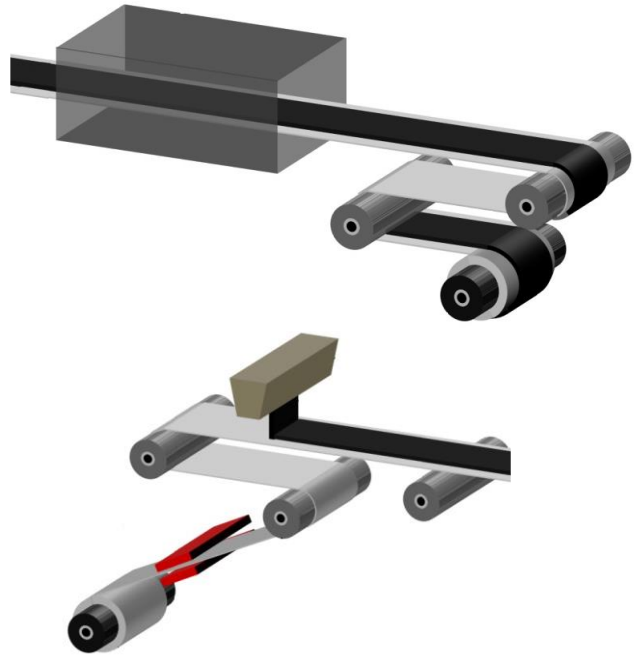


Prediction model

Prediction model goal → Predict the pump rotation speed in order to achieve the desired value of surface loading after drying.

Due to the nature of available data the model is divided into two parts:

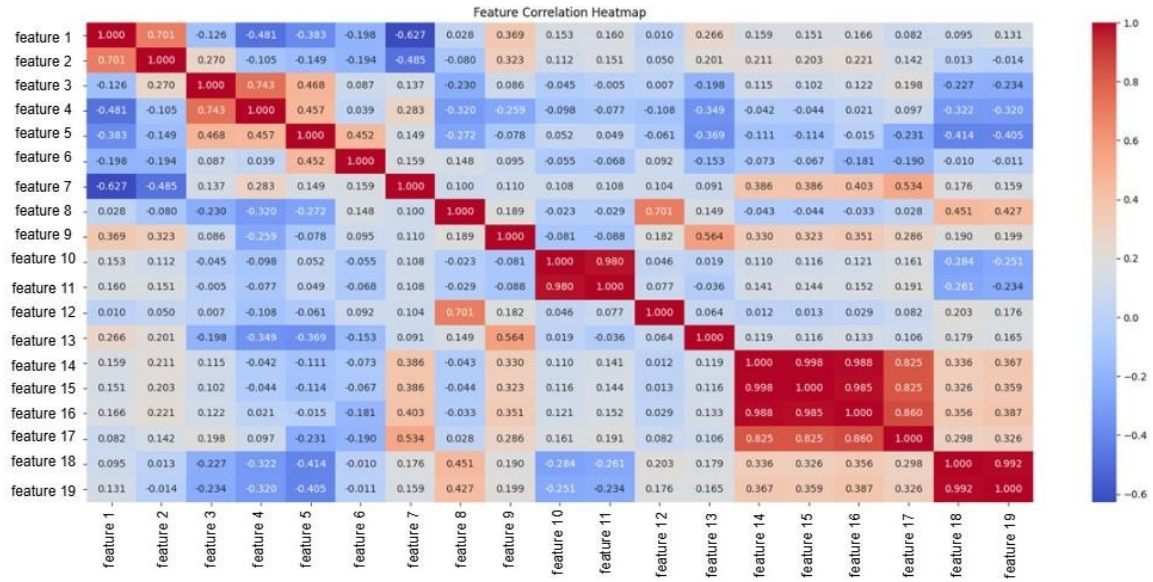
1. **Surface loading before drying**
2. **Pump rotation speed**

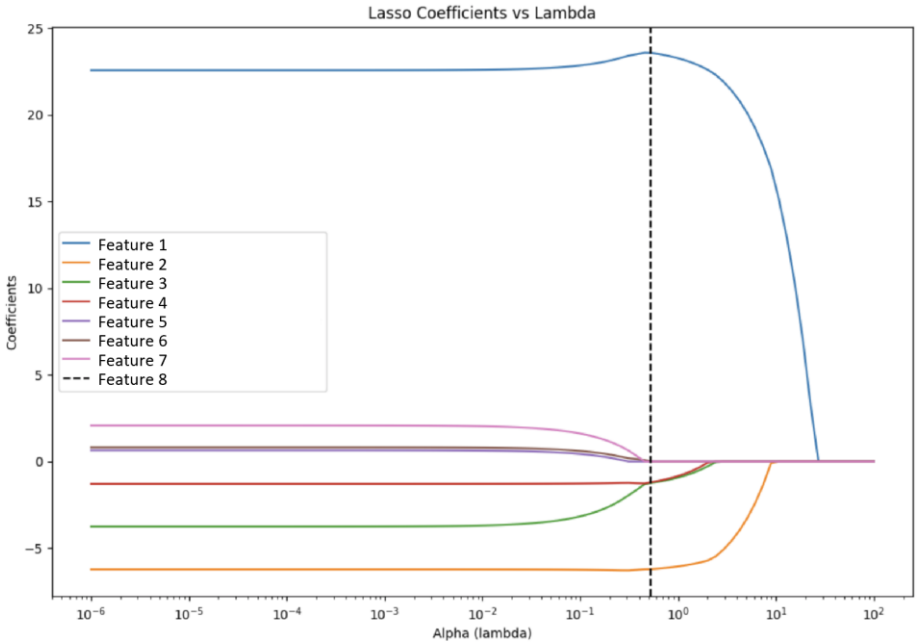


Desired surface loading after drying → **1. Model** → Surface loading before drying → **2. Model** → Pump rotation speed

Prediction model

1. Feature correlation heatmap





2. Dimensionality reduction - Using VIF (Variance Inflation Factor) to identify multicolinearity.
3. After multiple features have been removed →check the feature importance to further reduce the dimensionality.
   Evaluation methods: k-fold cross validation, Leave-one-out cross validation (LOOCV), Bootstraping
4. Developed prediction models based on LASSO regression, XGBoost, Decision Tree, Random Forest.

Initial results

Desired surface loading after drying → **1. Model** → Surface loading before drying → **2. Model** → Pump rotation speed

Implementation on the Test set: →

Accuracy
> 95%

Once implemented in production the developed model has a potential to reduce the following:

- Coating preparation phase reduction ~ **40 min**
- Material reduction for preparation ~ **10%**

Future steps → Small improvements and implementation of the model in the production.

Thank you.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