



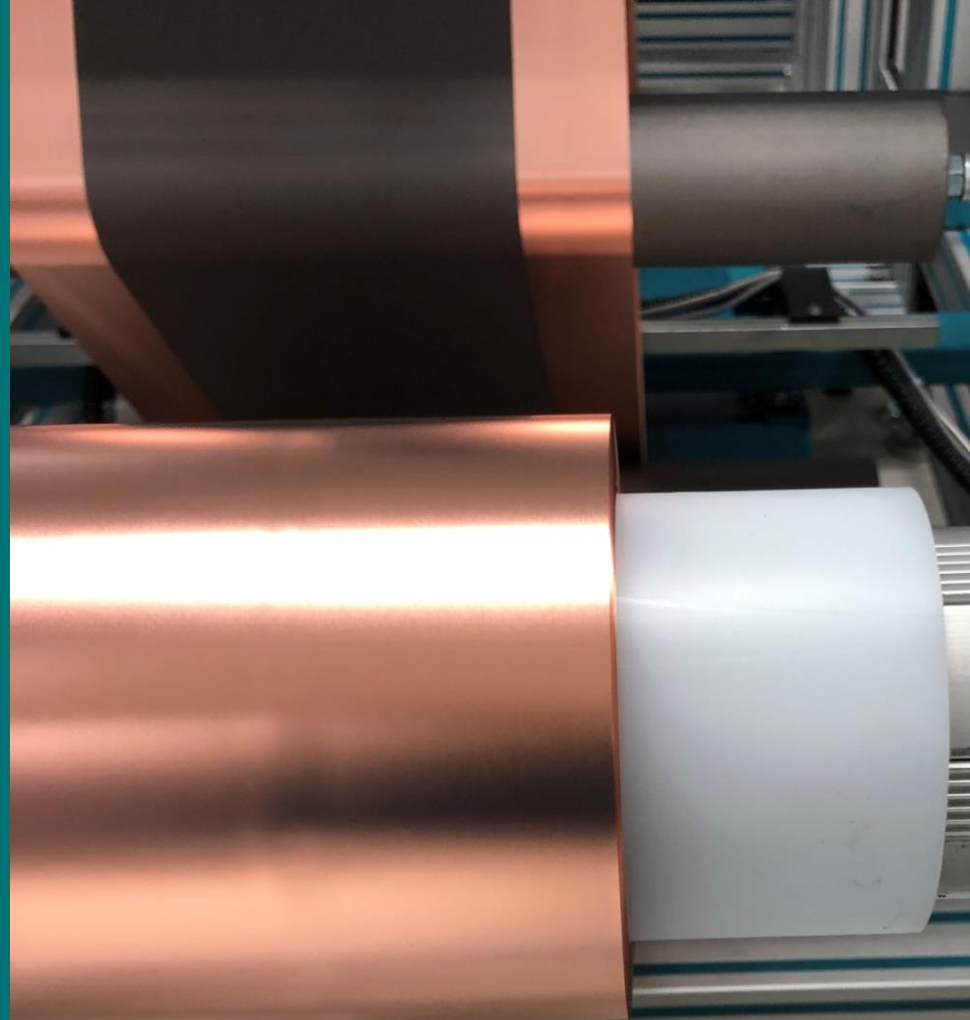
Coating solutions for batteries lab 2 fab concept

Coatema

25/03/22

MEMBER OF ATH

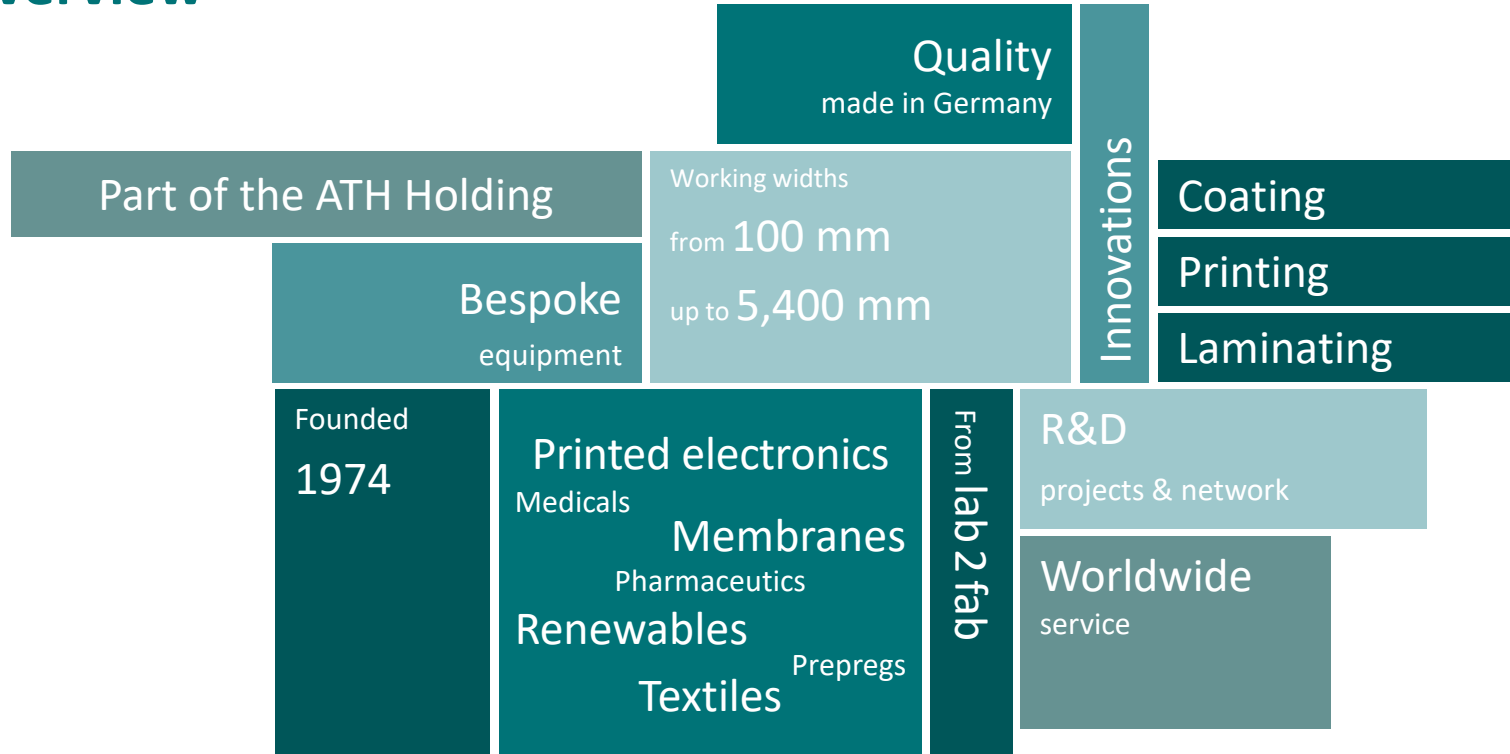
1. Introduction
2. Battery basics
3. Process technology
4. Coating systems
5. Slot die coating for batteries
6. Drying technologies
7. Today`s equipment for batteries
8. Battery production lines
9. Li-ion battery Project INTRES
10. Solid state battery
11. Quality control systems
12. Simulation
13. Spatial ALD
14. The battery fab
15. Summary



Introduction



Overview



Group of companies

ATH ALTONAER
TECHNOLOGIE
HOLDING



- ✓ Founded 1903
- ✓ Approx. 200 employees
- ✓ Located in Hamburg

DRY/TEC

- ✓ Founded 1995
- ✓ Approx. 50 employees
- ✓ Located in Norderstedt



- ✓ Founded 1974
- ✓ Approx. 50 employees
- ✓ Located in Dormagen

Vision – from lab 2 fab



Lab



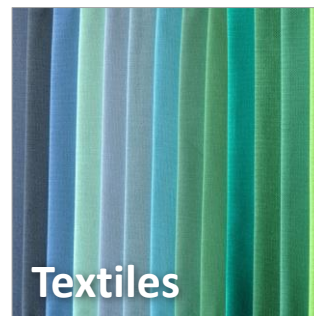
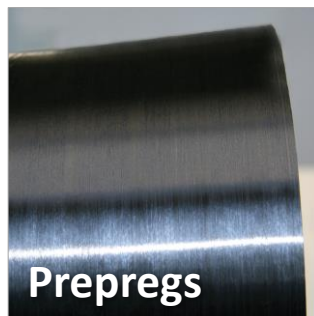
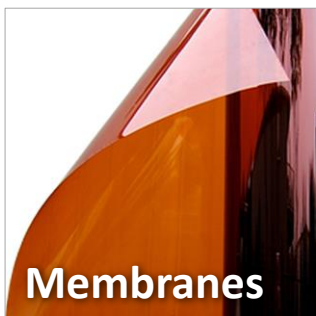
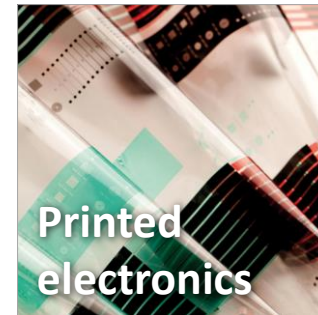
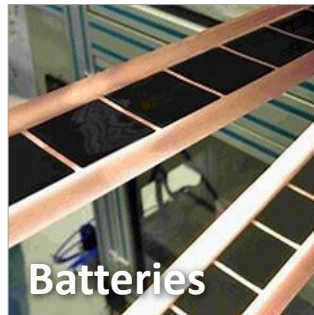
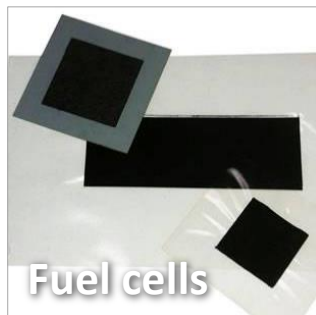
Pilot



Production

Coatema equipment platform strategy for lab 2 fab

Our markets



Lab units

Lab



Test Solution S2S



Easycoater



Test Solution R2R

Pilot lines

Pilot



Click&Coat™



Smartcoater



Basecoater 3rd Generation

Production lines

Production



Production lines



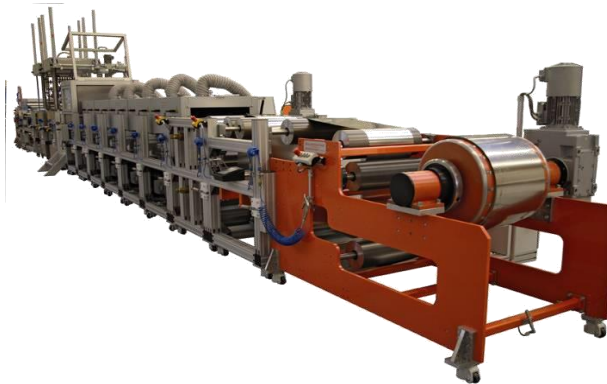
Prepreg plant

Bespoke equipments

Custom
made



Printed oleds



Batteries



Composite fibres

Use of the Coatema research & development centre



Technologies

Coating, printing, laminating, imprinting, pretreatment, drying, curing, cross linking, cutting

Number of units available

10 – 12 units on 1 200 sqm

Sheet-to-Sheet – S2S

up to 300 mm x 500 mm

Roll-to-Roll – R2R

up to 500 mm width

Operation speed

0.1 to 100 m/min

Product portfolio

Process development

- ✓ Feasibility study
- ✓ Ink – process study
- ✓ Process analysis
- ✓ Proof of concept
- ✓ Small scale prototype

Test production

- ✓ Prototyping
- ✓ Near to market testing
- ✓ TRL evaluation
- ✓ Training of staff

Education

- ✓ Coatema conference
- ✓ Training of customers
- ✓ Education of students

After sales service and ramp up of processes

- ✓ of Coatema units

Development of custom made design for equipment

- ✓ Prototyping
- ✓ Proof of concept

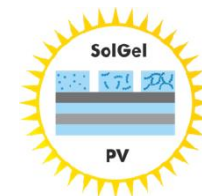
Funded research projects

- ✓ German funded
- ✓ Horizon 2020
- ✓ Global 2+2 projects
- ✓ B2B projects

R&D customers



R&D projects overview 2022

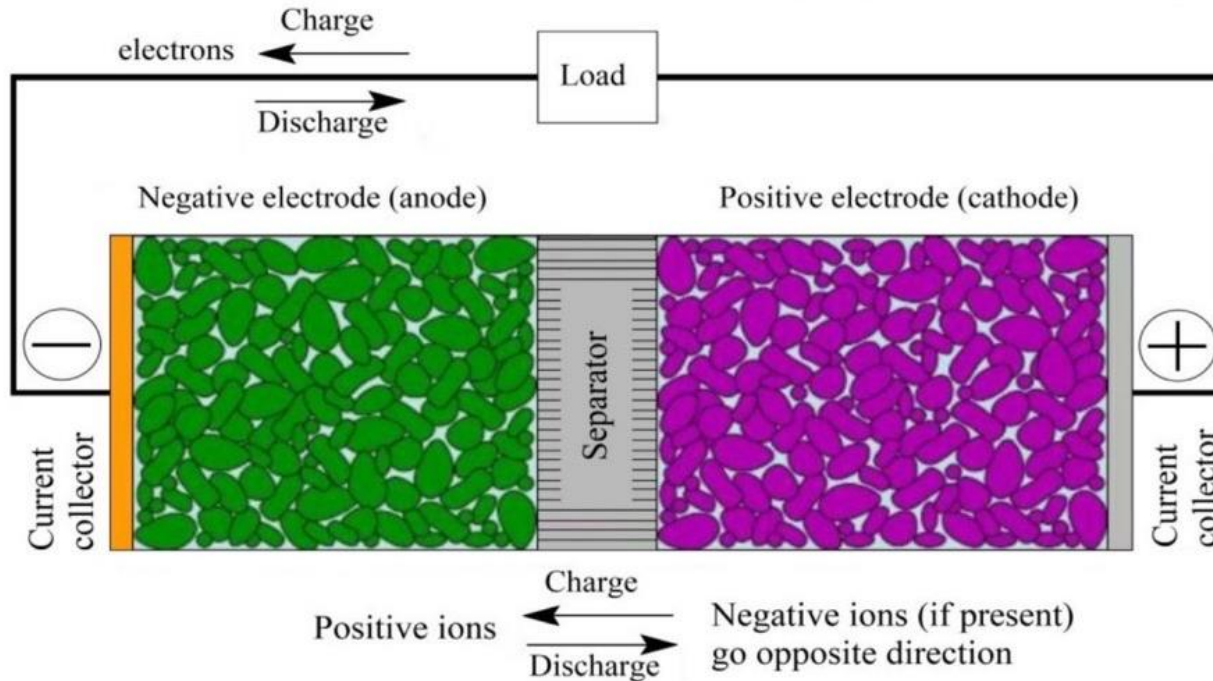


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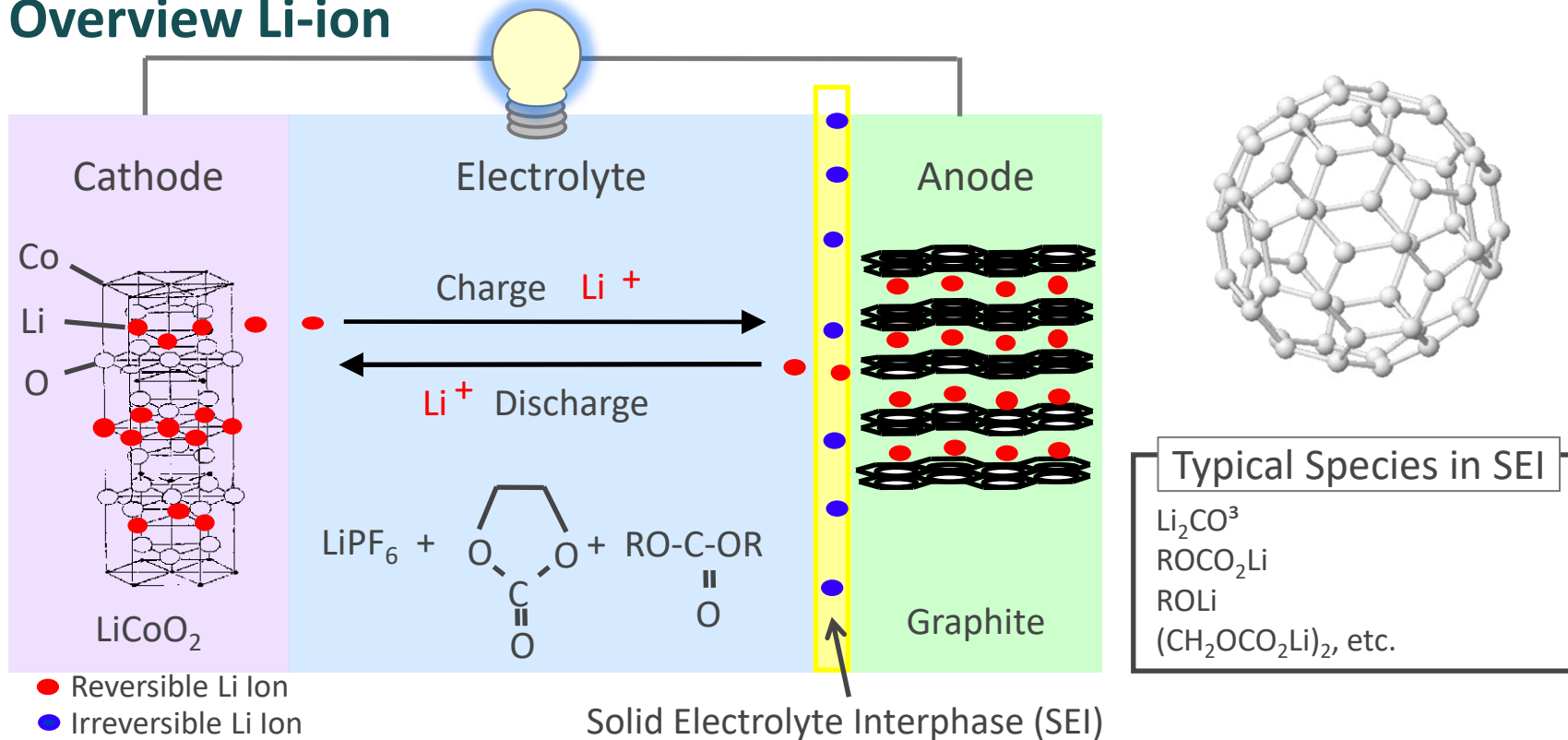
Battery basics



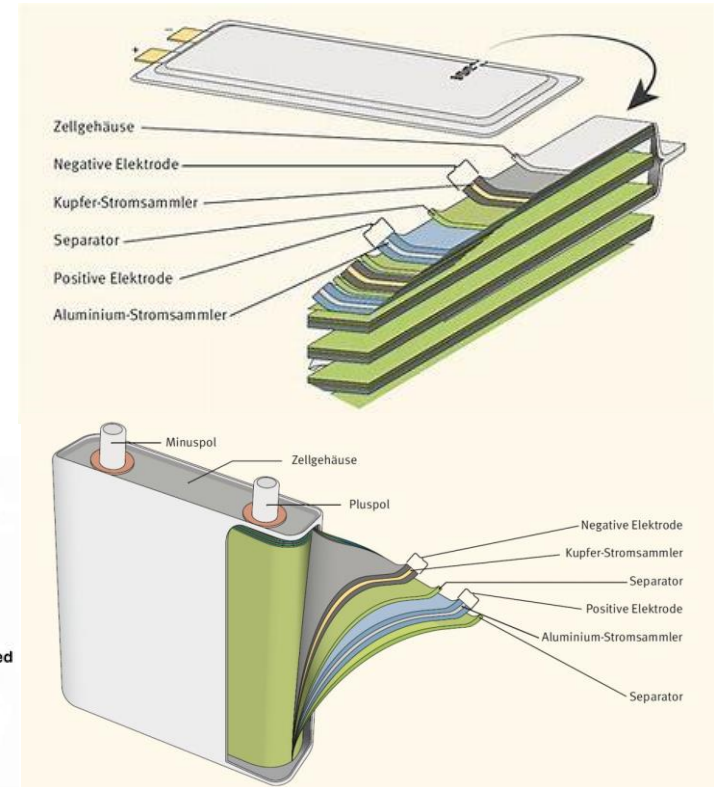
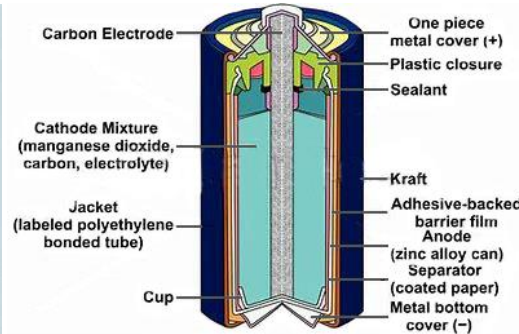
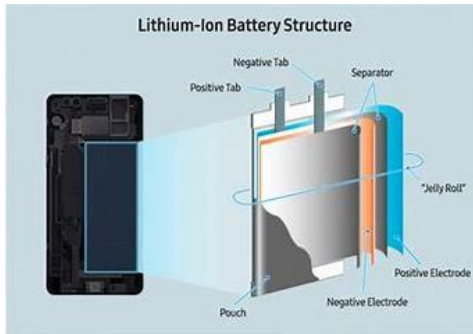
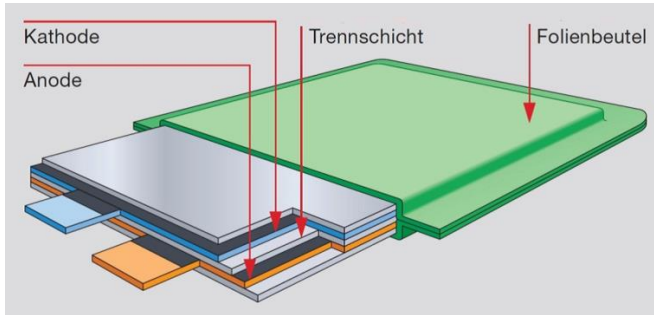
Lithium-ion Batteries



Overview Li-ion



Overview Li-ion



Li-on developments – European producers and cell types

TYPES OF CELL FORMATS PRODUCED BY MANUFACTURERS OF ELECTRIC VEHICLE BATTERIES

CIC energigUNE
MEMBER OF BASQUE RESEARCH & TECHNOLOGY ALLIANCE

MANUFACTURER	FORMAT
LG Chem	CYLINDRICAL POUCH
SAMSUNG	CYLINDRICAL PRISMATIC
SK Innovation	POUCH
CATL	PRISMATIC
Panasonic	CYLINDRICAL
northvolt	PRISMATIC
VECOR	POUCH
Gotion	PRISMATIC
SARASIS	POUCH
Envision AESC	POUCH

Source: Public information

CHART OF THE WEEK

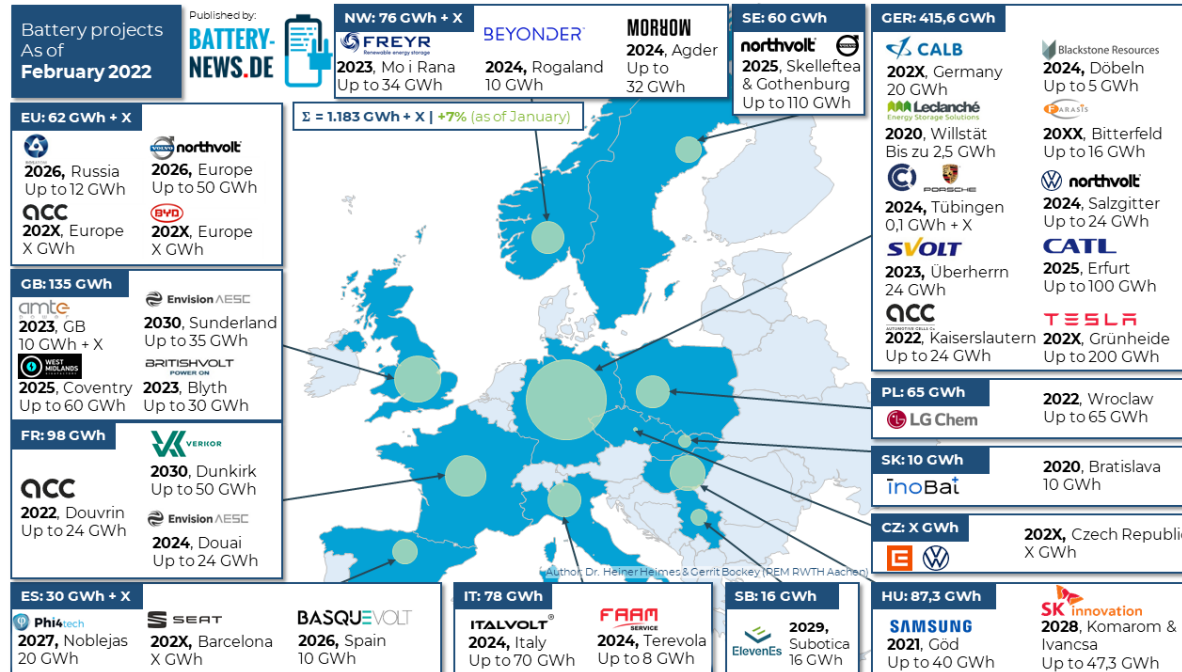
EUROPEAN ELECTRIC VEHICLE CELL SUPPLY CHAIN SUMMARY

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OEM	Cathode Type	Format	Some Key Suppliers
Ford	NMC	Pouch	LG Chem SK Innovation
RENAULT NISSAN MITSUBISHI	NMC	Pouch	VECOR Envision AESC LG Chem
BMW	NMC	Prismatic	CATL northvolt SAMSUNG
VW	NMC LFP	Prismatic	SAMSUNG northvolt Gotion
VOLVO	NMC	Pouch Prismatic	LG Chem northvolt
DAIMLER	NMC LMFP	Pouch Prismatic	CATL LG Chem SARASIS NCC
JAGUAR	NCA	Cylindrical	SAMSUNG
HYUNDAI	NMC	Pouch	LG Chem
STELLANTIS	LMFP NMC	Prismatic	NCC SVOLT
TESLA	LFP	Prismatic	CATL

Source: Public information

Li-ion Giga fab projects in Europe



Li-on developments – Equipment supply chain

Eine zentrale Herausforderung besteht in der Integration der einzelnen technologisch diversen Prozessschritte zu einer robusten Produktionskette.

Lieferanten von Maschinen & Anlagen entlang der Prozesskette der Batteriezellproduktion

Produktionsprozessschritte [Auszug]

	Mischen	Beschicht.	Kalandr.	Slitten	Vakuumtr.	...
Bühler	■					
Netzsch	■					
Eirich	■					
Hohsen	■					
Coatema		■	■			
B&W		■	■			
Hirano					■	
Kroenert		■				
Breyer			■			
Saueressig			■			
Kampf				■		
Meier					■	
...						

Maschinen- & Anlagenbauer [Auszug]

■ Maschinen- & Anlagenbauer besitzt Kompetenzen im Produktionsprozessschritt
□ Maschinen- & Anlagenbauer besitzt keine Kompetenzen im Produktionsprozessschritt

Quellen: PEM Datenbank für Maschinen & Anlagen in der Batteriezellproduktion

- Die Produktionskette einer Lithium-Ionen-Batterie zelle beinhaltet eine Vielzahl technologisch stark unterschiedlicher Prozessschritte.
- Unternehmen fokussieren sich auf Basis ihrer bestehenden Kompetenzen auf einzelne Prozessschritte bzw. Teilprozessketten.

Es existiert kein Maschinen- & Anlagenbauer mit Kompetenzen entlang der gesamten Prozesskette der Batteriezellproduktion.

- Der Produktionsprozess von Lithium-Ionen-Batterie zellen ist hochgradig automatisiert.
- Zwischen den einzelnen Prozessschritten bzw. Maschinen & Anlagen existiert eine Vielzahl von Interdependenzen und verschiedenen Schnittstellen.

Für den Aufbau und den Betrieb einer wettbewerbsfähigen Batteriezellproduktion sind ein Gesamtssystemverständnis und Erfahrungen erforderlich.

Gigfab calculation – Li-ion Gigafab for 14 GWh/a

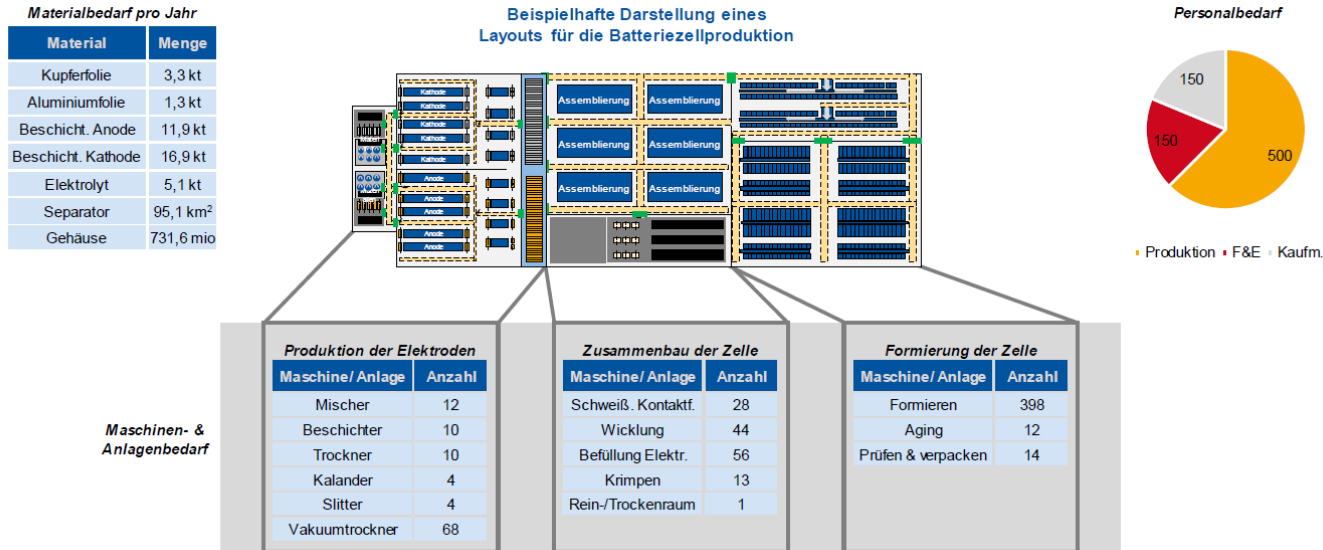
Prämissen, Annahmen und Daten für einen beispielhaften Entwurf einer Batteriezellfabrik

Produktprämissen		Produktionsannahmen und Maschinendaten	
Leistungseigenschaften: 5,2 Ah 3,68 V 290 Wh/kg 790 Wh/l		Produktionsannahmen	
Zellformat/-dimensionen/-gewicht: - Zylindrisch 21 mm (Durchmesser); 70 mm (Höhe) 66 g		Produktionskapazitäten: 14 GWh/a 731.600.000 Zellen/a	Schichtmodell: 301 d/a, 3 Schichten/d, 8 h/Schicht
Zellchemie: - Elektroden: Graphit vs. NMC 622 - Elektrolyt: EC:DMC + LiPF₆ - Separator: Polyolefinbasis mit keram. Beschichtung		Maschinendaten	
Zelldesign:		Mischen - Mischvolumen: 300 l - Mischdauer: 45 min	Beschichten & Trocknen - Beschicht.-breite: 800 mm - Beschichtgeschwindigkeit: 30 m/min
Zellstruktur:		Kalandern & Slitten - Kalandrierbreite: 800 mm - Kalandriergeschwindigkeit: 100 m/min	
Zellmaterialien:		Vakuumtrocknen - Coils/ Trockner: 4 - Trocknungsdauer: 24 h	Kontaktflächen Anbringen - Zellen/ Schweißanlage: 6 - Schweißdauer/ Kontaktfahne: 5 sek
Zellabmessungen:		Elektrolyt Befüllen - Zellen/ Befüllungsanlage: 500 - Befüllungsdauer/ Zelle: 840 sek	Krimpen - Zellen/ Krimpanlage: 8 - Krimpdauer/ Zelle: 3 sek
Zellkomponenten:		Wickeln - Zellen/ Wickelanlage: 2 - Wickeldauer/ Zelle: 2,6 sek	Formieren - Zellen/ Lagersystem: 4.500 - Formierungsdauer/ Zelle: 15 h
Zellmaterialien:		Aging - Zellen/ Lagersystem: 5 Mio - Agingdauer/ Zelle: 20,5 d	Prüfen & Verpacken - Zellen/ Ladesystem: 4.500 - Ladedauer/ Zelle: 30 min

Quelle: PEM Datenbank für Maschinen & Anlagen in der Batteriezellproduktion (konservative Annahmen bei Maschinendaten)

Gigfab calculation

Exemplary design of a battery cell factory with an annual output of 14 GWh



Quelle: PEM Datenbank für Maschinen & Anlagen in der Batteriezellproduktion

Soucre: RWTH Aachen University

New type of batteries – The world after Li-ion

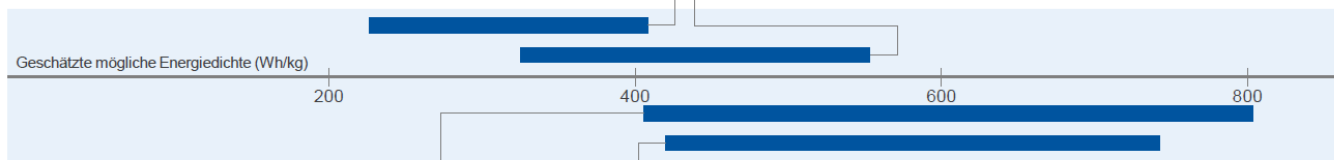
Unter „Post-Lithium-Ionen-Technologien“ werden verschiedene neue, vielversprechende Ansätze zusammengefasst

Hochenergie-Lithium-Ionen-Batterie

- Evolutionäre Verbesserung durch Hochenergie-Materialien
- Höhere gravimetrische und volumetrische Energiedichten durch Nickelreiche NMC- oder NCA-Kathoden und Silizium-Komposit-Anoden
- Nur leichte Anpassungen im Produktionsprozess notwendig

Lithium-Schwefel-Batterie

- Kathode: Lithium verbindet sich mit Schwefel zu Lithiumsulfid
- Schwefel als häufiges und kostengünstiges Material
- Unklare zyklische und kalendarische Lebensdauer sowie große Temperaturabhängigkeit
- Volumetrische Energiedichte derzeit für den Automotive-Einsatz zu gering



Lithium-Luft-Batterie

- Kathode: Lithium reagiert mit Sauerstoff zu Lithiumperoxid und Lithiumoxid
- Theoretisch sehr hohe Energiedichte bei Verwendung von Umgebungsluft
- Automotive-Einsatz im kommenden Jahrzehnt unrealistisch

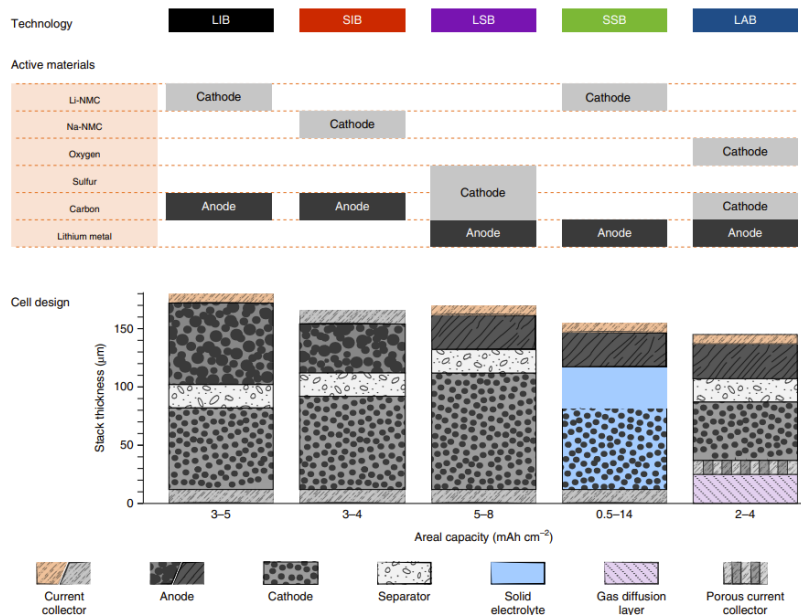
All-Solid-State-Batterie

- Elektrolyt in fester Form, keine Flüssigkeiten
- Sehr hohe Energiedichte und Sicherheit auf Laborebene, essentiell für Automotive-Einsatz
- Herausforderungen bei Materialkompatibilitäten und Herstellbarkeit in Serie

Mit Ausnahme evolutionärer Verbesserungen der Lithium-Ionen-Batterie befindet sich keine der Technologien derzeit in einem serienreifen Entwicklungsstand, auf dessen Basis die industrielle Produzierbarkeit vollumfänglich bewertet werden könnte

New type of batteries – Background on SSB and other batteries

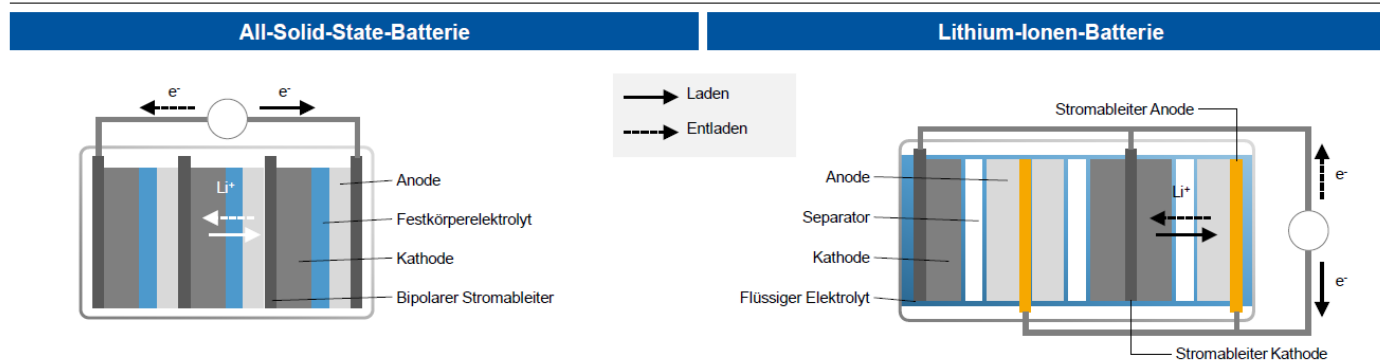
Nature Energy Review Article



- ✓ Application under dry room
- ✓ Application with Li metal as Anode
- ✓ under Ar atmosphere
- ✓ Coating and laminating processes
- ✓ Difference between sulfid SSB and oxide based SSB technologies
- ✓ Calendering processes
- ✓ SALD for protection layer

New type of batteries – Difference between LIB and SSB

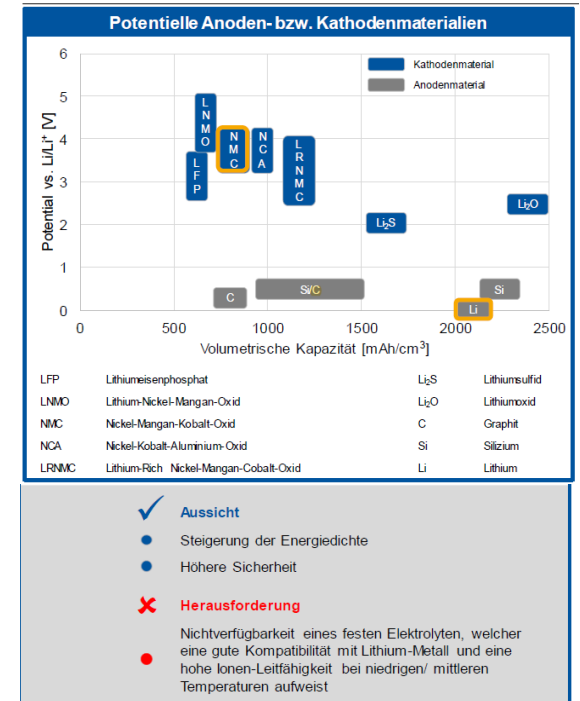
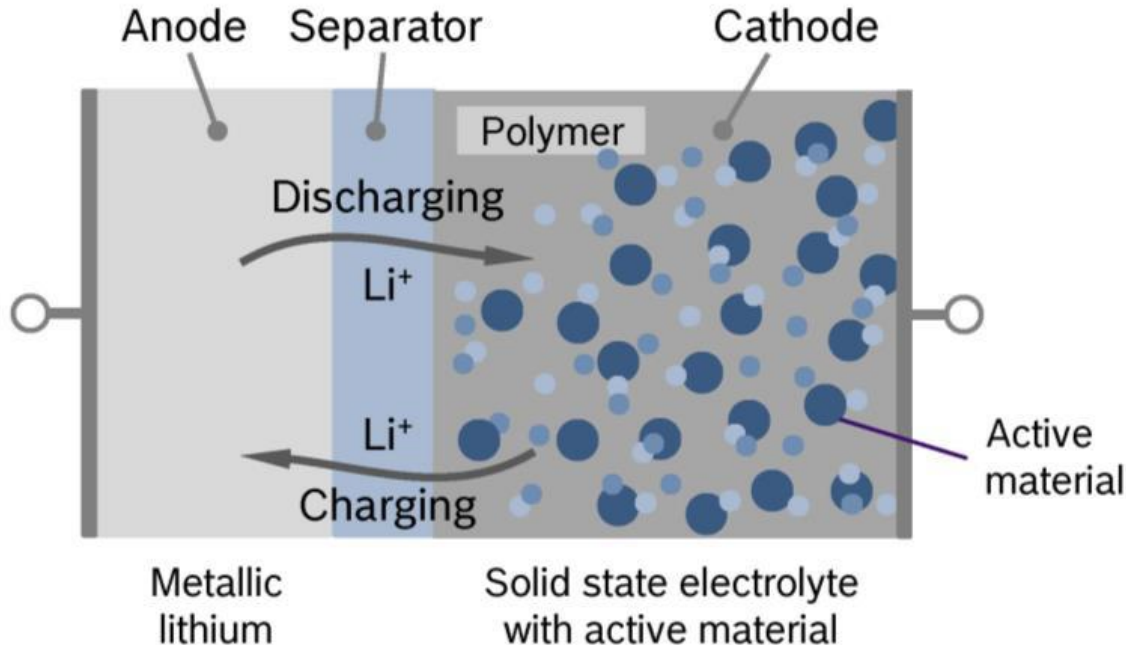
Die All-Solid-State-Batterie unterscheidet sich im Aufbau von der herkömmlichen Lithium-Ionen-Batterie



Unterschiede im Aufbau der All-Solid-State-Batterie:

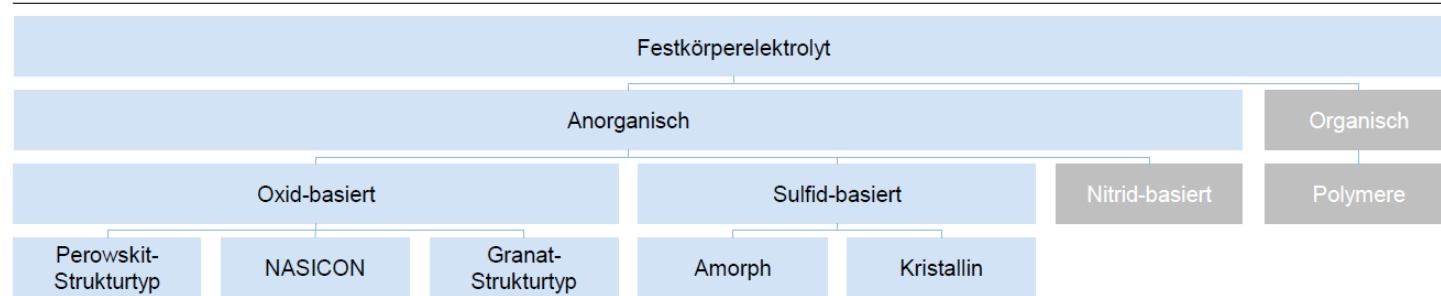
- Ionen-durchlässiger **Festkörperelektrolyt** sorgt für elektrische Trennung zwischen Kathode und Anode
- Festkörperelektrolyt dient gleichzeitig als **Separator**
- Verschiedene Zell-Designs denkbar: **Dünnschichtzelle** (ähnlich zur Abbildung links) oder dickere Schichten durch Aufbau mit **Mischkathode**
- **Entladevorgang:** Lithium-Ionen bewegen sich von Anode durch Festkörperelektrolyt zu Kathode → Strom fließt an äußerer Last
- **Bipolare Stapelung** aufgrund festem Elektrolyten möglich → **serielle Verschaltung** der Elementarzellen

New type of batteries – Basics of solid state batteries



New type of batteries – Basics of solid state batteries

Verschiedene Arten von Elektrolyten für Festkörperbatterien können unterschieden werden



Oxid-basierte Elektrolyte

- Gute chemische Stabilität
- Kompatibel mit hochenergetischen Kathodenmaterialien
- Ionen-Leitfähigkeit niedriger als bei sulfid-basierten Elektrolyten

Sulfid-basierte Elektrolyte

- Höhere Ionenleitfähigkeit als bei Oxid-basierten Elektrolyten
- Chemisch unbeständiger gegenüber der Atmosphäre

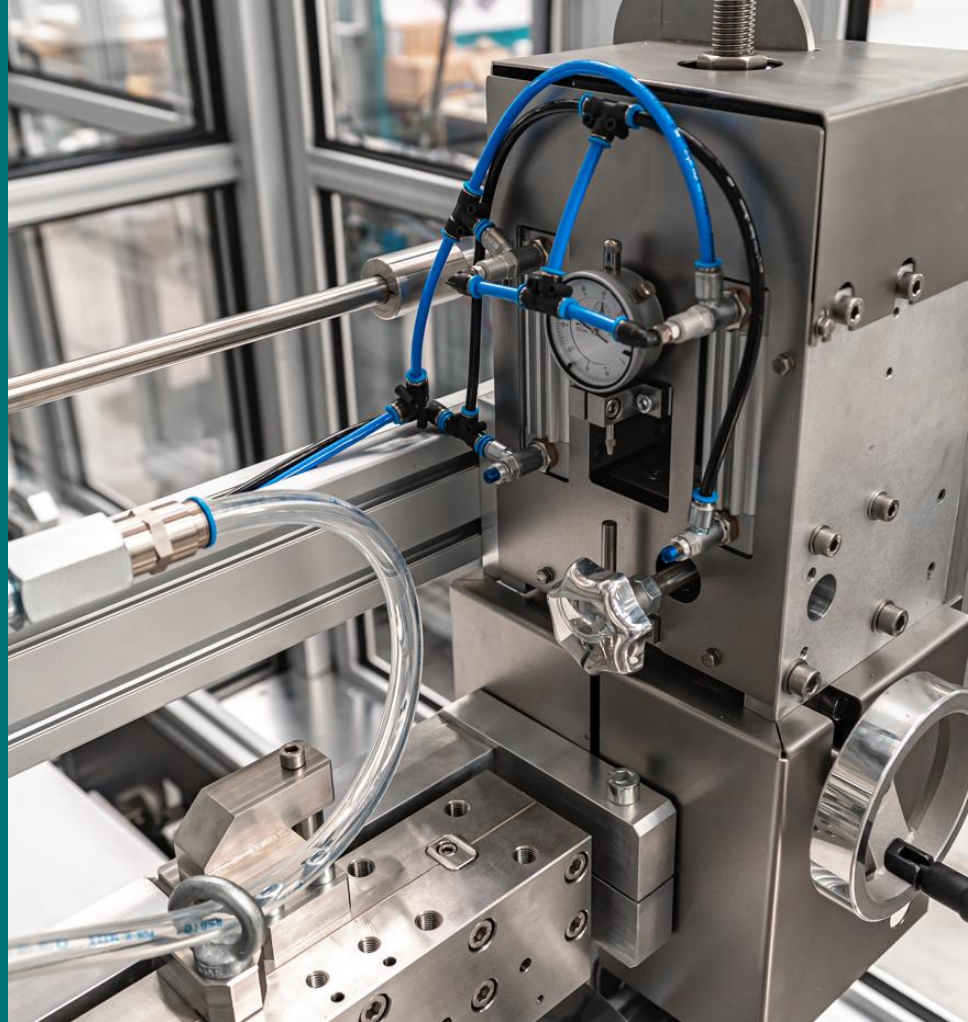
Polymer-Elektrolyte

- Geringer Widerstand zwischen Elektrode und Elektrolyt
- Teilweise entflammbar und toxisch
- Chemisch unbeständiger

Bei der Betrachtung der Elektrolytvarianten ist vor allem deren Produzierbarkeit zu berücksichtigen

3.

Process control

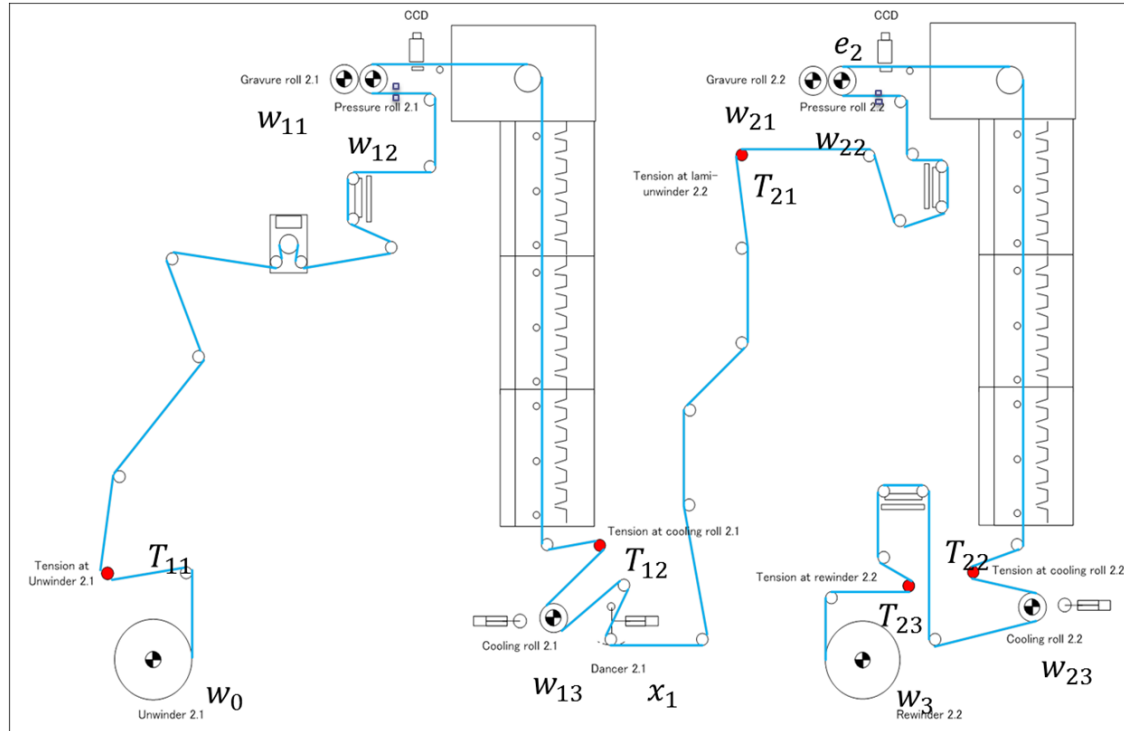


Technologies & processes – process parameters

Process parameters are:

- ✓ Operation speed
- ✓ Rheology of coating and printing inks
- ✓ Substrate condition
- ✓ Tension control MD / CD
- ✓ Edge control
- ✓ Resolution and registration accuracy of printing / laminating systems
- ✓ Precision of coating operations
- ✓ Curing / drying / crosslinking

Inline process control



Processes



Bridging the gap

From lab 2 fab



Data generation in million of data points

Inline process integration

Tension control

- ✓ Load cell
- ✓ Segmented load cell
- ✓ Dancer
- ✓ Pulling devices
- ✓ Design of drives

Registration control

- ✓ Camera
- ✓ Fiber optic
- ✓ Design of drives
- ✓ Algorithm control

Edge guide control

- ✓ Different sensors
- ✓ Mechanical stress
- ✓ Data collection

Process analysis

- ✓ Statistic parameters
- ✓ Product flow analysis
- ✓ Yield
- ✓ Cost of ownership
- ✓ Artificial intelligence

Quality control

- ✓ Particle contamination analysis
- ✓ Defect detection
- ✓ Thickness control
- ✓ Function control of the device or layer
- ✓ Big data (Cloud)
- ✓ IoT
- ✓ AI / ML

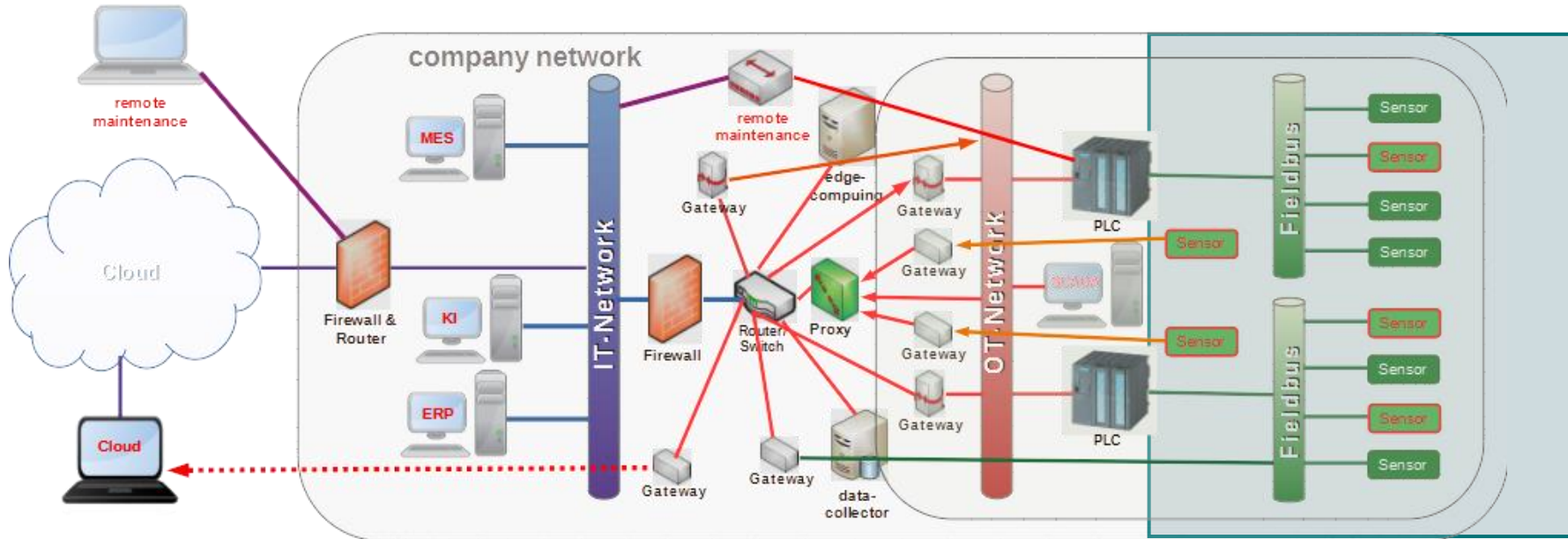
in der speed / Diameter / Cross position / tension / particle contermination / substrate defects / registration marks



- Number of measuring points
- Amount of measurements per time



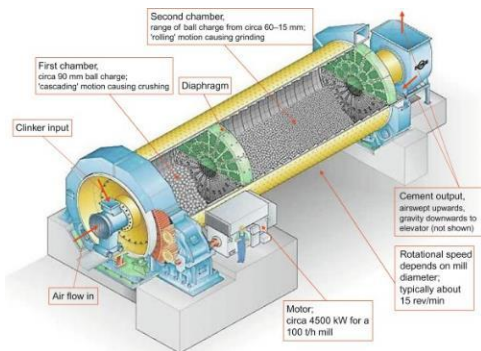
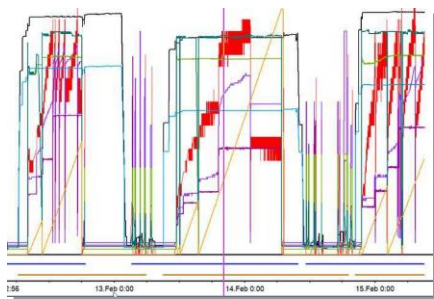
Complexity introduced through connectivity



Heterogeneous connectivity landscape:
complex, prone for errors, multiple penetration points, difficult to maintain,

Solution based approach

ARENDAR



Monitoring
Sensors and Logs (e.g. torque, vibrations, documentation, maintenance manuals, ...)

Detection
Analysis of specific system states (e.g. characteristic frequencies)



Diagnostics
Root cause analysis (e.g. damaged bearings, clogged filter, ...)

Control
Maintaining productivity (e.g. increasing viscosity)

Prediction
Spare parts and maintenance (next service, service tasks, ...)

ARENDAR and AI: options for process optimization

Consistent Data Recording

Transparent extraction of data points from connected systems, machines, and field sensors

Data (Pre)-processing and visualization:

Edge computing capabilities allow to combine data points; Scalable SCADA

ARENDAR as data collector

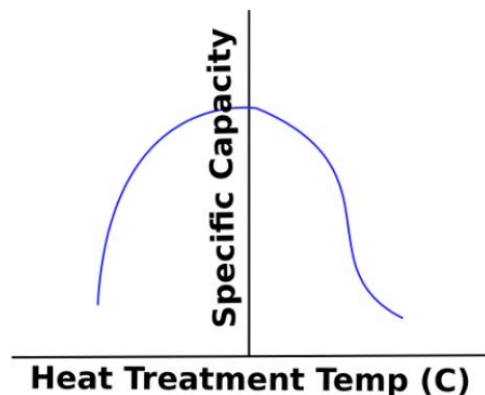
for advanced AI model generation

machine learning approaches

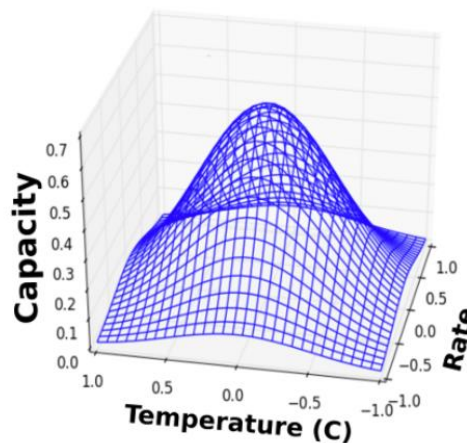
NN / Deeplearning approach

- ✓ Edge-Computing
- ✓ Data (Pre) Processing, Data Storage (on premise / Cloud) Data Visualization
- ✓ Resilient: (semi) autonomous operation
- ✓ Advanced possibilities: utilizing historical data for AI model generation rollout of AI models on edge device

Understanding the data



A



B

Target of all the efforts:

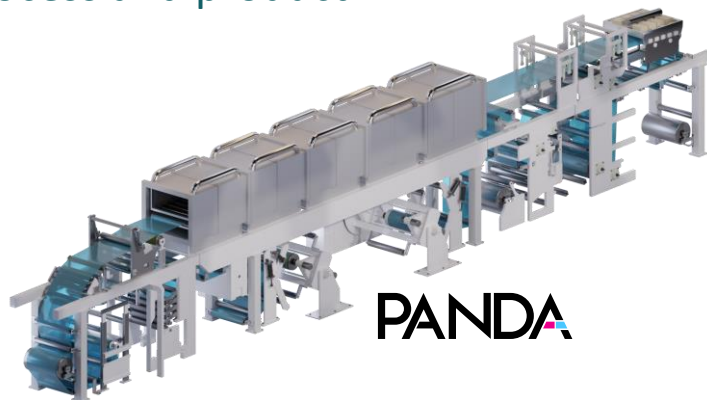
Finding the parameters
which will lead to failure

Reducing the number of
parameters to be controlled

Coating Equipment -Artificial Intelligence for better coatings

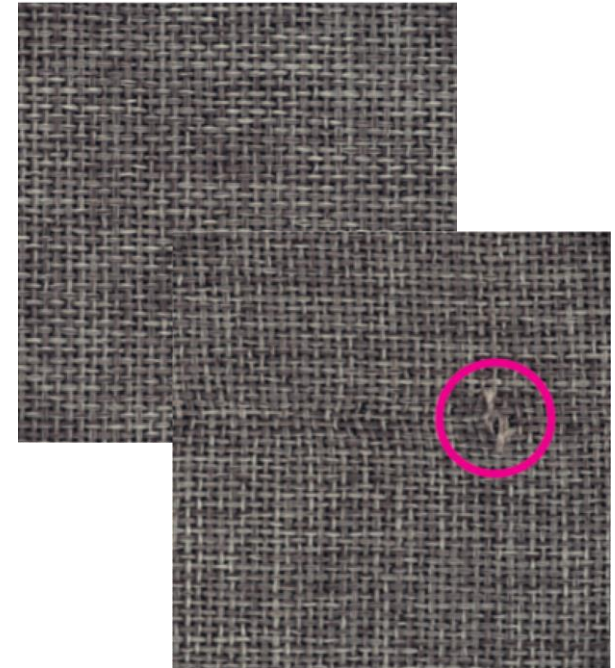
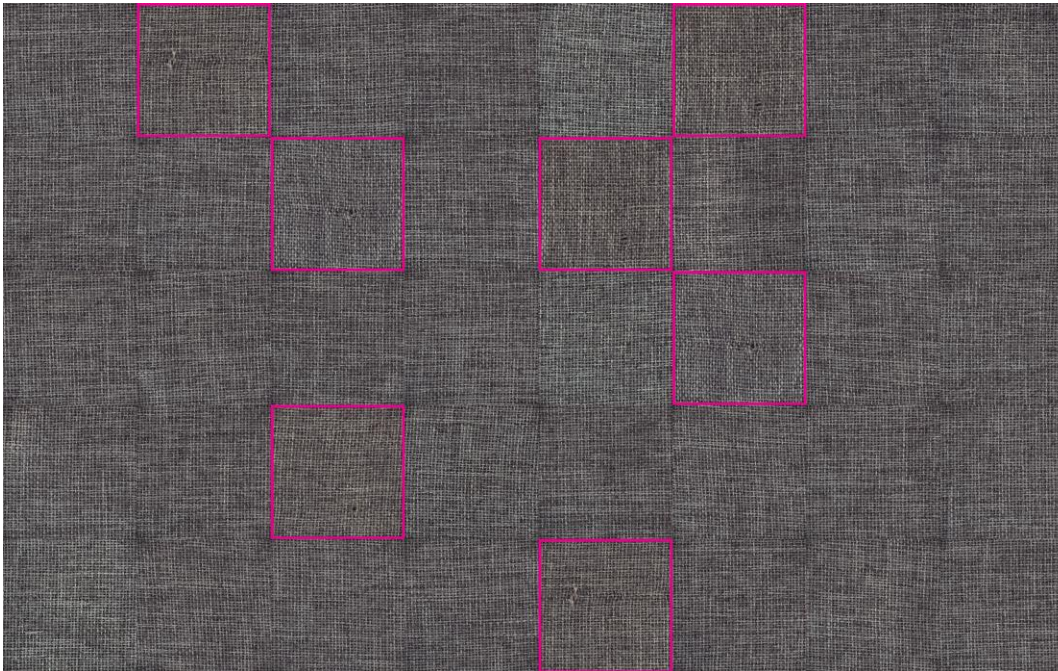
Artificial Intelligence ...

Uses all machine data for the optimization of the coating project with the vision to build equipment which is able to control autonomously the quality of the process and product

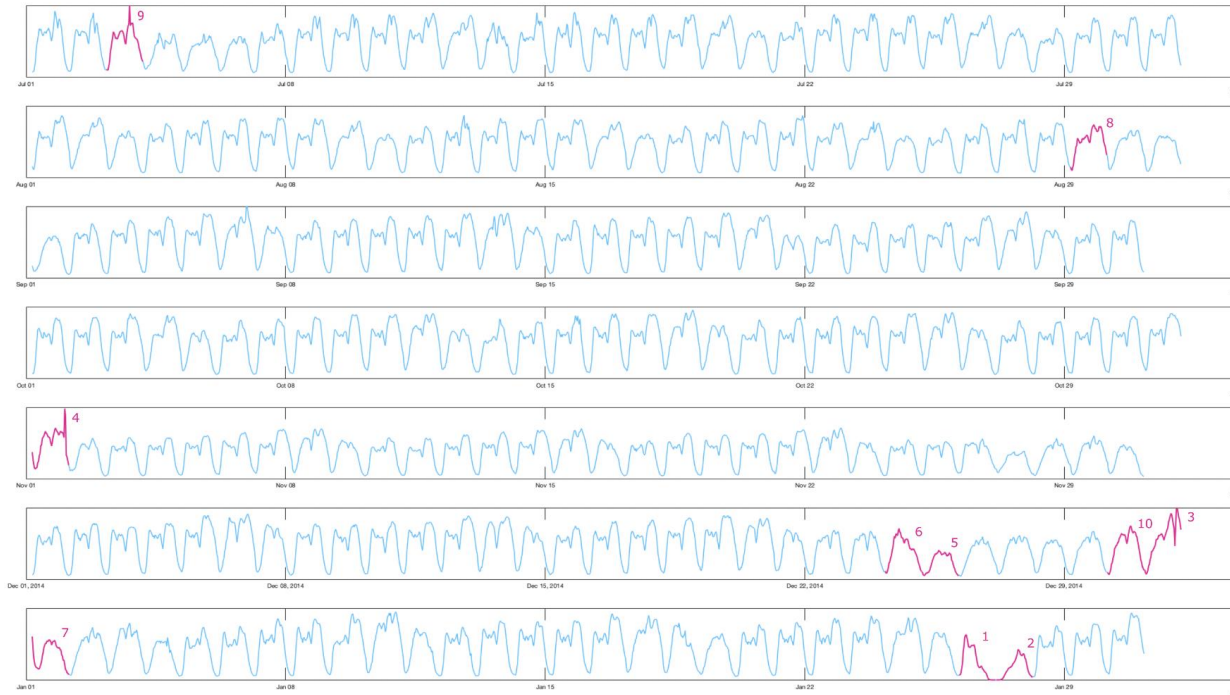


Automatic anomaly detection for surfaces

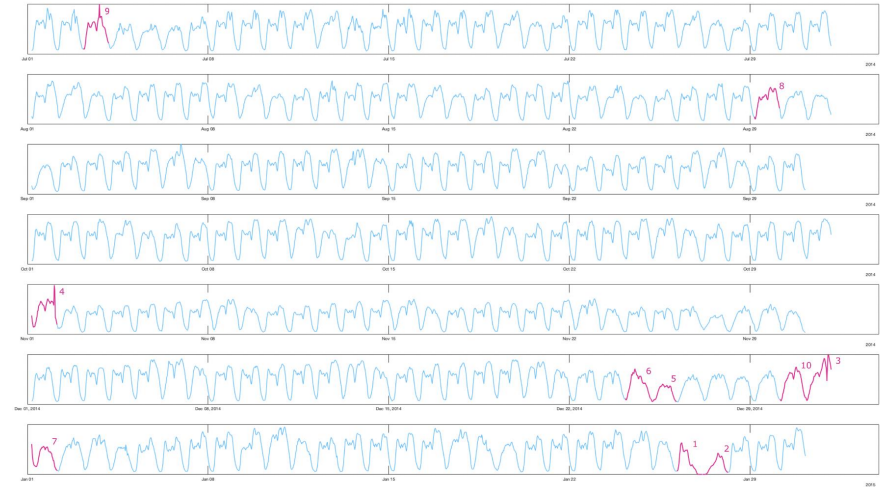
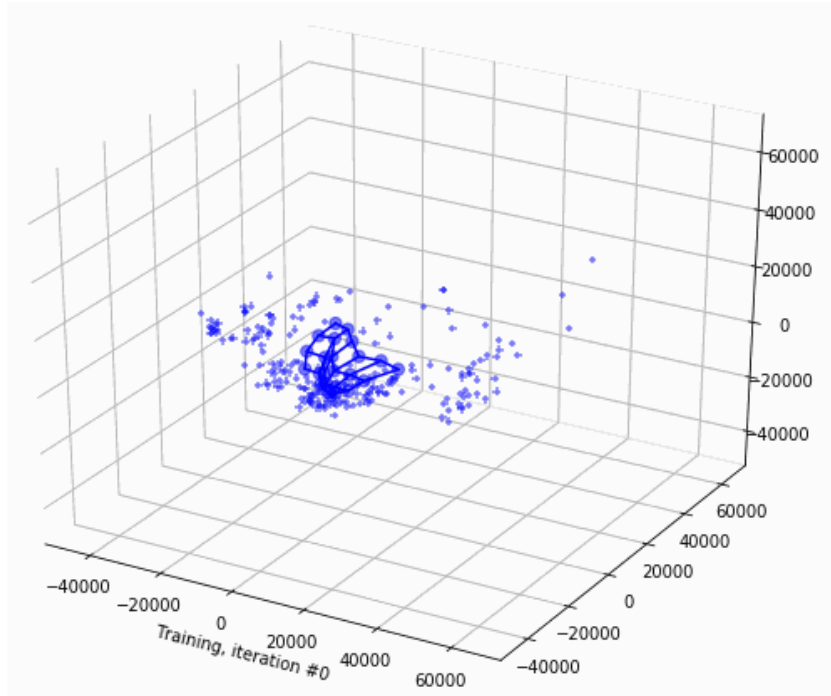
PANDA



Automatic anomaly detection for time series

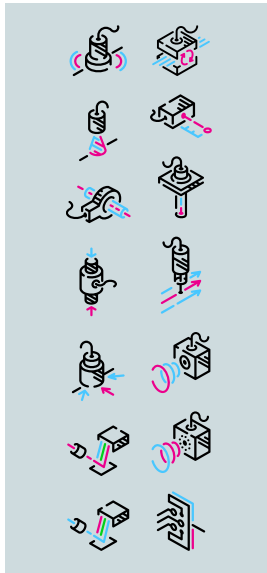


... what the algorithm is doing



4 pillars for a build up of an AI solution

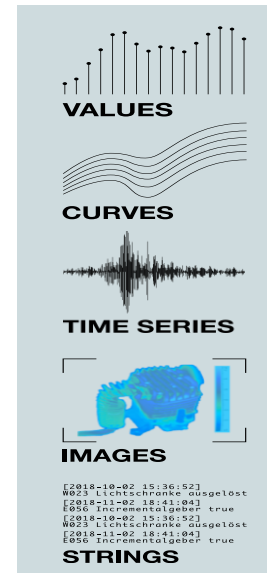
PANDA



Sensors



Embedded



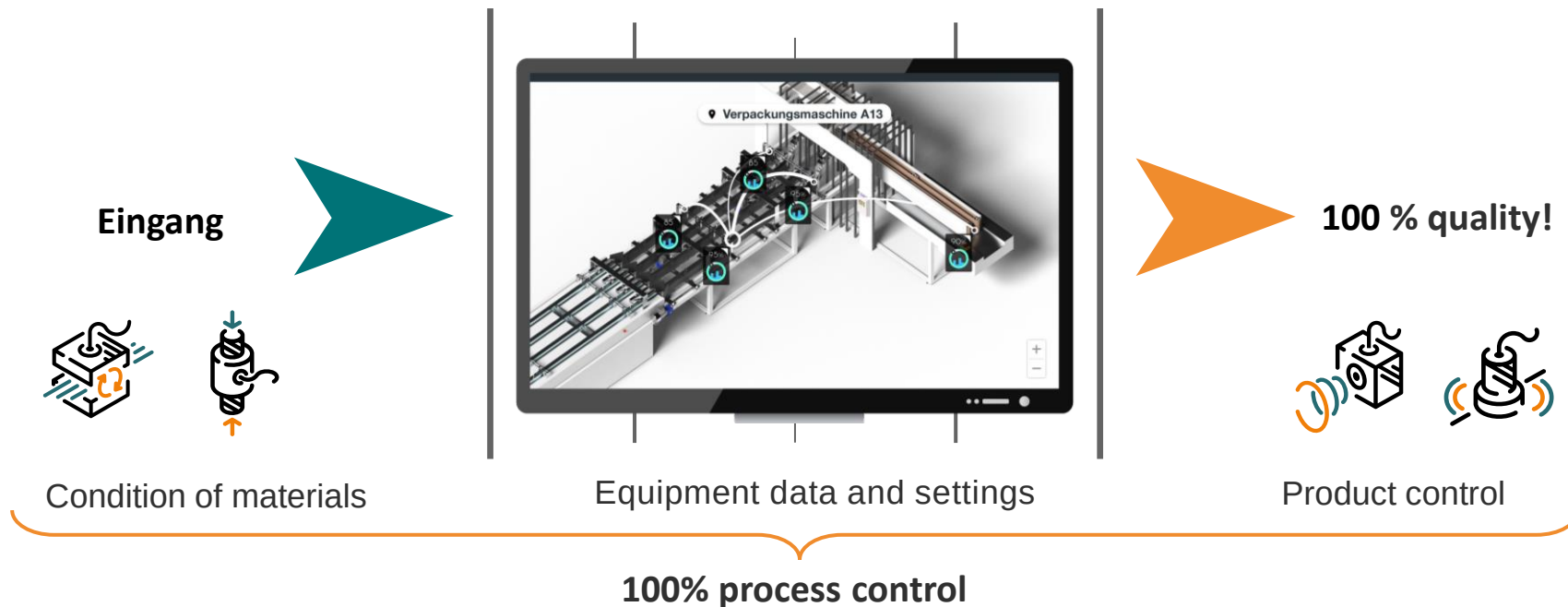
Algorithms



Software

Requirements for AI-based interaction modelling

PANDA



WEB GUIDING

Web Guiding for the Electrode production and Cell assembly process of the Lithium-Ion Battery Industry

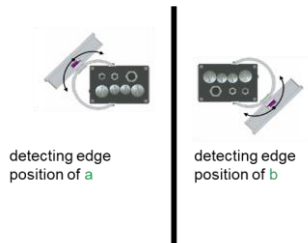
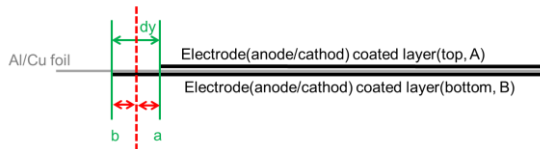
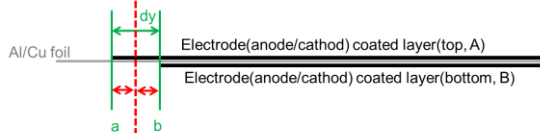
modular • intelligent • precise



CLS PRO 600 – APPLICATION EXAMPLE

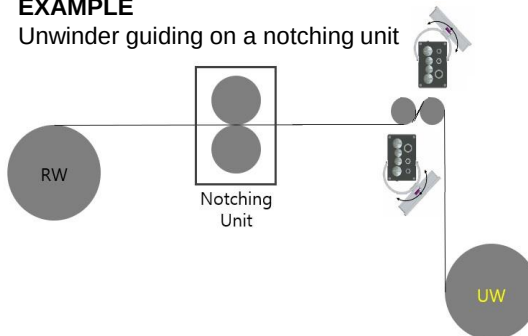
TASK

Realization of an unwind guiding according to the center line of an occurred deviation between the upper edge and the lower edge on both coated surfaces.



EXAMPLE

Unwinder guiding on a notching unit



SYSTEM CONFIGURATION

- 1x ekr 500 digital Touch
- 2x CLS Pro 600
- 1x EMS

Note:

- 1) Backup rollers moving together with unwind stand
- 2) Both cameras mounted to the static machine frame

SYSTEM SET UP

Firmware (existing):
Controller minimum: 2.2.7
Commander minimum: 1.6.8
CLS Sensor head: 1.16.3
CLS Commander: 1.16.5

Setting of addresses of the CLS cameras
Edge 1: Sensor head and commander: id 5
Edge 2: Sensor head and commander: id 7

Perform on both CLS's the installation function:
"Teach mounting position"

If guiding direction wrong: alter DIL 4.1

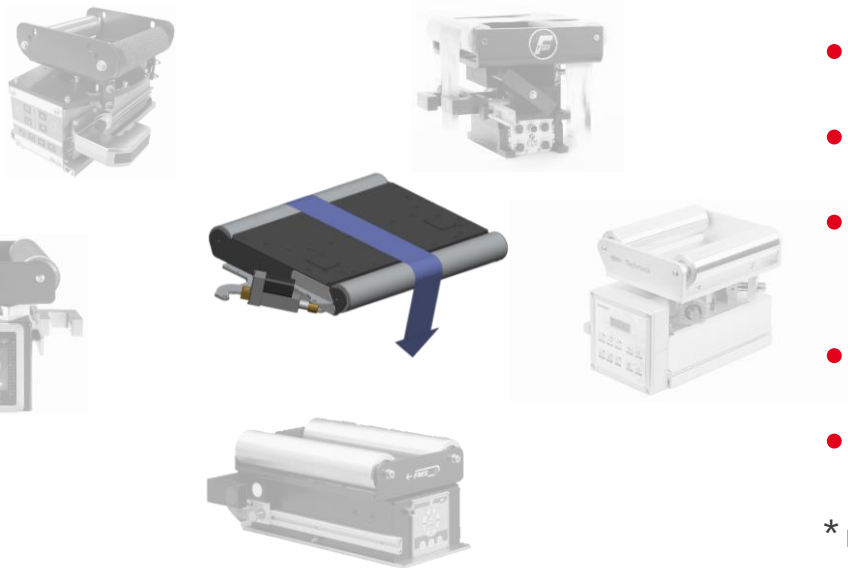
CONTACT

In case of further questions, please use your responsible contact person from our technical web guiding competence division of BST GmbH.

NEWEST INNOVATION – WHAT IS FRAMEGuide?

FRAMEGuide

The revolution in innovative web guiding solution!

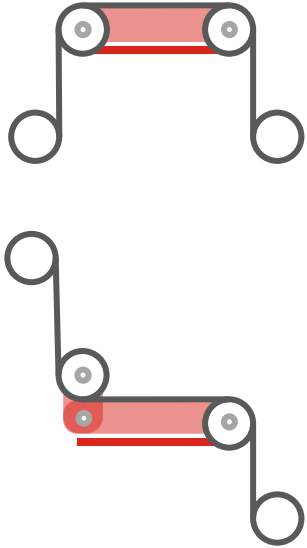


- The worlds unique web guiding frame
- High performance mechanical design*
- Highly accurate and precise positioning
- Smallest footprint ever
- Compact modular concept to adapt all BST sensors
- High dynamic brushless motor
- Backlash and maintenance free

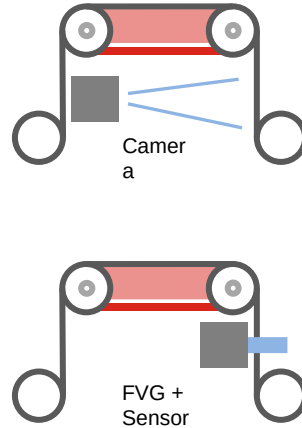
* legal protection of industrial design

EXAMPLES OF DESIGN-ADVANTAGES

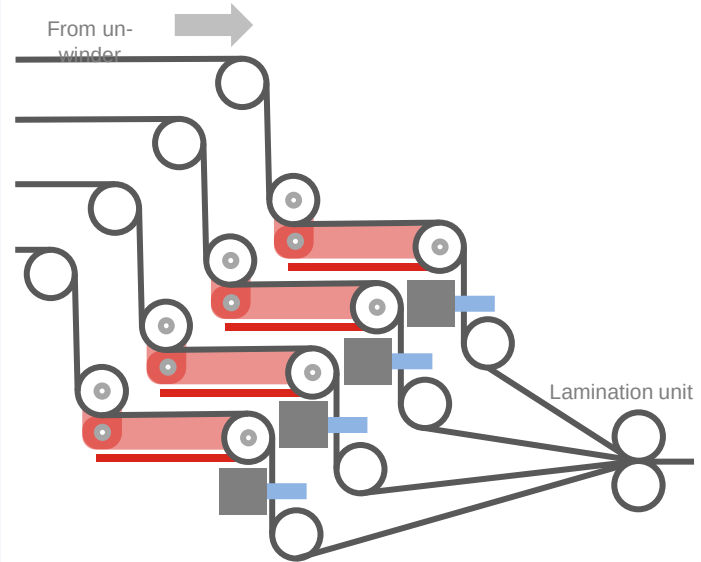
Two (2) fits for all



Highest integration of sensors



Highest compact applications



IMPRESSIONS



Lower frame
(fixed on machine frame)

Upper frame

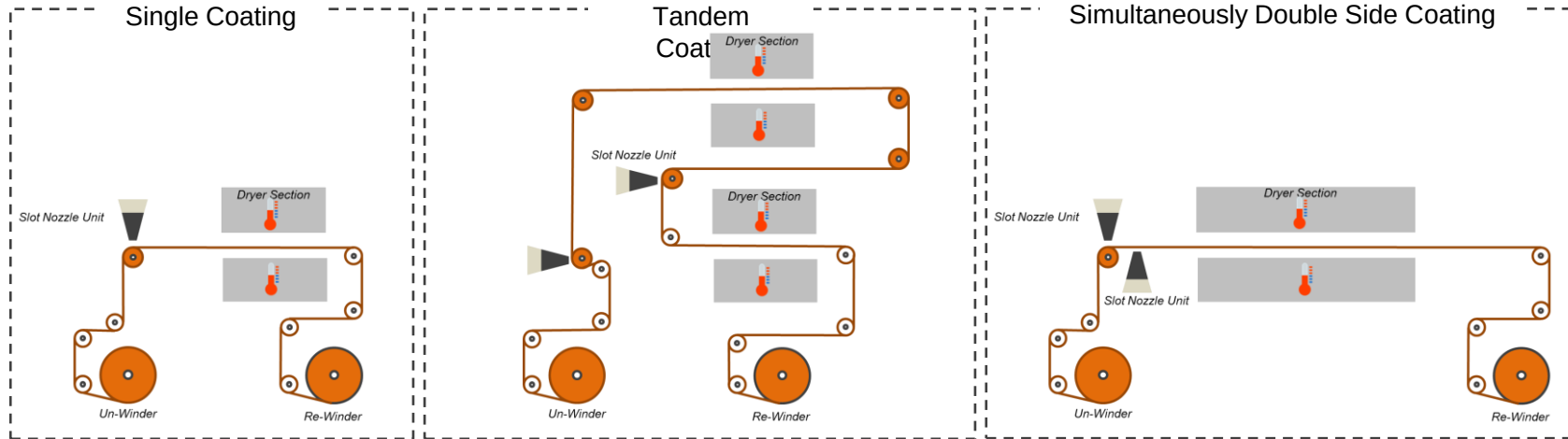


Motorized traverse bar for
scanners



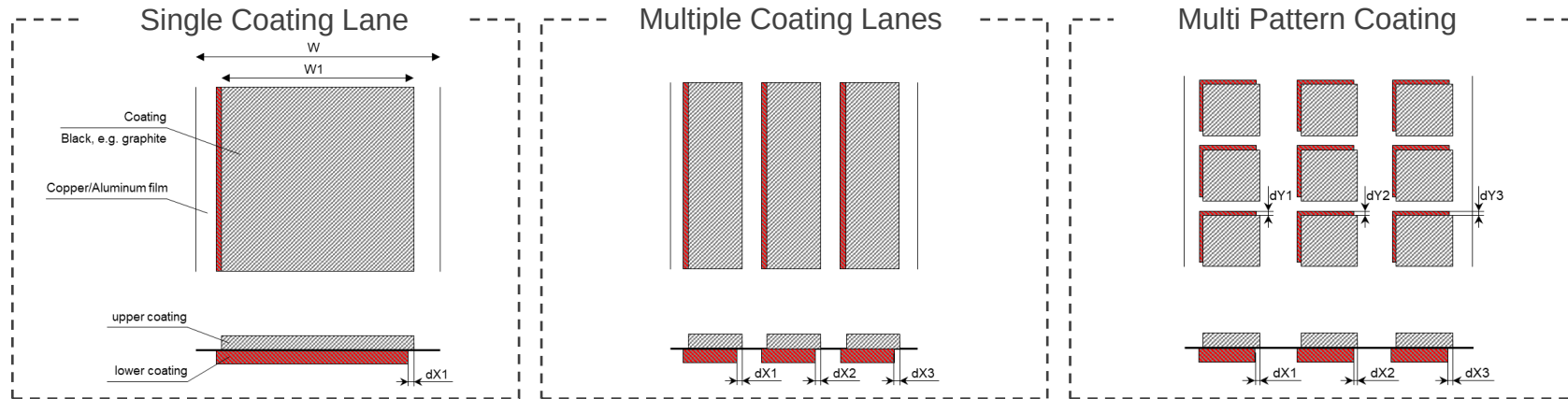
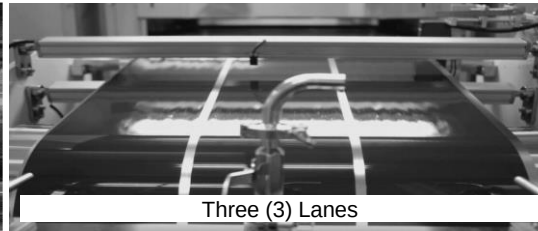
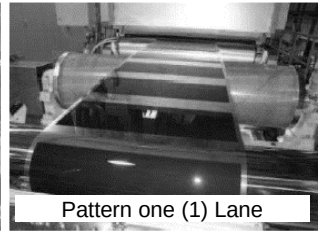
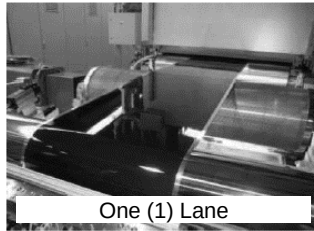
COATING & DRYING

Different applications supported



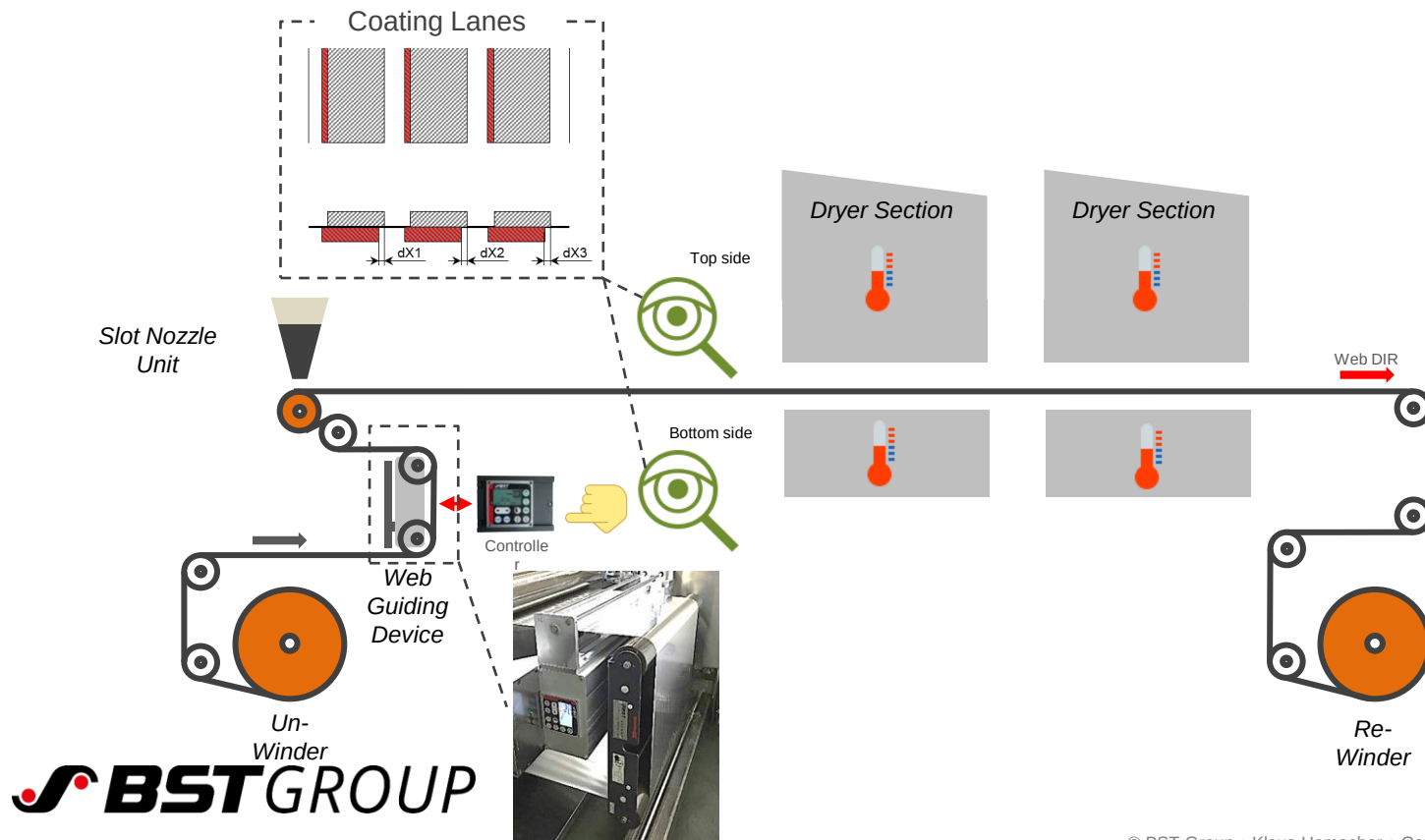
COATING & DRYING

Different coating designs supported



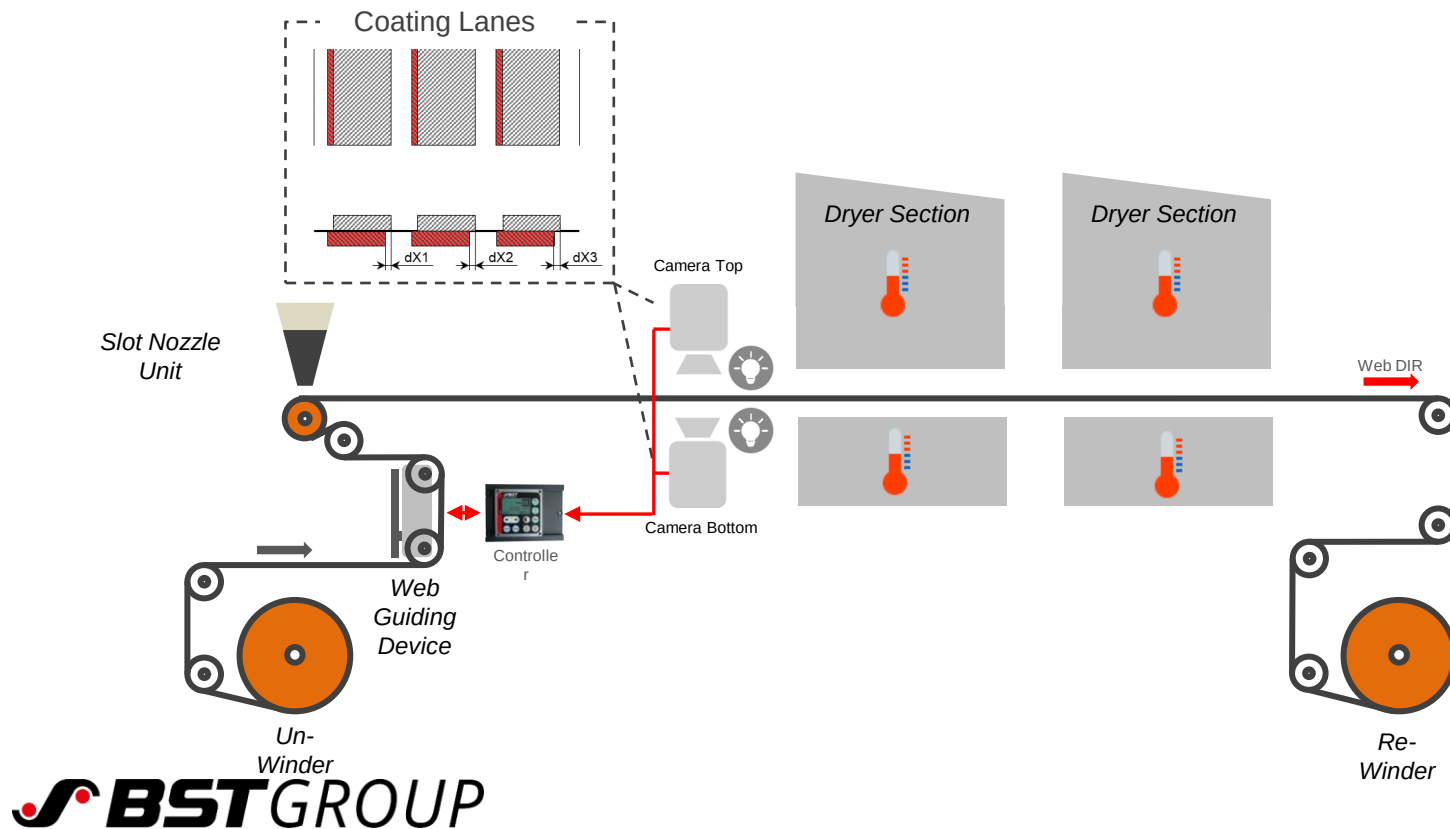
COATING & DRYING

Principle of coating control



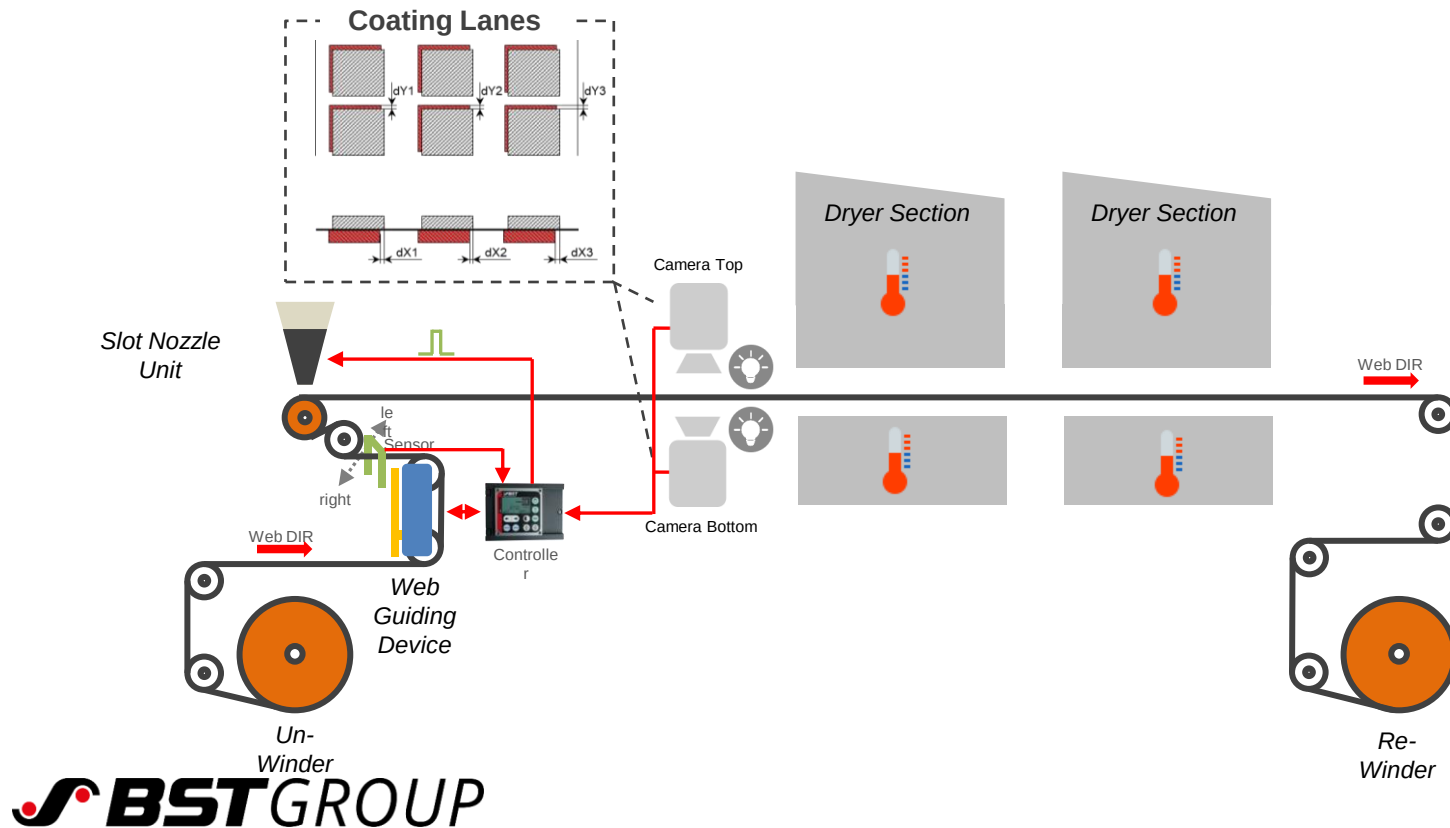
COATING & DRYING

Principle of coating control for lane coating



COATING & DRYING

Principle of coating control for pattern coating

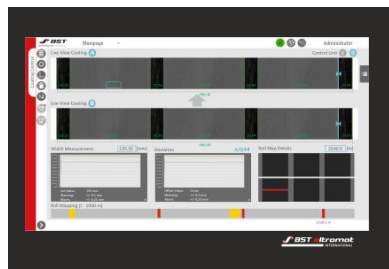


COATING CONTROL

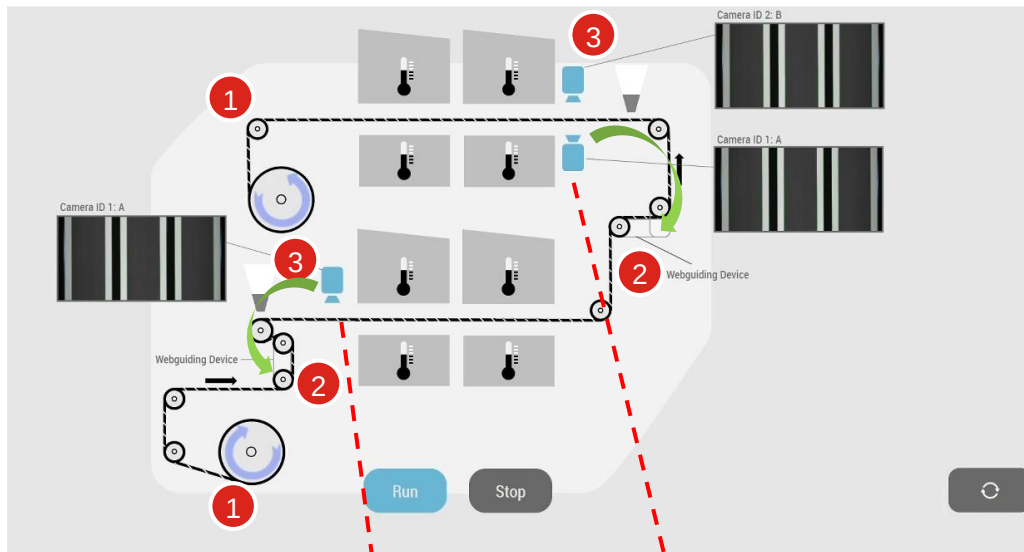
Function overview

Description

- 1 Winder control sensor, controller & actuator
- 2 Guiding Frame high precision guiding frame incl. sensor, controller & actuator
- 3 CCD CAM line chip camera incl. illumination unit
- 4 PROSolutions automation platform coating control



4



Control Unit 1



Control Unit 2

COATING CONTROL

GUI (scanning on simulator)



COATING CONTROL - Control Layout (example)

BST Line Chip Camera

Machine PLC

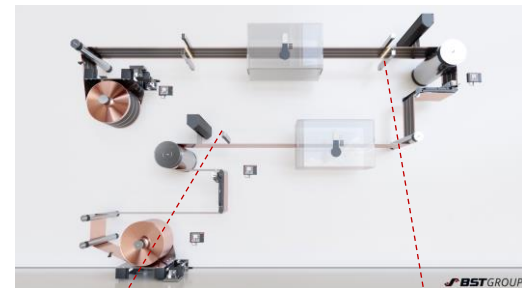
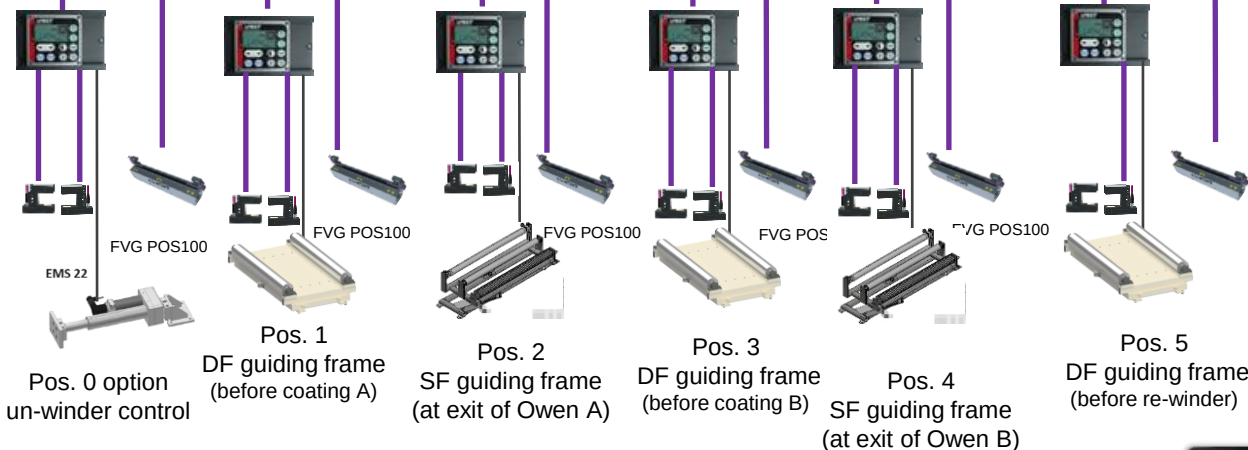
OPC UA
Fieldbus
Profinet
Ethercat
CCLink
Ethernet/IP



Internal camera bus

Image processing and control unit

Internal CAN Bus



Coating Control I

Coating Control II



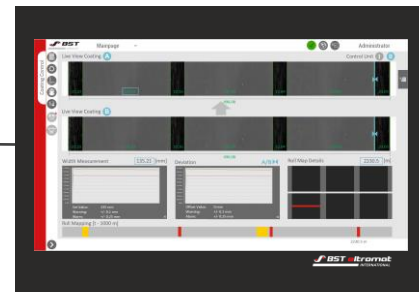
Coating
A



Coating
A



Coating
B

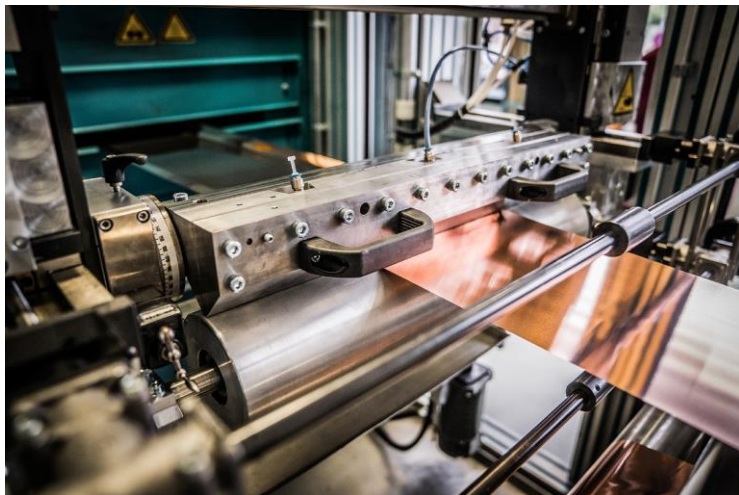


Web based GUI



BST GROUP

Forschungsfertigung Batteriezelle Münster



Coating Control



iPQ-Surface NEW ENERGY



4.

Coating systems



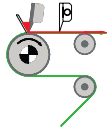
Coating parameters

Coating chemistry	Coating processes	Process control	Drying
✓ Rheology ✓ Viscosity ✓ Viscoelasticity ✓ Type of solvents ✓ Solid content ✓ Van der Waals force ✓ Sheer ratio ✓ Adhesion/Cohesion	✓ Coating systems ✓ Single or multilayer coatings ✓ Direct coatings ✓ Transfer (indirect) coatings ✓ Substrate speed ✓ Layer thickness ✓ Coating accuracy	✓ Process layout ✓ Tension control system ✓ Material guiding system ✓ Inline parameter control ✓ Quality control	✓ Convection drying ✓ Contact drying ✓ Infrared drying ✓ Sintering ✓ NIR ✓ High frequency ✓ UV crosslinking systems
Substrate	Pretreatment	Environment	Finishing
✓ Surface tension ✓ Dimension stability ✓ Surface structure ✓ Contact angle	✓ Corona ✓ Plasma ✓ Cleaning	✓ Humidity ✓ Temperature ✓ Inert conditions	✓ Calendaring ✓ Embossing ✓ Slitting

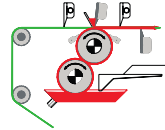
Processes – definition of coating systems

Category of coating methods	Examples of coating methods belonging to the category	Characteristics
Self-metered	✓ Dip roll ✓ Nip forward roll ✓ Reverse roll	✓ Wet thickness is determined by the conditions of the coating meniscus
Doctored	✓ Mayer rod ✓ Blade / Knife ✓ Air knife ✓ Dip & scrape	✓ Post applicator device determines the wet thickness
Pre-metered	✓ Slot die ✓ Slide curtain ✓ Spray	✓ All the ink fed into an applicator is transferred to the web

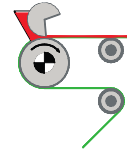
Coating systems



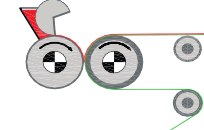
Knife system



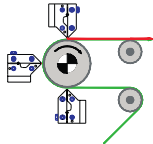
Double side coating system



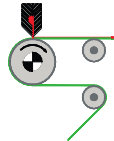
Commabar system



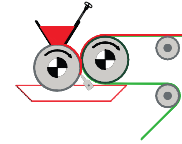
Reverse commabar system



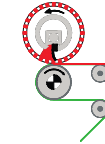
Slot die system



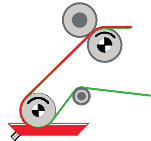
Curtain coating system



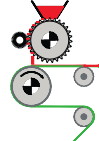
Case knife system



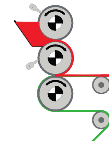
Rotary screen system



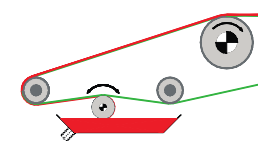
Dipping system (Foulard)



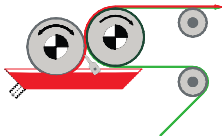
Powder scattering system



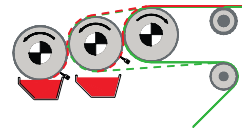
Reverse roll coating system



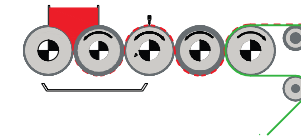
Micro roller coating system



2-roller coating system

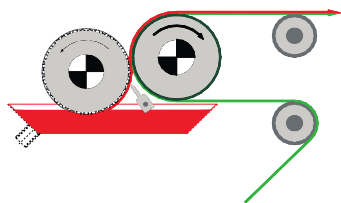


3-roller combi coating system

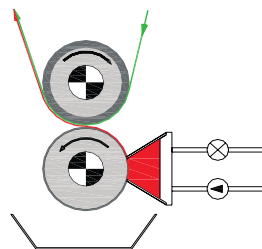


5-roller coating system

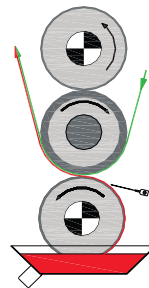
Printing systems



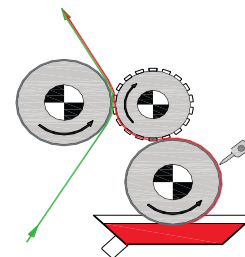
Engraved roller system



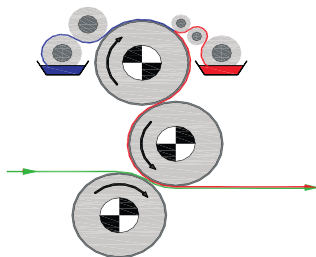
Gravure roller system



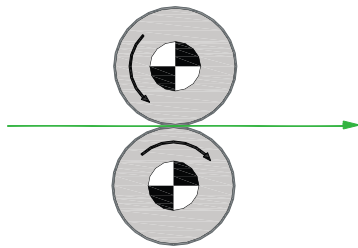
Gravure indirect system



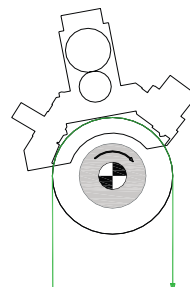
Flexography system



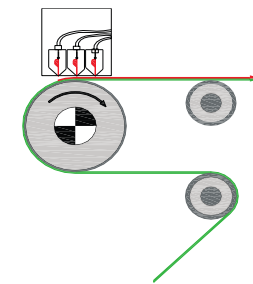
Offset lithography system



Hot embossing system

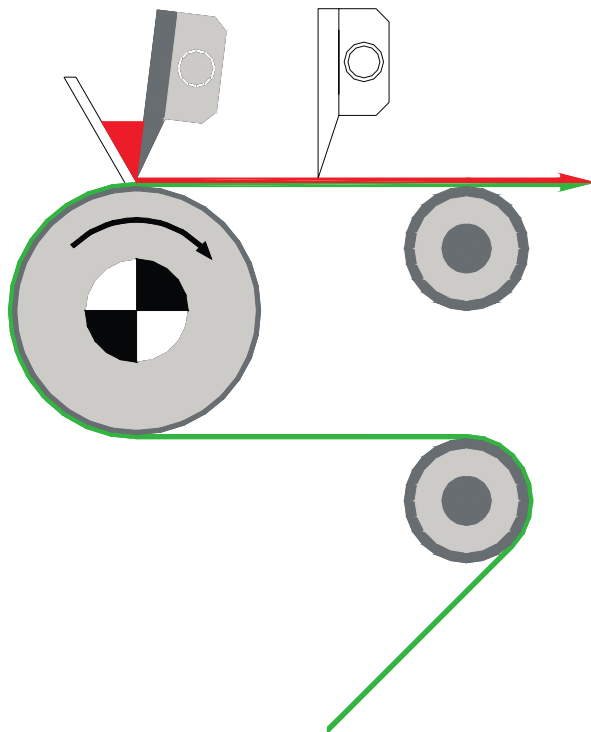


Nanoimprint system



Inkjet system

Knife coating



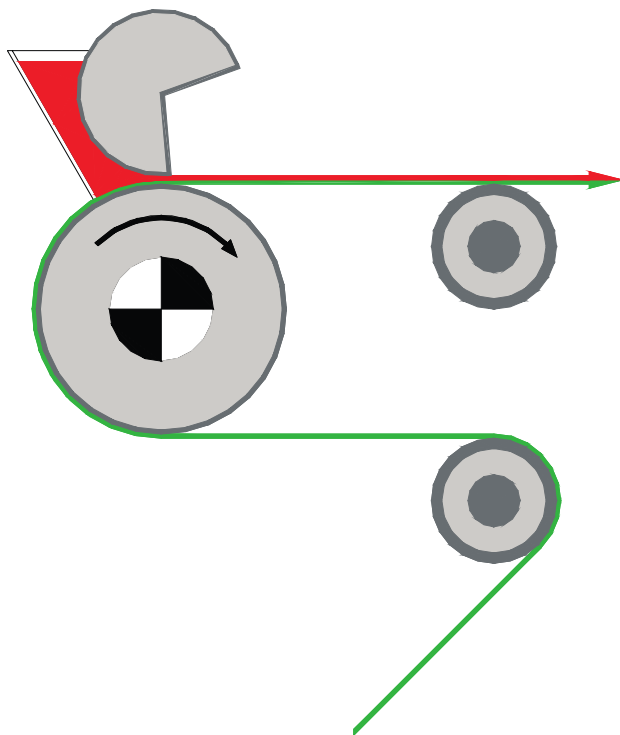
Variation of the coating weight

- ✓ Roller knife
10 – 1.250 g/m²
- ✓ Air knife 5 – 6 to 60 g/m²

Range of viscosity

- ✓ Paste (1000)
100 – 50 000 mPas
- ✓ Foam
10 000 – 25 000 mPas
- ✓ Air knife
5 – 10 000 mPas

Commabar coating



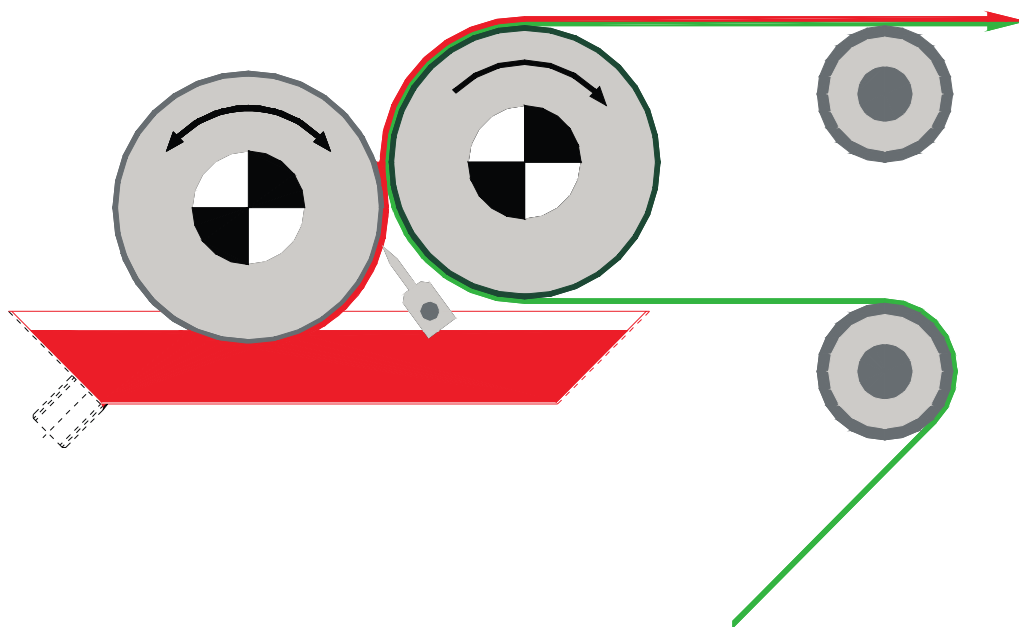
Variation of the coating weight

- ✓ Air knife
5 – 6 to 1.250 g/m²

Range of viscosity

- ✓ Paste
5 – 6 to 60 g/m²
- ✓ Foam
10 000 – 25 000 mPas

Gravur coating



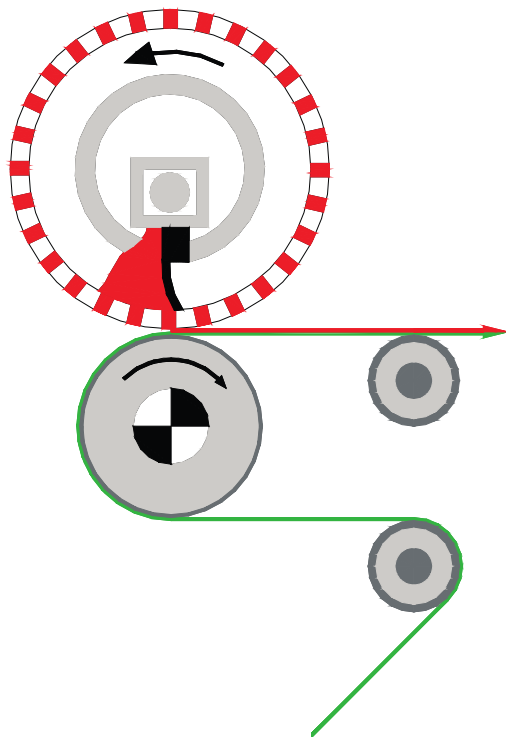
Variation of the coating weight

✓ 2 – 200 g/m²

Range of viscosity

✓ 1 – 15 000 mPas

Rotary screen coating



Variation of the coating weight

✓ 10 – 300 g/m²

Range of viscosity

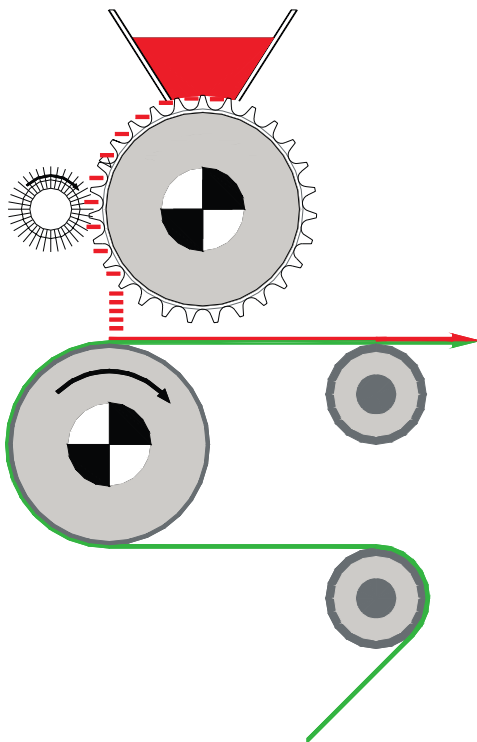
✓ Paste

10 000 – 80 000 mPas

✓ Paste

10 000 – 25 000 mPas

Powder scattering coating



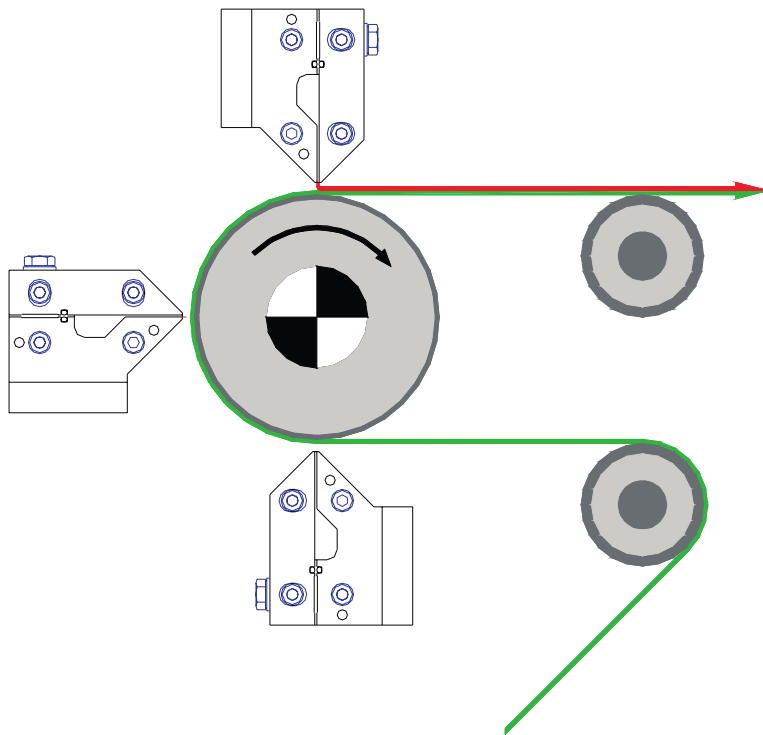
Variation of the coating weight

✓ 10 – 300 g/m²

Range of viscosity (mPas)

✓ Application of powdery materials

Slot die coating



Variation of the coating weight

✓ 1 – 200 g/m²

Range of viscosity

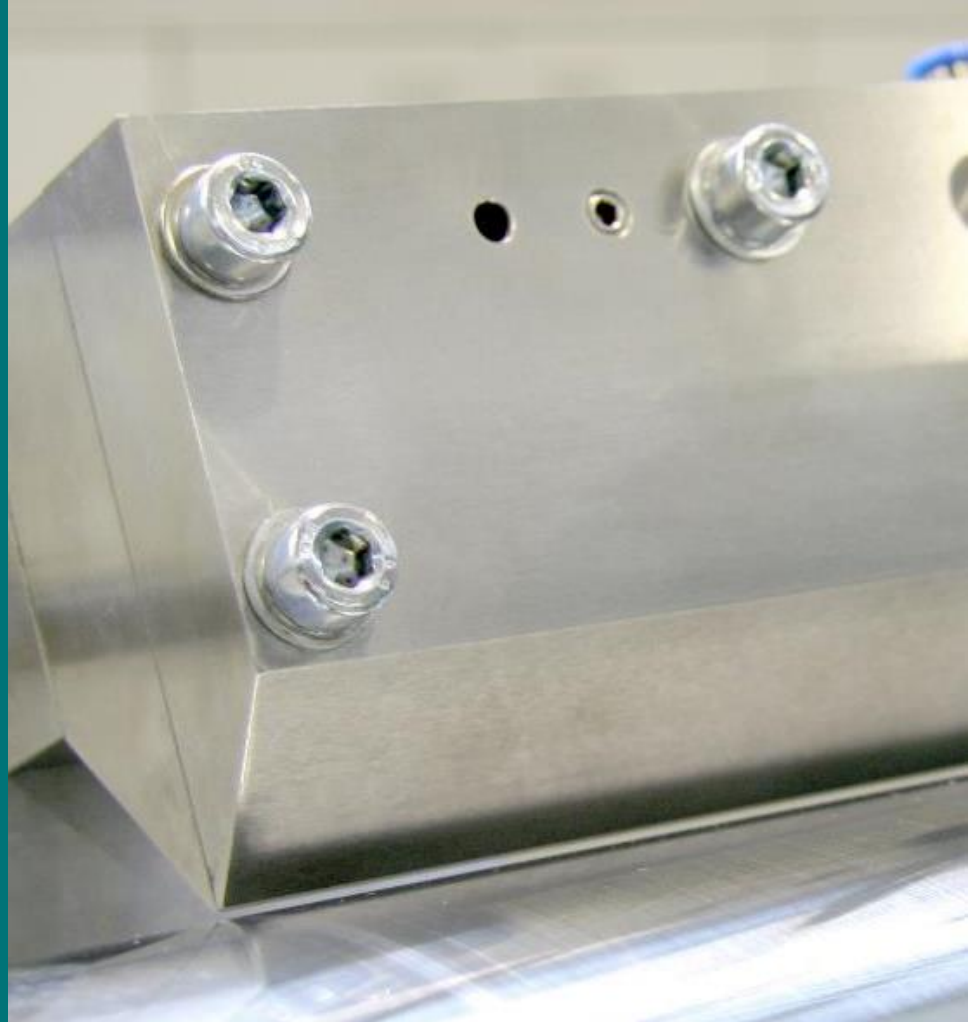
✓ 1 – 30 000 mPas

New design principle

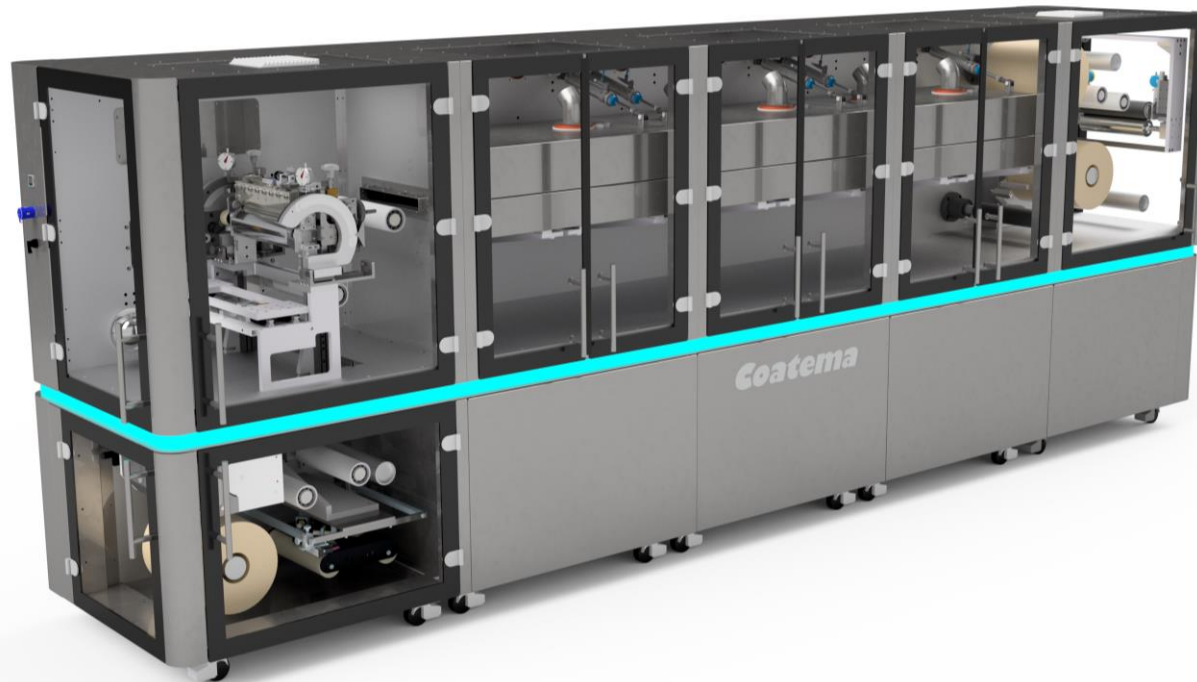


5.

Slot die coating for batteries



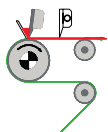
Basic principle



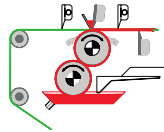
Coating parameters

Ink properties	Coating processes	Process control	Drying
✓ Rheology ✓ Viscosity ✓ Viscoelasticity ✓ Type of solvents ✓ Solid content ✓ Van der Waals force ✓ Sheer ratio ✓ Adhesion/Cohesion	✓ Coating systems ✓ Single or multilayer coatings ✓ Direct coatings ✓ Transfer (indirect) coatings ✓ Substrate speed ✓ Layer thickness ✓ Coating accuracy	✓ Process layout ✓ Tension control system ✓ Material guiding system ✓ Inline parameter control ✓ Quality control	✓ Convection drying ✓ Contact drying ✓ Infrared drying ✓ Sintering ✓ NIR ✓ High frequency ✓ UV crosslinking systems
Substrate	Pretreatment	Environment	Finishing
✓ Surface tension ✓ Dimension stability ✓ Surface structure ✓ Contact angle	✓ Corona ✓ Plasma ✓ Cleaning	✓ Humidity ✓ Temperature ✓ Inert conditions	✓ Calendaring ✓ Embossing ✓ Slitting

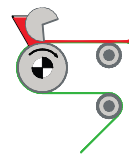
Coating systems



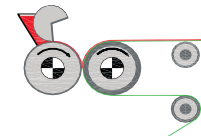
Knife system



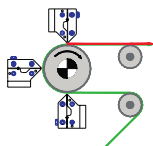
Double side coating system



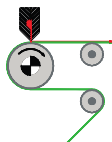
Commabar system



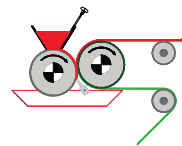
Reverse commabar system



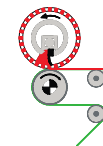
Slot die system



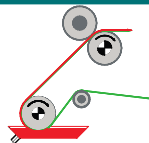
Curtain coating system



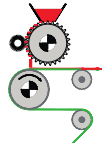
Case knife system



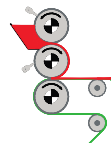
Rotary screen system



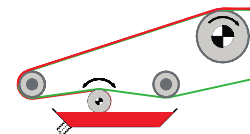
Dipping system (Foulard)



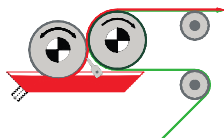
Powder scattering system



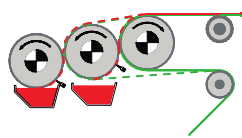
Reverse roll coating system



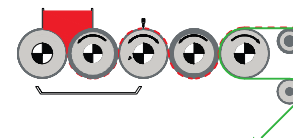
Micro roller coating system



2-roller coating system

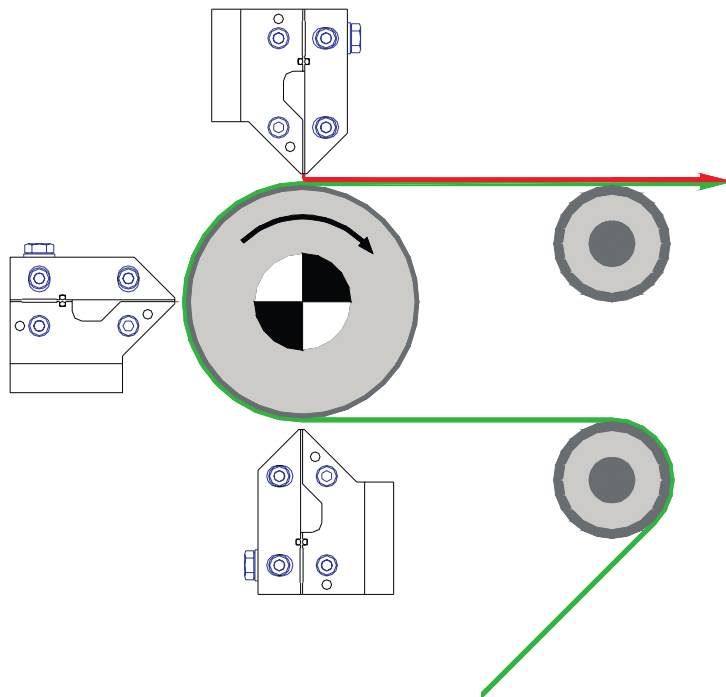


3-roller combi coating system



5-roller coating system

Basics of slot die coating – range of parameters



Coating speed

✓ 0.1 – >1000 m/min

Ink viscosity

✓ 1 – 300 000 mPas

Layer thickness (dry)

✓ 0.1 – >200 μm

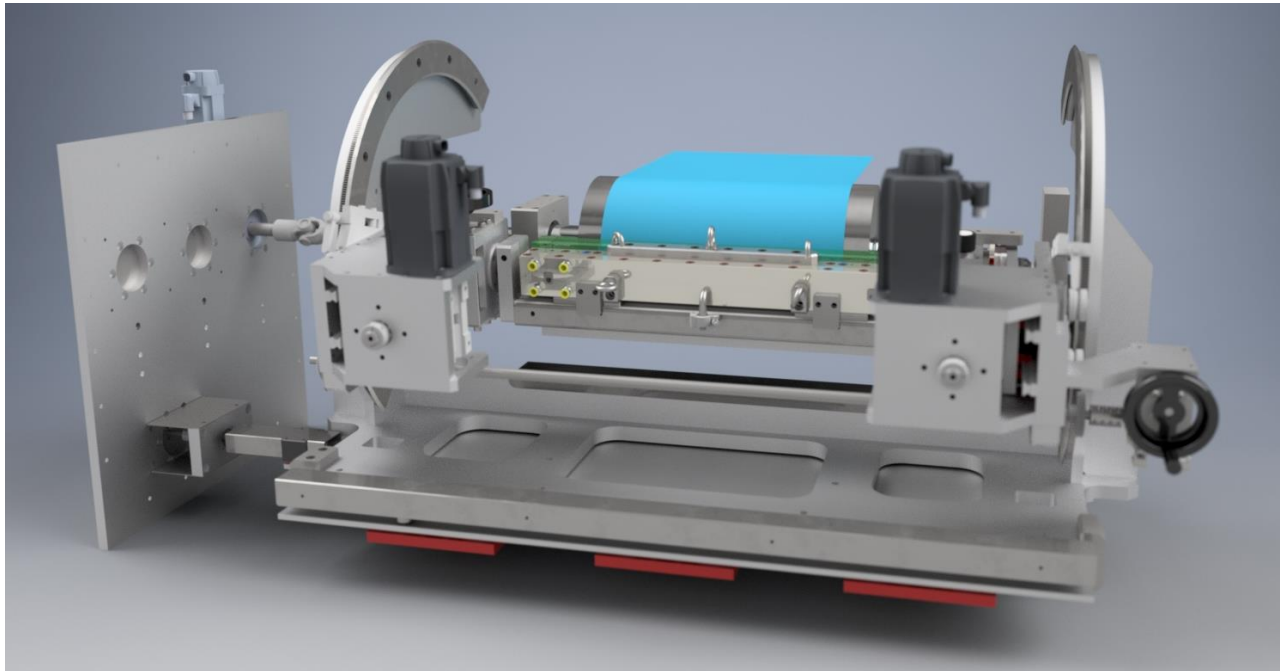
Coating accuracy

✓ <1% (2 – 5%)

Coating width

✓ up to approx. 3 m

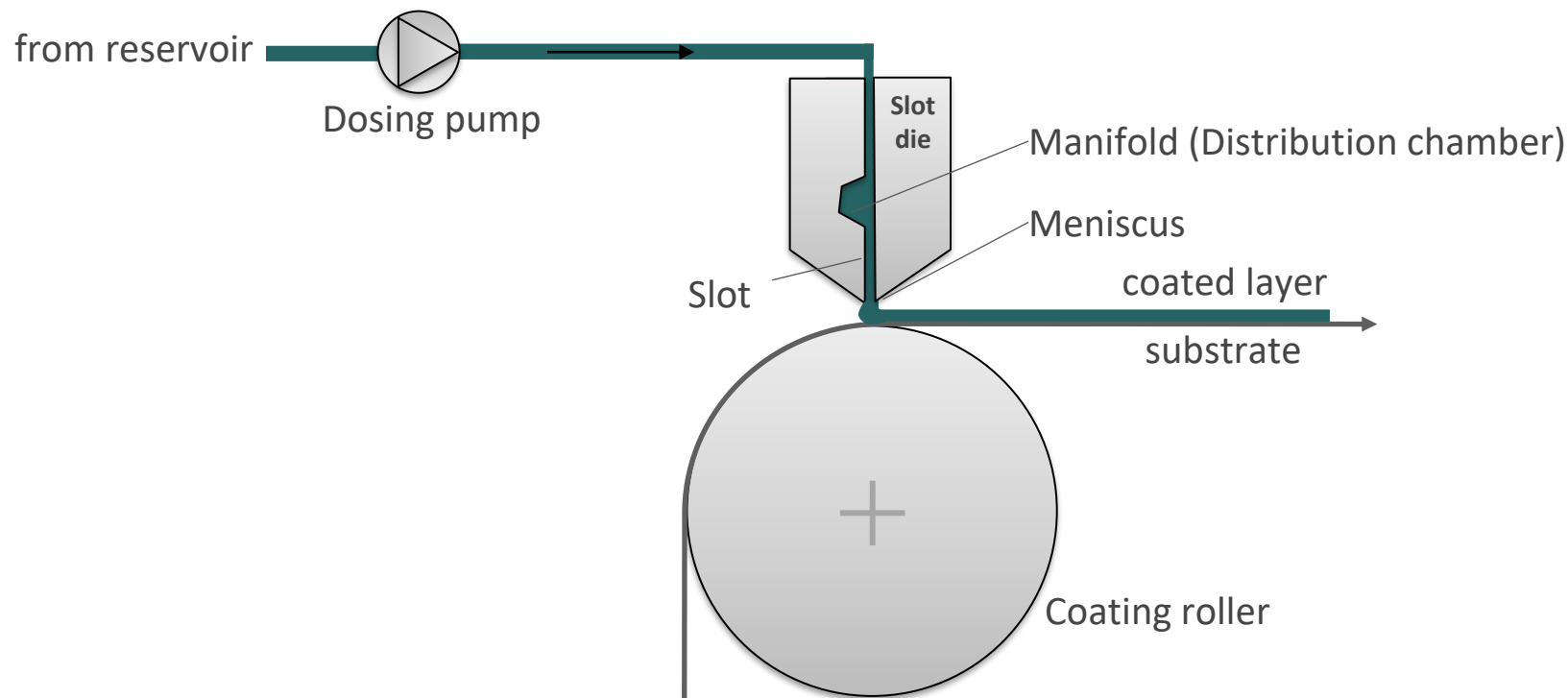
Basic principle



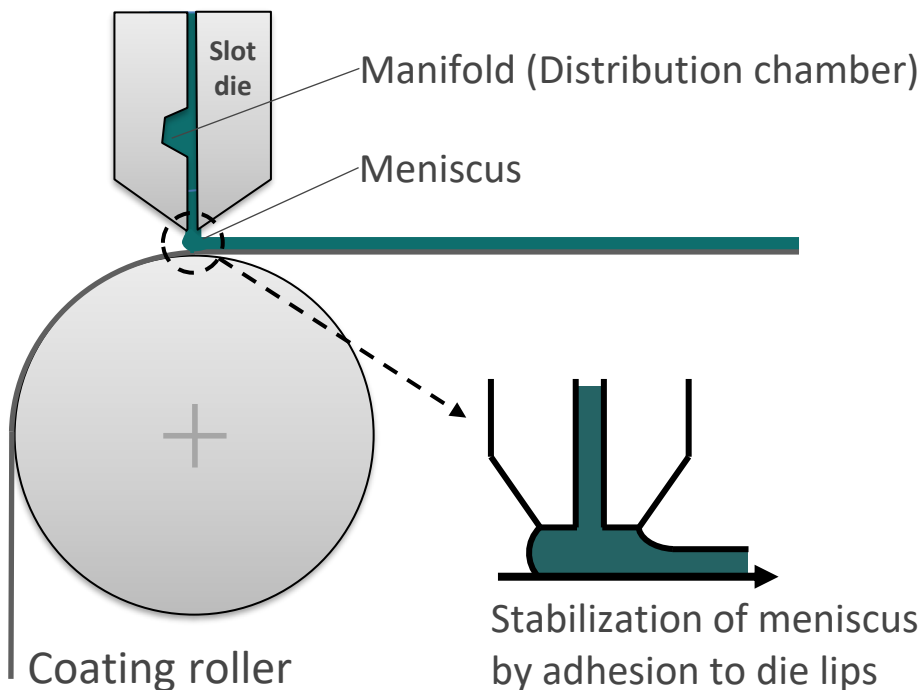
Basic principle



Basic principle

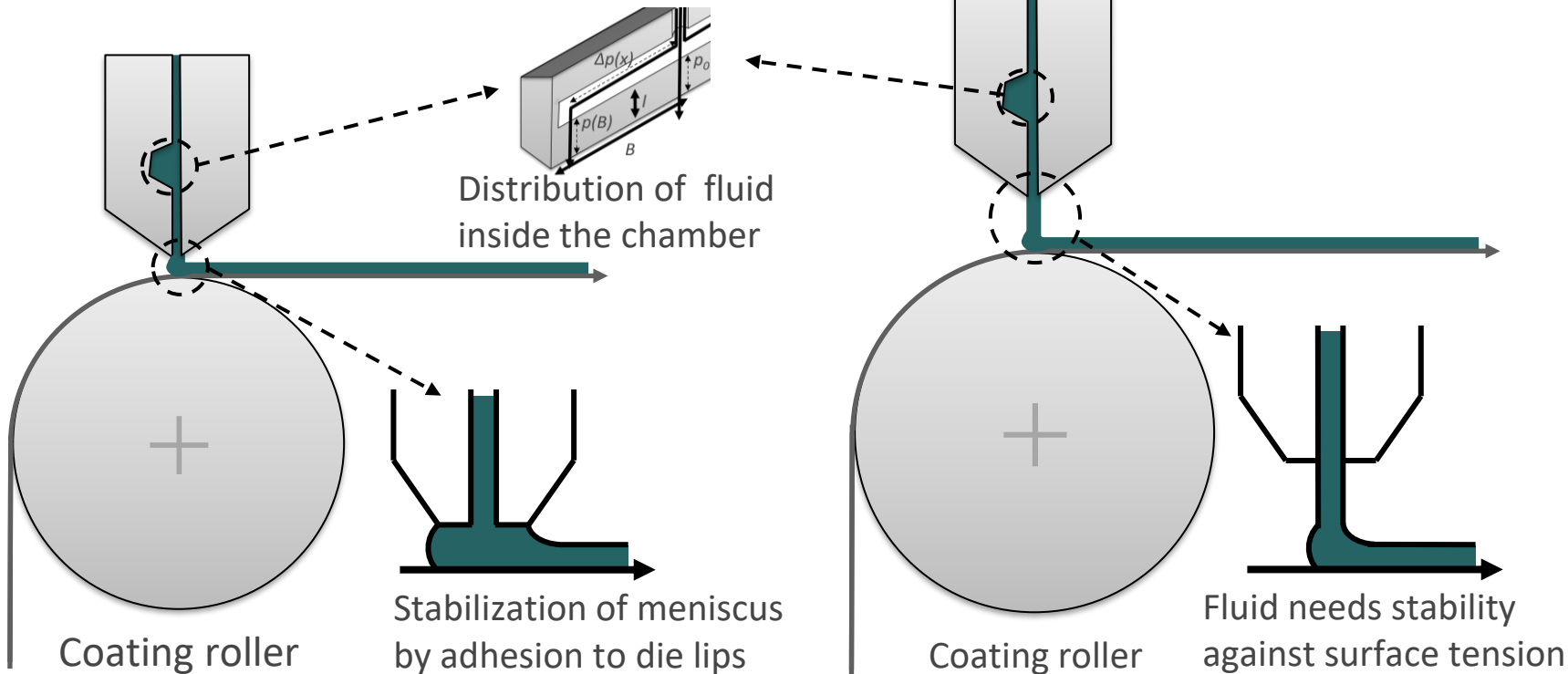


Bead mode



- ✓ Meniscus is formed between die lips and substrate
- ✓ Adhesive stabilization of meniscus by die lips
- ✓ Very low minimum flow rate possible
- ✓ For a stable process the range of rheological parameters is limited
- ✓ Preferably for low coating speed

2 + 2 = 3 aspects of slot die coating



Theoretical background – „Basic“ fluid dynamics for advances geometries

$$\oint \rho v dA = 0$$

Continuity equation
(conservation of mass)

Any flow of liquids is described by a set of differential equations:

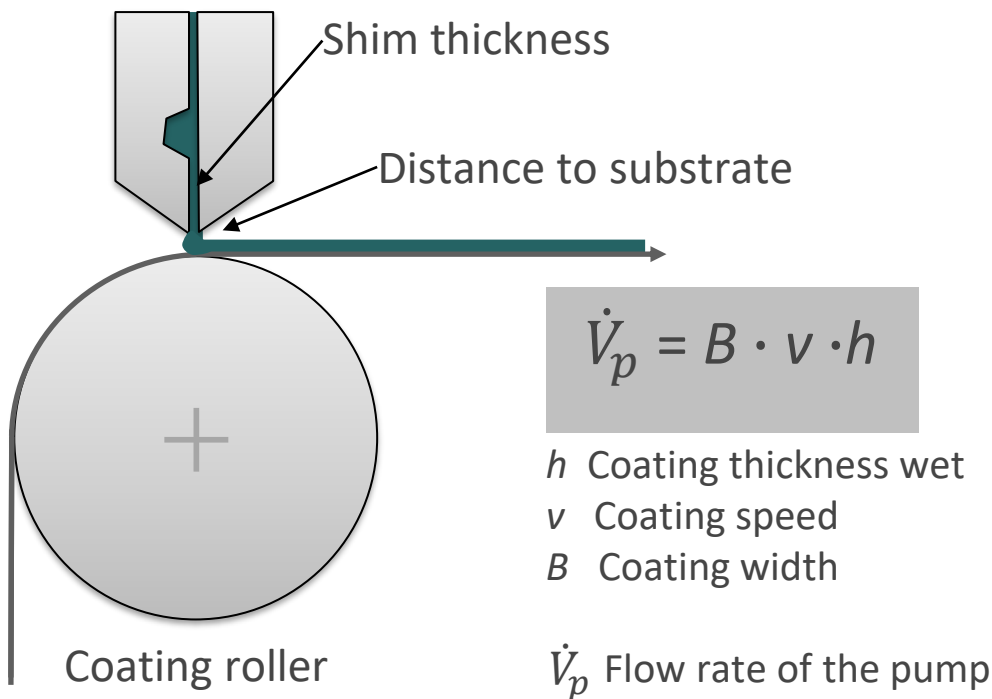
To describe the meniscus flow of a slot die means, to solve these differential equations for given boundary conditions.

Can be done by appropriate computer programs.

$$\frac{\partial v}{\partial t} + (v \nabla) v = \frac{(-\nabla p + \eta \Delta v + f)}{\rho}$$

Navier-Stokes-equations (equations of motion for incompressible fluids, $\rho = \text{const}$)
 Δ, ∇ = differential operators

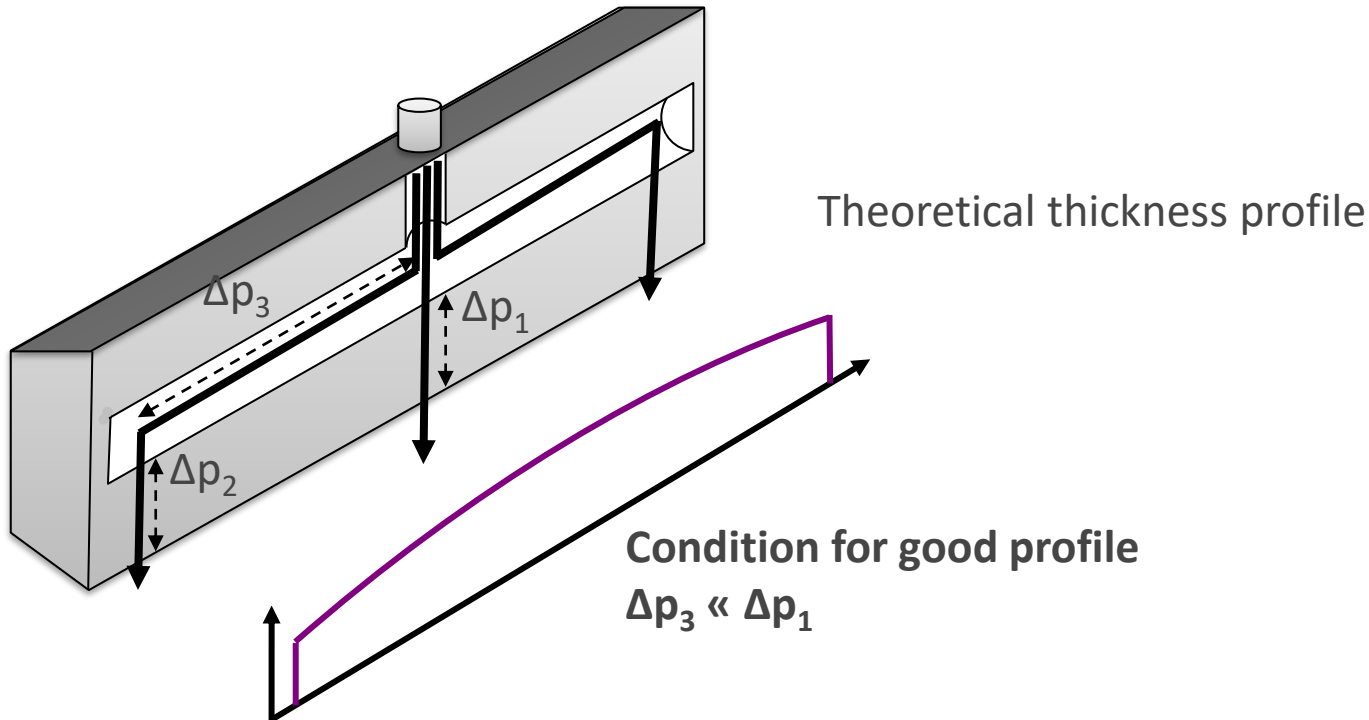
Theoretical background



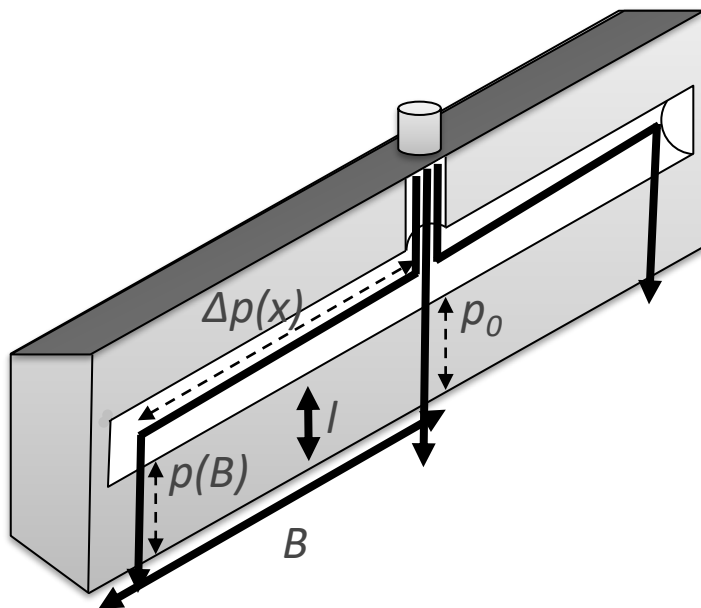
Contrary to a widespread misunderstanding the wet coating thickness does not depend on the shim thickness.

Shim thickness and distance to substrate only help to stabilize the meniscus.

Why should a slot die coat homogeneously?



Fluids in the manifold: 1.5D approximation



Pressure drop $\Delta p(x)$ via pumping through finitely sized distribution chamber leads to:

Theoretical pressure profile:

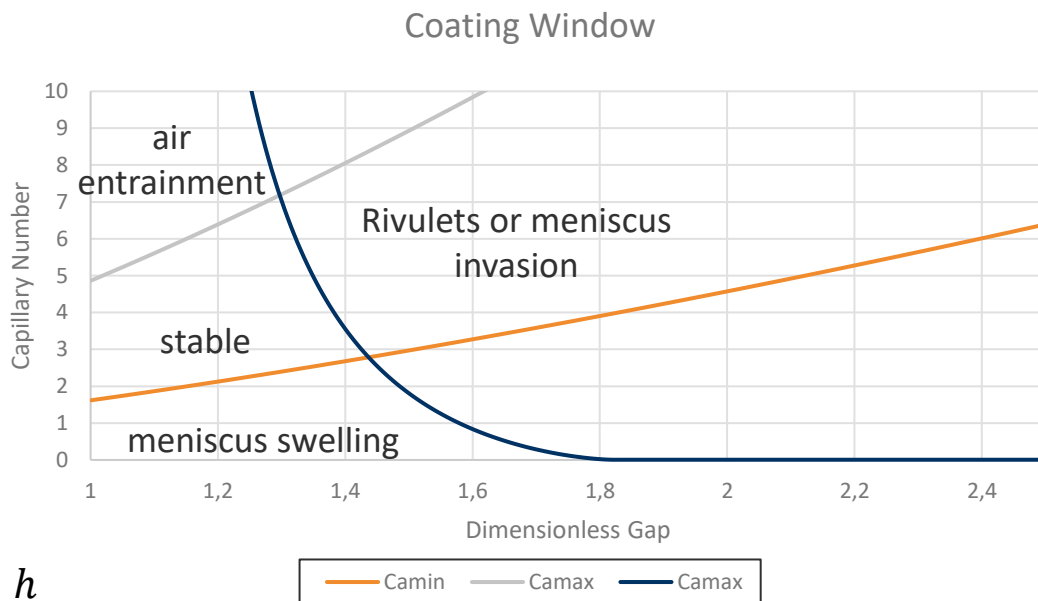
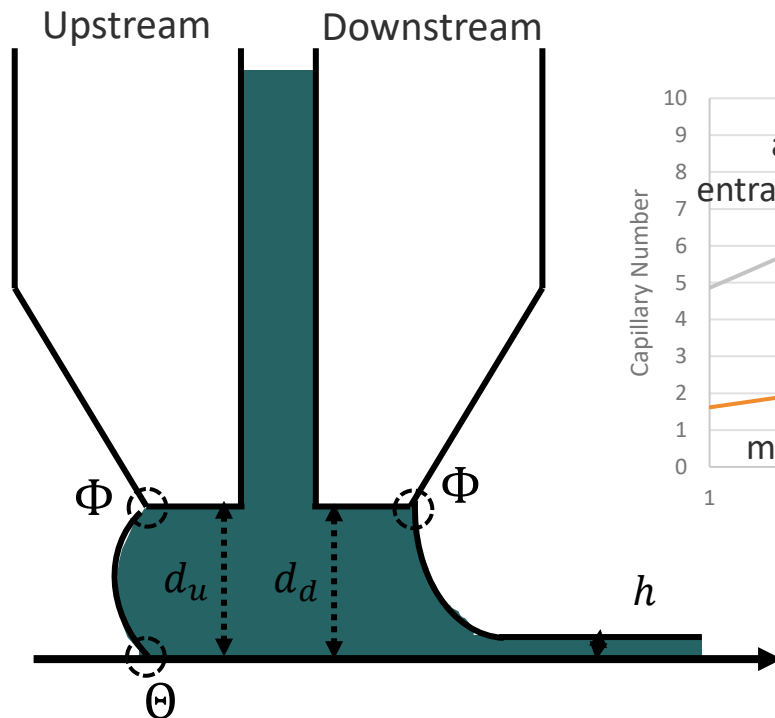
$$p(x) = p_0 \cdot \frac{\cosh \frac{W-x}{\lambda}}{\cosh \frac{W}{\lambda}}$$

Theoretical thickness profile:

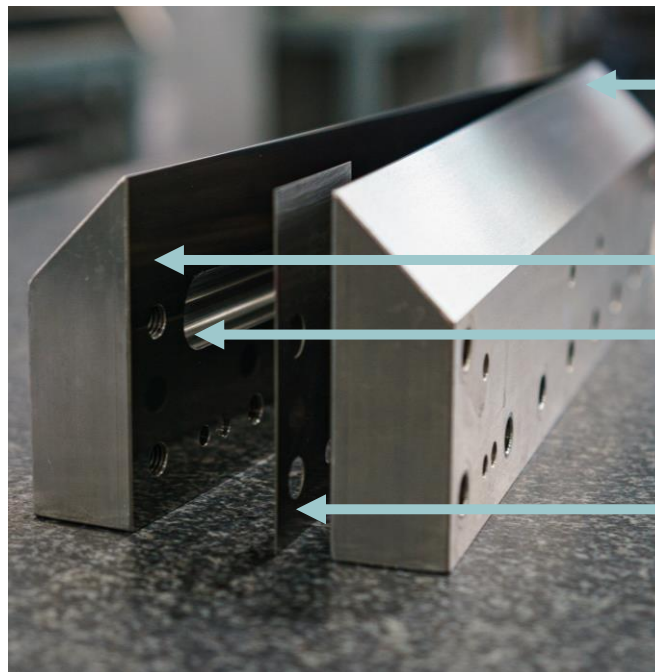
$$h(x) = \frac{B \cdot h_0}{\lambda} \cdot \frac{\cosh \frac{W-x}{\lambda}}{\sinh \frac{W}{\lambda}}$$

$$\lambda = \sqrt{\frac{3\pi \cdot l \cdot r^4}{2\delta^3}} \quad \text{„slot die geometry parameter“}$$

Calculation of the meniscus stability



Coatema standard layout – one design among many available



Lips

Slot area

Manifold

Shim

Improving the coating profile

- ✓ Large manifold, long slot area, highly parallel lips (standard)
- ✓ Coat hanger design
 - ✓ Profile is compensated by a tilted manifold
 - ✓ Conical manifold cross section to keep flow speed constant (optional to prevent precipitation)
 - ✓ Works perfect for adequate rheology only
- ✓ Slot width adjustment
 - ✓ Slot width is locally narrowed or widened to adjust the local flow resistance
 - ✓ Slot width can be modified by microns only. So despite adjustability the die has nevertheless to be highly precise and a sufficient manifold volume is necessary (the adjustment is a fine tuning only)

Increasing homogeneity: Coat hanger design

Manifold small
to minimize dead
volume
(optional conical
to prevent
precipitation)

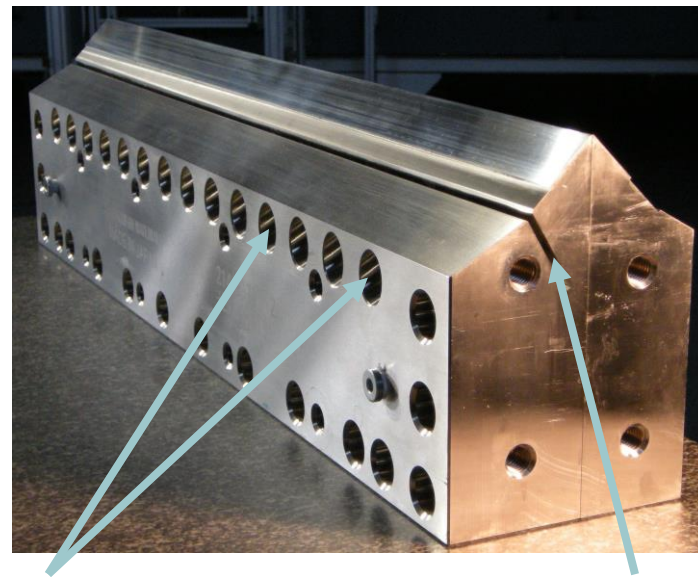
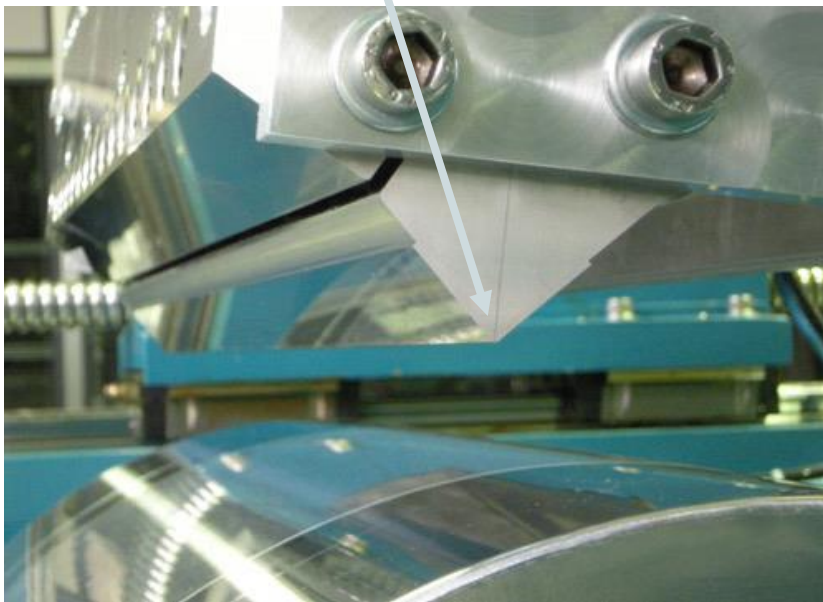
Tilted manifold
to correct the
pressure profile

Long slot area



Increasing homogeneity: The last 1 %

slot (shim edge)



Differential adjustment
screws

space for bending the
die lip

Increasing homogeneity: The last 1 % automatized



Computerized
adjustment of
slot width
or gap width

Slot width:
for uniformity

Gap width:
for very small
coating windows

Structured coating – levels of complexity

	Web direction		Current status
1		Full area, homogeneous	Requirements are met, thickness profile variation of 0.5 %
2		Stripes downweb	Requirements are met, good edge definition
3		Stripes crossweb (intermittent coating)	Requirements are partially met, edge definition of 0.5 – 1 mm depending on liquid
4		Arbitrary patterns	Requirements are not met, concepts for realization exist, research project is going on

Level 2 – downweb stripes



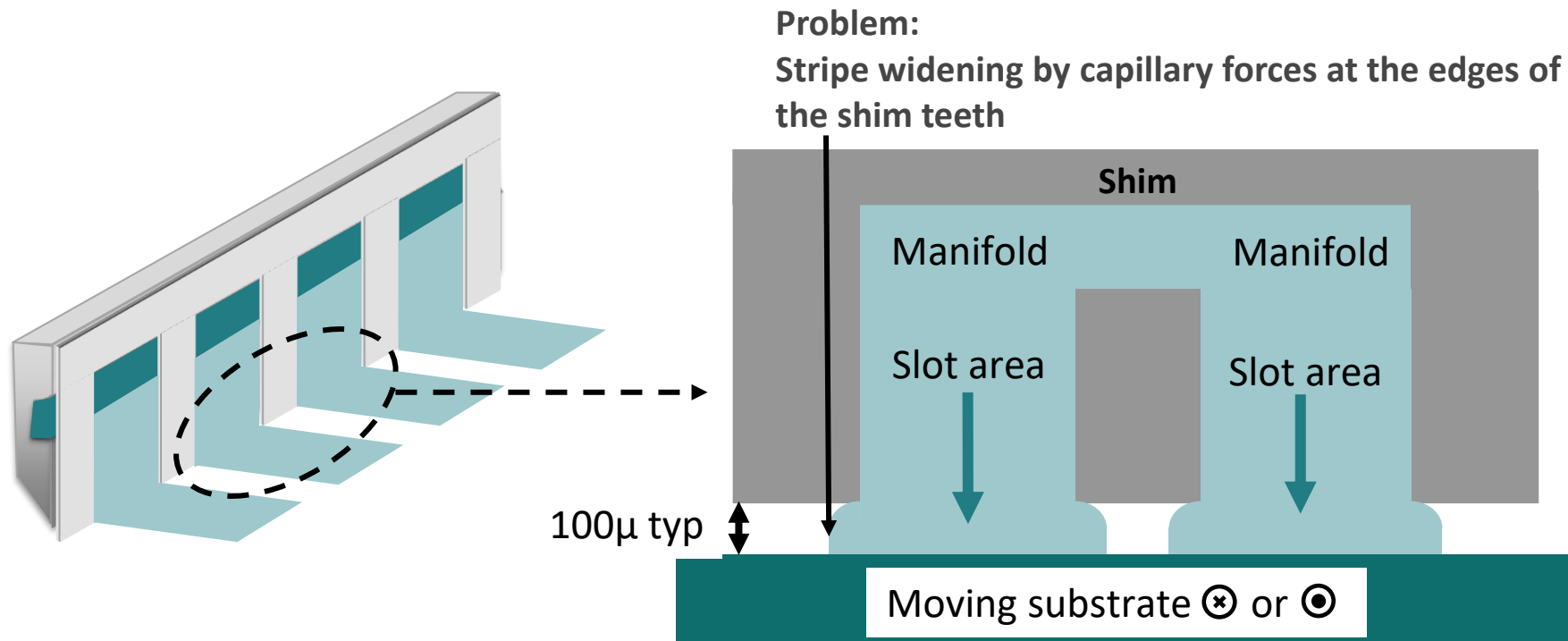
Downweb stripes of different width ...



... are made by appropriate shims, lasercut from steel or kapton

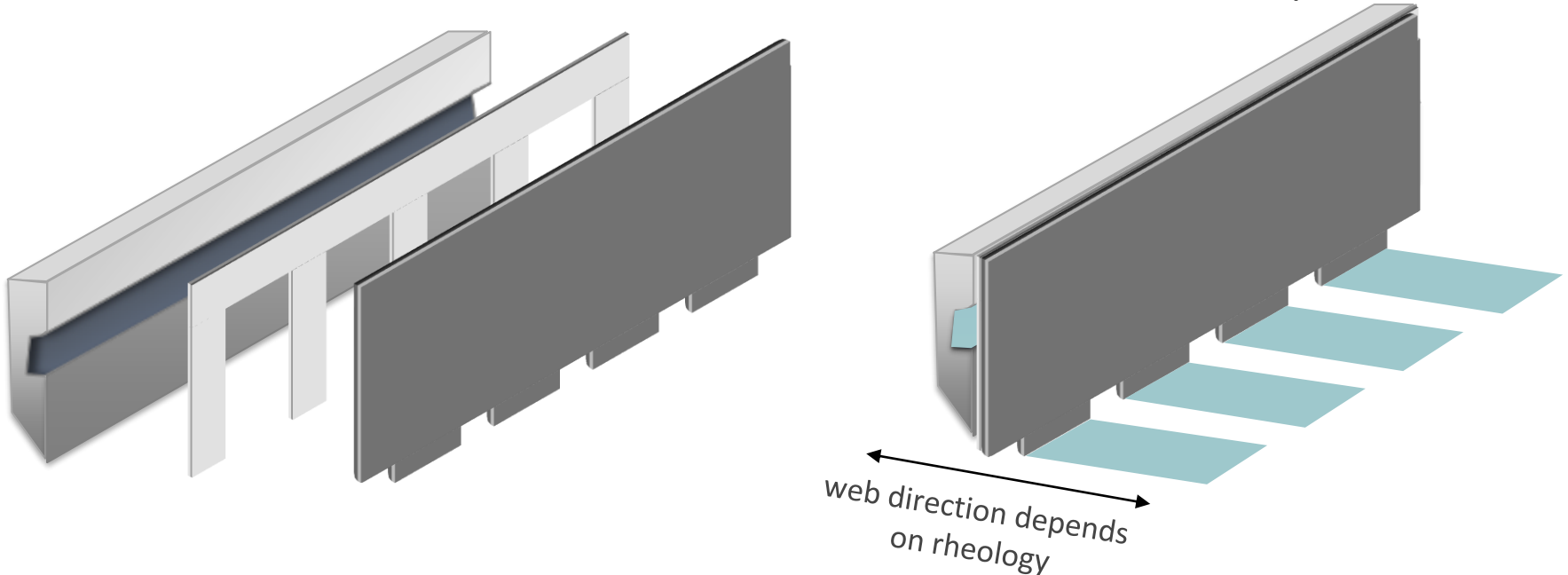


Level 2 – downweb stripes

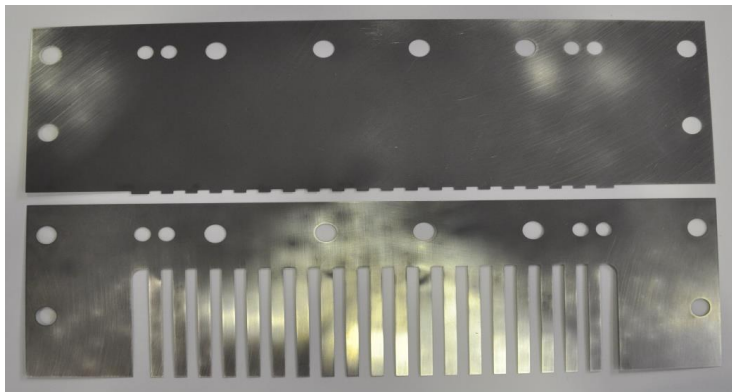


Level 2 – downweb stripes

Manifold + Shim + Meniscus guide = well defined stripes

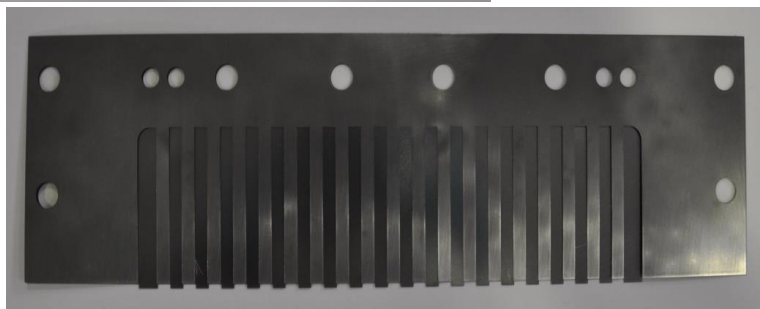


Level 2 – downweb stripes

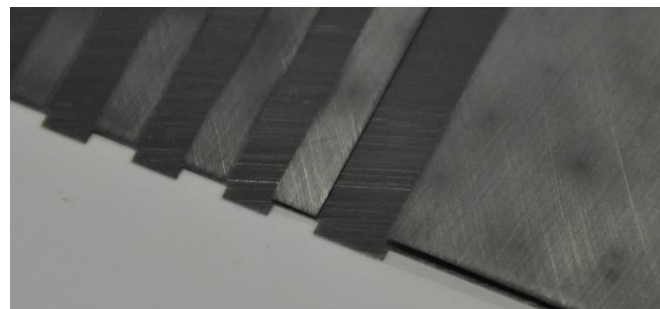


Meniscus guide

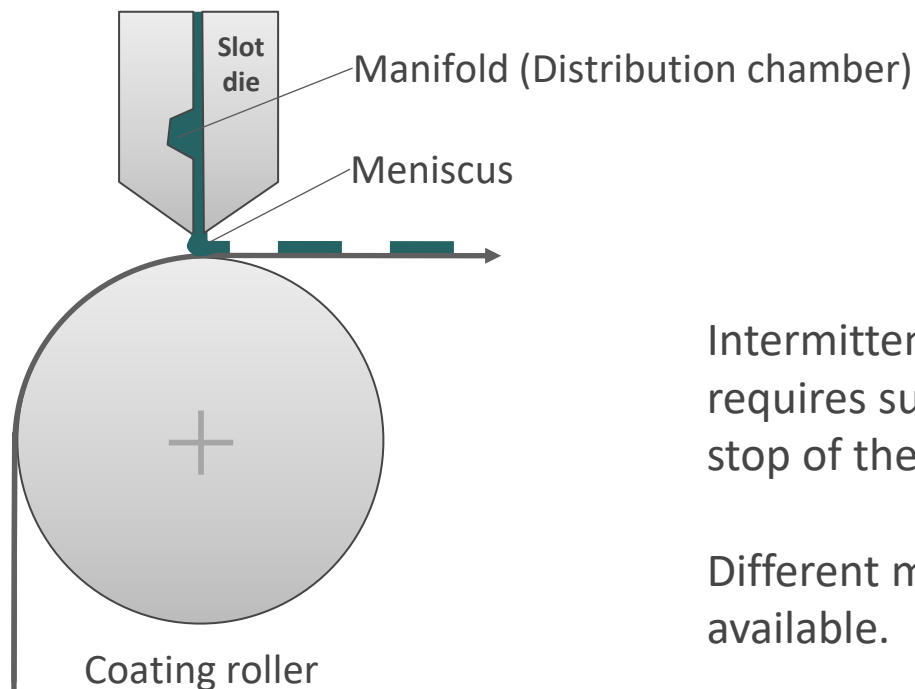
Shim



Meniscus guide + shim



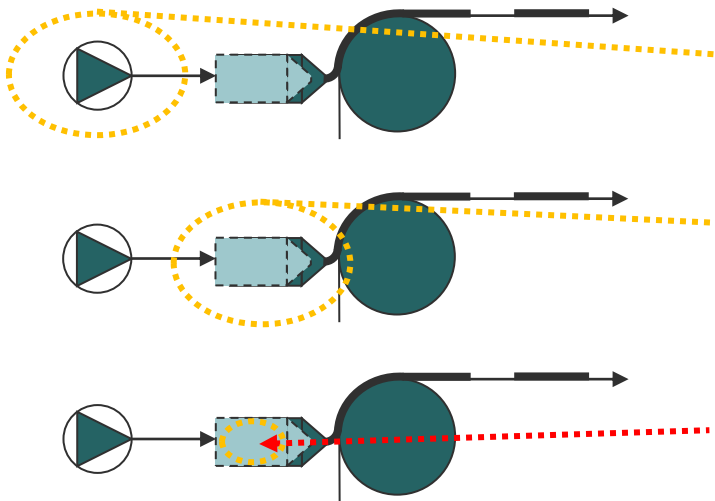
Structured coating – crossweb stripes (intermittent)



Intermittent coating requires sudden start / stop of the fluid flow.

Different methods are available.

Standard techniques for intermittent coating



Pump:

stop – reverse – restart

Slot die body:

move back – move forth to minimum gap –
move back to working gap (wedge procedure)

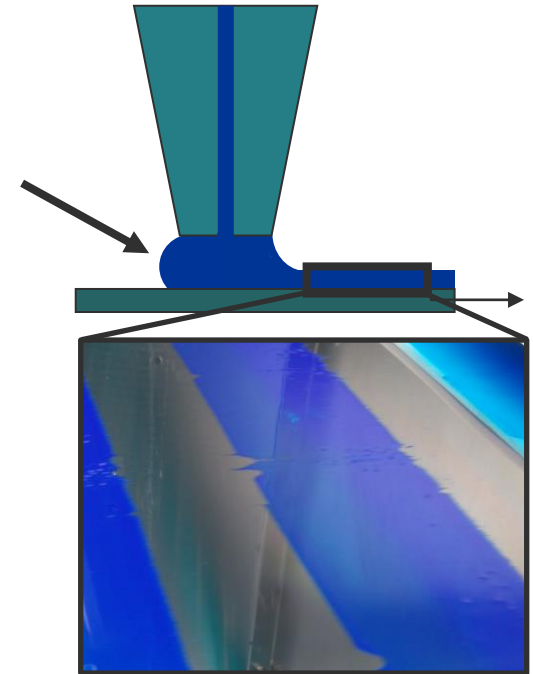
Slot die internal:

stop and redirect the flow by shutters and
valves. Pump flow continues, die flow stops.

All 3 techniques (single or in combination) work quite well, if the viscosity is rather high and the required edge definition is not more precise than around 1 mm. All techniques may be combined with a vacuum pump upstream to stabilize the meniscus and suck away residual liquid.

Structured coating – reason for bad edges at low viscosity

- ✓ Meniscus has to be interrupted
 - ✓ Low viscous liquids do not break along a straight line
 - ✓ Meniscus has to be sucked back and restored
 - ✓ Speed is of essence
- For low viscosity, all of the three methods are too slow and too indirect

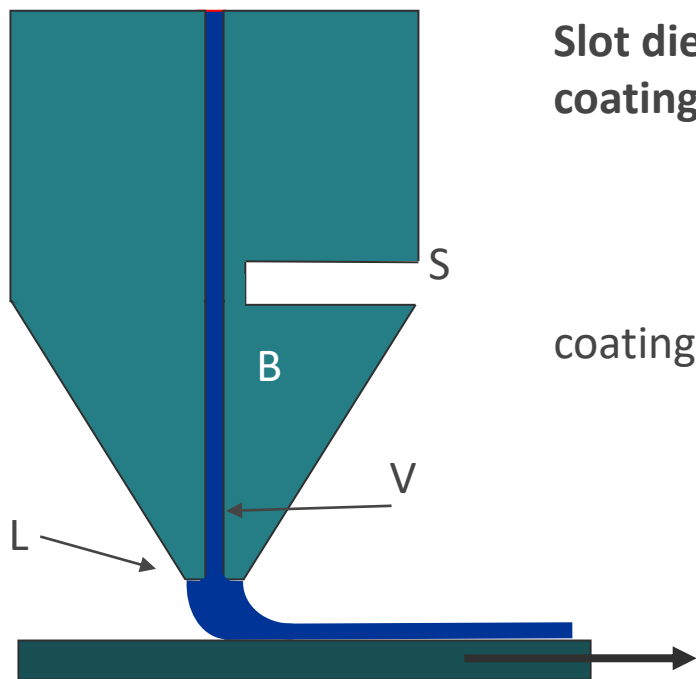


Structured coating – new concepts for low viscosity liquids

Two new concepts allow to interrupt and restore the meniscus much faster:

- ✓ **Double chamber slot die**
with modified chamber geometry and Piezo driven suck back pump
- ✓ **Switching lip slot die**
with a Piezo driven lip opening mechanism that sucks back the meniscus right where it is

Structured coating – the switching slot die lip

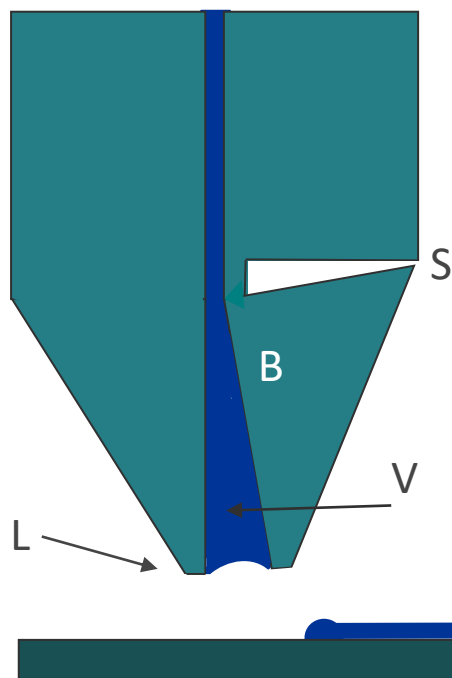


Slot die with movable lips:
coating mode

coating works as usual

- L lip
- V slot volume
- B bendable lip
- S bending slot

Structured coating – the switching slot die lip



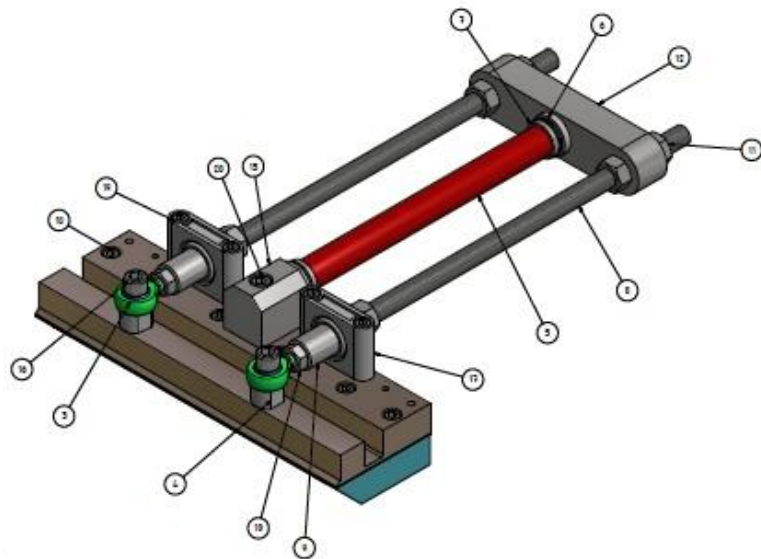
**Slot die with movable lips:
stop mode**

Bendable lip B flips open

Volume V increases and sucks
away the meniscus

L lip
V slot volume
B bendable lip
S bending slot

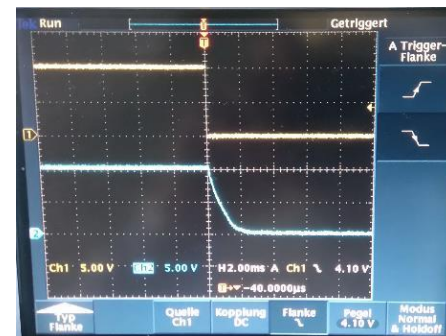
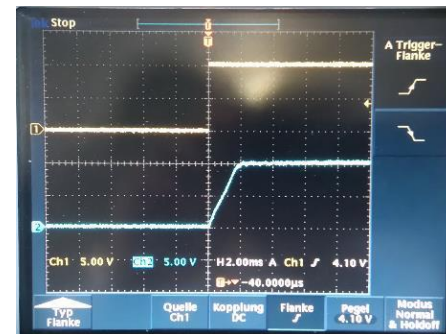
Structured coating – technical implementation with Piezo-Drive



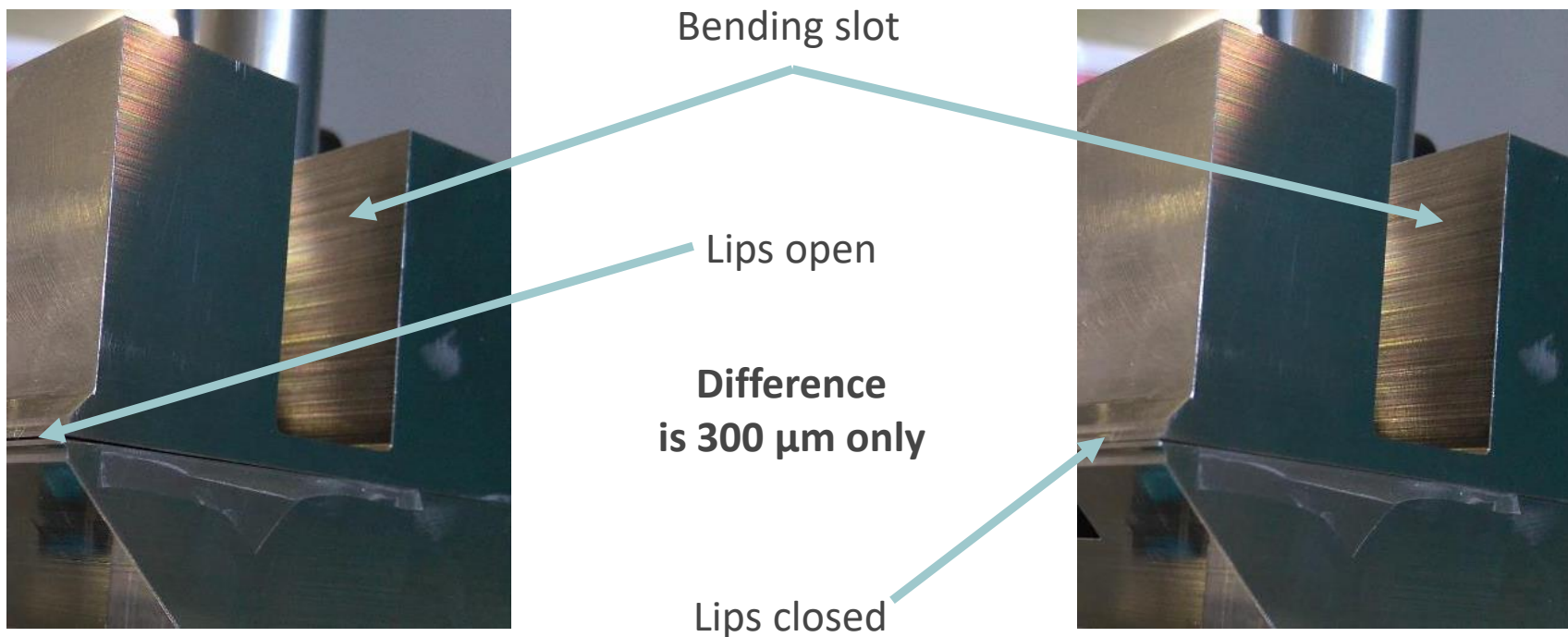
Extremely fast action:
within few ms from coating to
stop mode and vice versa

Control
Voltage

Piezo
Response



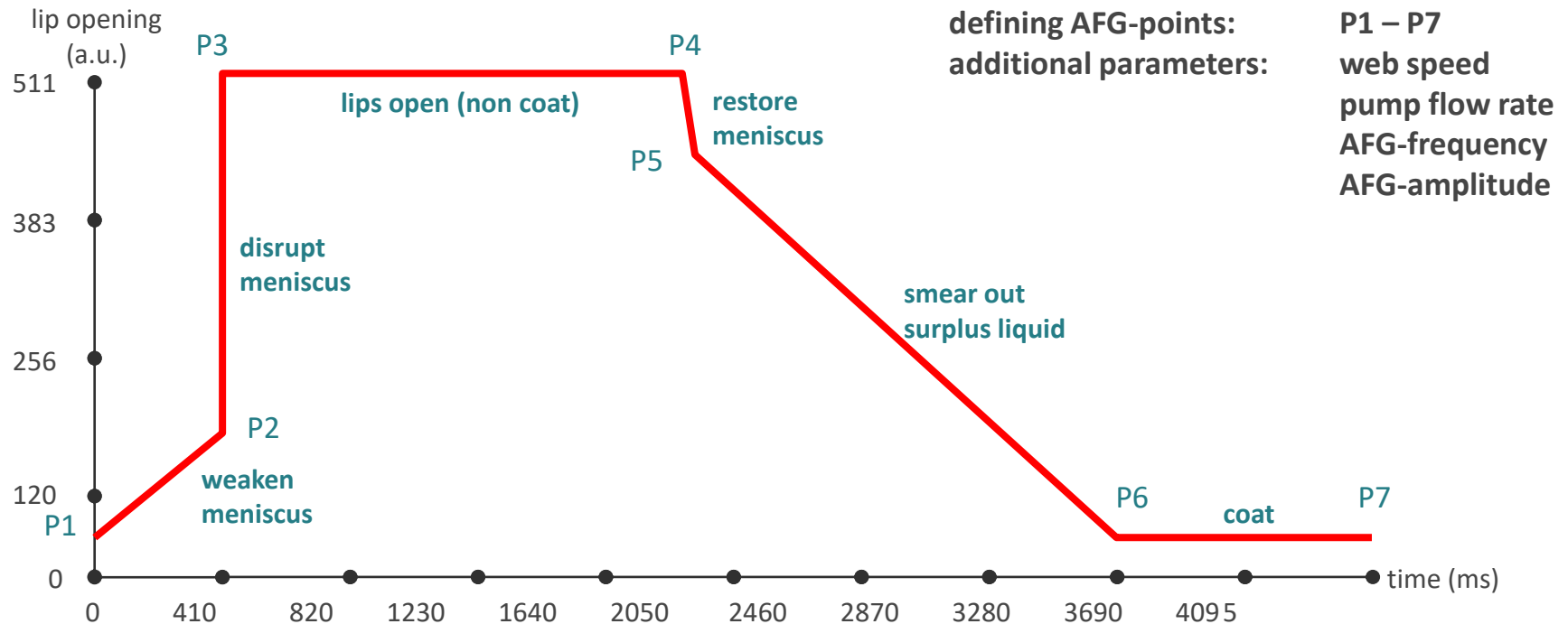
Structured coating – technical implementation with bendable lips



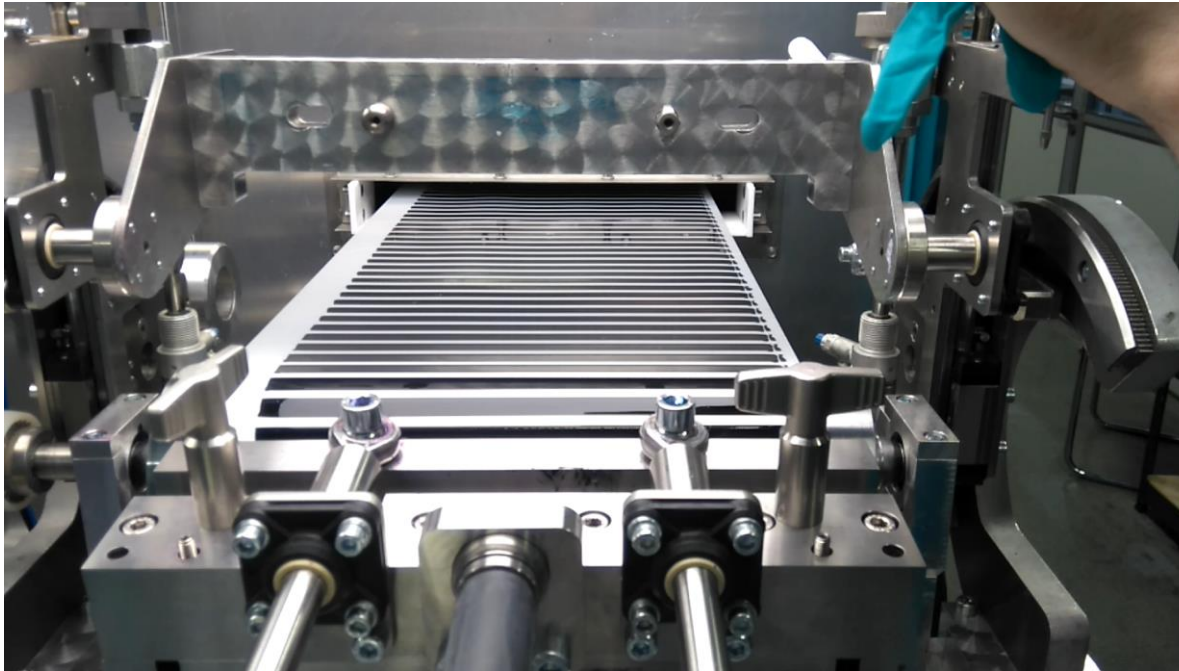
Technical implementation with bendable lips in action



Structured coating – stages of lip motion



Structured coating – ongoing trials: stripe coating of fuel cell paste



Ad on equipment for slot die coating

Pump Trolley solution



6.

Drying technologies



Introduction thermal drying – Coating parameters

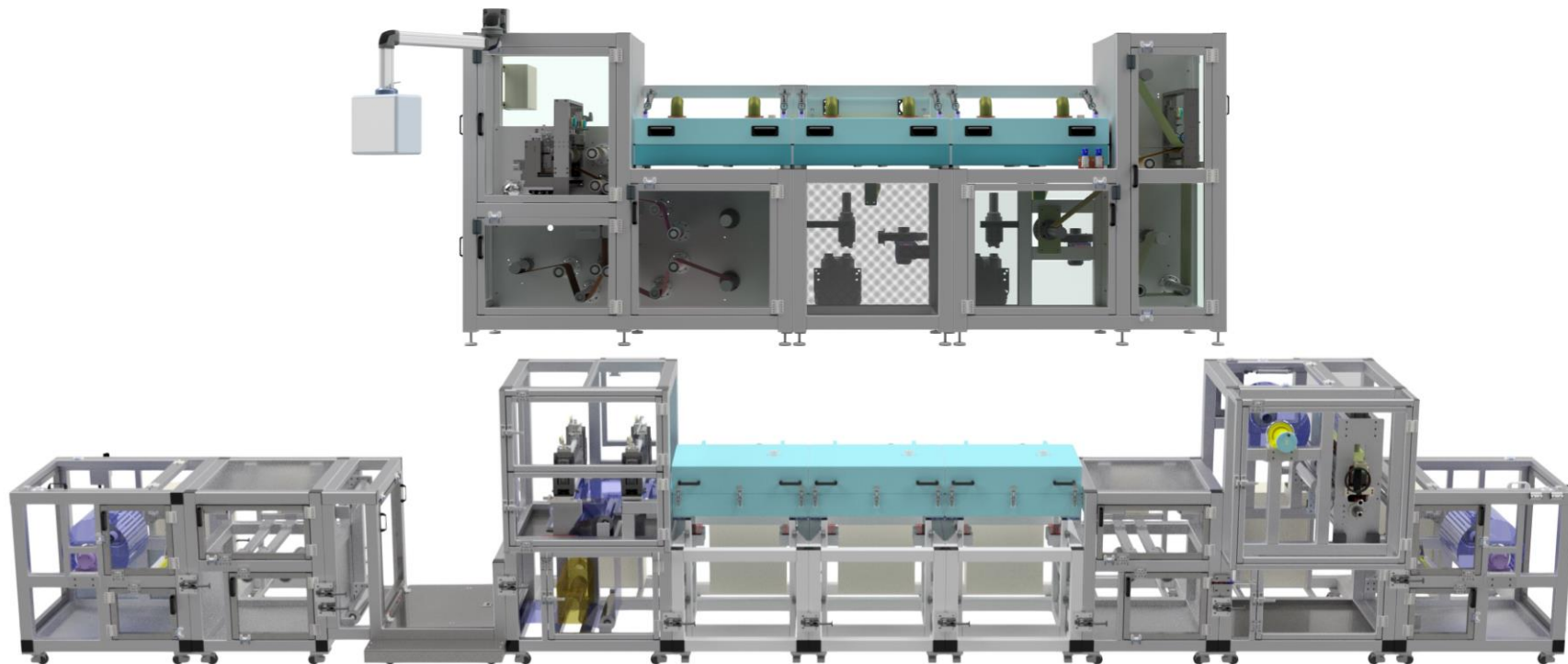
Coating chemistry	Coating processes	Process control	Drying
✓ Rheology ✓ Viscosity ✓ Viscoelasticity ✓ Type of solvents ✓ Solid content ✓ Van der Waals force ✓ Shear ratio ✓ Adhesion/Cohesion	✓ Coating systems ✓ Single or multilayer coatings ✓ Direct coatings ✓ Transfer (indirect) coatings ✓ Substrate speed ✓ Layer thickness ✓ Coating accuracy	✓ Process layout ✓ Tension control system ✓ Material guiding system ✓ Inline parameter control ✓ Quality control	✓ Convection drying ✓ Contact drying ✓ Infrared drying ✓ Sintering ✓ NIR ✓ High frequency ✓ UV crosslinking systems
Substrate	Pretreatment	Environment	Finishing
✓ Surface tension ✓ Dimension stability ✓ Surface structure ✓ Contact angle	✓ Corona ✓ Plasma ✓ Cleaning	✓ Humidity ✓ Temperature ✓ Inert conditions	✓ Calendaring ✓ Embossing ✓ Slitting

Dryer specs needed for the layout

Information about the substrate

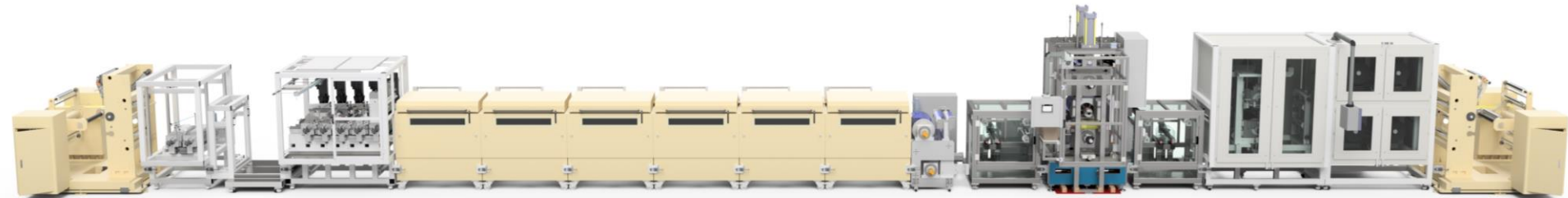
- ✓ Web weight – weight per unit area
- ✓ Web material
- ✓ Specific heat of web
- ✓ Temperature limitations
- ✓ Operating web tension – tension sensitivity
- ✓ Special characteristics

Basic principle



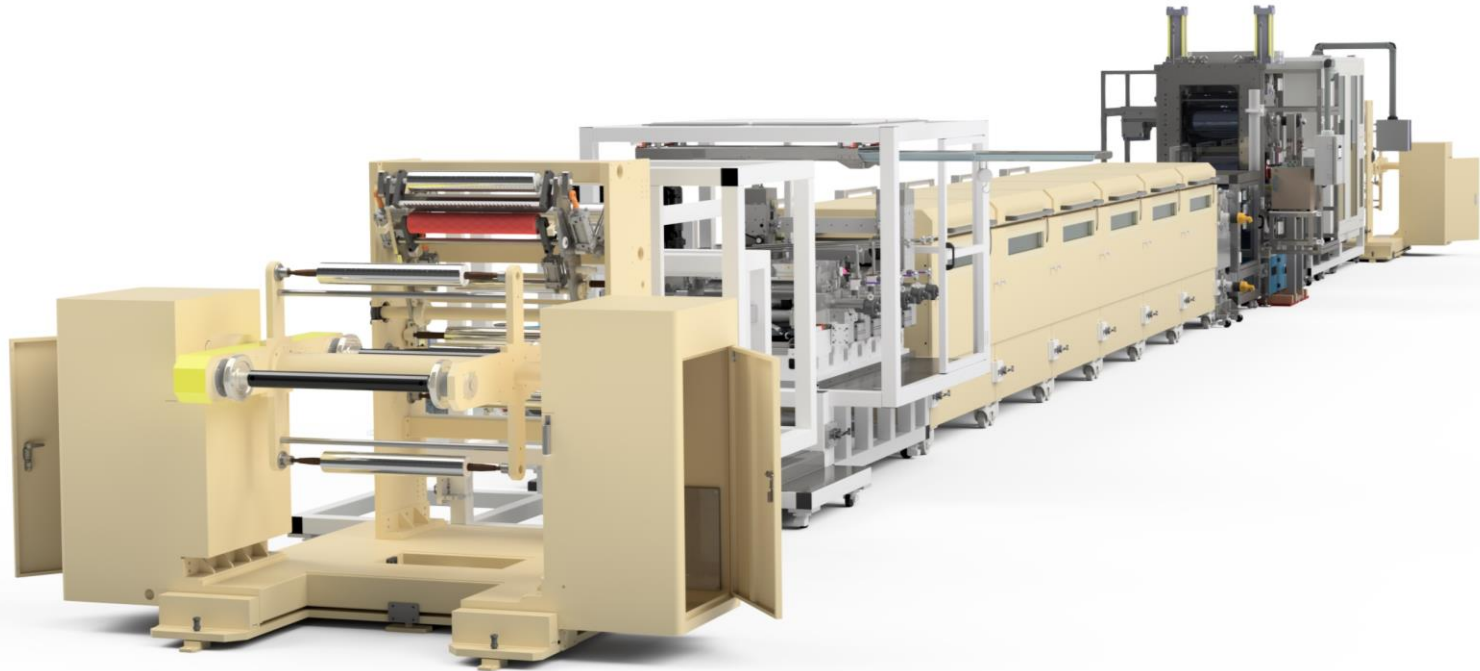
Today`s equipment

The Click&Coat in production scale



Today`s equipment

The Click&Coat in production scale

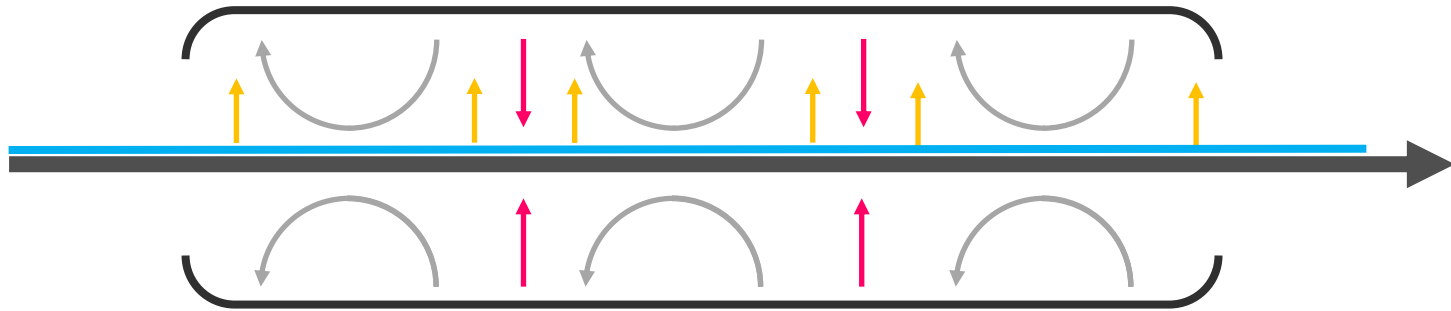


Drying technologies



Soucre: Drytec

Introduction thermal drying – As general as possible(!?)



- ✓ Heat Conduction/ Heat Diffusion
- ✓ Heat Convection/ **Mass Transfer**
- ✓ Radiation

Substrate

Coating

Heat transfer

Evaporating solvent

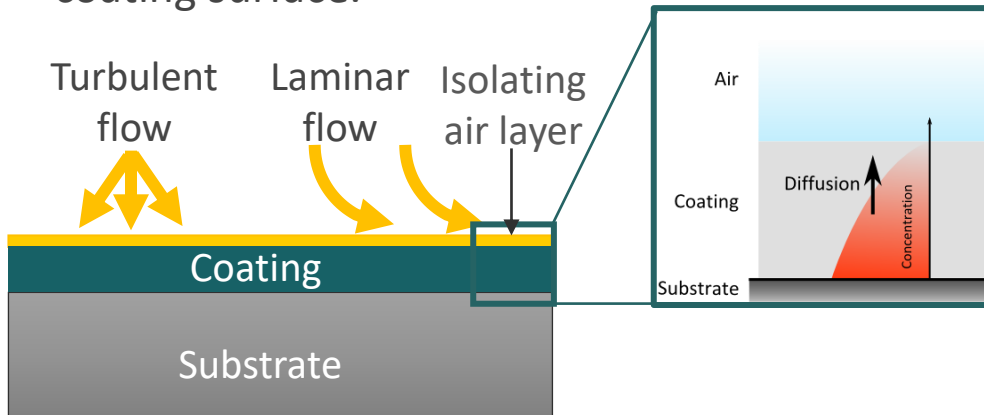
Solvent vapor transfer

Mass Transfer

Basics mass + heat transfer – Drying dynamics: The Boundary Layer

An isolating air layer forms just on top of the coated film

- ✓ Without convection mass+heat transfer is limited to diffusion and therefore slow.
- ✓ Convective (laminar or turbulent) flow needs to be applied without sacrificing the coating surface.

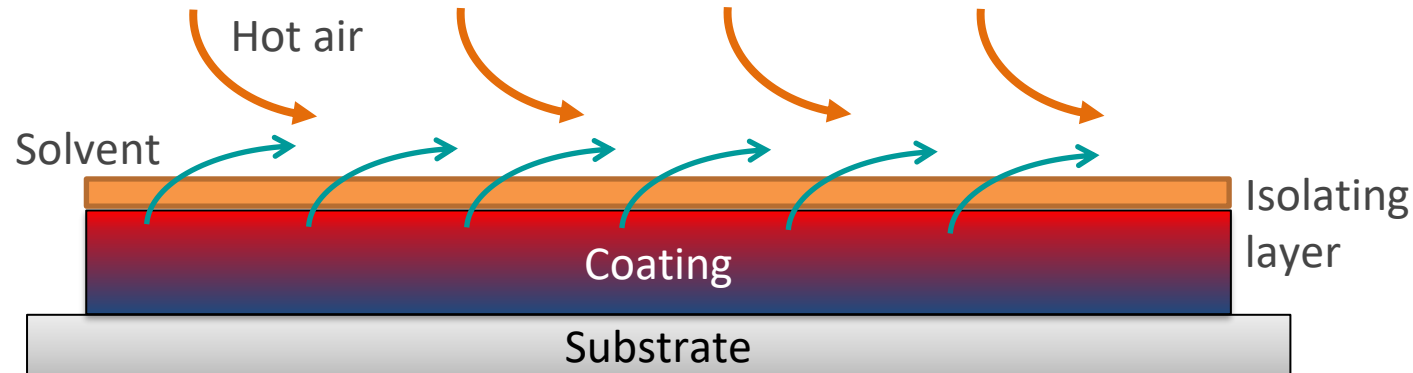


Usually there is a trade-off:

effective fast heat/mass transfer
or
gentle mild slow drying

Basics mass + heat transfer – Drying dynamics: Hot air drying

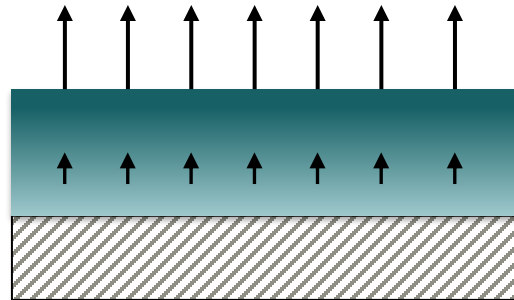
- ✓ Heating and vapor transport combined
- ✓ Bulk heating by thermal conductivity from surface
- ✓ Isolating layer to be overcome by air flow
- ✓ High air flow deteriorates surface
- ✓ Temperature easy to limit
- ✓ Slow



Basics mass + heat transfer

Nothing is as easy as it seems: Diffusion limit and skinning

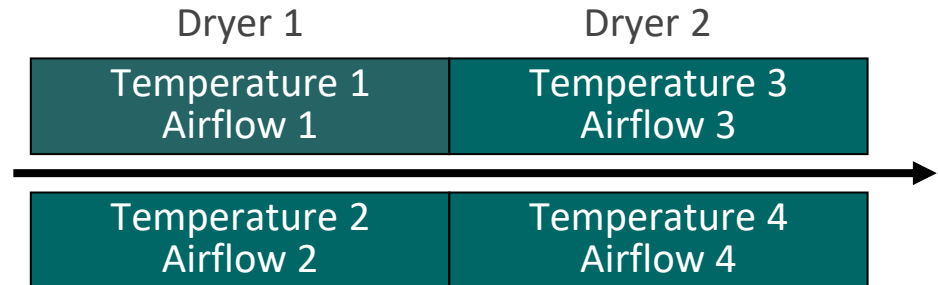
- ✓ Drying is also limited by solvent diffusion (at least in the final state of low residual solvent content).
- ✓ If the internal diffusion is slower than the evaporation from the surface, then a skin may be created.
- ✓ The skin acts as a barrier. The remaining diffusion through the skin may be slower than the wet diffusion by many orders of magnitude.



So the initial evaporation must be reduced by low temperature and/or by partially saturated atmosphere. Despite reduced evaporation the total drying time then may be shorter than at full initial evaporation.

Basics mass + heat transfer – Drying dynamics: Drying zone design

- ✓ Downweb temperature profiles can be realized by partitioning the dryer in different zones with different drying parameters.
- ✓ But temperature uniformity is difficult.
Possible cause: Mixing of hot and cool air at unintended leakages by Venturi effect.
- ✓ Experience shows, that there is always a compromise:
Good temperature uniformity requires low homogeneous air flow. High air flow results in less temperature uniformity.

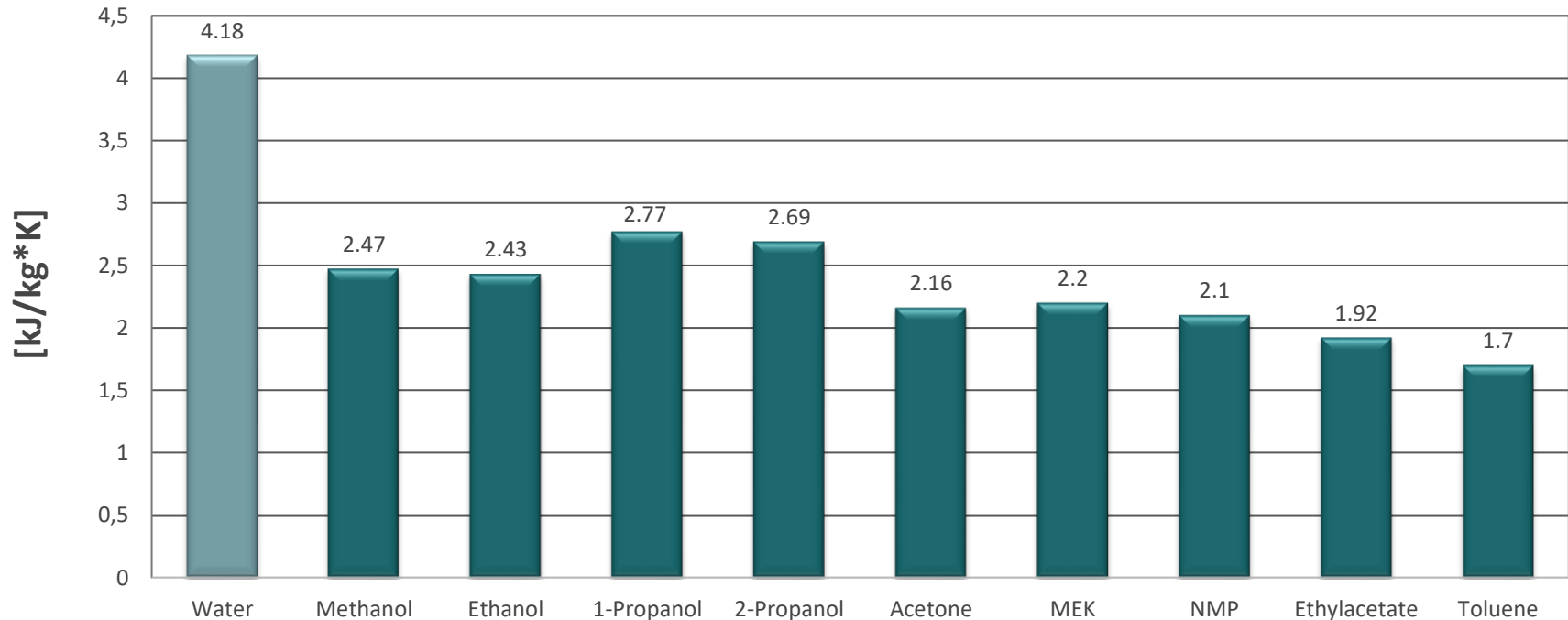


Typical solvents: Overview

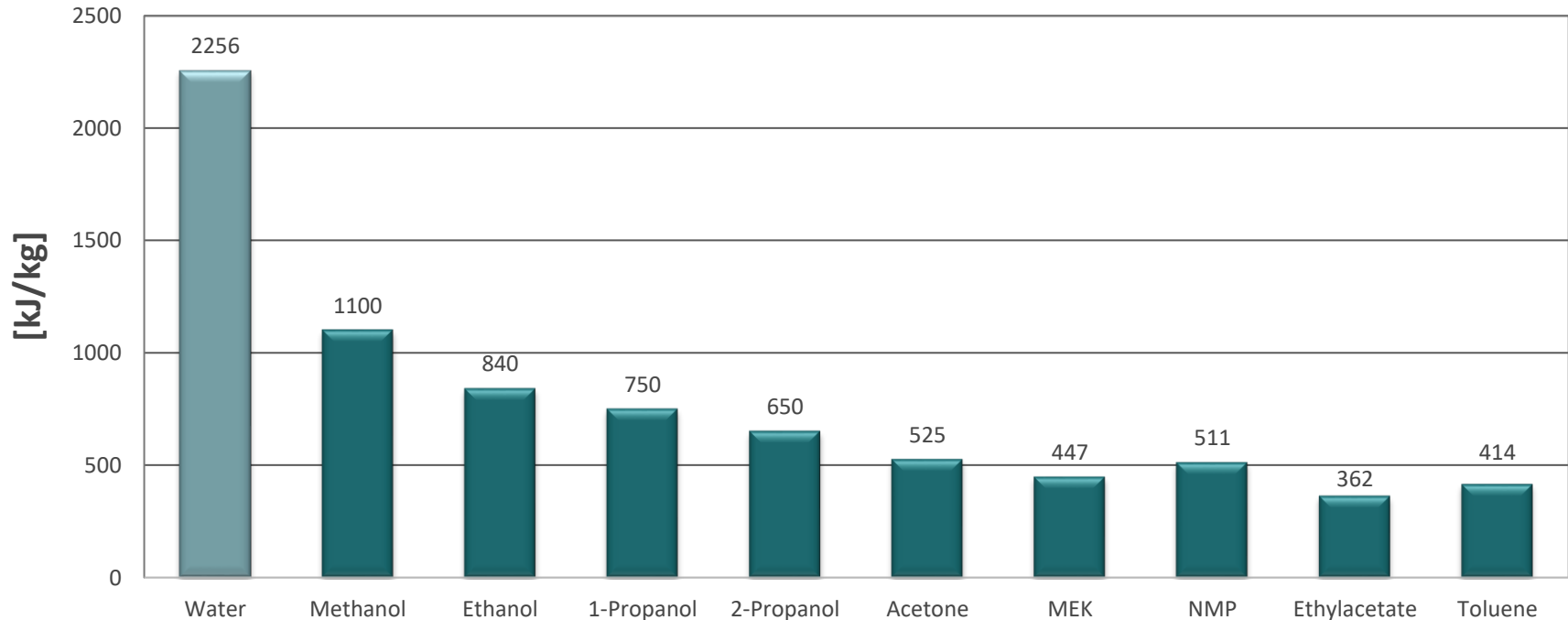
Solvent	Molar mass (g/mol)	Boiling point (°C)	Vapor pressure at 20°C (mbar)	Vapor pressure at 50°C (mbar)	Evaporation energy (kJ/kg)	Heat capacity (kJ/kg*K)	Surface energy at 20°C (mN/m=dyn/cm)
Water	18	100	23	123	2256	4.2	71.9
Methanol	32	65	129	535	1100	2.5	22.5
Ethanol	46	78	59	280	840	2.4	21.6
1-Propanol	60	97	20	112	750	2.8	23.0
2-Propanol	60	82	43	225	650	2.7	21.0
Acetone	58	56	246	830	525	2.2	22.8
MEK	72	80	105	373	447	2.2	24.6
NMP	99	203	0.3	2.9	511	2.1	40.9
Ethylacetate	88	77	98	380	362	1.9	23.0
Toluene	92	111	29	124	414	1.7	28.5

no guaranty

Typical solvents: Heat capacity



Typical solvents: Evaporation energy



Industrial drying systems

Coatema slot
nozle and
circulation
dryer on small
scale



Industrial drying systems

Coatema slot
nozle and
circulation
dryer on small
scale



Drytec Click&Coat dryer principle



Industrial drying systems

Coatema slot
nozle and
circulation
dryer on small
scale



Industrial drying systems

Coatema slot
nozle and
circulation
dryer on small
scale

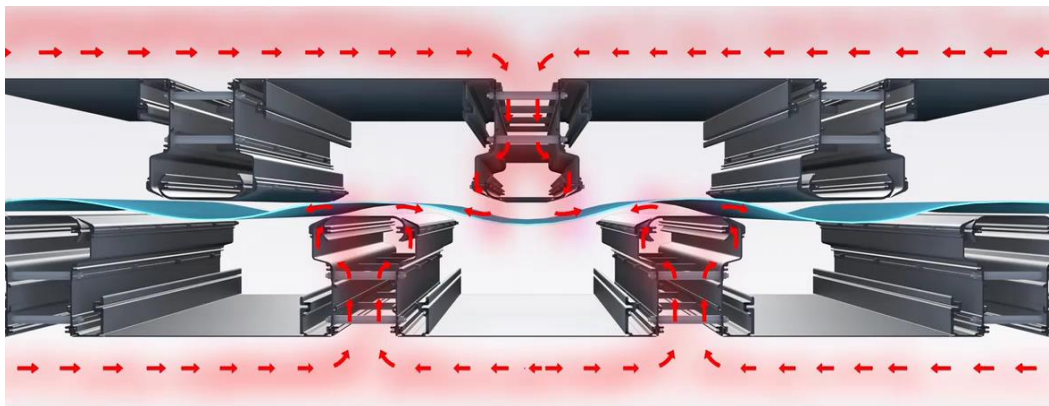


Industrial drying systems

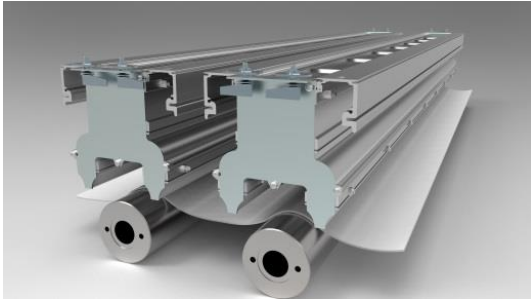
Coatema slot
nozle and
circulation
dryer on small
scale



Drytec Click&Coat dryer prinziple



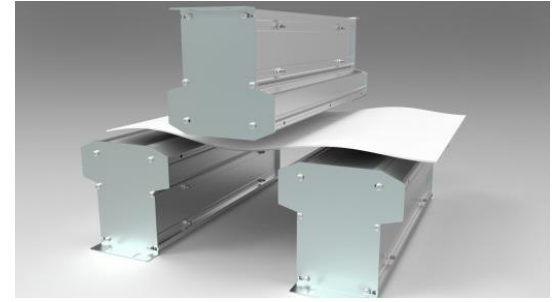
Industrial drying systems: Nozzle shapes 1



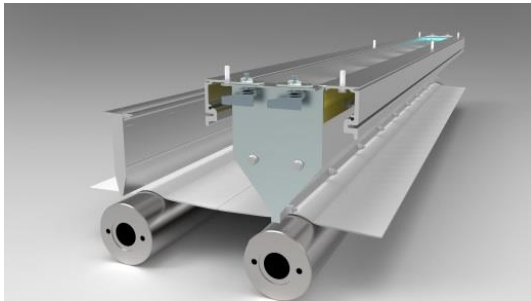
Impingement nozzles with two jets



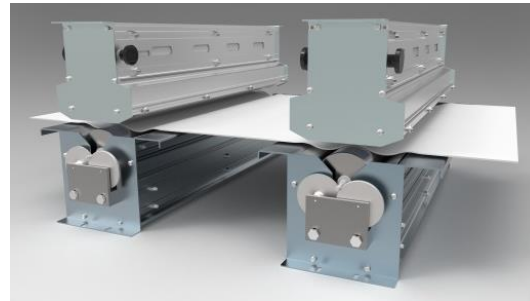
Flotation nozzles with adjustable air direction



Flotation nozzles



Impingement nozzles with one jet



Flotation nozzles with Contec 3 roller nozzle



Industrial drying systems: Nozzle shapes 2



Flotation nozzles with contec
1 roller nozzle



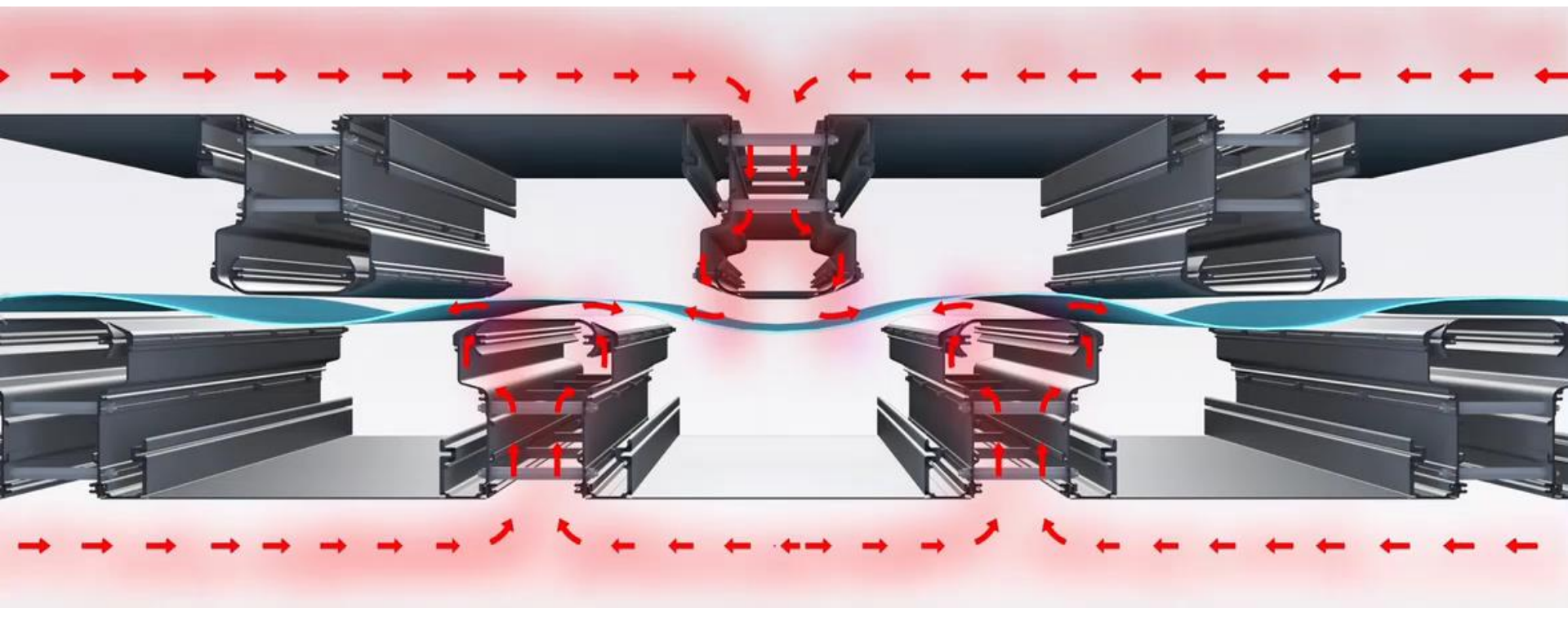
Flotation nozzles with contec
2 roller nozzle



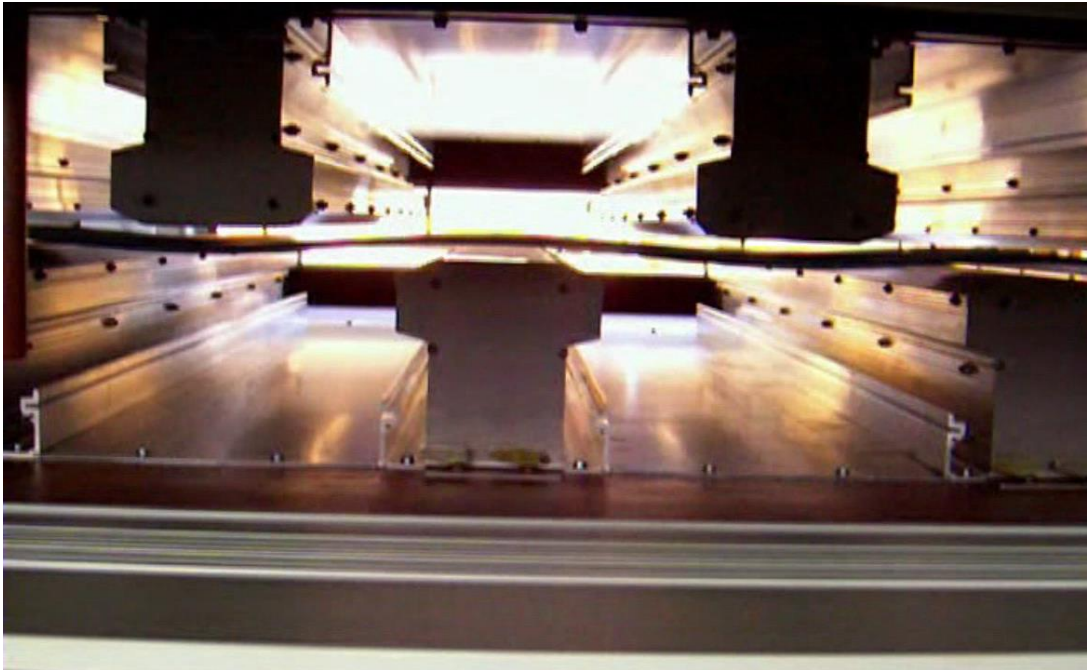
Flotation nozzles with contec
3 roller nozzle



Drying topics – drying technologies: HighDry HD500



Drying topics – drying technologies: HighDry HD500



Web behaviour in a
flowtation dryer

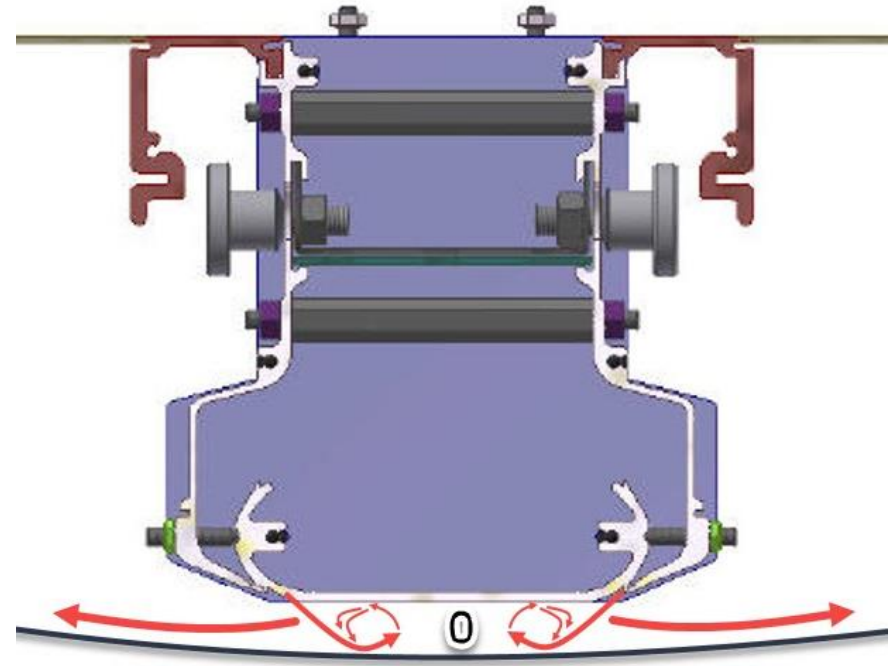
Click on the picture to show the video

Drying topics – drying technologies: HighDry HD500

The temperature-controlled circulating air exits the nozzle slots and creates turbulence as a result, thus enabling an effective convection behavior.

The nozzle slots are pre adjusted before delivery.

This setting can be used to influence the nozzle exit speed.

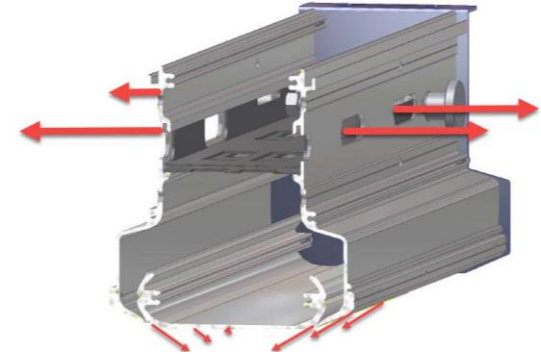
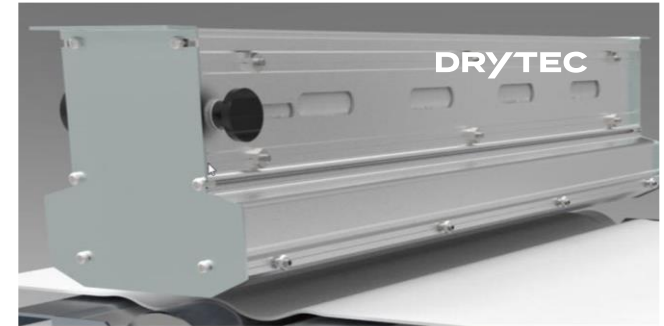


Drying topics – drying technologies: HighDry HD500

The temperature-controlled circulating air exits
As an additional function, DRYTEC offers
adjustable bypass openings integrated in the
side profiles of the FLOATEC nozzles.

This function is often used, for example, in
processes with low-viscosity coatings.

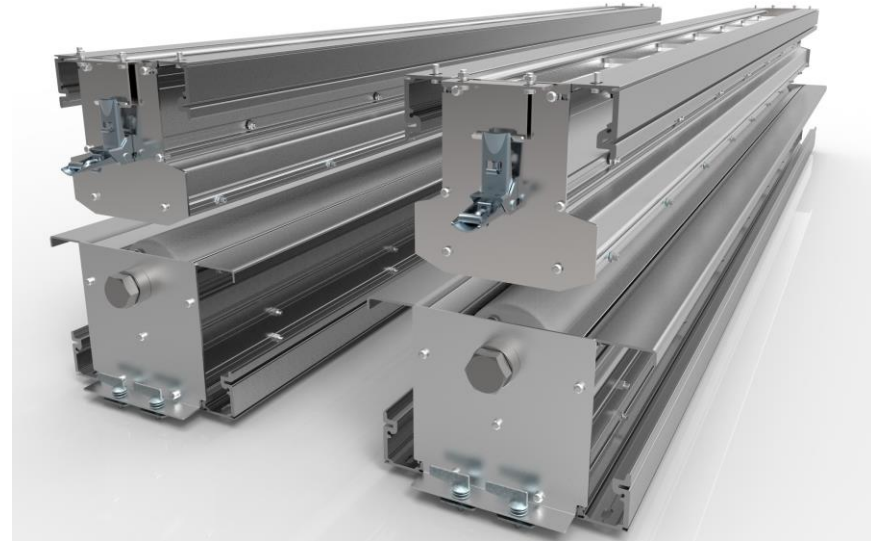
Hereby the operator is able to set different air
volume outlets from the bottom to the side.



Drying topics – drying technologies: HighDry HD500

The guide roller is installed in the nozzle housing of the CONTEC3 via ceramic bearings type: ZB10.

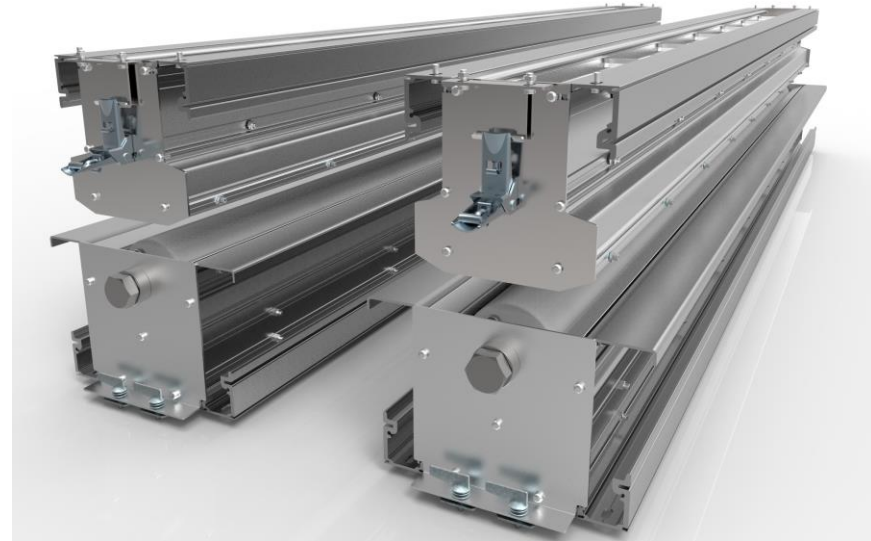
Just like all nozzle systems available from DRYTEC, the CONTEC3 nozzle can also be removed very quickly for maintenance purposes thanks to its quick-release fasteners.



Drying topics – drying technologies: HighDry HD500

The guide roller is installed in the nozzle housing of the CONTEC3 via ceramic bearings type: ZB10.

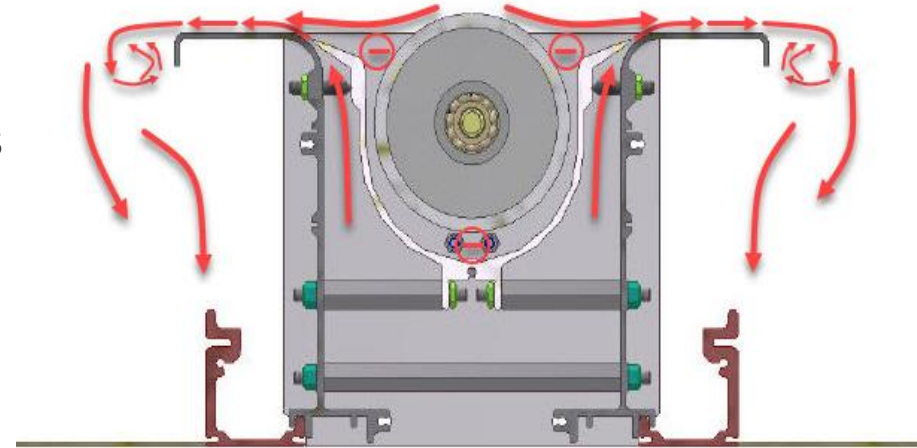
Just like all nozzle systems available from DRYTEC, the CONTEC3 nozzle can also be removed very quickly for maintenance purposes thanks to its quick-release fasteners.



Drying topics – drying technologies: HighDry HD500

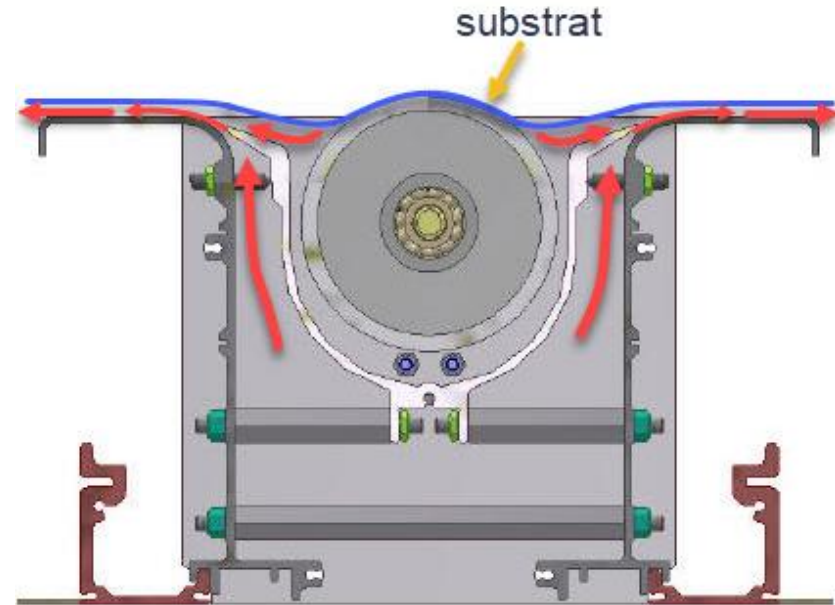
When the heated circulating air exits the wings of the CONTEC3 slots, a slight negative pressure is generated in the area of the roller chamber due to the venturi effect. This allows the substrate to lie on the roller in a slight wrap.

This behavior results in stable web transport and prevents the edge curl effect in many applications.

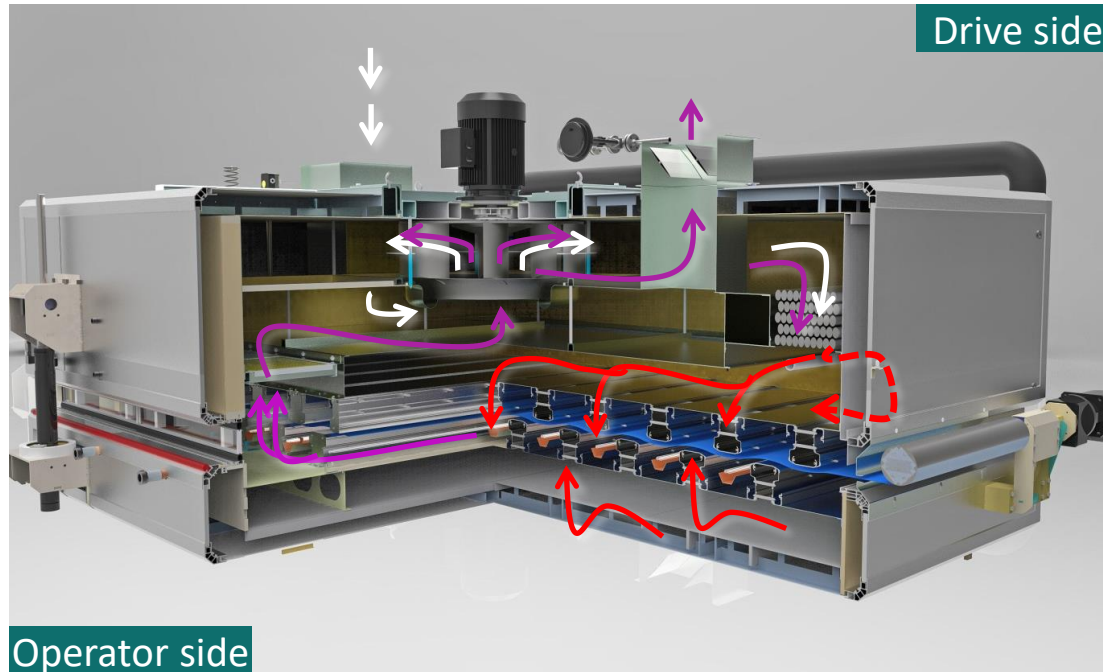


Drying topics – drying technologies: HighDry HD500

An air carpet is created on the supporting wings of the CONTEC3 by outflowing drying air, which on the one hand has the function of drying by convection, and on the other hand prevents grinding by touching the blades



Drying topics – drying technologies: HighDry HD500



Drive side

Air flow air inlet (cold)

Air flow heated air (hot)

Air flow reverse

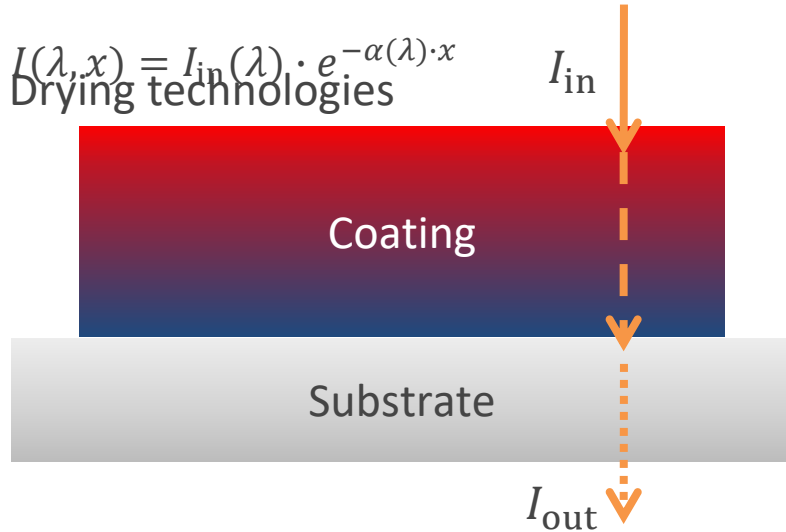
Clear arrows

Click „Air distribution“ to
show air flow direction

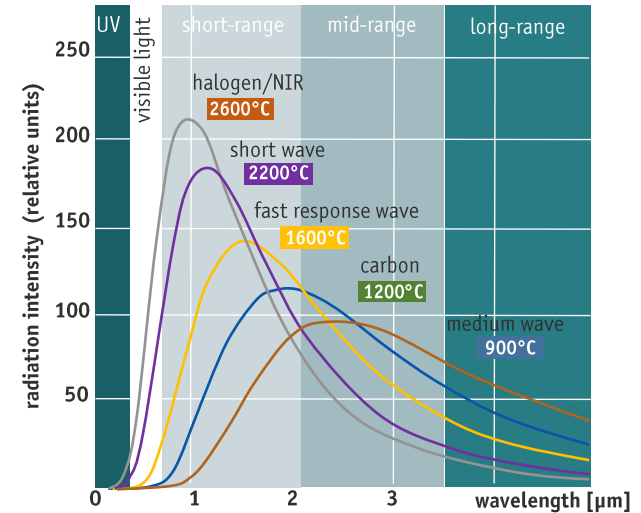
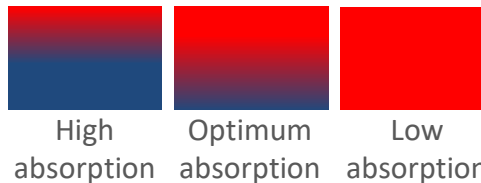
Operator side



Basics mass + heat transfer: (N)IR technology



$I_{in}(\lambda)$ Intensity in
 I_{out} Intensity out
 $\alpha(\lambda)$ Absorption coefficient
 d Layer thickness

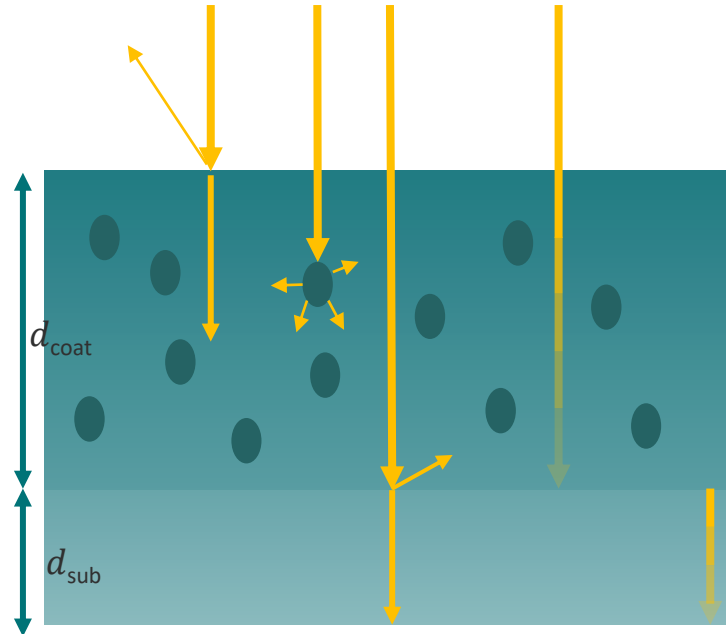


Relative intensity of radiators
at different wavelengths

Light-Structure interaction

Incident NIR/IR light: $I_{in}(\lambda)$

1) 2) 3) 4) 5)



Solute:

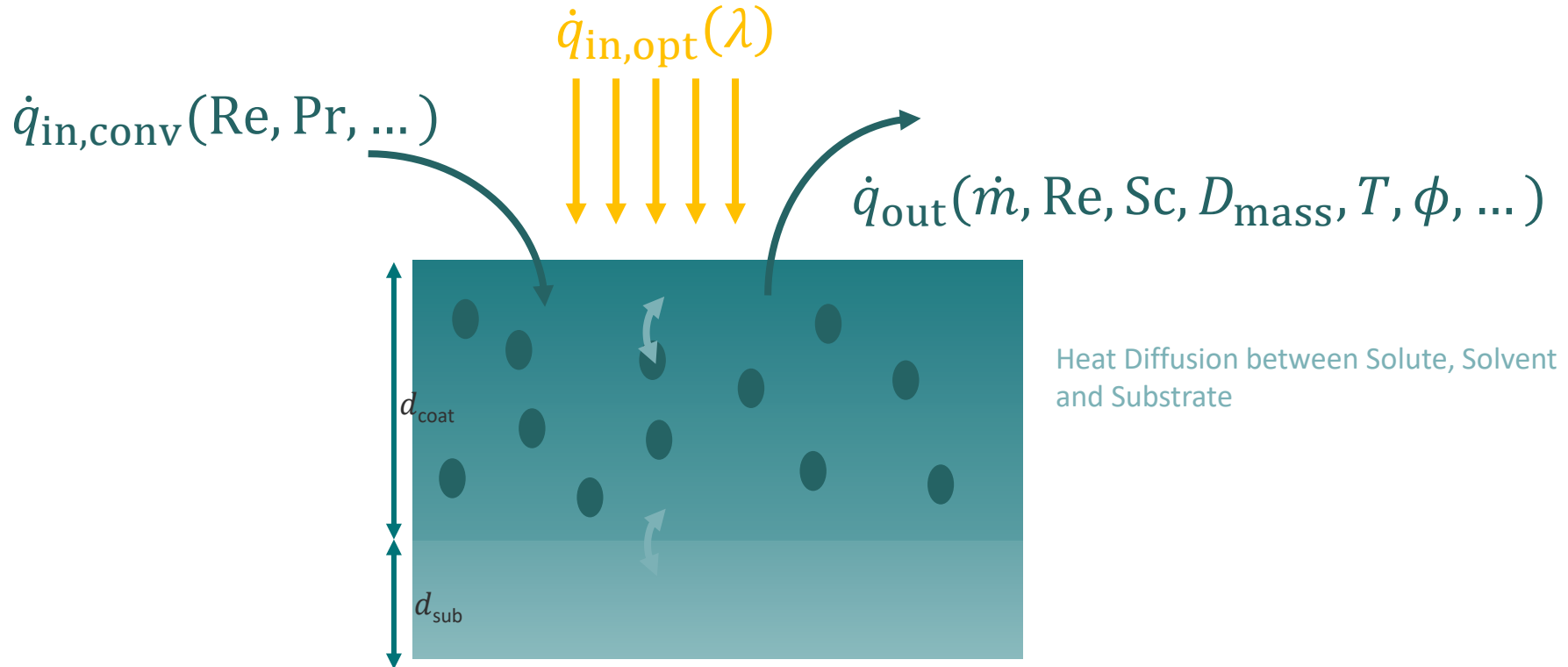
$c(d_{coat}(t), t), \epsilon(\lambda), d(t)$

Solvent: $R(\lambda), \alpha(\lambda), d(t)$

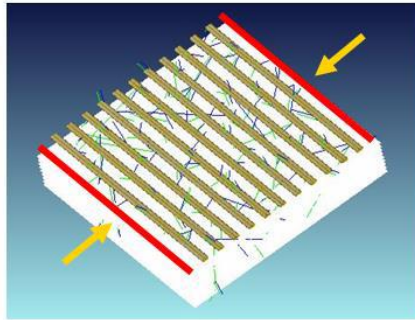
Substrate: $R(\lambda), \alpha(\lambda), d_{sub}$

- 1) Surface reflection R
- 2) Solute absorption α and scattering ϵ
- 3) Internal reflection R
- 4) Solvent absorption α
- 5) Substrate absorption α

Thermodynamic Model

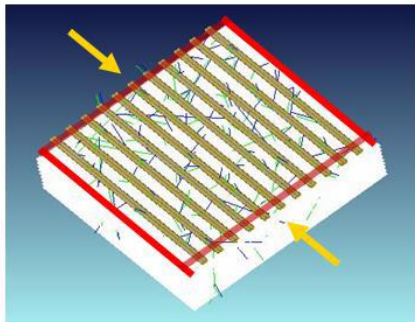
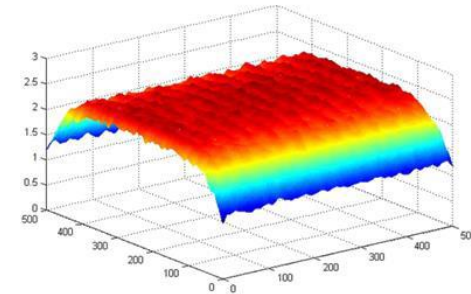


IR / NIR Drying – Infrared drying



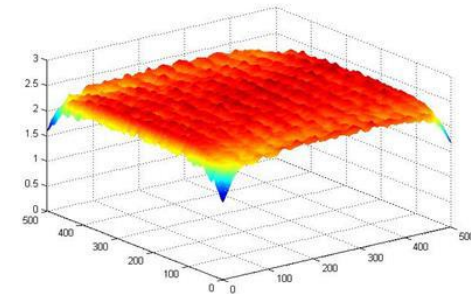
Continuous process

13 emitters, 2 types, 3 zones



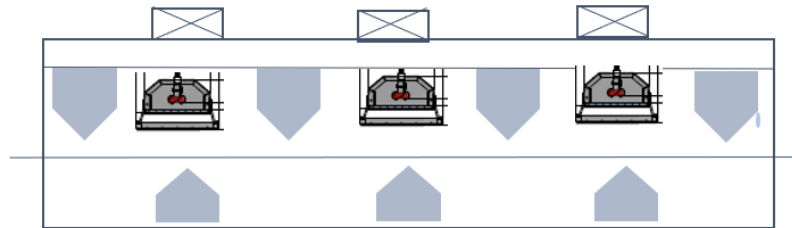
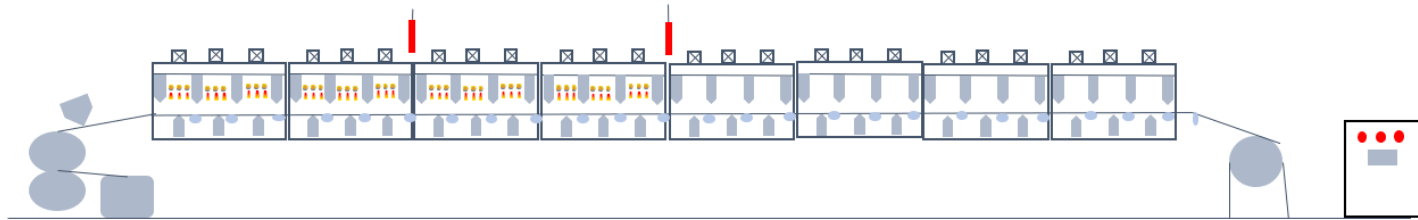
Batch process

15 emitters, 3 types, 5 zones



IR / NIR Drying – Infrared drying

Layout



Hotair oven: 50m (10 zone)

IR at first 25m (5 zone) for boost

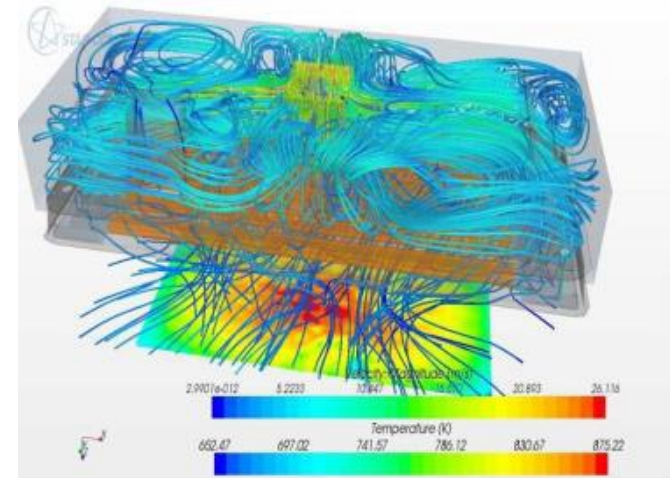
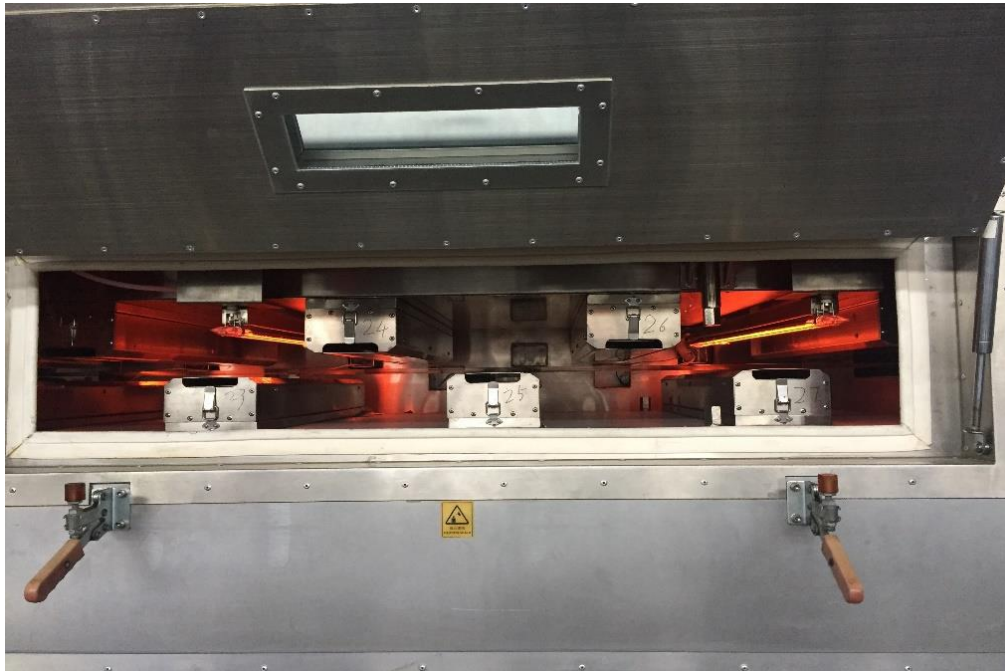
Heating distance : 100mm

Qty of IR : $60 \times 3.1\text{Kw} = 186\text{Kw}$

IR technology – combined hot air / IR dryer in 2010



IR / NIR Drying – Infrared drying



Soucre: Heraeus Noblelight

IR / NIR Drying – Infrared drying

INFRARED OFFERS MANY ADVANTAGES

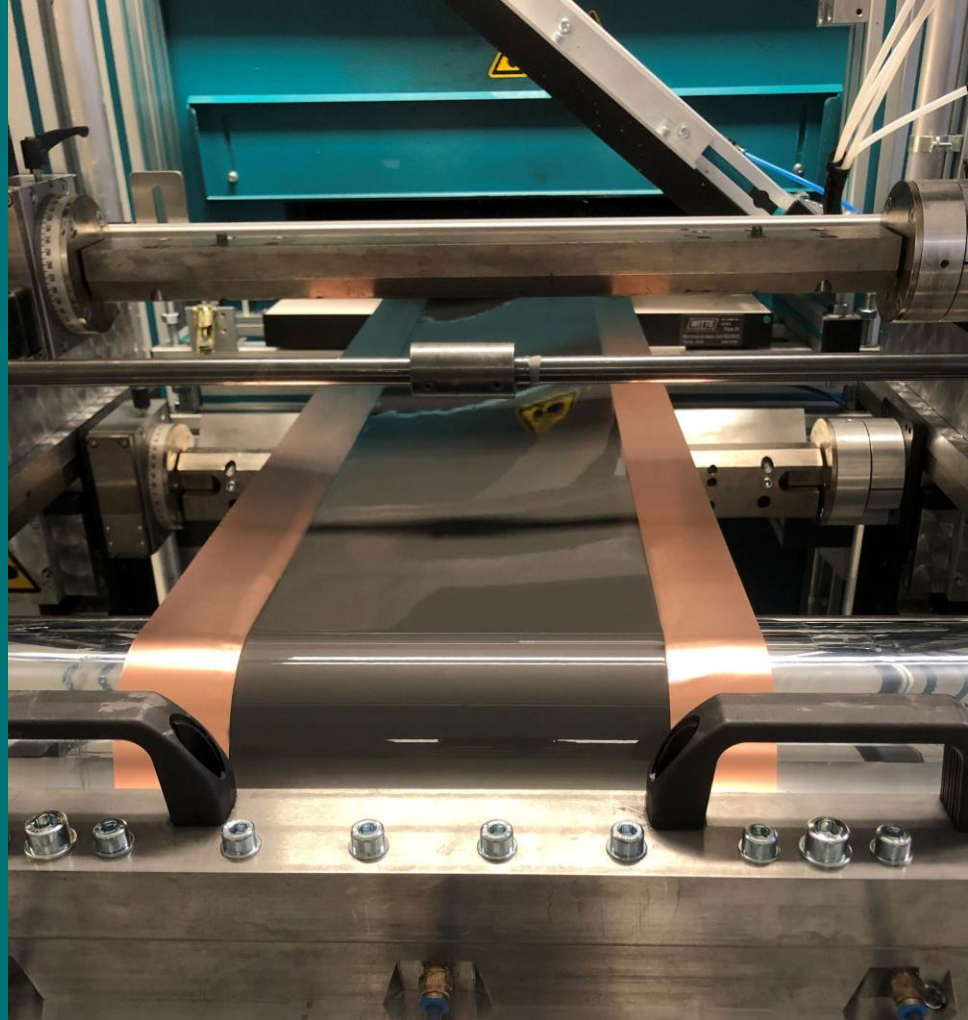
- ✓ Process advantage by implementing Infrared
- ✓ Line speed can be increased (up to 50%) by implementing Infrared into convection oven
- ✓ Oven space saving due to efficient drying combination „convection plus Infrared“

Advantage of Heraeus Infrared emitters

- ✓ Tailormade IR-emitters (by wavelength, power density and reflector design)
- ✓ Homogeneous IR field via Simulation program
- ✓ (by Ray Tracing or Computational Fluid Dynamic)

7.

Today`s equipment for batteries



Today`s equipment for batteries

Proof of concept – Li-ion battery Project INTRES

Upscaling of battery technologies –
Standard platform technologies



Proof of concept – Li-ion battery Project INTRES

Upscaling of new battery tech



Test Solution 2S2 (Tabletop)

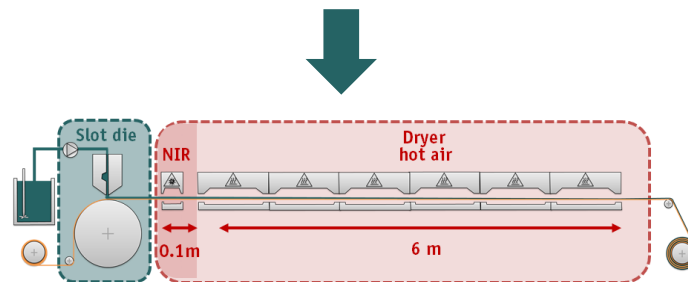
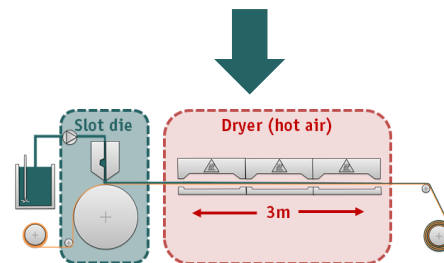


Smartcoater



Click&Coat® pilot line

Lab-scale R2S



Today`s equipment for batteries

The Easycoater

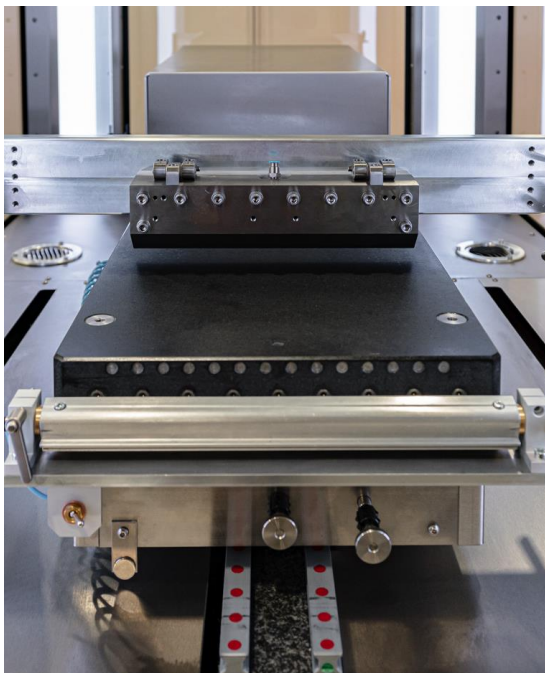


Today`s equipment for batteries

The Easycoater



The Easycoater



Facts

- ✓ Knife system
- ✓ Slot die system
- ✓ Screen system
- ✓ Heated vacuum table
- ✓ Integrated air heating

Today`s equipment for batteries

The Easycoater



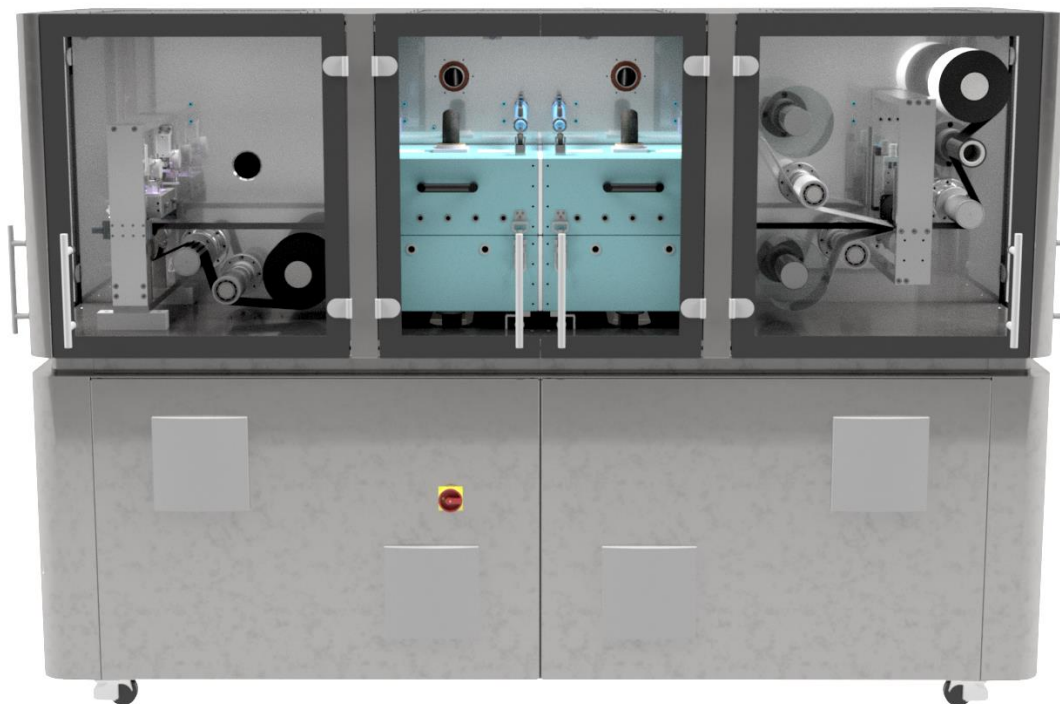
Today`s equipment for batteries

The Test Solution R2R



Today`s equipment for batteries

The Test Solution R2R



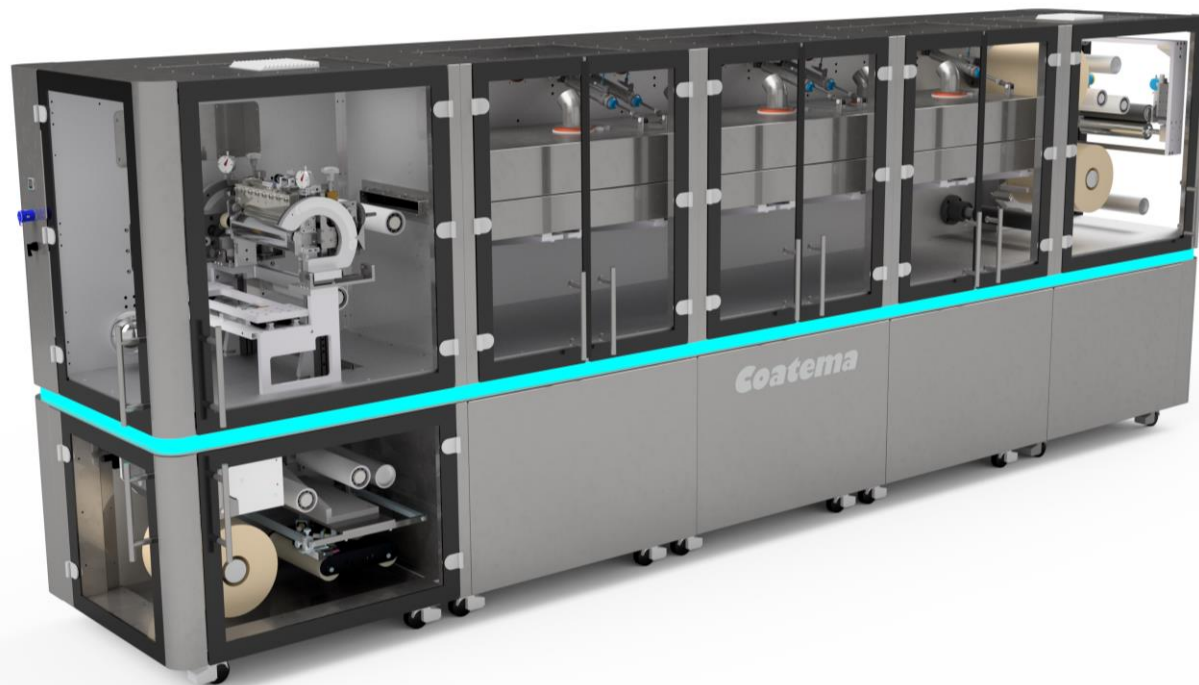
Today`s equipment for batteries

The Smartcoater



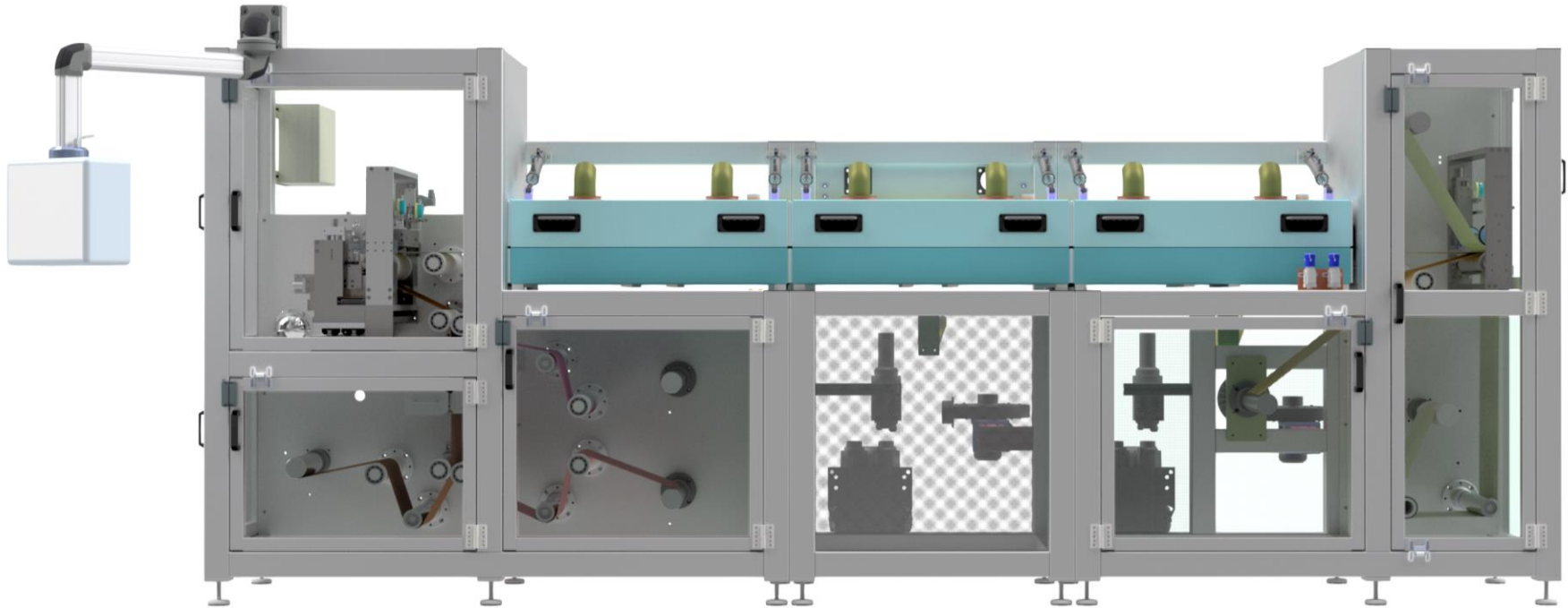
Today`s equipment for batteries

The Smartcoater



Today`s equipment for batteries

The Basecoater

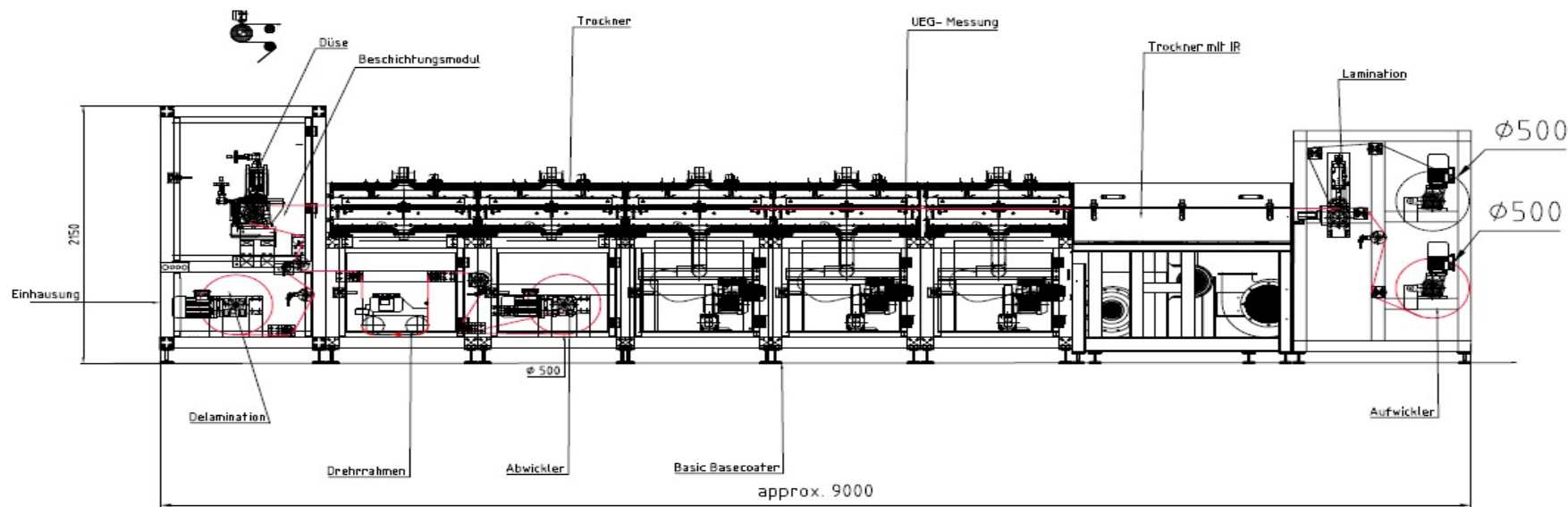


Today`s equipment for batteries

The Basecoater



The Basecoater



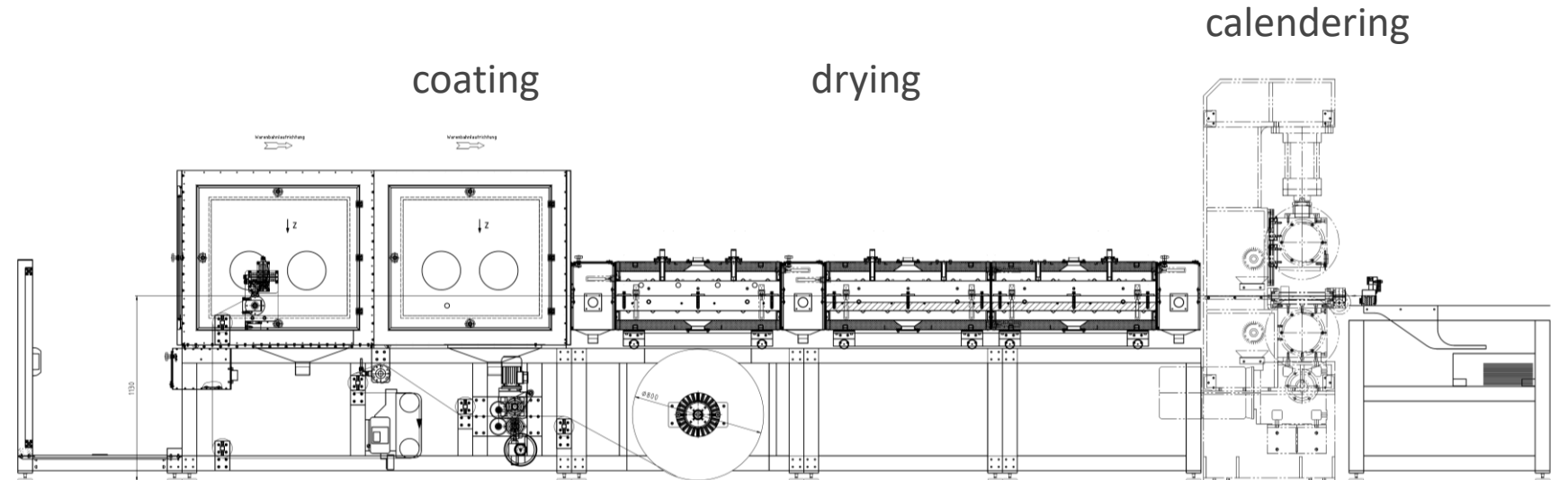
Today's equipment for batteries

Bespoke Basecoater battery equipment



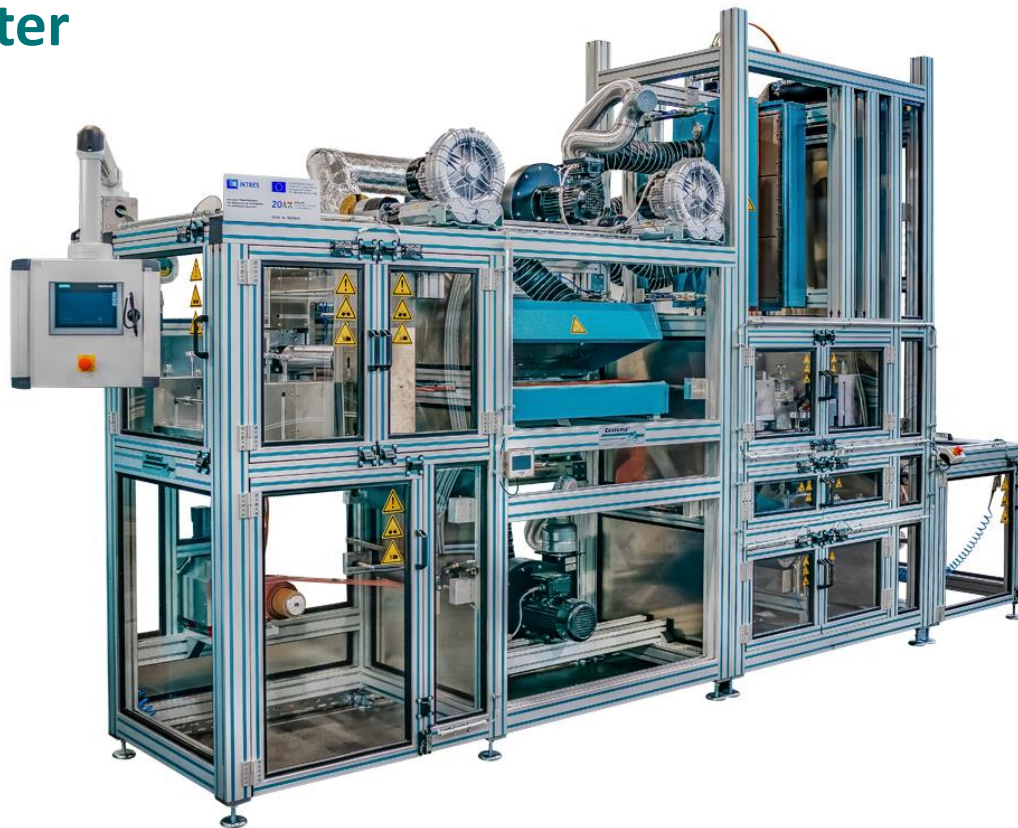
- ✓ Oxygen content <3%
- ✓ Saturated solvents below LEL
- ✓ IR Drying
- ✓ 50m³/h N₂ flow

Bespoke Basecoater battery equipment



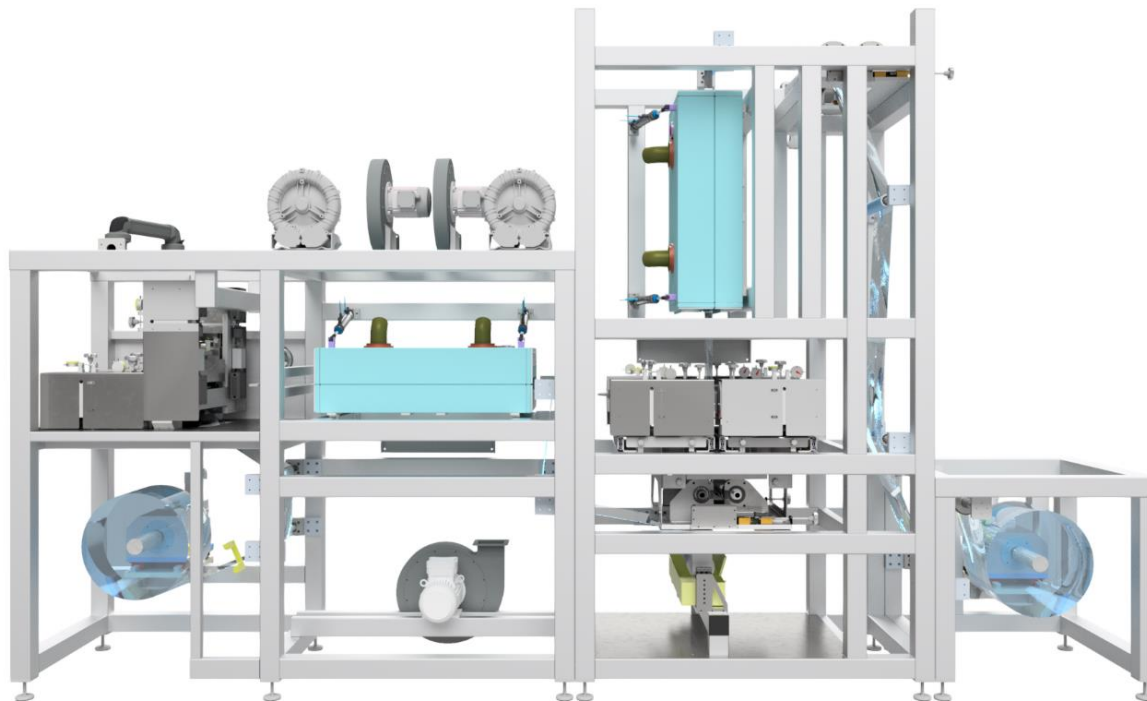
Today's equipment for batteries

The Basecoater



Today`s equipment for batteries

The Basecoater



Today`s equipment for batteries

The Basecoater



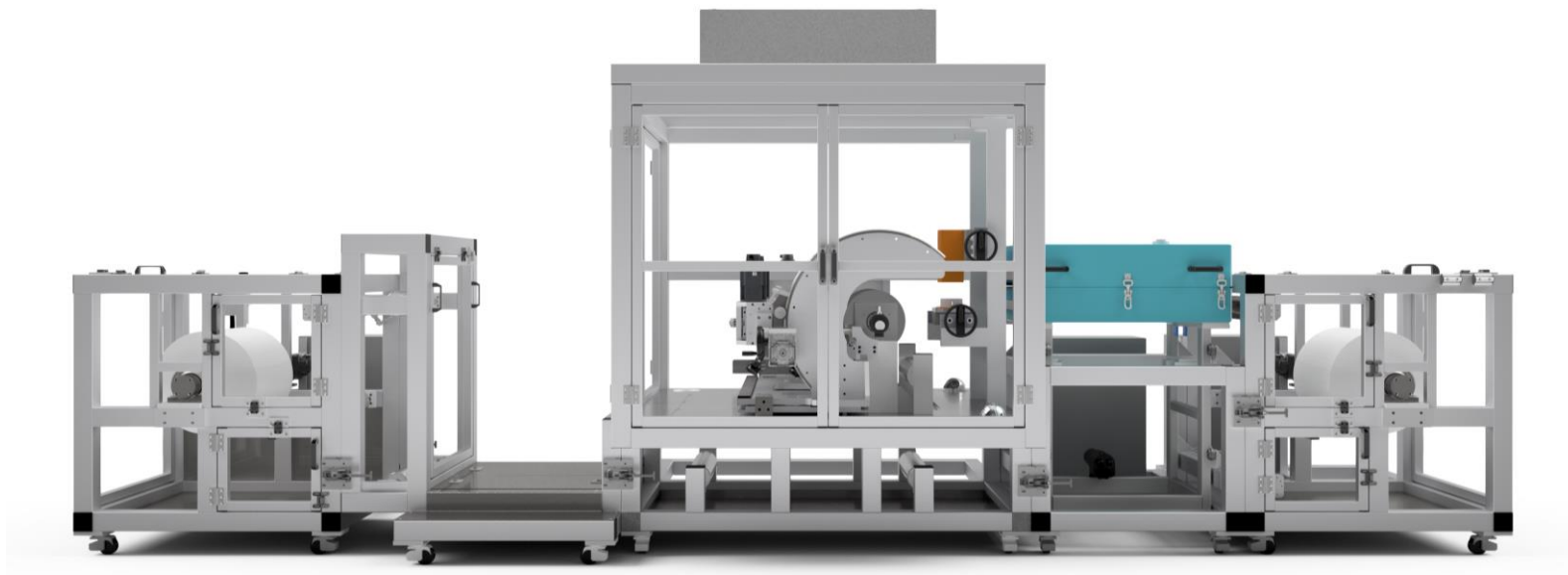
Today`s equipment for batteries

The Basecoater



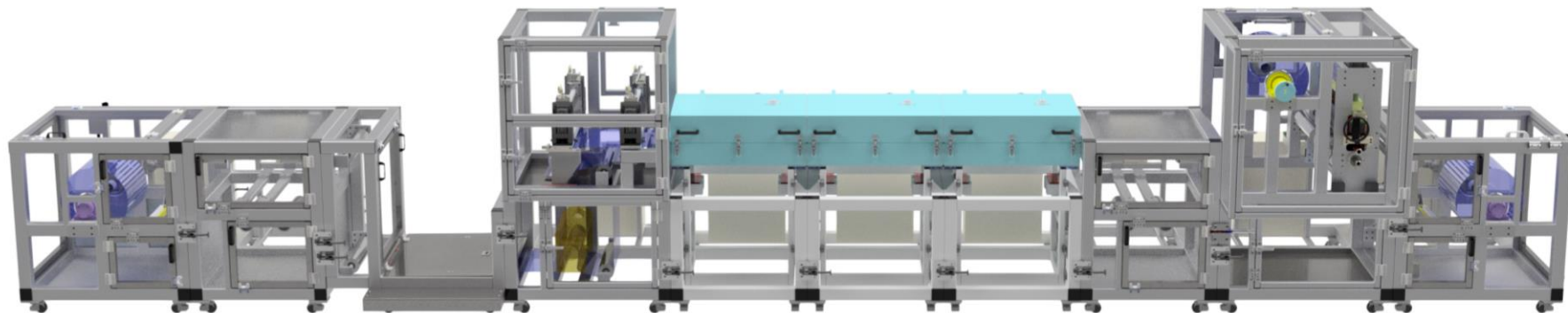
Today`s equipment for batteries

The Click&Coat



Today`s equipment for batteries

The Click&Coat



Today`s equipment for batteries

The Click&Coat™



Today`s equipment for batteries

The Click&Coat



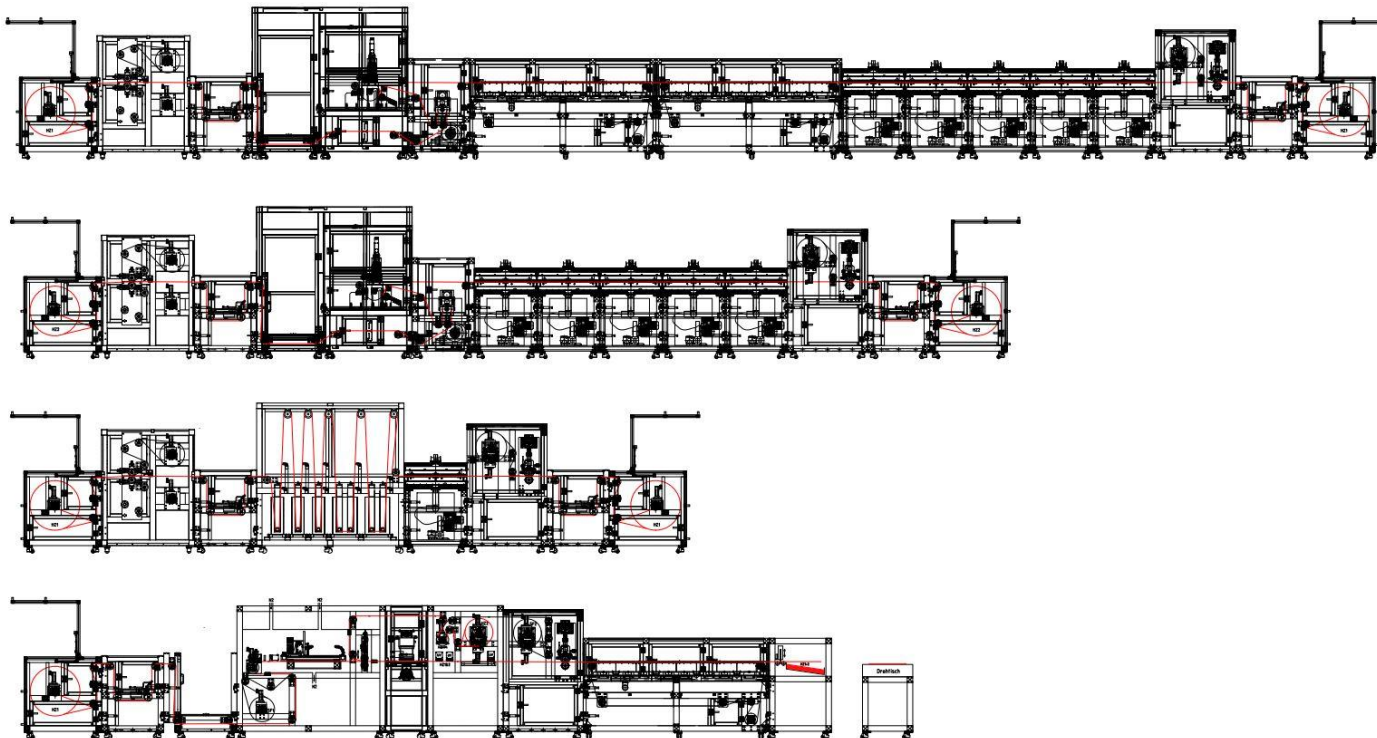
Today`s equipment for batteries

Specific battery equipment in Click&Coat™ layout



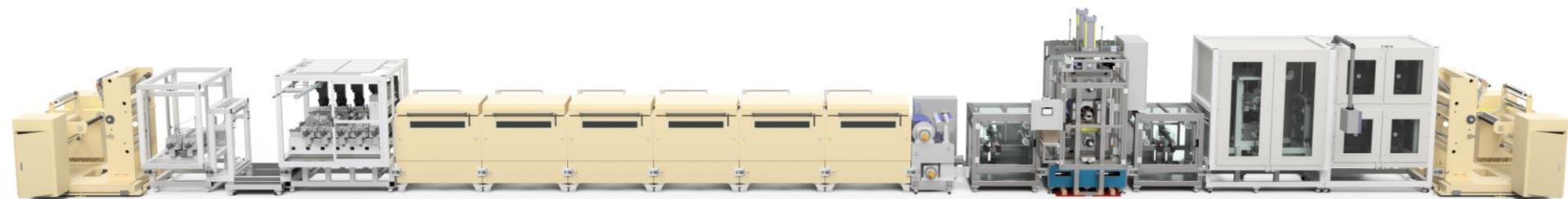
Today's equipment for batteries

Specific battery equipment in Click&Coat™ layout



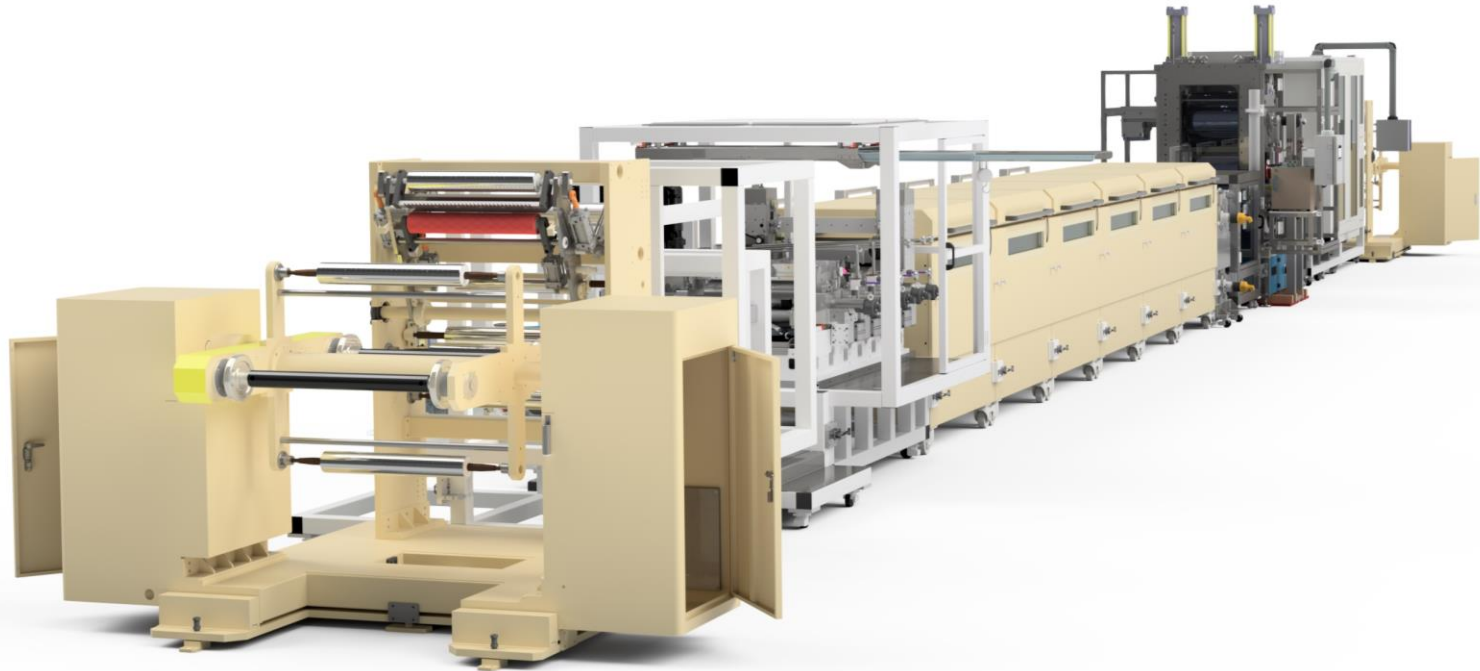
Today`s equipment

The Click&Coat in production scale



Today`s equipment

The Click&Coat in production scale



Today`s equipment for batteries

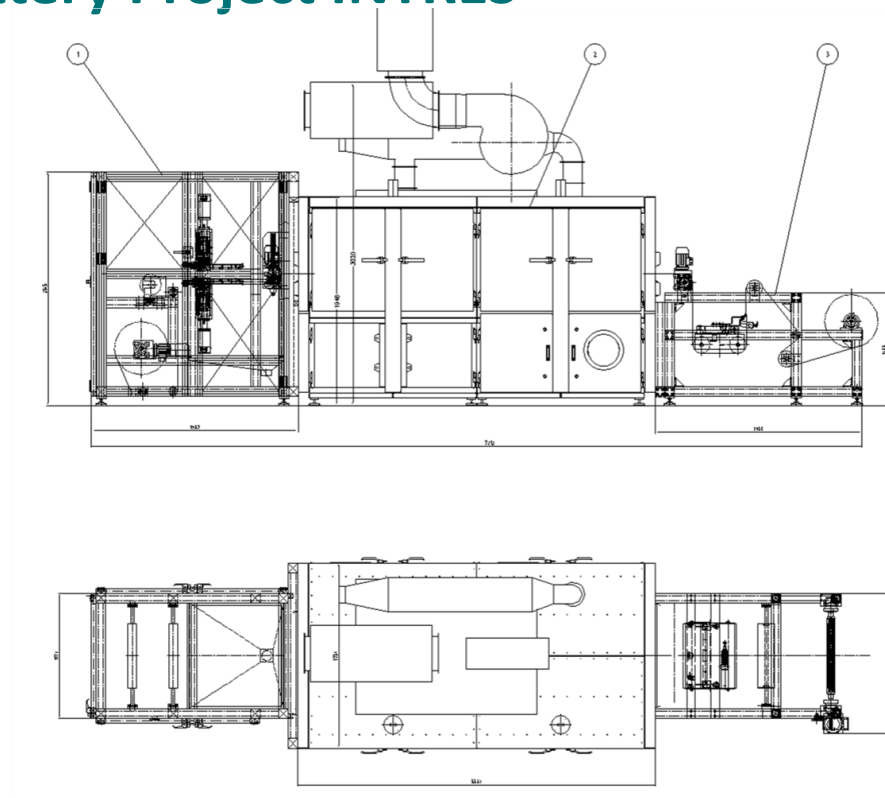
Proof of concept – Li-ion battery Project INTRES

Specific battery equipment

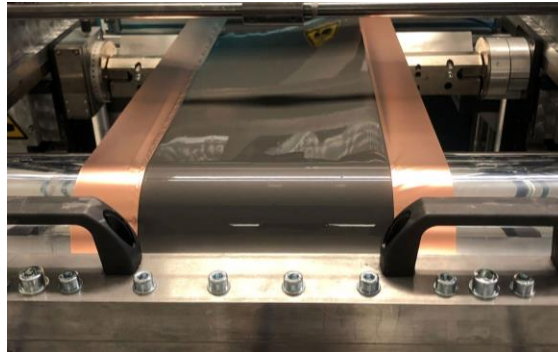
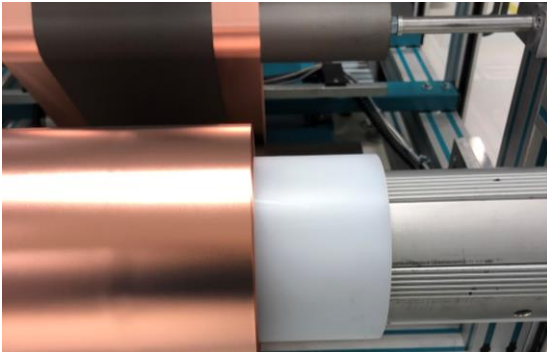
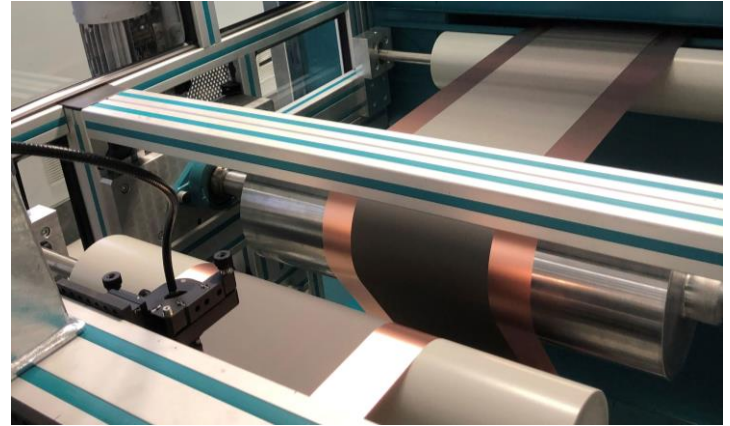
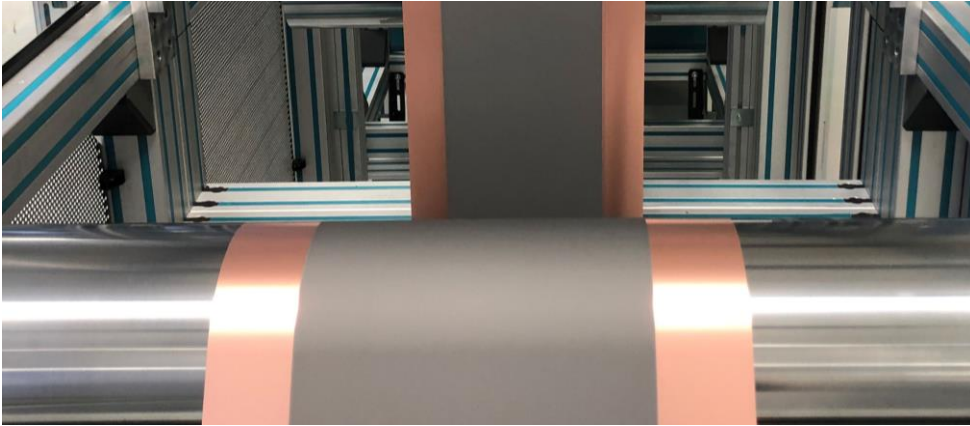


Proof of concept – Li-ion battery Project INTRES

Flotation dryer in double side pilotcoater concept

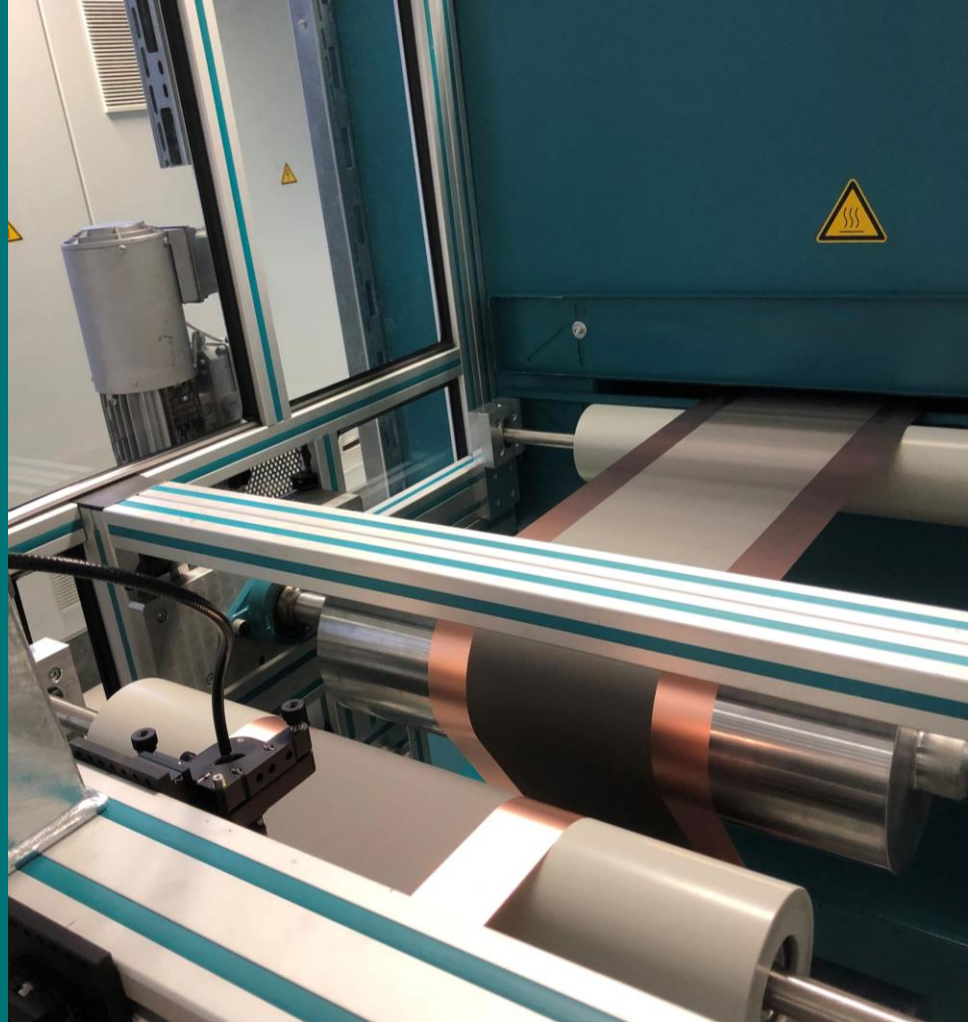


Today`s equipment for batteries

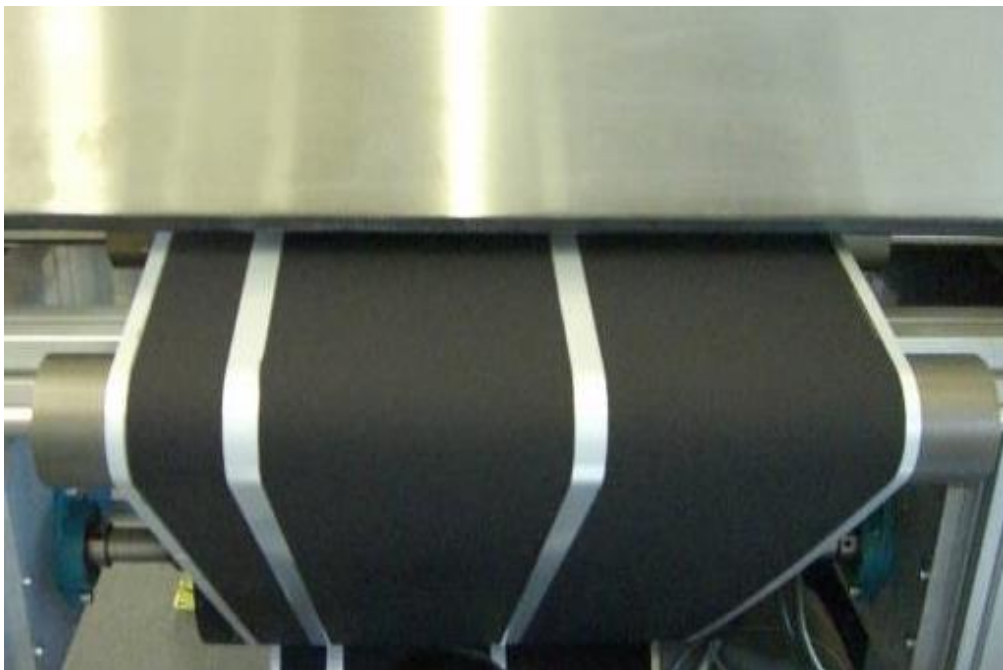


8.

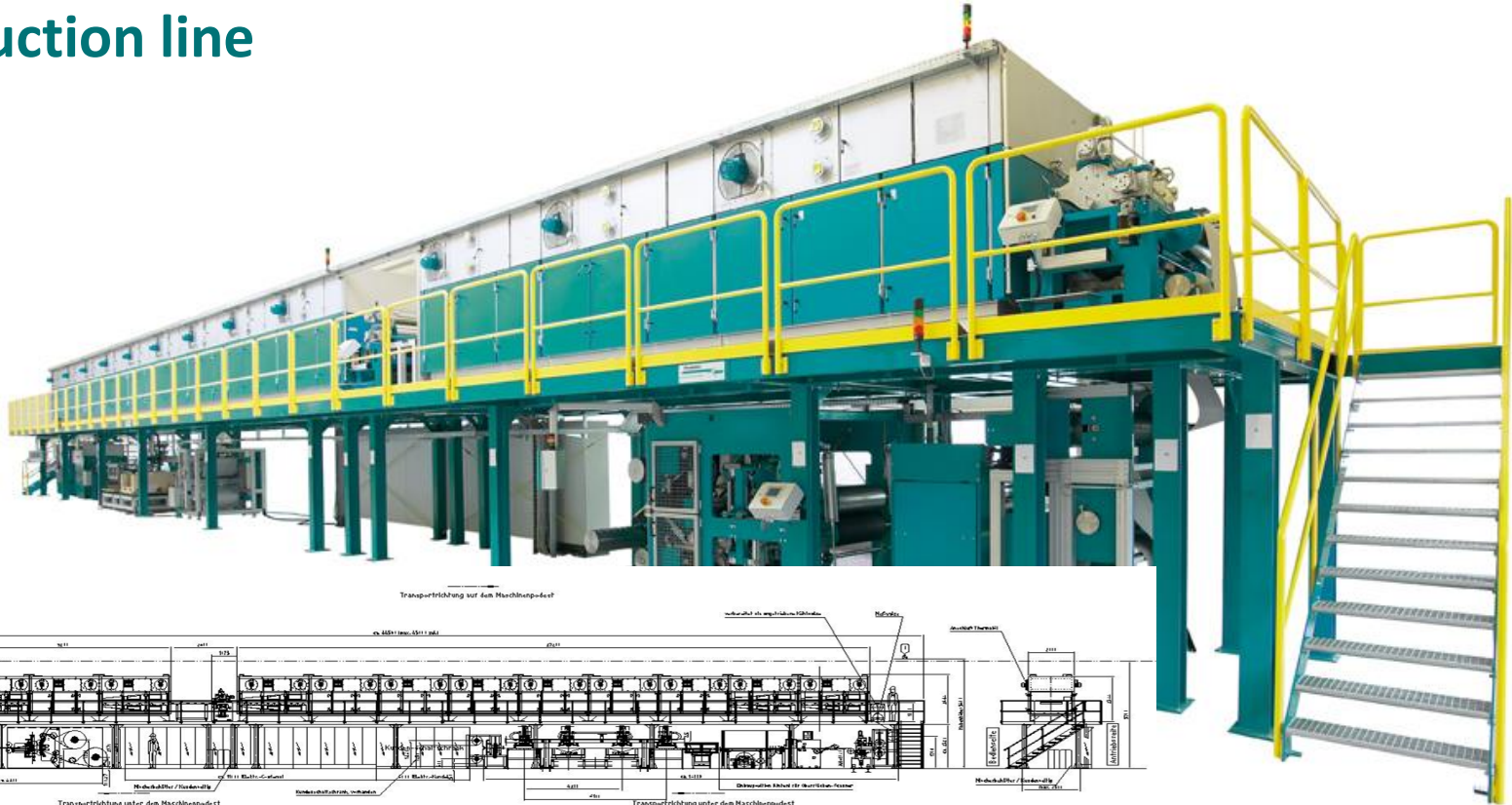
Battery production lines



Production line for batteries



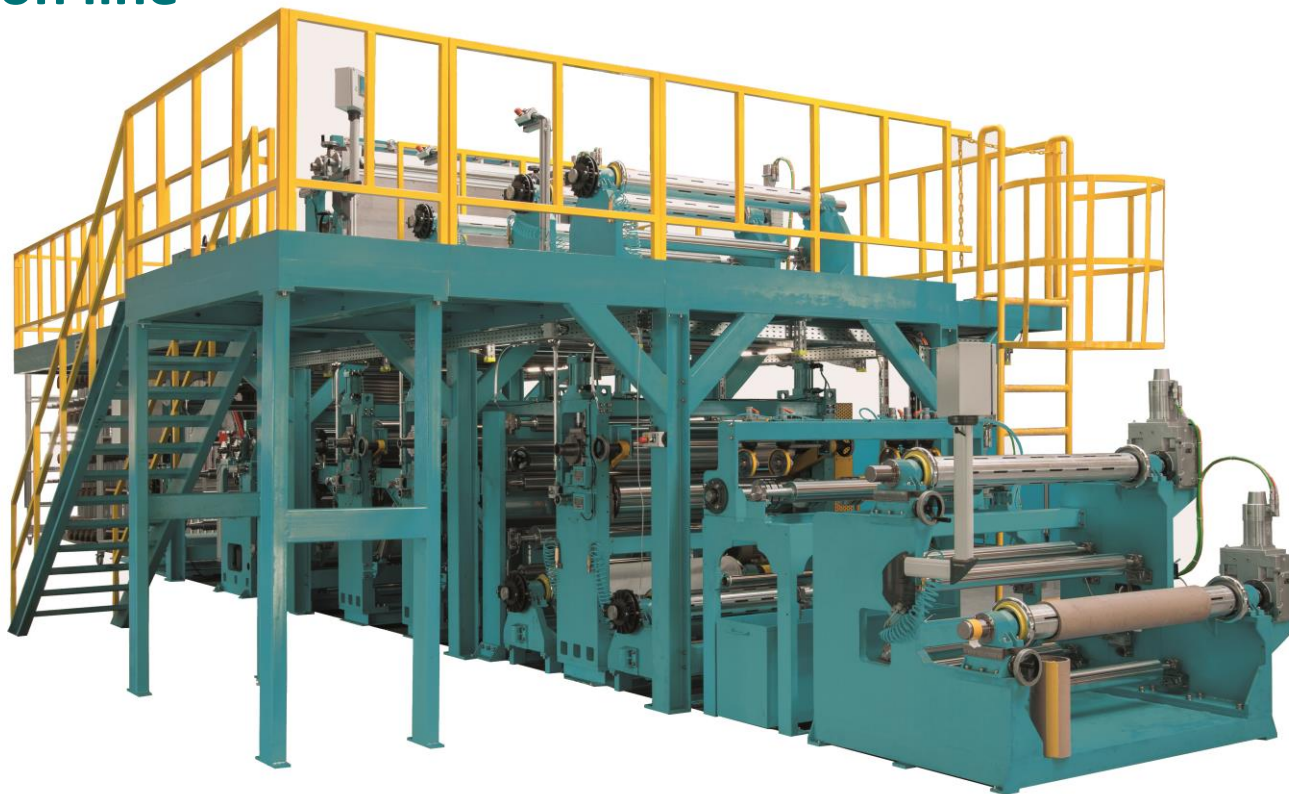
Production line



Production line



Production line



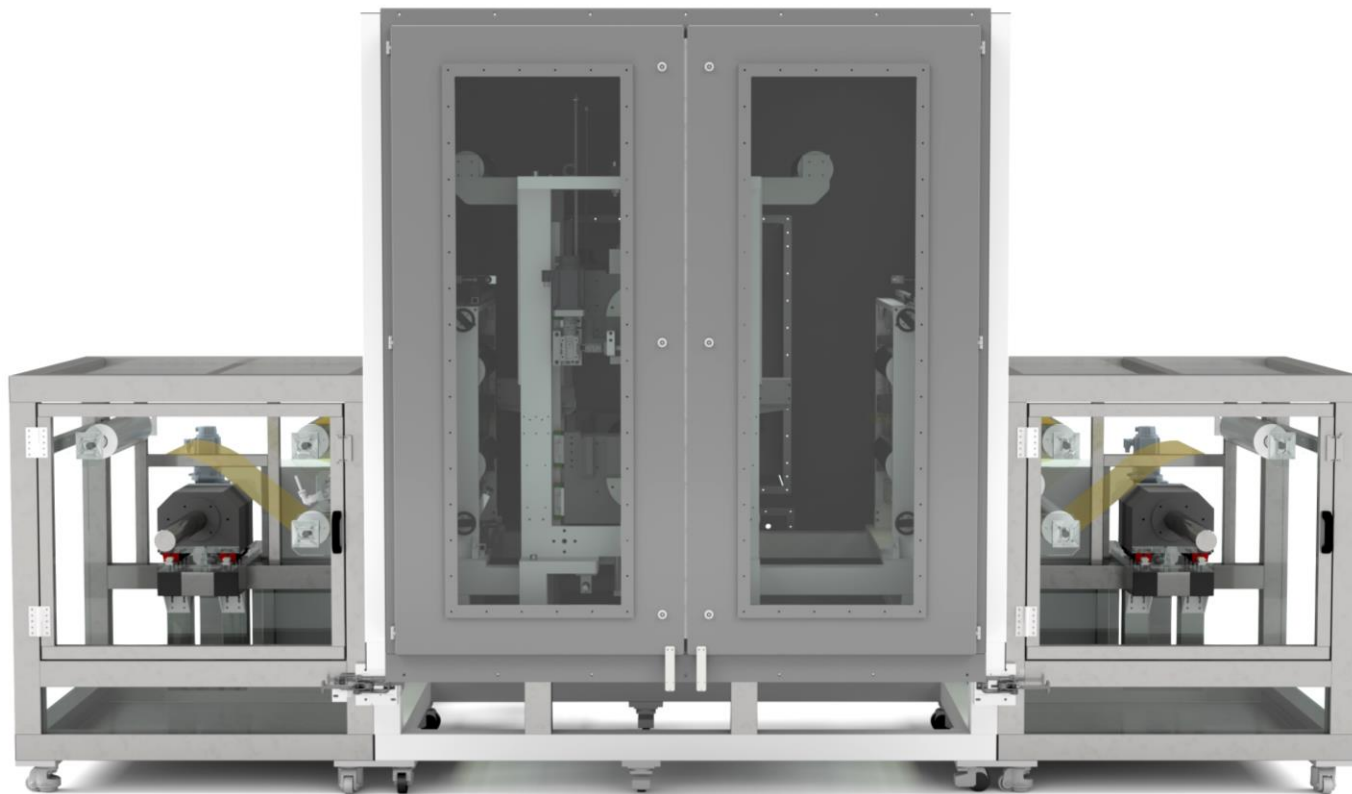
Production line



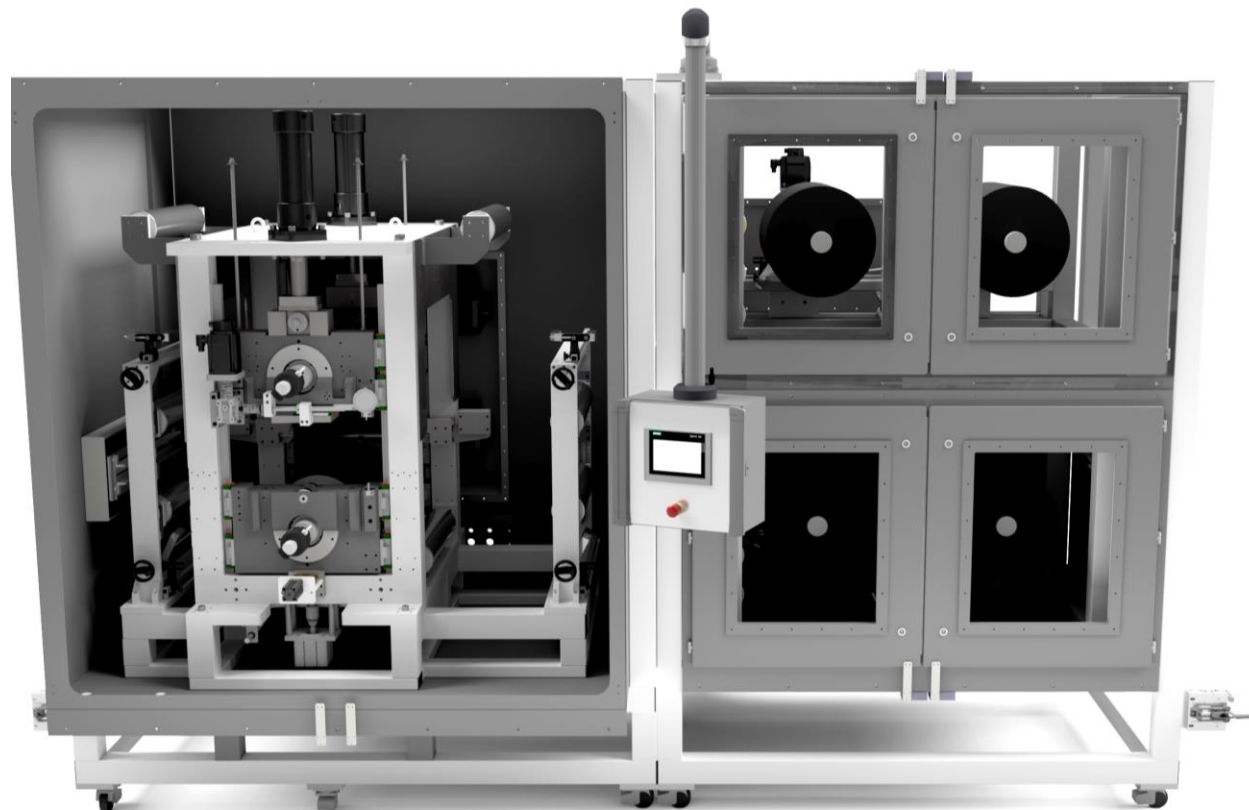
Production line



Battery production lines







9.

Li-ion battery research projects at Coatema



Li-ion battery Project INTRES



Innovative substrates for optimization of current collectors in batteries

- ✓ 01/2017 – 12/2019 1.5 Mio.€ funding
- ✓ 6 German partners
- ✓ Innovative Batteries
- ✓ Improved electrodes (3D structured)
- ✓ Expanded metals & foams
- ✓ Coating technology



Assoziierte Partner:



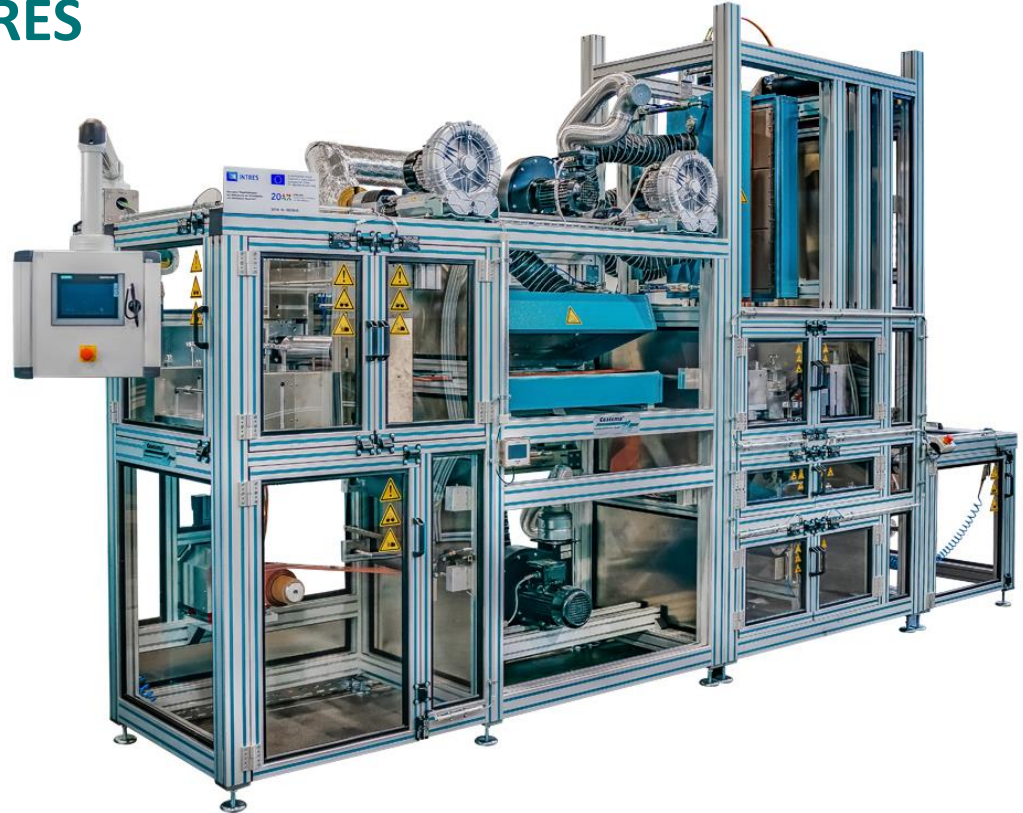
INTRES project – Project results summary

- ✓ Advantages of using expanded metal in Li-ion
- ✓ Stability of cycle stability of the battery
- ✓ Less weight than closed films
- ✓ Higher active area (3-dimensional structure)
- ✓ Elasticity of the overall system
- ✓ Advantages for systems with higher volumetric changes

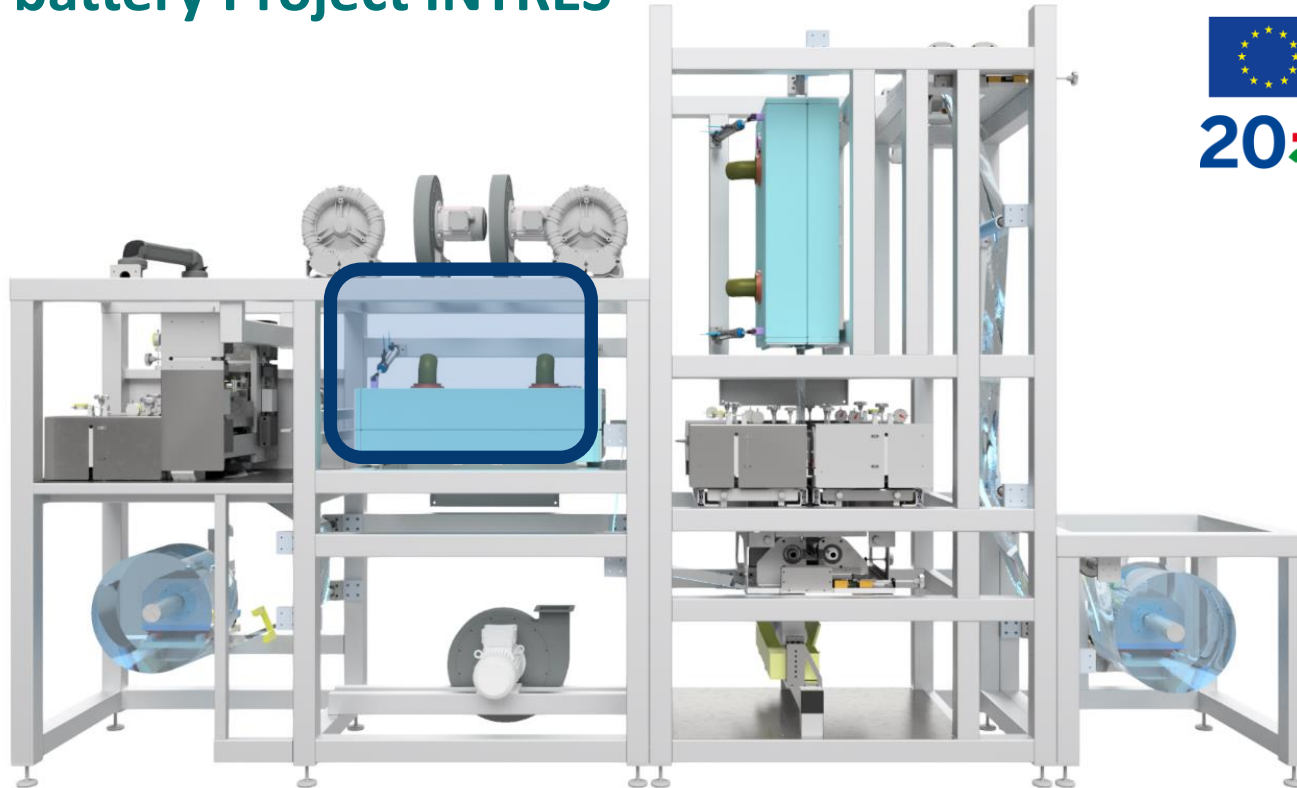


Li-ion battery Project INTRES

- ✓ Versatile coating unit
- ✓ Single sided slot die coating
- ✓ Horizontal drying
- ✓ Foulard
- ✓ Double sided slot die
- ✓ Vertical drying
- ✓ Expandable with extra units
- ✓ Open design



Li-ion battery Project INTRES



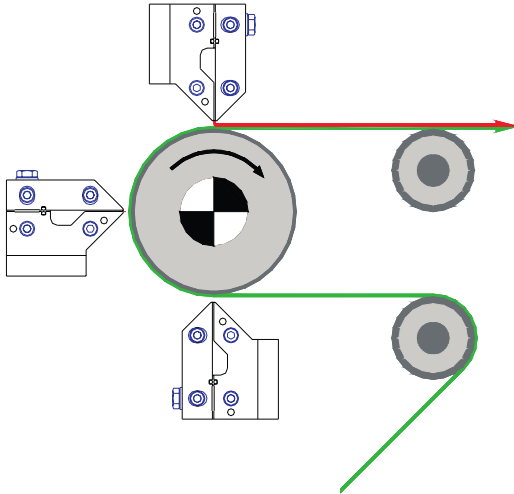
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Investing in our Future
European Regional
Development Fund

2014

ERDF.NRW
Investment for Growth
and Employment

Li-ion battery Project INTRES

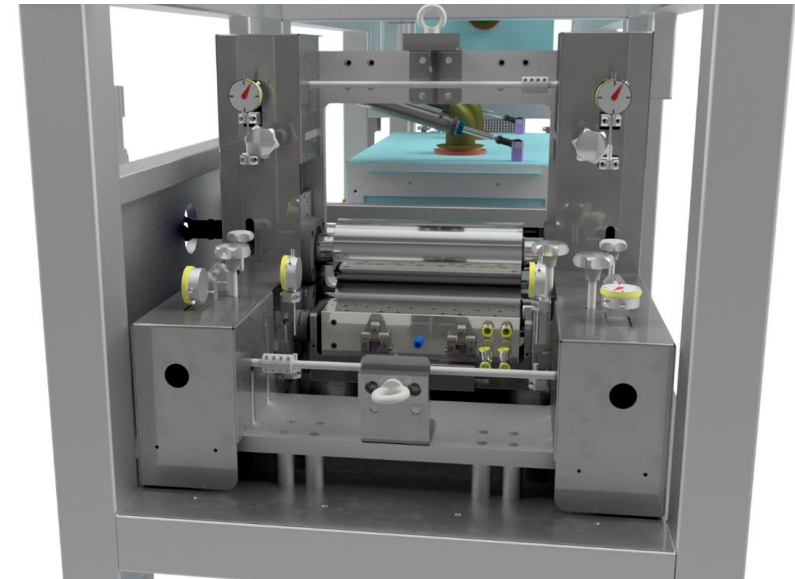
- ✓ Option to place first die coater at different angles
- ✓ Followed by drying unit



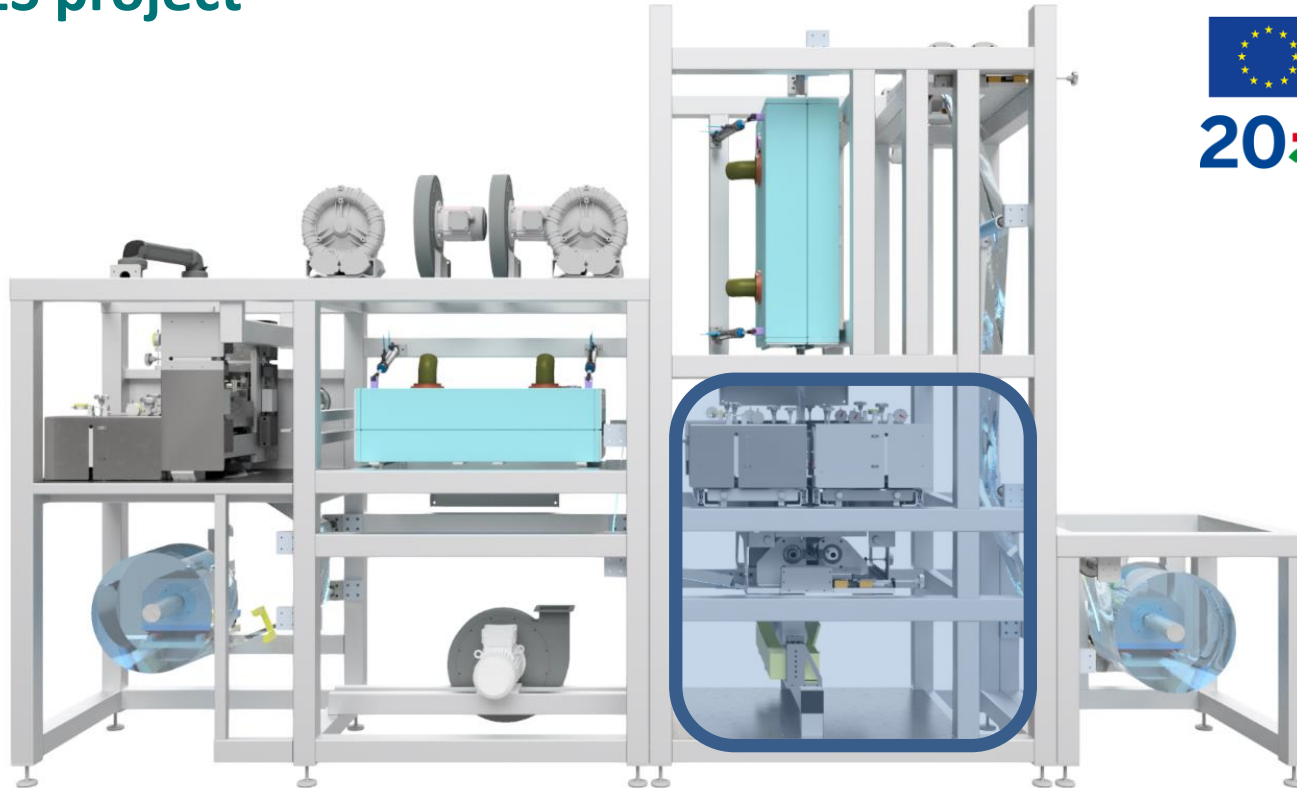
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INTRES project



EUROPEAN UNION
Investing in our Future
European Regional
Development Fund

2014

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Investment for Growth
and Employment

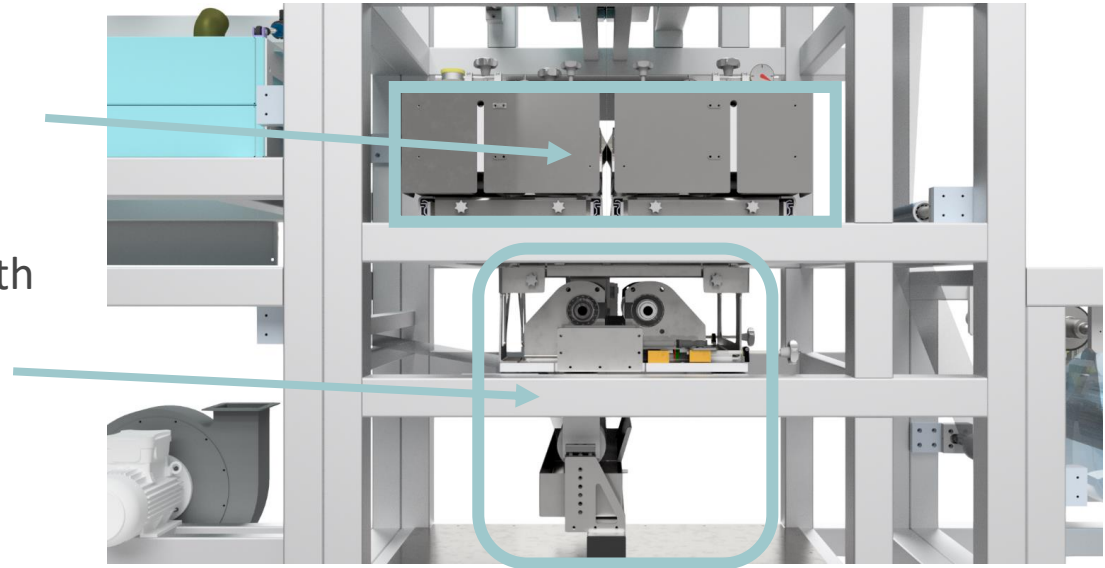
INTRES project

Double sided coater

- ✓ Slot die
- ✓ Both sides have own control knobs

Foulard module

- ✓ Foil runs through a liquid bath
- ✓ Two rolls after to squeeze liquid off the foil

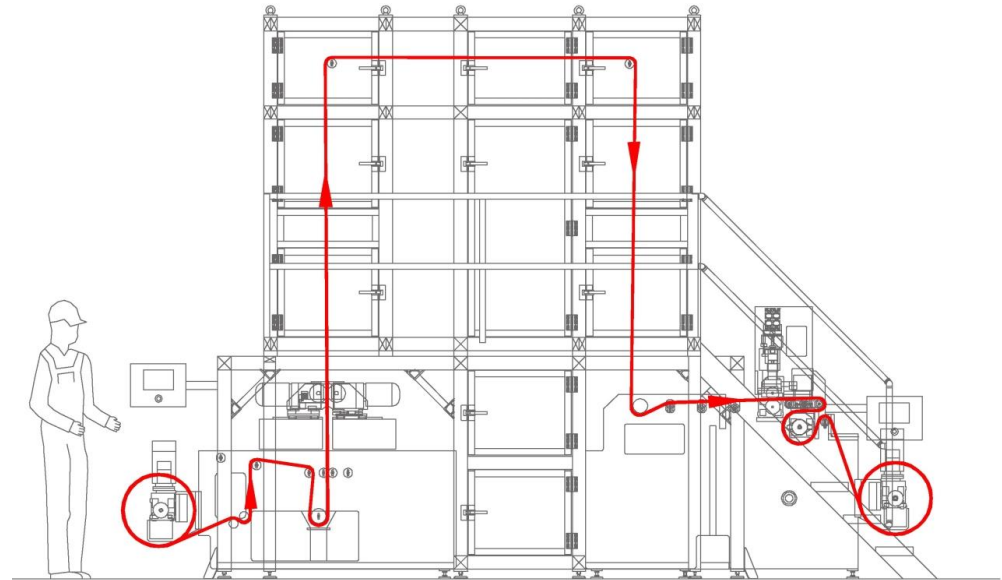


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and Employment

INTRES project – Upscaling the INTRES results





Presentation slide of the PEM CELLFAB as well as the research project "LaserScale"

Scaled laser structuring and drying of lithium-ion batteries to increase cell performance

Aachen, den 14.02.2022

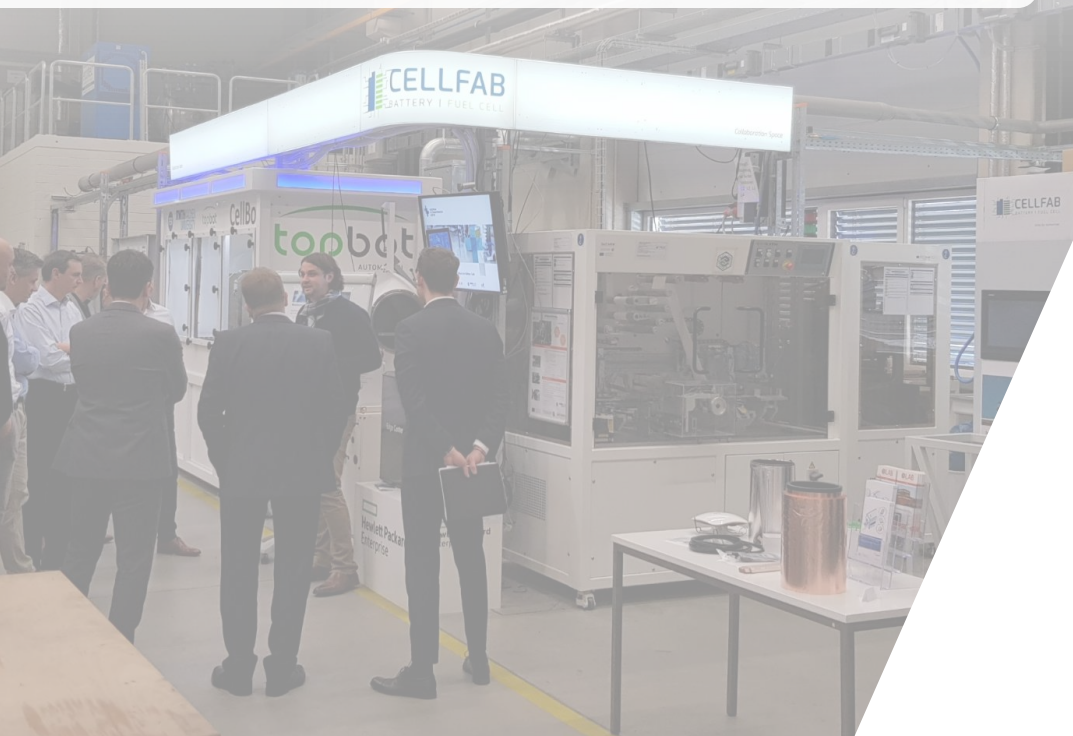


PEM of RWTH Aachen University – Science for E-Mobility

CELLFAB – Exploring innovations together



CELLFAB at the eLab of RWTH Aachen University combines innovative innovative research with the latest manufacturing and information technology.



Within the production line, battery cells can be manufactured in a **reproducible and flexible manner**. In addition, the **close network of associated partners** offers an ideal platform for exchanging ideas and making new contacts.

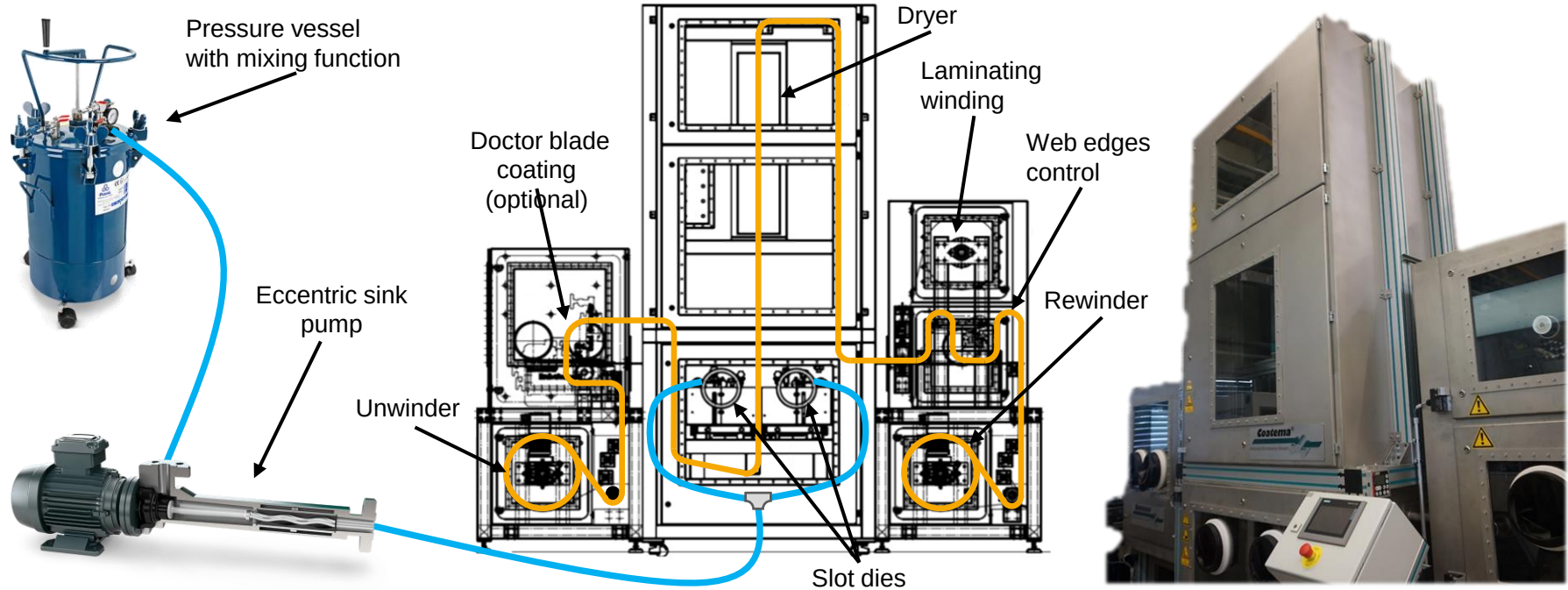
Highlights:

- Mini environments in production
- Double-sided simultaneous vertical coating machine
- Modular expandable and flexible cell assembly robot (CellBot)
- Innovative measuring and testing technology
- Digitally interconnected production environment and Industry 4.0 tools (e.g. worker cockpit)

The **CELLFAB facilities at the eLab of RWTH Aachen University** are continuously being modernized and expanded. CELLFAB represents a **technical pioneer** in battery production.

Current research project: LaserScale

Schematic structure of the vertical coating machine



The coupled drying and coating plant has a modular design. The vertical, double-sided coating takes place within a closed protective atmosphere ("Mini Environment").

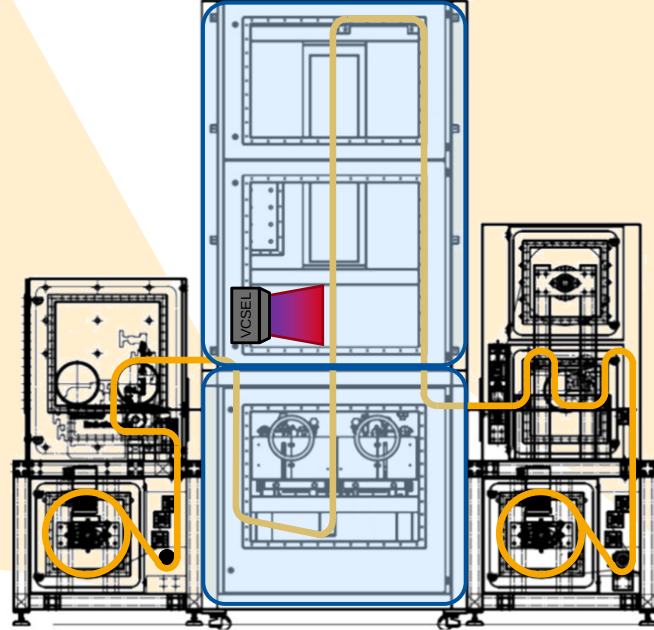
Current research project: LaserScale

Scaled laser drying of electrodes for the use in lithium ion battery cells

Slot die



Double-sided simultaneous vertical electrode coating



Laser drying



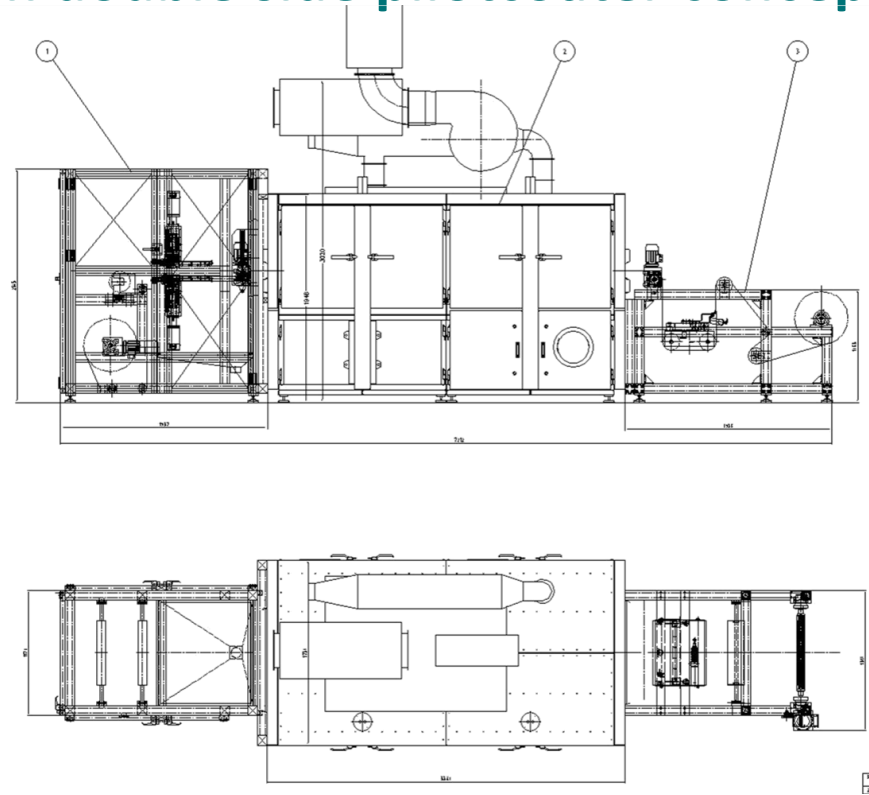
Laser drying of electrodes using an 8 kW VCSE Laser module

Fraunhofer Research Institution for Battery Cell Production FFB

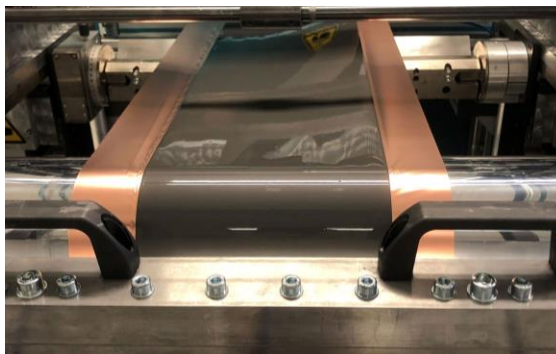
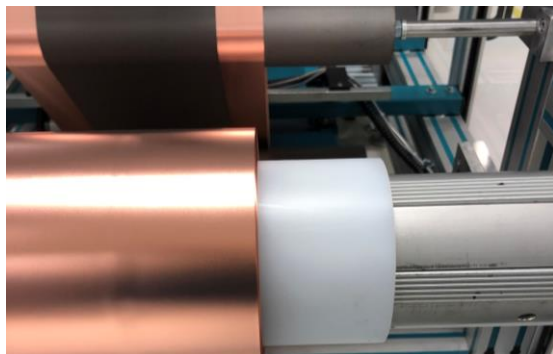
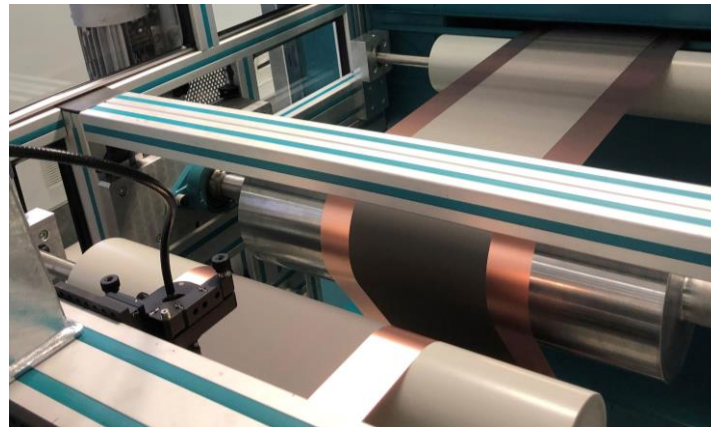
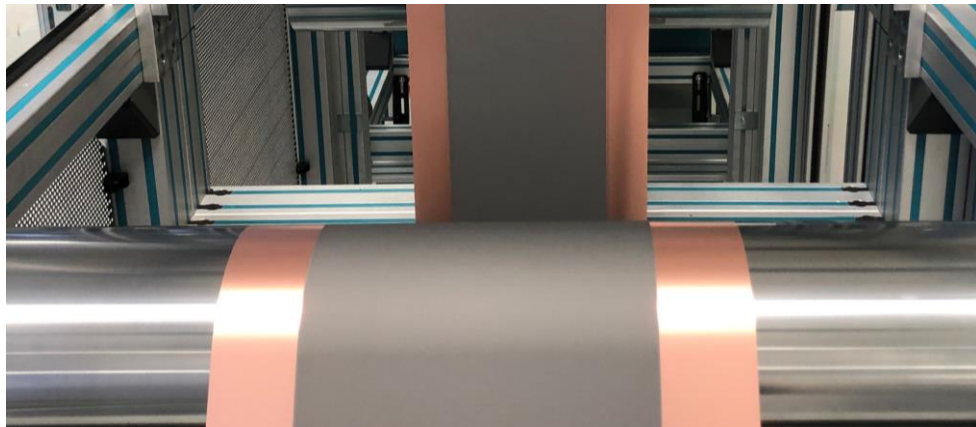
Introduction to Fraunhofer FFB



Flotation dryer in double side pilotcoater concept



Li-ion battery research projects at Coatema



Funding

SPONSORED BY THE



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Ministry of Economic Affairs,
Innovation, Digitalization and Energy of the
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Ministry of Innovation, Science
and Research of the German State
of North Rhine-Westphalia

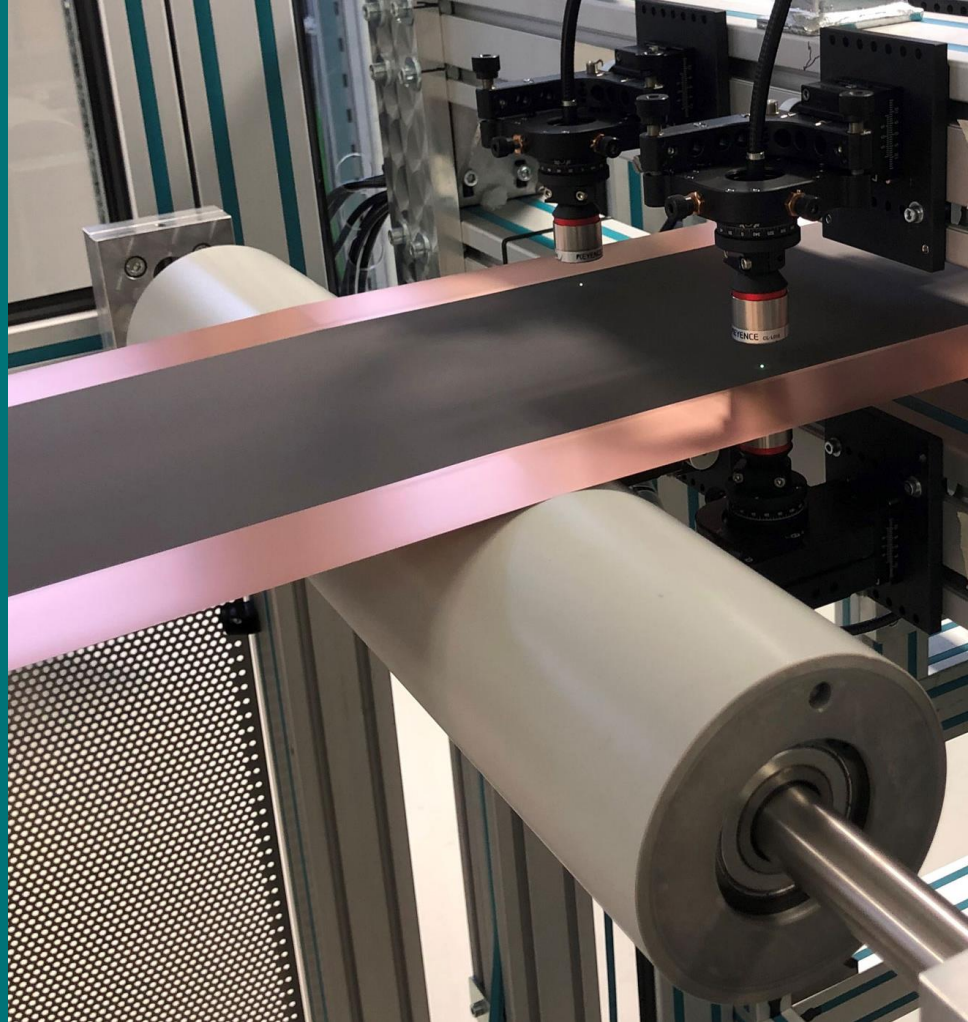


The project »Forschungsfertigungsfertigung Batteriezelle (FoFeBat)« is being funded by Federal Ministry of Education and Research Germany.

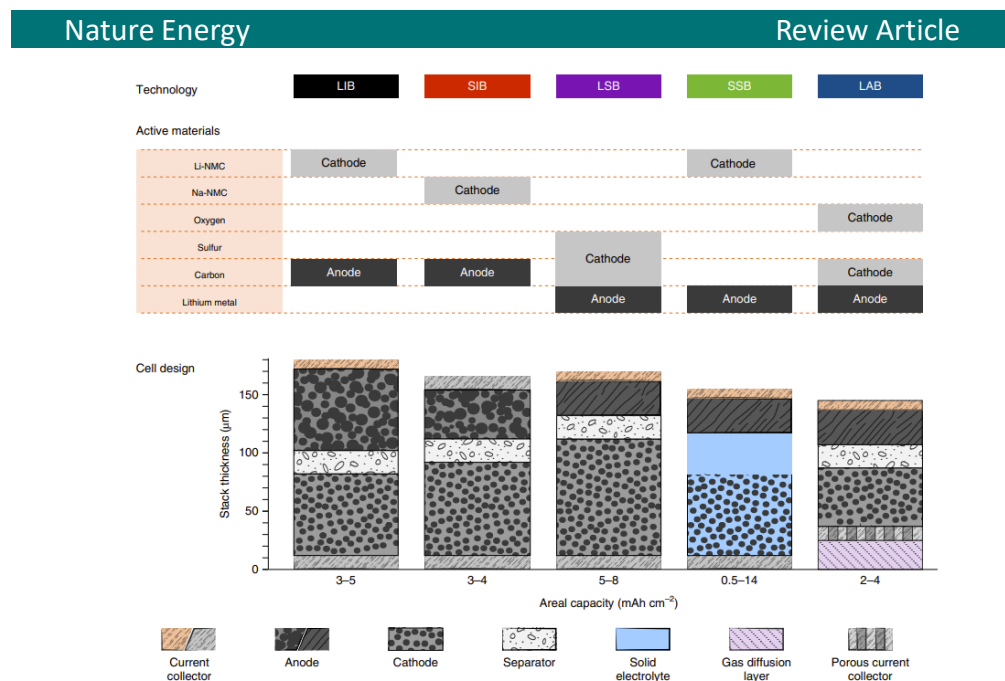
(Funding Reference: 03XP0256, 03XP0416)

10.

Solid state battery



Background on SSB



- ✓ Application under dry room
- ✓ Application with Li metal as Anode
- ✓ under Ar atmosphere
- ✓ Coating and laminating processes
- ✓ Difference between sulfid SSB and oxide based SSB technologies
- ✓ Calendering processes
- ✓ SALD for protection layer

Flexible enclosed processes coating processes under Ar atmosphere



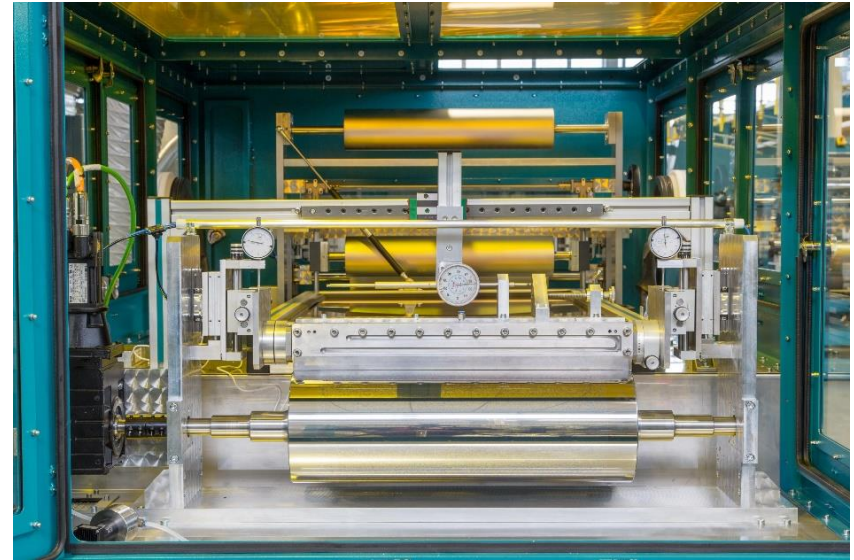
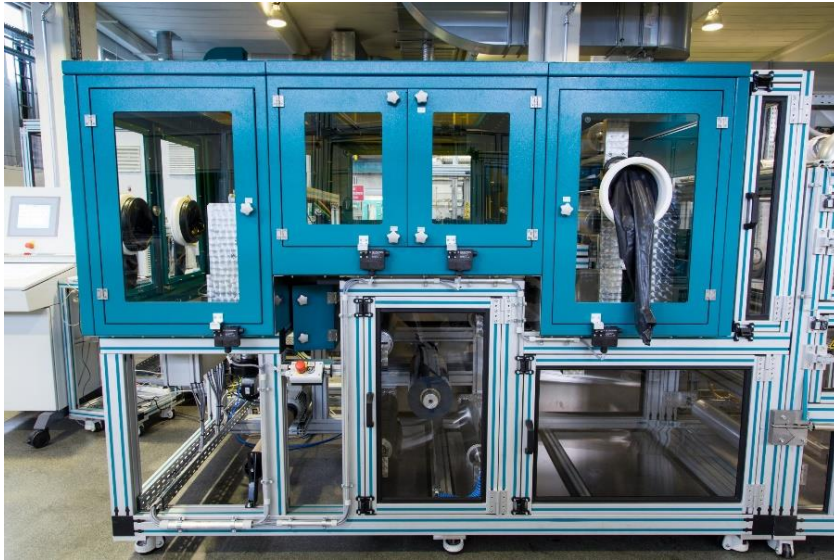
What is a controlled environment?

Coating under controlled environment

“An environment which is artificially regulated to ensure conditions such as temperature, air quality, etc., remain stable; the condition or state of such an environment.”

Oxford Dictionary

What is a controlled environment



✓ Dry atmosphere

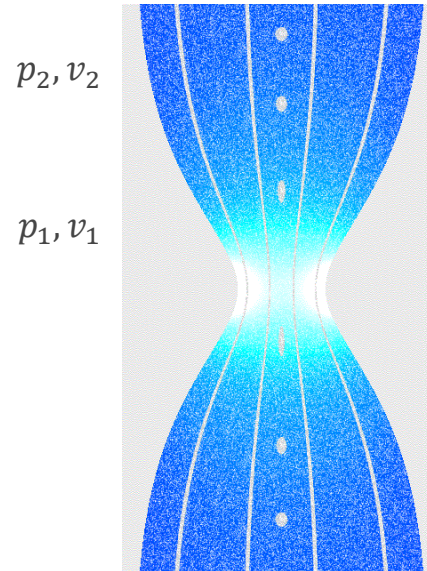
✓ Nitrogen atmosphere

✓ 500ppm H₂O

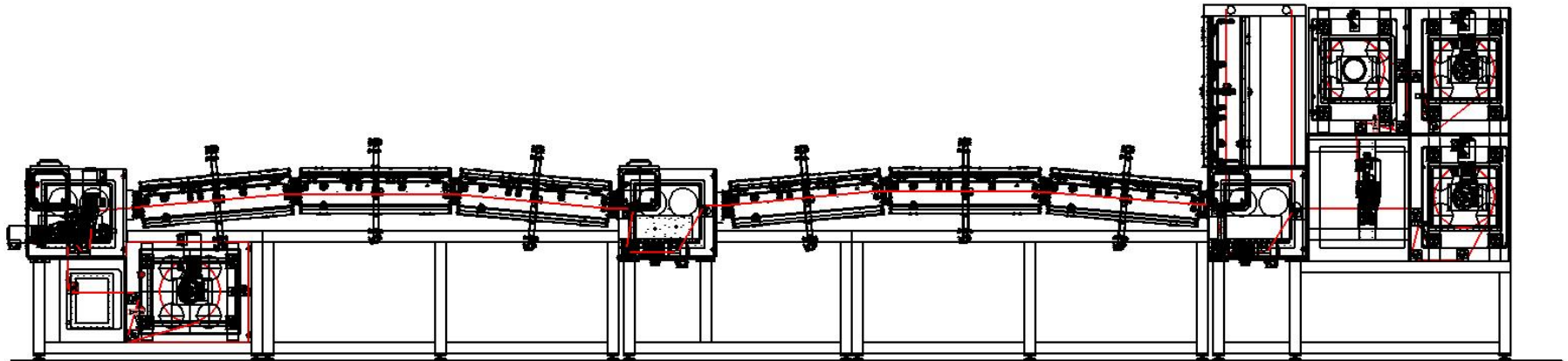
Recycling of Ar via Venturi-effect

- ✓ Venturi tube creates low pressure
- ✓ Recycled Ar gets sucked in by low pressure

$$p_1 - p_2 = \frac{\rho}{2} (v_2^2 - v_1^2)$$



Coating processes under inert atmosphere



Coating under controlled environment

- ✓ Working width 300 mm
- ✓ Speeds of 1 – 20 m/min
- ✓ Doctor blade / slot die coating
- ✓ IR Drying
- ✓ Reduction from 3500 m³/h to 20 m³/h Argon flow
- ✓ Argon recycling with Venturi effect

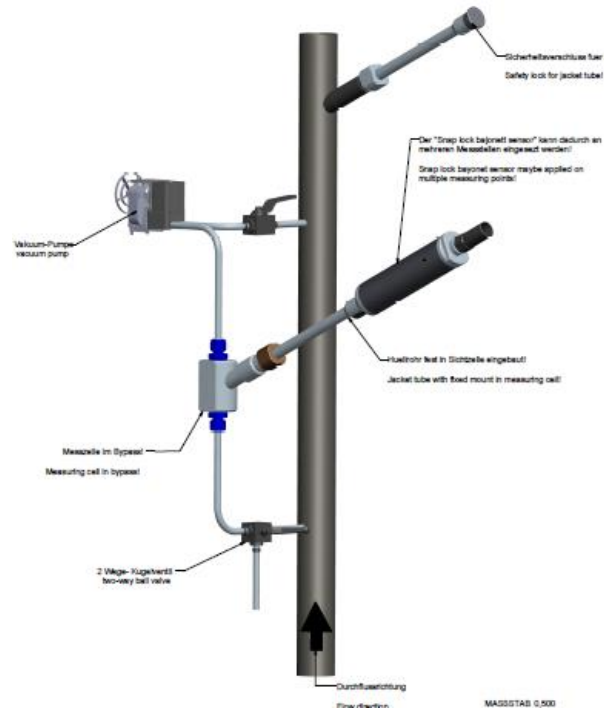


11.

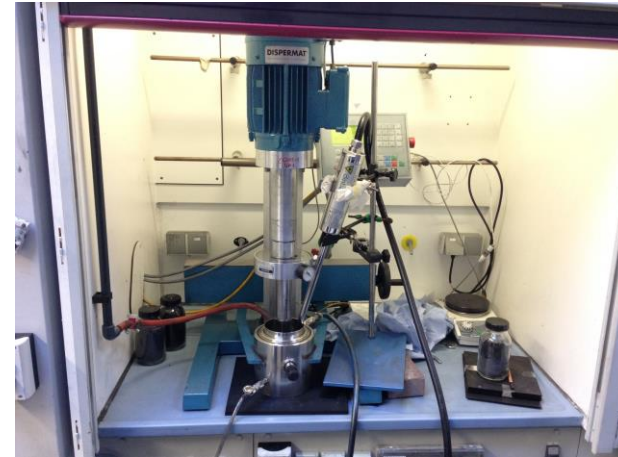
Quality control systems



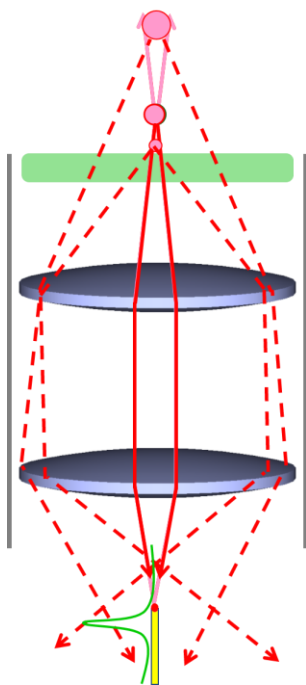
Particle size measurement



SEQUIP
IN PROCESS PARTICLE-SIZE POPULATION



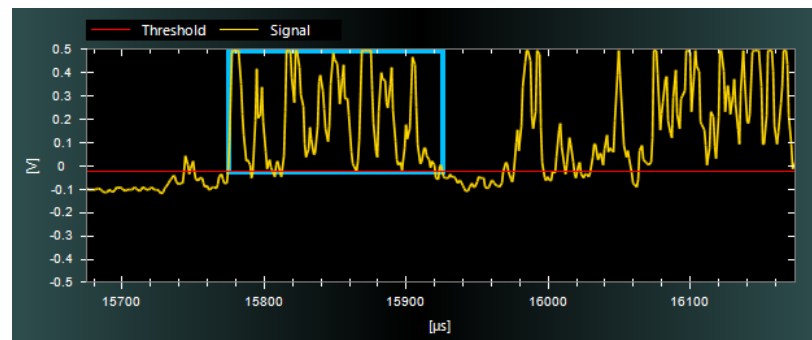
Particle size measurement



Sequip 3D ORM measurement principle

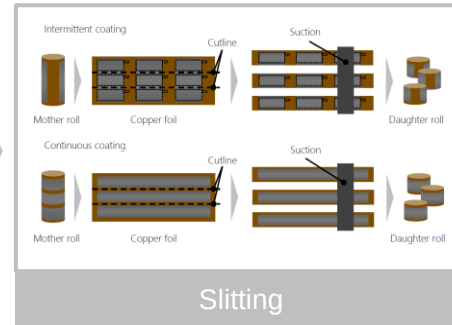
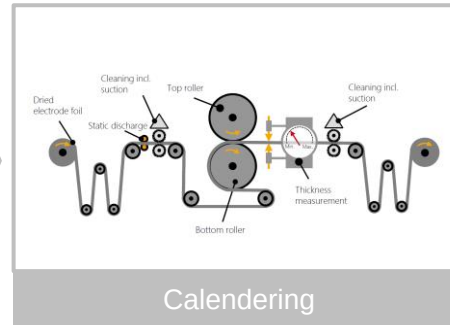
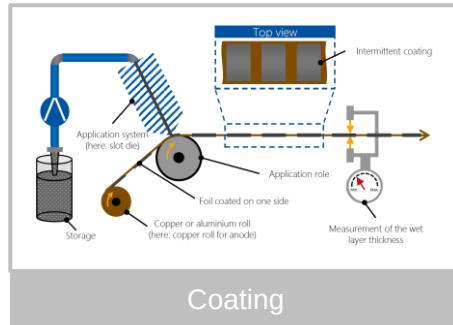
The principle of the proven inline measurement is based on the so-called dynamic optical back reflection measurement, 3D ORM.

With this system, even the finest distributions of $0.5\ \mu\text{m}$ can be measured without any problems. The resolution of the sensor systems is up to $<0.1\ \mu\text{m}$. Particularly characteristic for this technology is the special form of the selective measuring range in combination with the special electronic evaluation of the back pulse. Only particles that are in focus are evaluated, all particles outside this range are automatically excluded by the patented optics. The sizes of the particles are calculated from the time span that the sensor moving circularly over the particle stream assigns to a sweeping particle, this value is called "Time of Flight" (ToF).



SURFACE INSPECTION IN CELL-MANUFACTURING

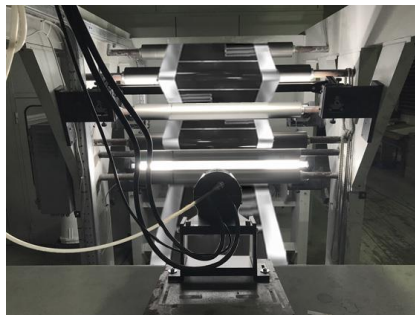
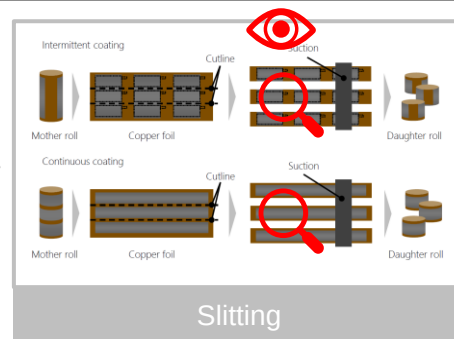
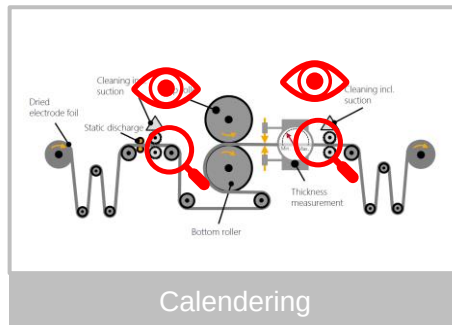
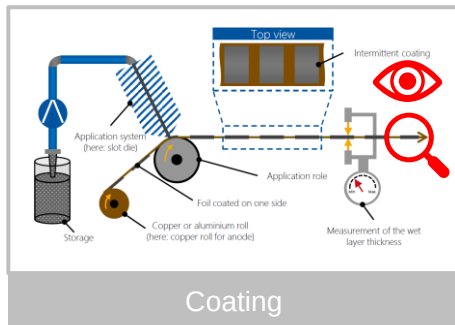
State-of-the-art inspection technology



SURFACE INSPECTION IN CELL-MANUFACTURING

State-of-the-art inspection technology

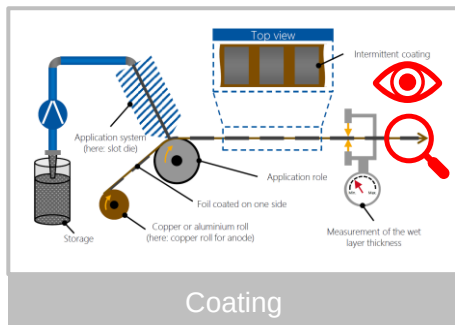
Electrode Manufacturing



SURFACE INSPECTION IN CELL-MANUFACTURING

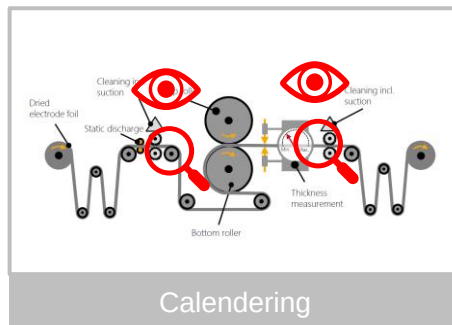
Requirements of the individual process steps

Electrode Manufacturing



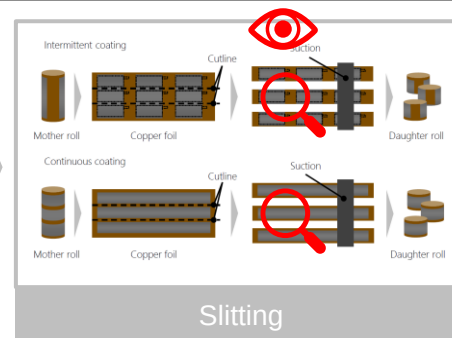
Key requirements

- Defect detection top and bottom
- Inspection of lane- and pattern coating
- Validation of edge straightness
- Geometric measurements of coating
- Top to bottom coating alignment
- Digital reel report / flagging
- Defect traceability (workflow)



Key requirements

- Defect detection top and bottom
- Inspection of lane- and pattern coating
- Automatic "lift off function" before drum (wrinkles, holes, agglomerates)
- Digital reel report / flagging
- Defect traceability (workflow)



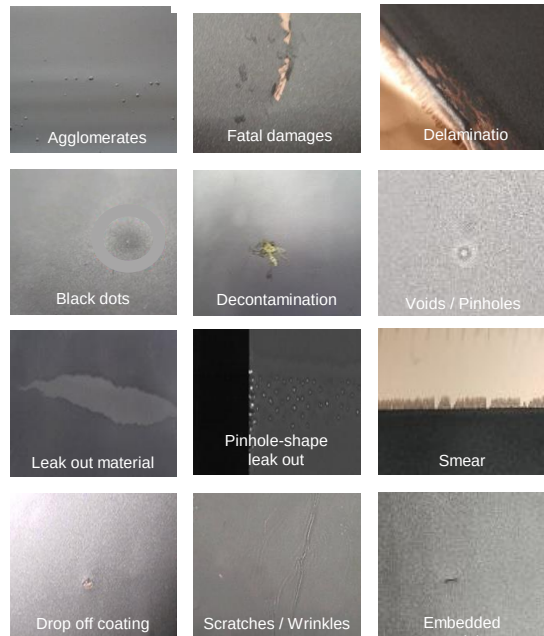
Key requirements

- Defect detection top and bottom
- Inspection of lane- and pattern coating
- Geometric measurements knife to coating edges
- Digital multi reel report / multi reel flagging
- Defect traceability (workflow)

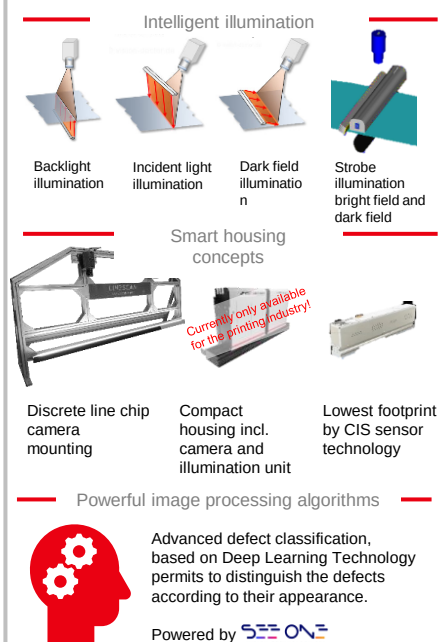
CUTING-EDGE-TECHNOLOGY

State-of-the-art inspection technology made for the Lithium-Ion Battery industry

Defects



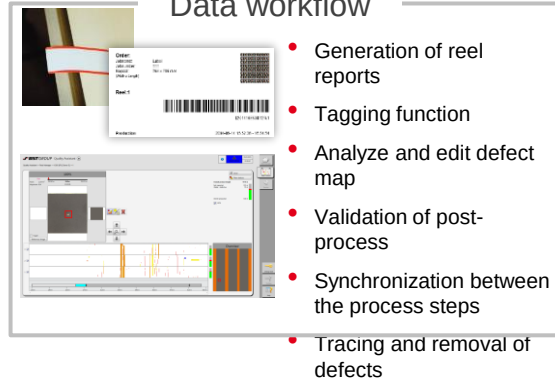
100% Inspection



Defect visualization



Data workflow



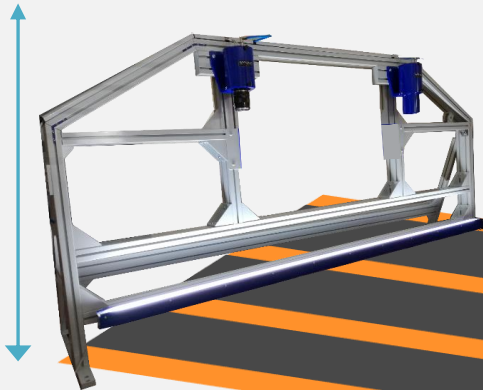
CUTTING-EDGE-TECHNOLOGY

Lowest footprint concepts made for the Lithium-Ion Battery industry

Discrete mounting

Line chip camera mounted on frame unit

600-1200 mm



Sophisticated housing

Compact ready to integrate housing incl. illumination unit and line chip camera

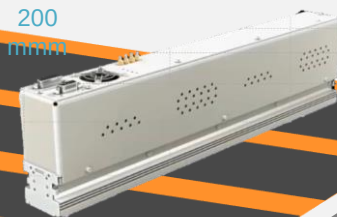
560 mm



CIS sensor

Lowest footprint by ready to integrate CIS sensor incl. illumination unit

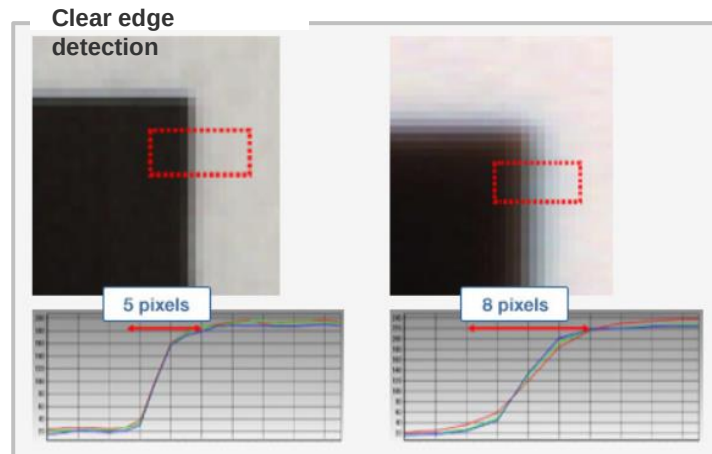
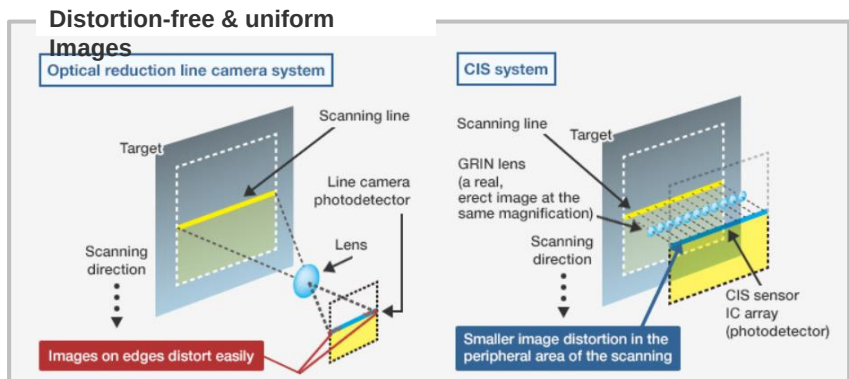
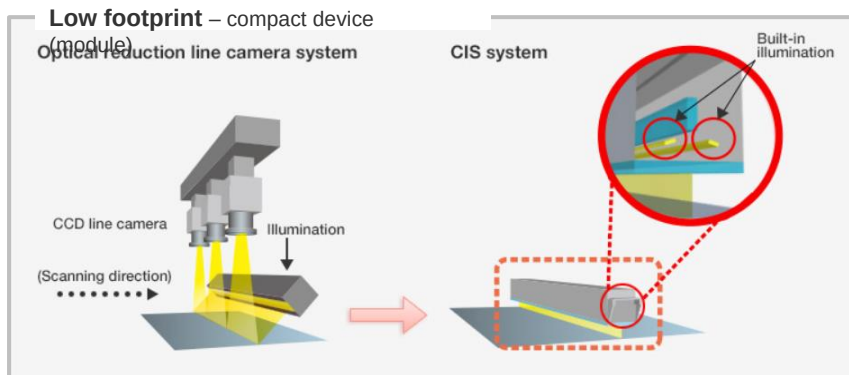
200 mm



800 mm

CUTING-EDGE-TECHNOLOGY

Lowest footprint concept by Contact Image Sensor (CIS module)



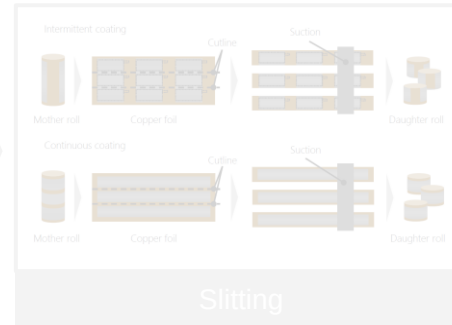
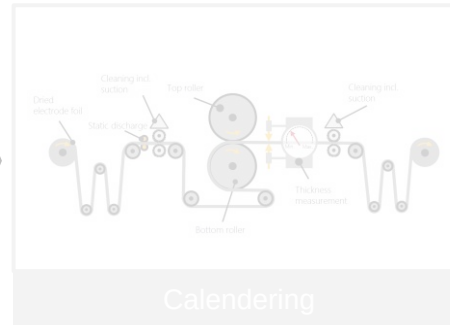
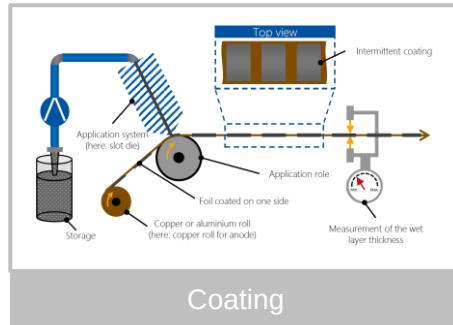
Example of application

Sensor width	1064 mm	1.247 mm	1.688 mm
No. of Pixel	25.056	29.354	39.735
Resolution			
Line rate @ 600 dpi	55 KHz	47 KHz	

600 dpi:
Pixel size = 0,042 mm (0,002 mm²)
Vmax = 118 m/min

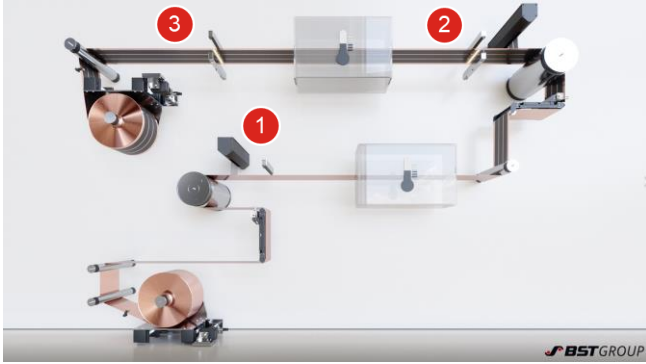
INSPECTION TASKS ON HIGHEST LEVEL

Reliable defect- and edge inspection incl. geometrical measurements in the coating process



INSPECTION TASKS ON HIGHEST LEVEL

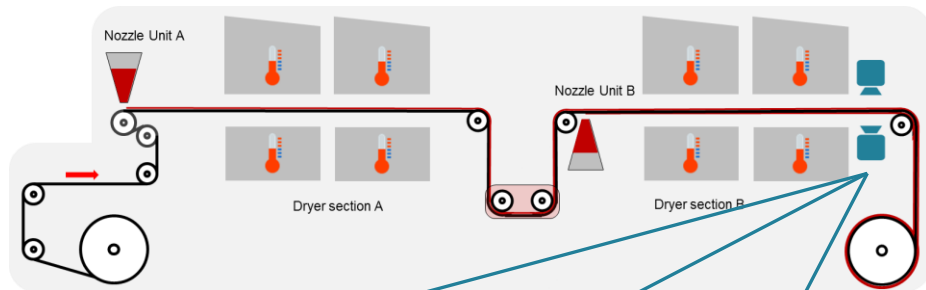
Reliable defect- and edge inspection incl. geometrical measurements in the coating process



- 1 Coating Position Control (A)
- 2 Coating Position Control (A / B)
- 3 Surface defect- and geometrical inspection

INSPECTION TASKS ON HIGHEST LEVEL

Reliable geometrical measurements in the coating process



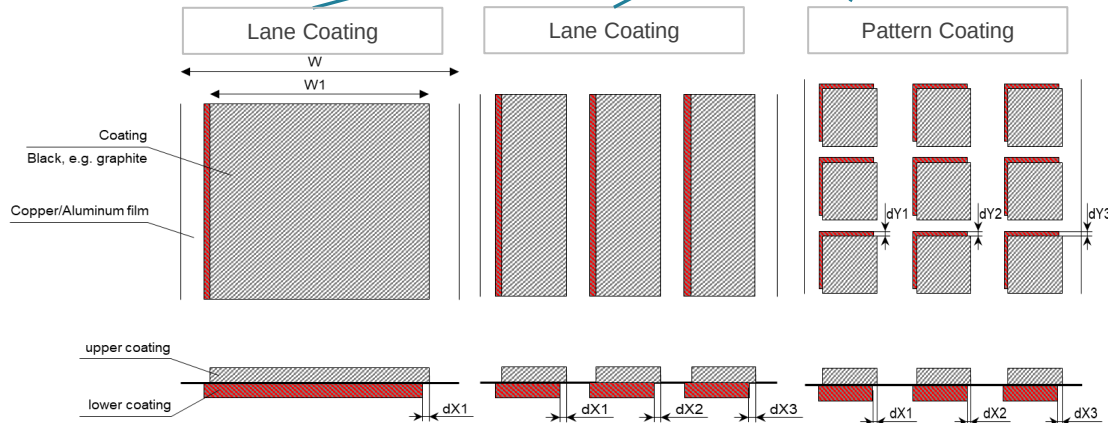
Front to back geometrical

Lane Coating

- total width of material ($=W$)
- width of lanes ($=W1$)
- cross deviation top to bottom coating ($=dX1, \dots$)
- cross distance of lanes
- edge profile quality

Pattern Coating

- length deviation top to bottom coating ($=dY1, \dots$)
- length deviation top to bottom coating ($=dX1, \dots$)
- width of pattern ($W1$)
- length of pattern
- length distance of pattern
- cross distance of pattern



INSPECTION TASKS ON HIGHEST LEVEL

Reliable geometrical measurements in the coating process

System configuration in brief

Resolution Acquisition with monochrome camera 16.384 pixel: 0.043 mm * 0,043 mm (0,002 mm²)

Minimum defects*) greater than 0.007 mm²

*) The minimum defect is about of size 2x2 pixel, to avoid "positive rejection".

Camera Selection	Web Width (mm)	Web Speed (m/min)	Resolution (mm)	Min. Defect Size (mm ²)
1x16k HS Fiber	700	100	0.043	0.007

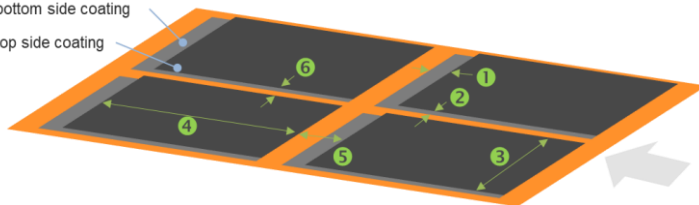
Measurement performances *) :

Measurement Repeatability = +/- 0.01mm (about 1/4 of pixel)

Measurement Accuracy = +/- 0.02mm (about 1/2 of pixel)

*) cross web by using subpixel elaboration and based on experiences

bottom side coating
top side coating



- 1 length deviation top to bottom coating
- 2 cross deviation top to bottom side coating
- 3 width of pattern
- 4 length of pattern
- 5 length distance of pattern
- 6 cross distance of pattern

BSTGROUP

EXAMPLE



12.

Simulation



Slot die chamber – Simulation parameters

- ✓ Example for anode coating
- ✓ Copper Substrate
- ✓ Pseudo-Carreau Fluid match power law ($\mu_{inf}=1\text{mPas}$ time-constant =1sec)
- ✓ Typical Coatema Slot-die
- ✓ Process parameters for 90m/min 400 μm coating in 300mm width

Name	Expression	Value	Description
W	0.8[mm]	8E-4 m	Slot gap
Hc	5[mm]	0.005 m	Inlet height
W_dd	1[mm]	0.001 m	Die width downstream
W_ud	1[mm]	0.001 m	Die width upstream
alpha_u	35[deg]	0.61087 rad	Upstream die angle
alpha_d	35[deg]	0.61087 rad	Downstream die angle
L_u	4.5[mm]	0.0045 m	Upstream length
L_d	10[mm]	0.01 m	Downstream length
H	0.7[mm]	7E-4 m	Coating gap
U_wall	90[m/min]	1.5 m/s	Coating velocity
m_power...	24.08	24.08	Estimated parameter m
gammadot	0.01	0.01	Shear rate optimization p...
n_powerL...	0.49	0.49	Estimated parameter n
Hcoat	0.4[mm]	4E-4 m	Coating Thickness
phi_die	25.9[deg]	0.45204 rad	Contact Angle Fluid-die
phi_sub	24[deg]	0.41888 rad	Contact Angle Fluid-Sub...
gamma_fl...	51.32[mN/m]	0.05132 N/m	Surface Tension Fluid

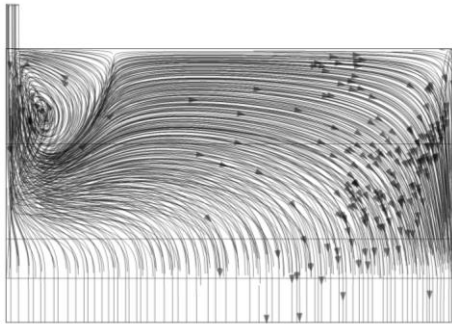
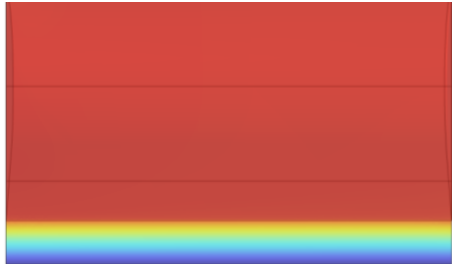
Slot die chamber – Simulation of anode Coating

- ✓ Example for anode electrode coating
- ✓ Fluid data taken from real world (shear-thinning power law fluid)
- ✓ Process parameters for 90m/min 400μm coating and 300mm width
- ✓ No “fancy” slot-die “just” Coatema standard

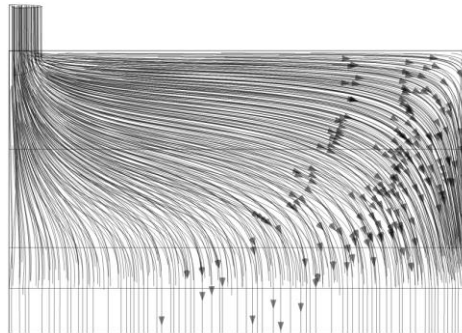
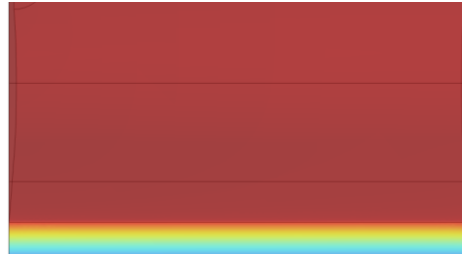


Slot die chamber – Streamlines and pressure distribution

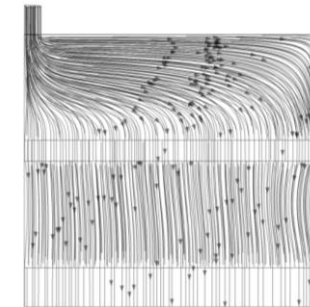
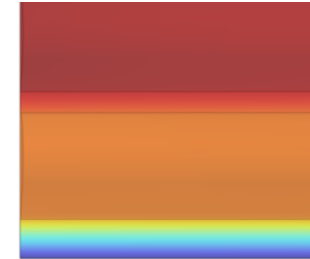
Single Chamber with too small inlet (4 mm)



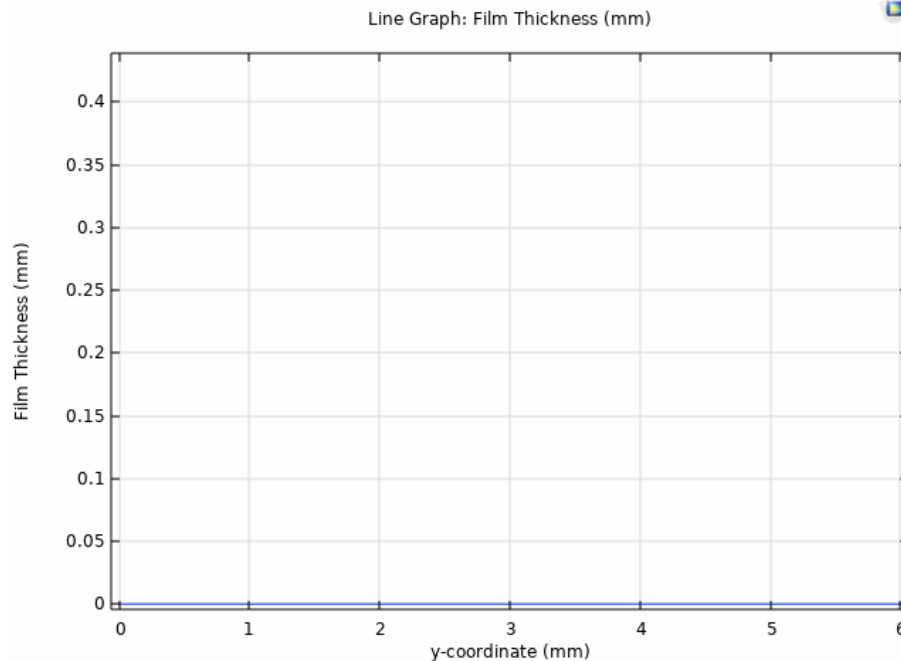
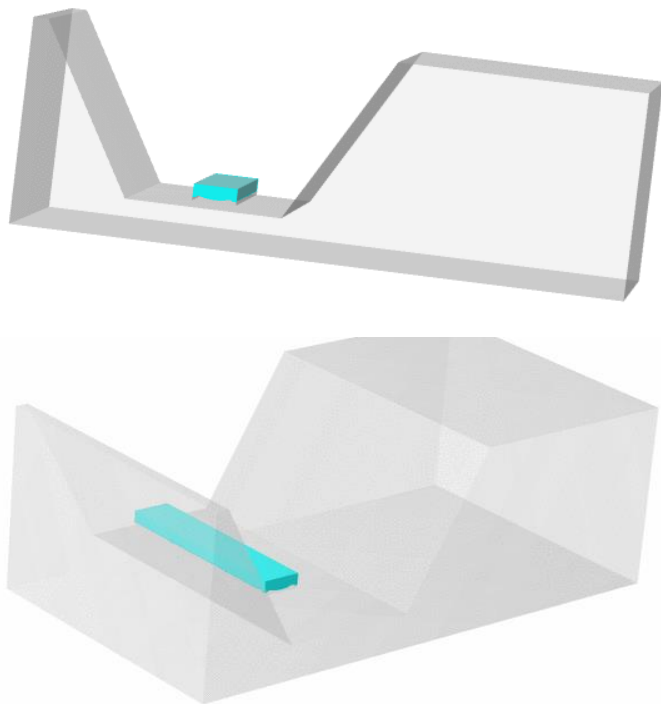
Single Chamber with correct chamber layout (10 mm inlet)



Dual chamber slot die (8 mm inlet same dead volume)



Slot die chamber – Meniscus makes or breaks Homogeneity



13.

Spatial ALD





SPATIAL A/D
INNOVATORS

Explore. Develop. Integrate. **Together.**





SPATIAL ALD
INNOVATORS

Explore. Develop. Integrate. **Together.**

SALD BV is an Eindhoven (NL) based Spatial ALD-equipment specialist serving the following green growth markets:

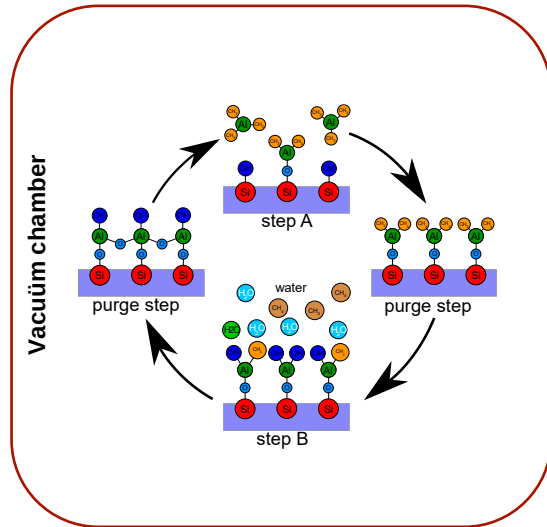
- Li-ion **batteries & SSB** coatings
- next-gen **thin-film solar** (OPV, perovskites)
- **fuel-cells** and **electrolyzers**
- Membranes & packaging **foils**
 - We have over 10 years industrial experience with Spatial ALD processes
 - We supply compact Spatial ALD machine for Research and small-scale production
 - Our technology is scalable from lab-scale up to 24/7 high-volume production

Classic ALD vs. Spatial ALD

Temporal ALD:

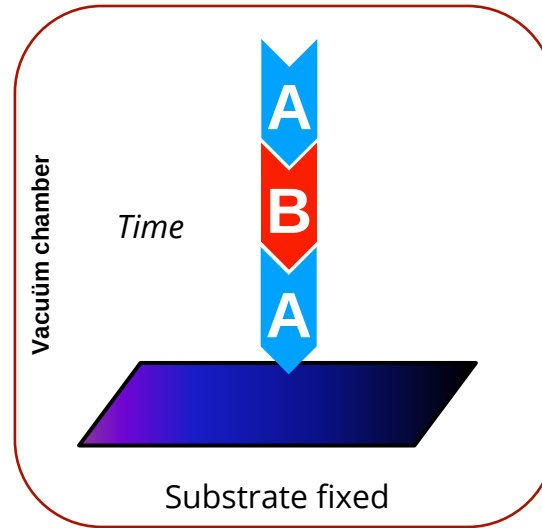
Gas-phase self-limiting deposition process.

One atomic layer per cycle



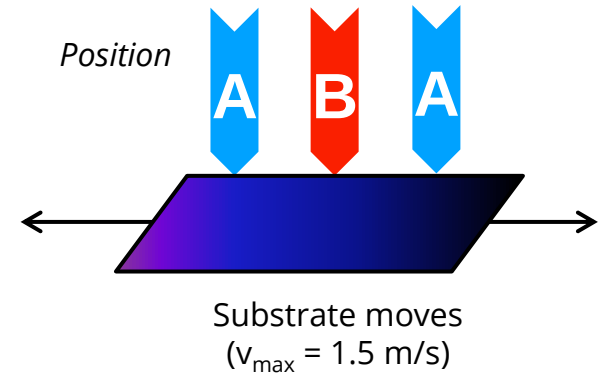
Temporal ALD:

Precursor (A) and co-reactant (B) are **separated in time** in vacuum



Spatial ALD (SALD):

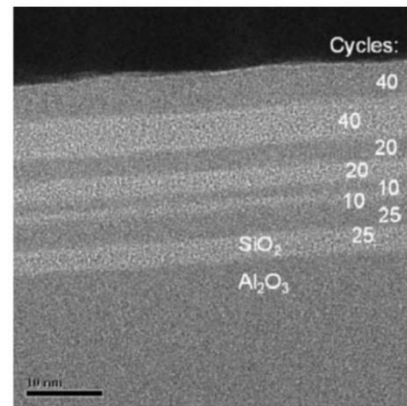
Precursor (A) and co-reactant (B) are **separated in space** in atmospheric pressure



Temporal ALD vs. Spatial ALD & benefits ALD

	Temporal ALD	Spatial ALD (SALD)
Processing	Batch only	In-line / continues / R2R
Atmospheric pressure	No	Yes
Single-sided deposition possible	No	Yes
Typical deposition rate (Al_2O_3)	0.2 nm/min	60 nm/min

- High quality material
- Precise control in film-thickness
- Excellent uniformity
- Wide range of materials such as: metaloxides, metalnitrides, sulfides, fluorides, metals etc.
- **Directly available:** Al_2O_3 , ZnO , ZnO:Al , SnO_2 , TiO_2 , SiO_2
- Low- and high temperature processing possible (50°C – 350°C)



Versatile Process Development R&D System



Li-ion battery innovation to address market needs

1. **Battery stability / long cycle life**

Capacity decrease as function of charge/discharge cycles. At the (natural) interface of anode and cathode to the electrolyte several reactions take place which decrease the capacity of the battery.

2. **Battery safety**

Flammable organic electrolyte. Thermal runaway with dendrites piercing through the separator. Fire and/or explosion hazard. Formation starts on the interface between electrolyte and cathode/anode.

3. **Energy density**

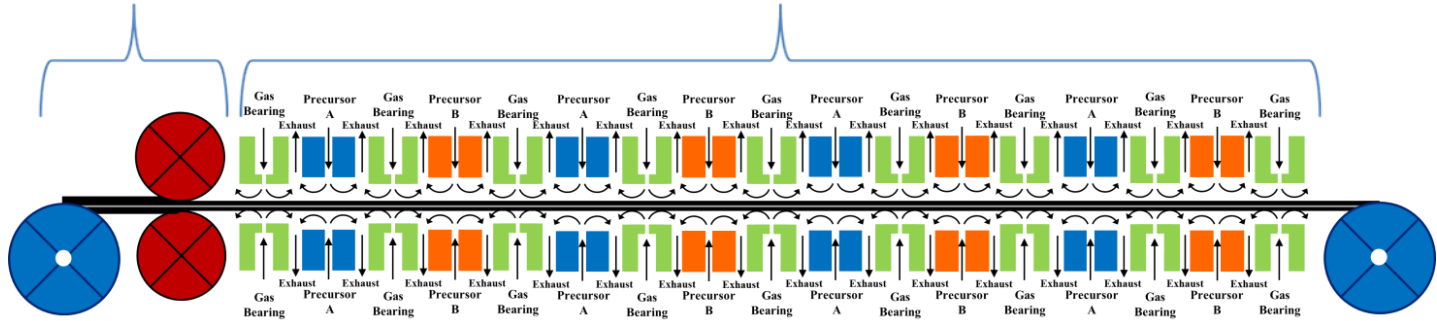
High-voltage, cobalt-free batteries suffer from decomposition of the electrolyte and leaching of certain elements. Solid-state batteries, the next step in energy density and safety, pose considerable challenges in materials stability at the interface between anode/electrolyte/cathode.

4. **SEI formation / wetting time**

The formation time of the natural Solid Electrolyte Interphase (SEI) is long, which makes this an expensive production step. With an artificial SEI there is lower formation time. The battery production cost is reduced.

Key enabler : managing the interface chemistry and stability

Deposition Head



- 243

Partners in Spatial ALD for Roll-to-Roll production



In Summary

- Thermal and Plasma enhanced Spatial ALD concepts for lab and scalable into high volume production
- SALD is the only company with field experience of Spatial ALD for high volume production
- Spatial ALD can be integrated in existing high volume production lines
- SALD has experience with: Al_2O_3 , ZnO , ZnO:Al doped, SnO_2 , TiO_2 and plasma enhanced SiO_2
- SALD systems can be equipped with a protective environment like N_2 or Ar.

SALD is an open and flexible company:

- Open for joint development programs
- Feasibility studies and sampling for new materials and/or applications
- Collaborate to find the best thin-film solution for your application
- Open for investments

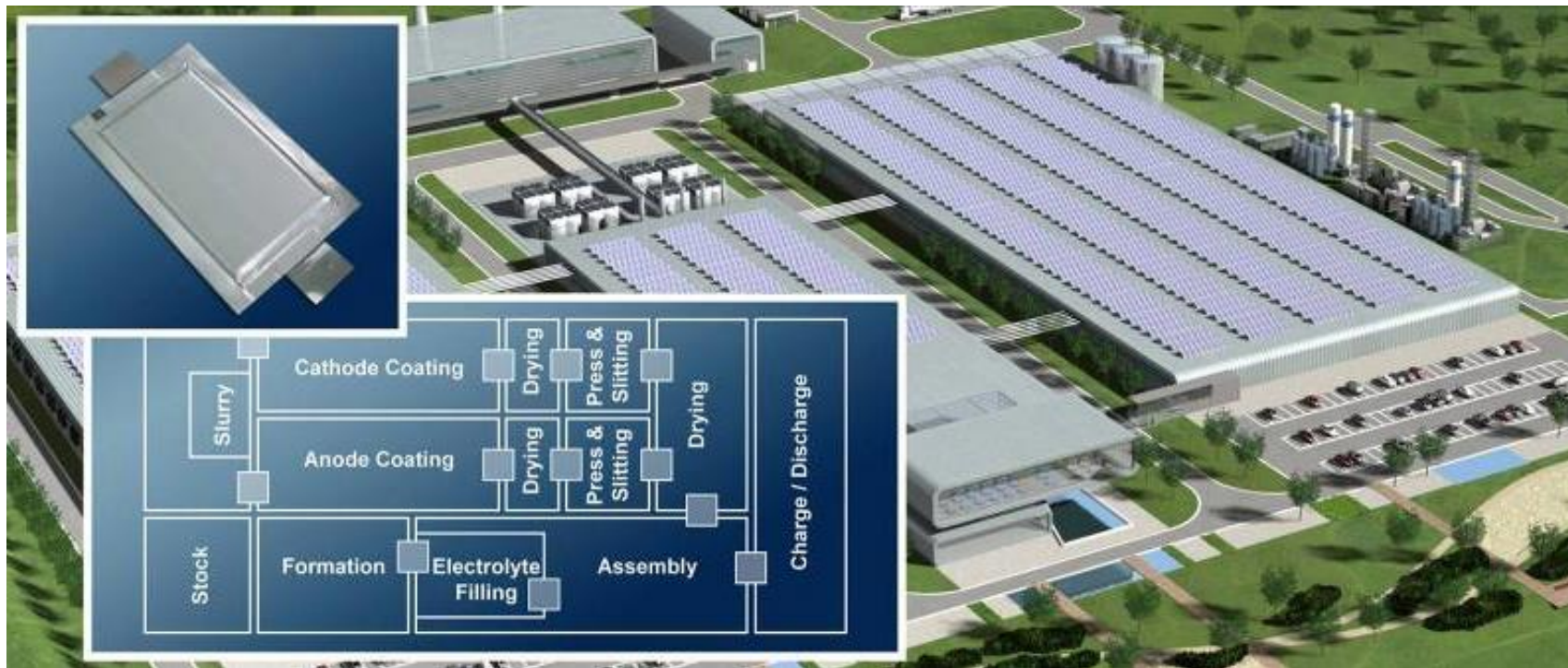


14.

The battery fab

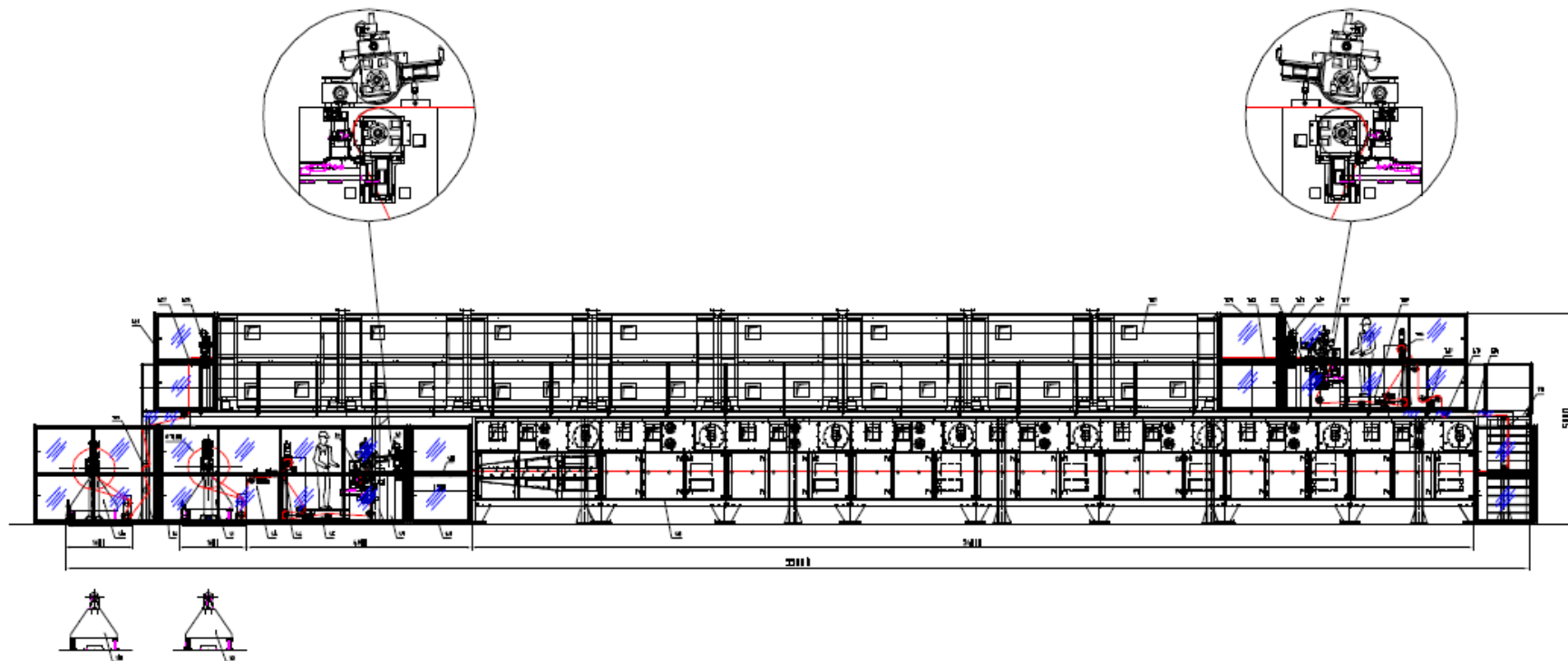


Overview



The battery fab

Coatema battery fab concept



Lithium battery markets

Transportation

HEV / PHEV / EV



Heavy-Duty hybrids



Electric grid services

Grid stabilization



Uninterrupted power supply

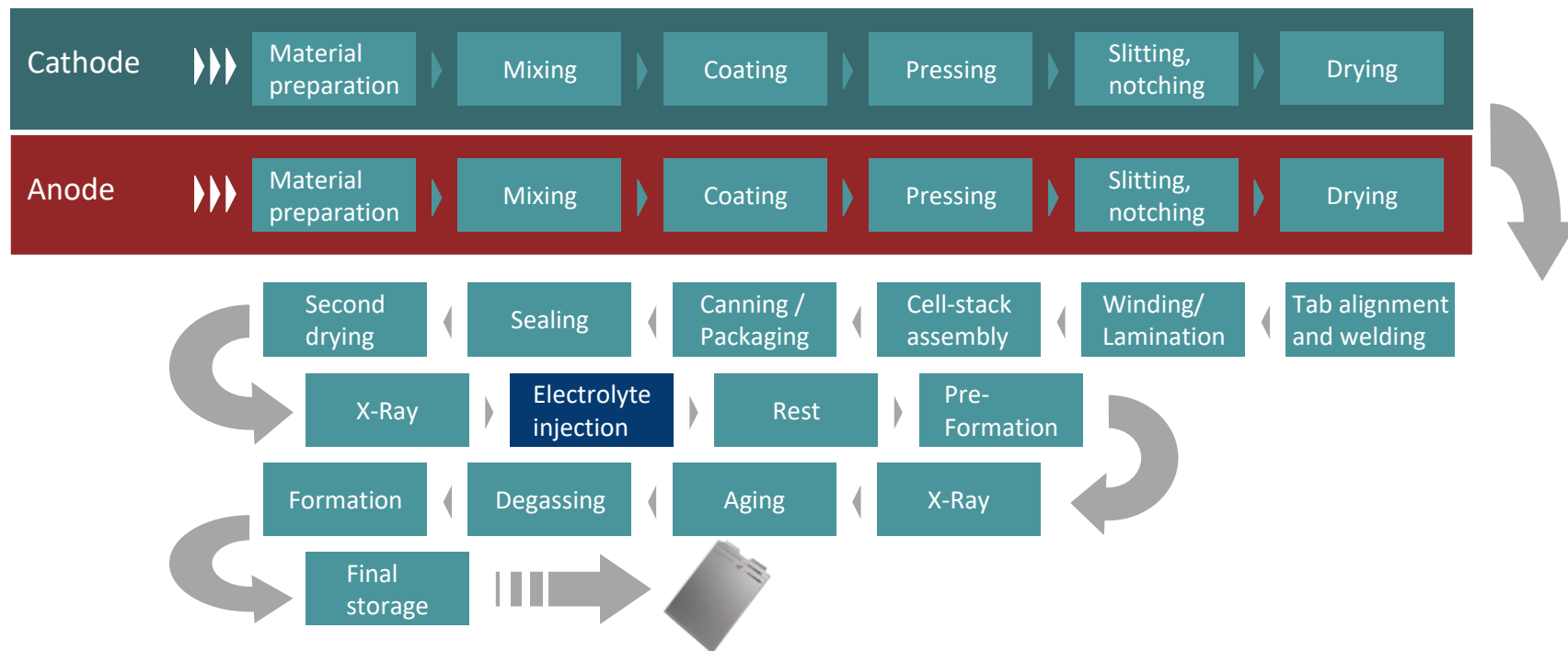


Facts

- ✓ Fuel economy
- ✓ Reduced emissions
- ✓ Energy independence

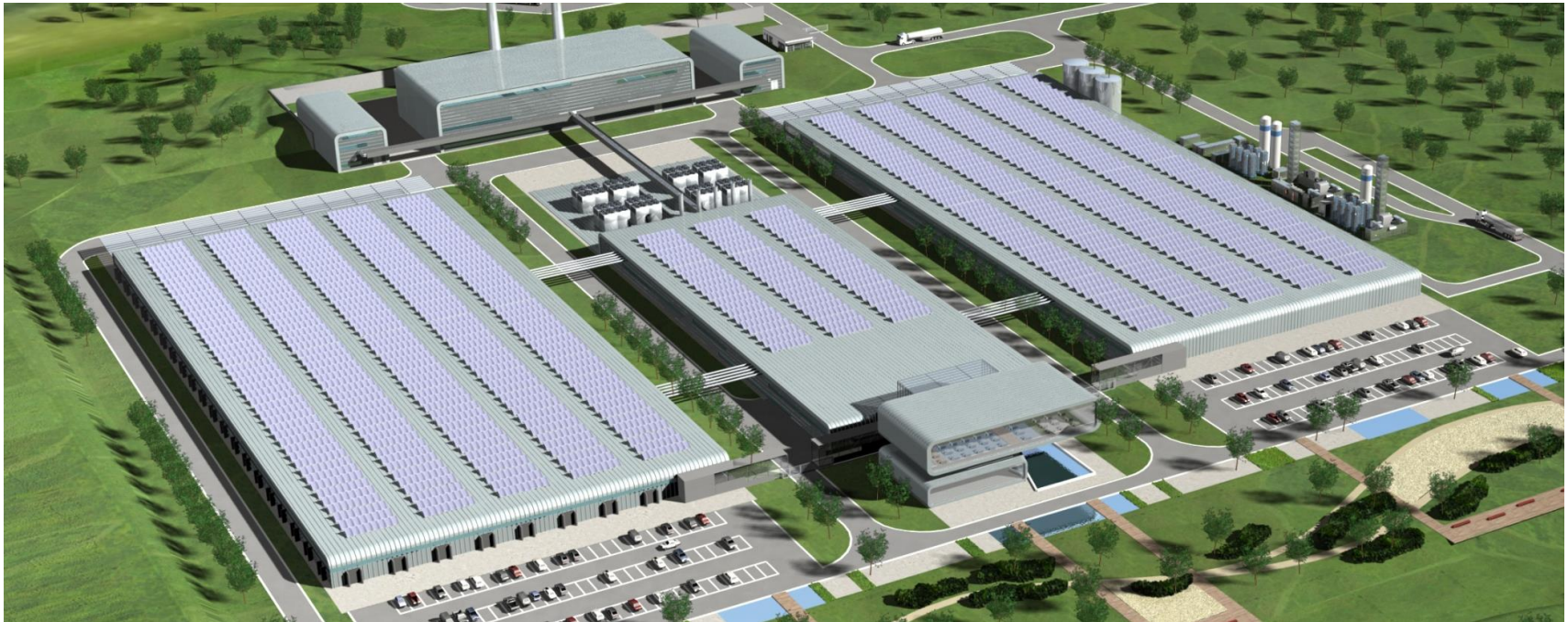
- ✓ Increase plant efficiency
- ✓ Increase grid reliability
- ✓ Energy independence

Production process Li-Ion batteries



The battery fab

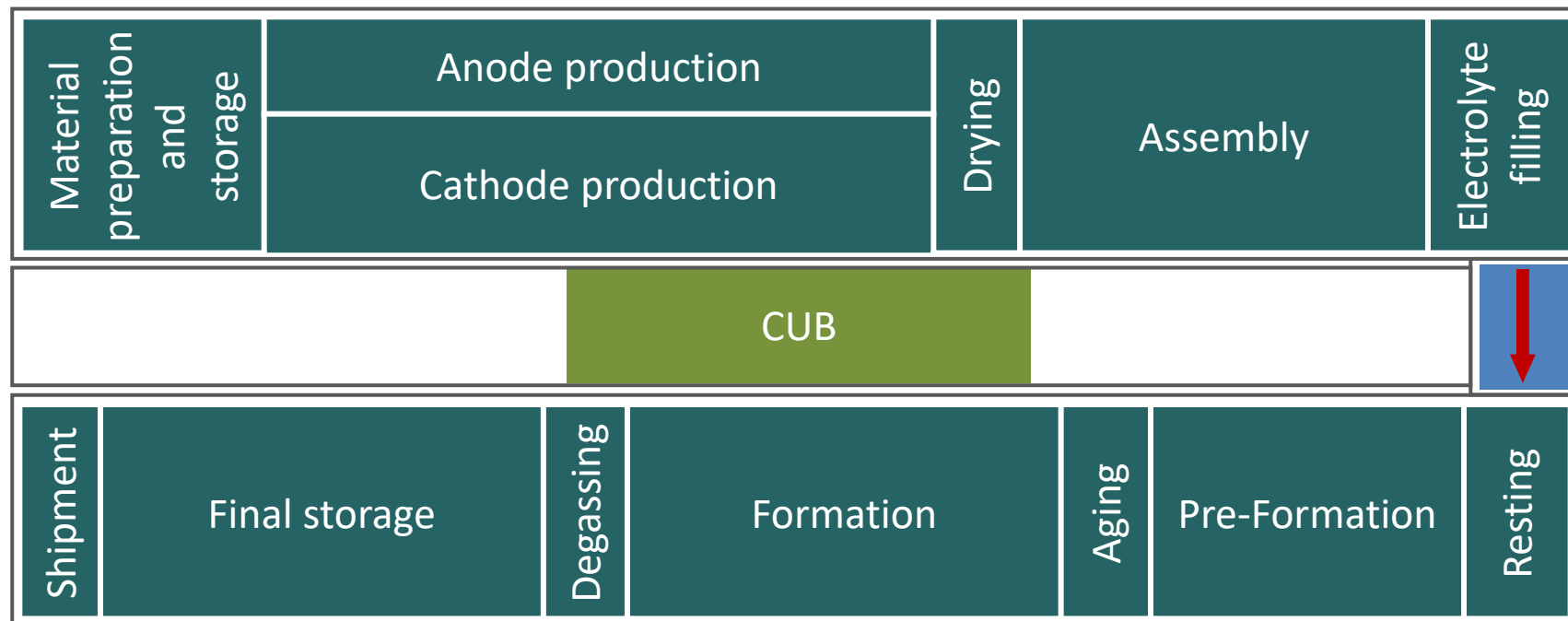
Factory concept: master site plan



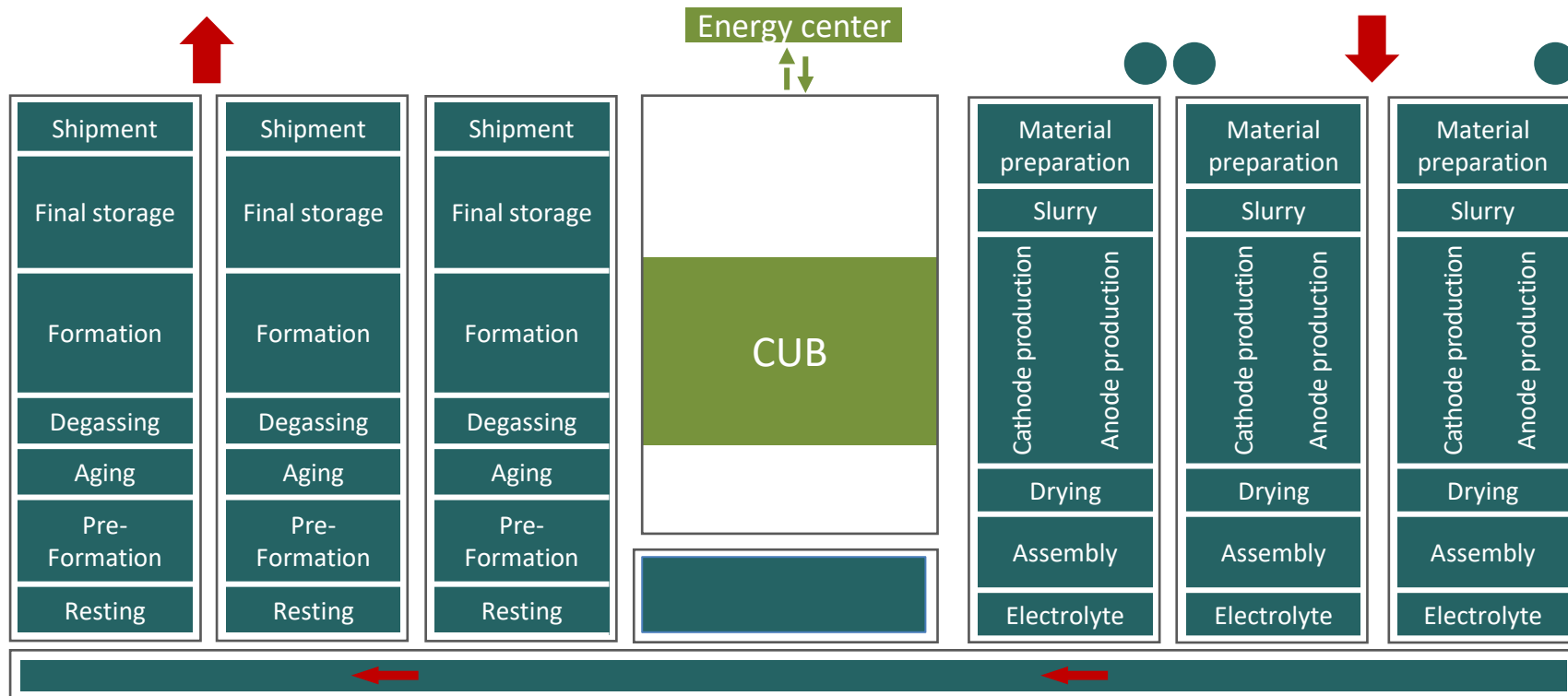
Factory concept: buildings & facilities



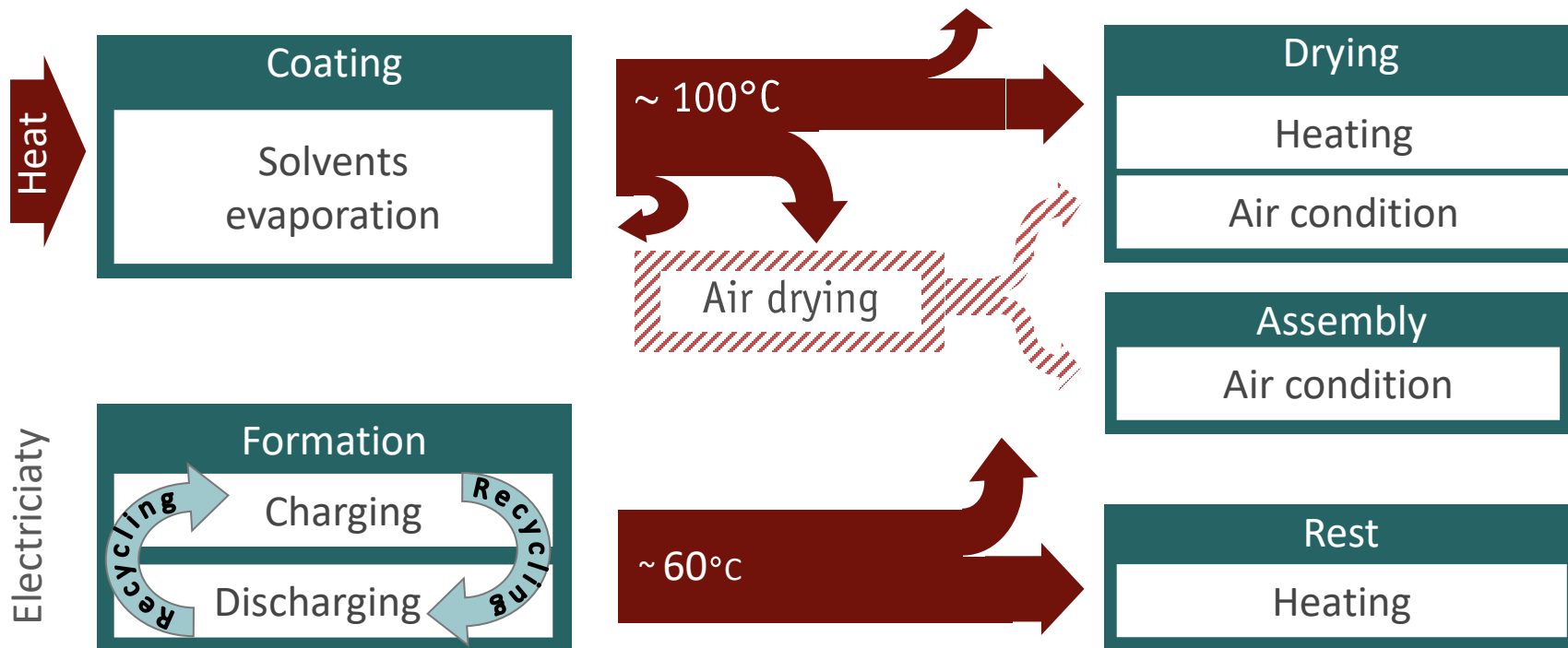
Concept – phase I



Concept – phase II: capacity 1200 – 1800 MWh/a



Most relevant energy flows



15.

Summary



Summary

- ✓ Latest 2030 – 2050 the whole automotive car fleet has to be zero emission
- ✓ Impact markets will be automotive, light trucks, and smart grids
- ✓ New green deal of the European Commission
- ✓ Markets will be Li-ion, Solid state and Redox flow batteries
- ✓ Coatema has over 22 years experience in the market of battery equipment
- ✓ The ATH group is able to deliver state of the art production equipment for battery giga fabs

Do not hesitate to contact us!



Anything missing?

Let us know and we will make it happen!

Our R&D centre is worldwide the most versatile centre for coating, printing and laminating.

Sales department:
sales@coatema.de



Coatema

Thank you

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www.coatema.com

MEMBER OF ATH