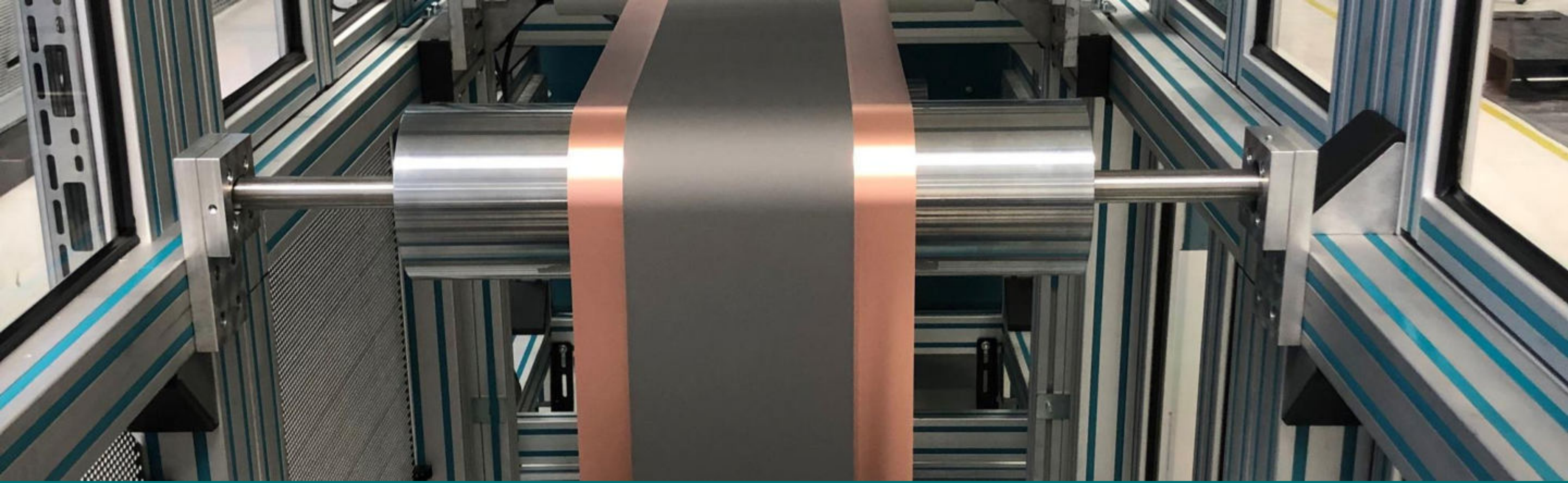


Coating solutions for batteries lab 2 fab concept

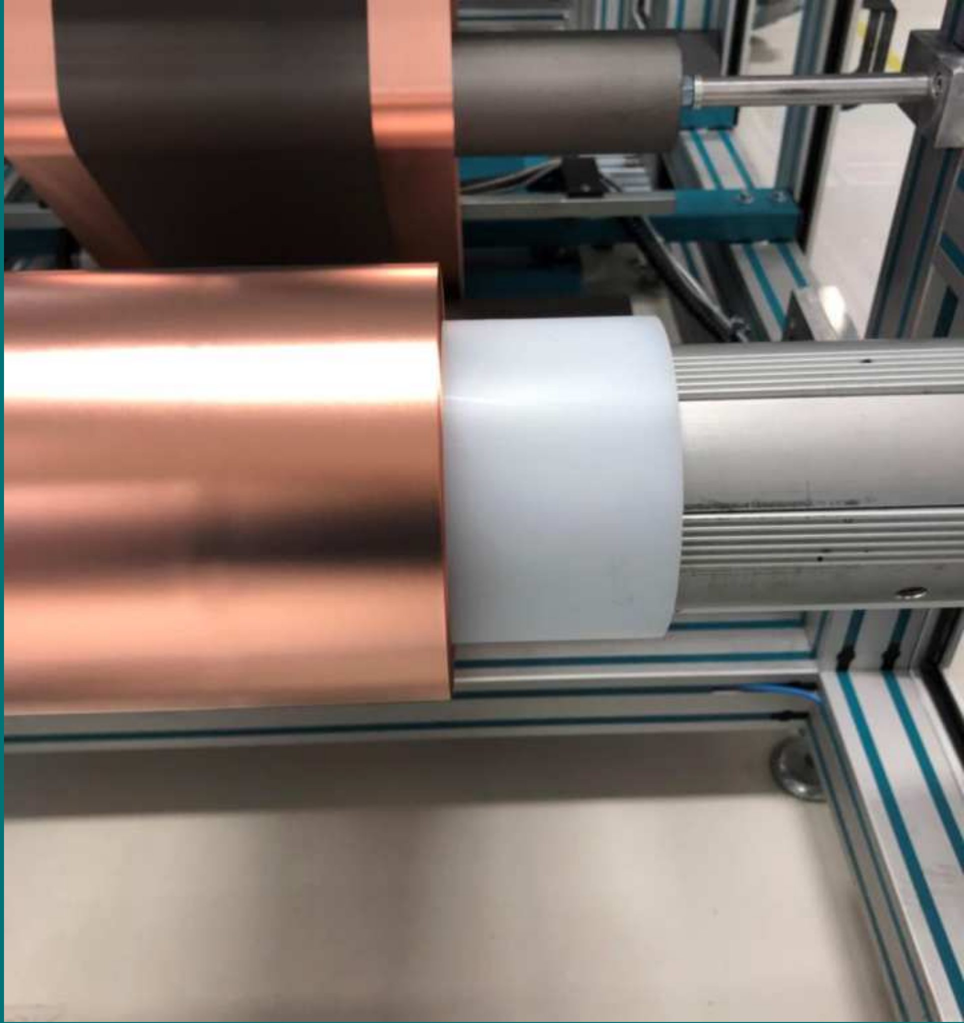
Coatema

02/06/25

MEMBER OF ATH

Agenda

1. Introduction
2. Battery markets
3. Today’s equipment for batteries
4. Process control
5. Coating systems
6. Slot die coating for batteries
7. Drying technologies
8. Calendering
9. Battery production lines
10. Summary



1.

Introduction

Thomas Kolbusch, Director Sales, Marketing, Technology, VP

Introduction

Thomas Kolbusch

COATEMA Coating Machinery GmbH

Overview

Introduction

Quality
made in Germany

Part of the ATH Holding

S2S equipment

R2R equipment

Innovations

Coating

Printing

Laminating

Bespoke
equipment

Founded
1974

Printed electronics
Fuel cells
Membranes
Pharmaceutics
Solar
Batteries
Prepregs
Green Hydrogen

From lab 2 fab

R&D
projects & network

Worldwide
service

Group of companies

Introduction

ALTONAER
TECHNOLOGIE
HOLDING

KROENERT	DRYTEC	Coatema® Coating Machinery GmbH
✓ Founded 1903	✓ Founded 1995	✓ Founded 1974
✓ Approx. 200 employees	✓ Approx. 50 employees	✓ Approx. 50 employees
✓ Located in Hamburg	✓ Located in Norderstedt	✓ Located in Dormagen

Coatema equipment platform strategy for lab2fab

Lab

- ✓ State-of-the-art research and development equipment
- ✓ Sheet-to-sheet to roll-to-roll systems on smale scale & footprint

Pilot

- ✓ Proven processes for printing, coating and laminating equipment
- ✓ Highest-quality pilot lines enable stable pilot production and reduce cost of operation
- ✓ Scaling laboratory equipment to enable pilot production

Production

- ✓ Full-scale production lines
- ✓ Optimize the manufacturing process, including streamlining assembly, reducing material waste, and optimizing the carbon footprint

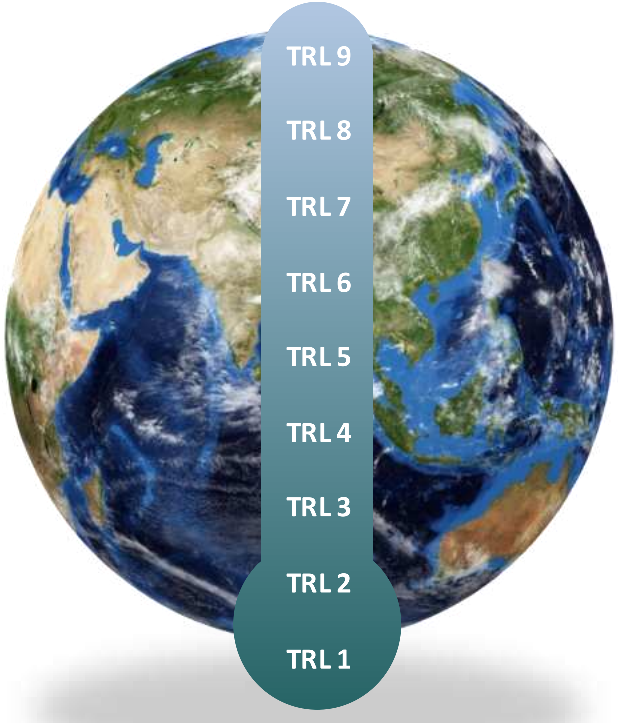
Our markets – Coatema focus areas

Green Hydrogen

Fuel cells

Batteries

Solar



Sustainability

Digital fabrication

Printed electronics

The next thing

Coatema services as an overview

Introduction

The Coatema R&D centre

Accelerate your innovation in our dedicated pilot facility with advanced lab & pilot lines and expert guidance – bridging the gap from #lab2fab.

The Coatema Coating Symposium

Join the global network of coating experts at our annual event, where cutting-edge developments meet industry collaboration for next-level innovation.

The Coatema Slot Die Masterclass

Master precision coating in our hands-on training program, led by industry specialists to optimize slot-die performance and product excellence.

R&D centre USP

Process development
- ✓ Feasibility study
- ✓ Ink – process study
- ✓ Process analysis
- ✓ Slot die coating simulations
- ✓ Proof of concept
- ✓ Small scale prototype

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

Education
- ✓ Coating conference
- ✓ Partner trainings
- ✓ Education of students
- ✓ Workforce training

Development of custom-made design for equipment
- ✓ Prototyping
- ✓ Proof of concept

Public funded research projects know-how
- ✓ German funded
- ✓ Horizon 2020
- ✓ Global 2+2 projects
- ✓ B2B projects

Introduction – R&D centre

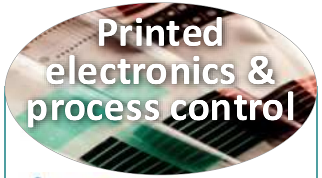




R&D customers

- TECHNISCHE UNIVERSITÄT DRESDEN
- KIT Karlsruhe Institute of Technology
- Agency for Science, Technology and Research SINGAPORE
- THE UNIVERSITY OF ARIZONA
- UNSW SYDNEY
- Queen Mary University of London
- ARISTOTLE UNIVERSITY OF THESSALONIKI
- TTRI Taiwan Textile Reasarch Institute
- ITA Institut für Textiltechnik und Lehrstuhl für Textilmaschinenbau
- RWTH AACHEN UNIVERSITY
- NREL Transforming ENERGY
- RUHR UNIVERSITÄT BOCHUM RUB
- TECHNICAL UNIVERSITY OF LIBEREC www.tul.cz
- hochschule hof University of Applied Sciences
- Deutsches Textilforschungszentrum Nord-West German Textile Research Centre North-West
- cea
- CSIRO
- Fachhochschule Kiel Hochschule für Angewandte Wissenschaften
- CENTI Centre for Nanotechnology and Smart Materials
- FILK Forschungsinstitut Leder und Kunststoffbahnen
- THE OHIO STATE UNIVERSITY
- Hochschule Niederrhein University of Applied Sciences
- Georgia Institute of Technology
- UNIVERSITY OF CAMBRIDGE
- Neue Materialien Fürth
- JOANNEUM RESEARCH
- HERIOT WATT UNIVERSITY
- SW
- DITF DEUTSCHE INSTITUTE FÜR TEXTIL+FASERFORSCHUNG
- JÜLICH FORSCHUNGSZENTRUM
- NATIONAL UNIVERSITY of MONGOLIA
- VTT
- TNO innovation for life
- eurecat Centre Tecnològic de Catalunya
- Fraunhofer IMM
- Fraunhofer LBF
- KITECH Korea Institute of Industrial Technology
- Holst Centre
- Hochschule Reutlingen Reutlingen University
- tecnalia
- Fraunhofer IAP
- Fraunhofer IAF
- Fraunhofer ILT
- Fraunhofer IFAM
- Fraunhofer ISC
- Fraunhofer FEP
- Fraunhofer IVV
- Fraunhofer ISE
- Fraunhofer ICT
- Fraunhofer PYCO
- Fraunhofer IPT
- Fraunhofer IWM

R&D projects overview 2022 – 2025

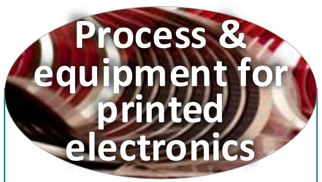


REAL NANO

In-line and real-time digital nano-characterization for flexible organic electronics

NOUVEAU

The NOUVEAU project will develop solid oxide cells (SOCs) with innovative La- and PMG-free electrode materials

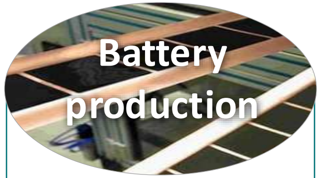


FLEX2ENERGY AUTOMATED MANUFACTURING PRODUCTION LINE FOR IPVS

R2R production line for OPV solar with integrated backend

FLEX-G 4.0

Upscaling and development of EC based switchable films to decrease energy use in buildings



IDEEL

Implementation of laser drying processes for lithium-ion battery production

SOLiD

R2R process optimization for solid state batteries

PEP LAT

Plasmonically enhanced photocatalysis for wastewater treatment

ROLL 2 SOL

R2R nanostructuring of functional films

WATER PROOF

The WaterProof project aims at developing an electrochemical process that converts CO_2 emission

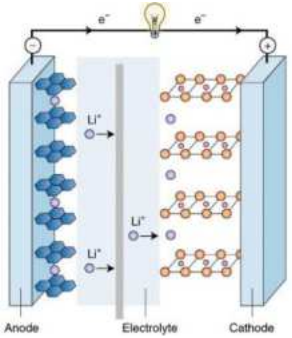
FLEX FUNCTION 2 SUSTAIN

Creating an open-innovation testbed for sustainable packaging

2.

Battery markets

Li-Ion Battery – Overview

Overv  tech

General KPIs

- ✓ Energy density
  70 – 410 Wh/kg
- ✓ Power density
  150 – 315 W/kg
- ✓ Cell Voltage:
  3.7 – 5.0 V
- ✓ Cost
  150 – 600 €/kWh
- ✓ Safety (-/0/+)
  0
- ✓ Lifetime
  300 – 3.000 cycles
- ✓ Efficiency:
  90 – 95 %

Application Scale

Time Horizon

Advantages & Disadvantages

- ✓ Cyclability
- ✓ Efficiency
- ✓ Lifetime

- ✓ Energy density
- ✓ Safety
- ✓ Cost

Classification

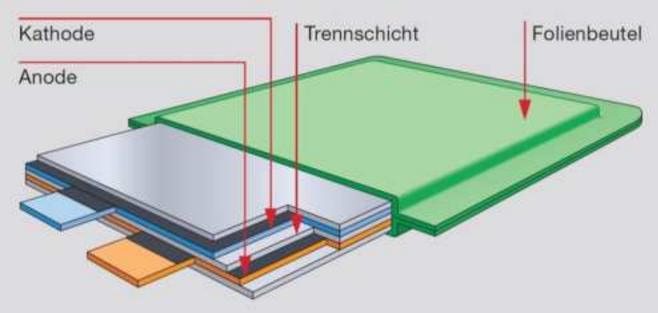
Intercalation Battery
↳ Li-Ion Battery

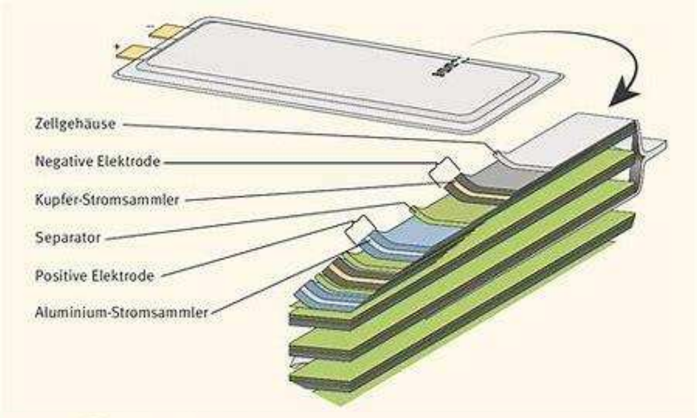
Conclusion

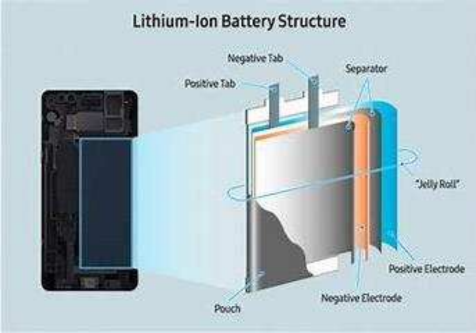
This battery type is commercialized and the most common battery type.

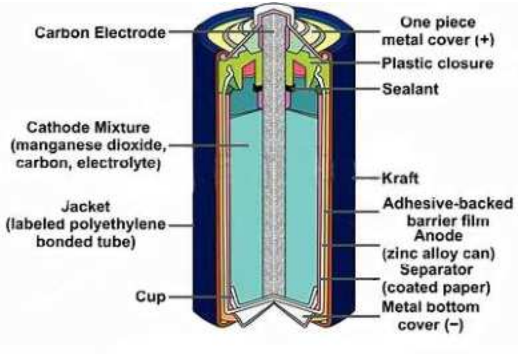
Source: Center Fuel Cell Industrialization | RWTH Aachen Campus

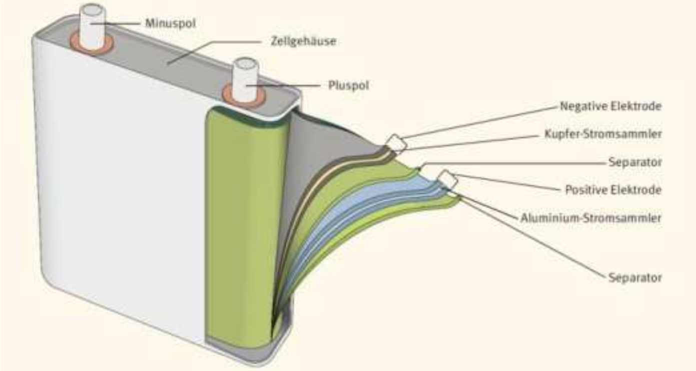
Overview Li-ion











Coatema® Coating Machinery GmbH

Li-on developments – European producers and cell types

TYPES OF CELL FORMATS PRODUCED BY MANUFACTURERS OF ELECTRIC VEHICLE BATTERIES

CIC energiGUNE

MANUFACTURER	FORMAT
LG Chem	CYLINDRICAL, POUCH
SAMSUNG	CYLINDRICAL, PRISMATIC
SK innovation	POUCH
CATL	PRISMATIC
Panasonic	CYLINDRICAL
northvolt	PRISMATIC
VERKOR	POUCH
Gotion	PRISMATIC
FARASIS	POUCH
Envision AESC	POUCH

Source: Public information

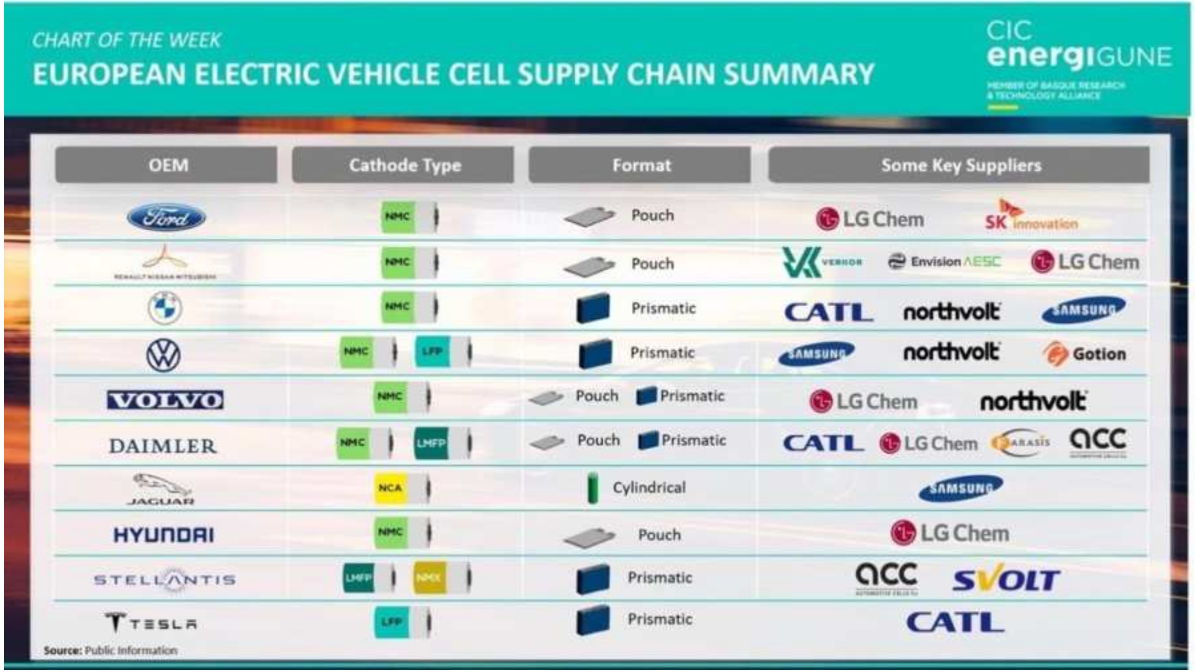


CHART OF THE WEEK

EUROPEAN ELECTRIC VEHICLE CELL SUPPLY CHAIN SUMMARY

CIC energiGUNE

MEMBER OF BASQUE RESEARCH & TECHNOLOGY ALLIANCE

OEM	Cathode Type	Format	Some Key Suppliers
Ford	NMC	Pouch	LG Chem, SK innovation
RENAULT NISSAN MITSUBISHI	NMC	Pouch	VERKOR, 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, FARASIS, ACC
JAGUAR	NCA	Cylindrical	SAMSUNG
HYUNDAI	NMC	Pouch	LG Chem
STELLANTIS	LMFP, NMX	Prismatic	ACC, SVOLT
TESLA	LFP	Prismatic	CATL

Source: Public Information

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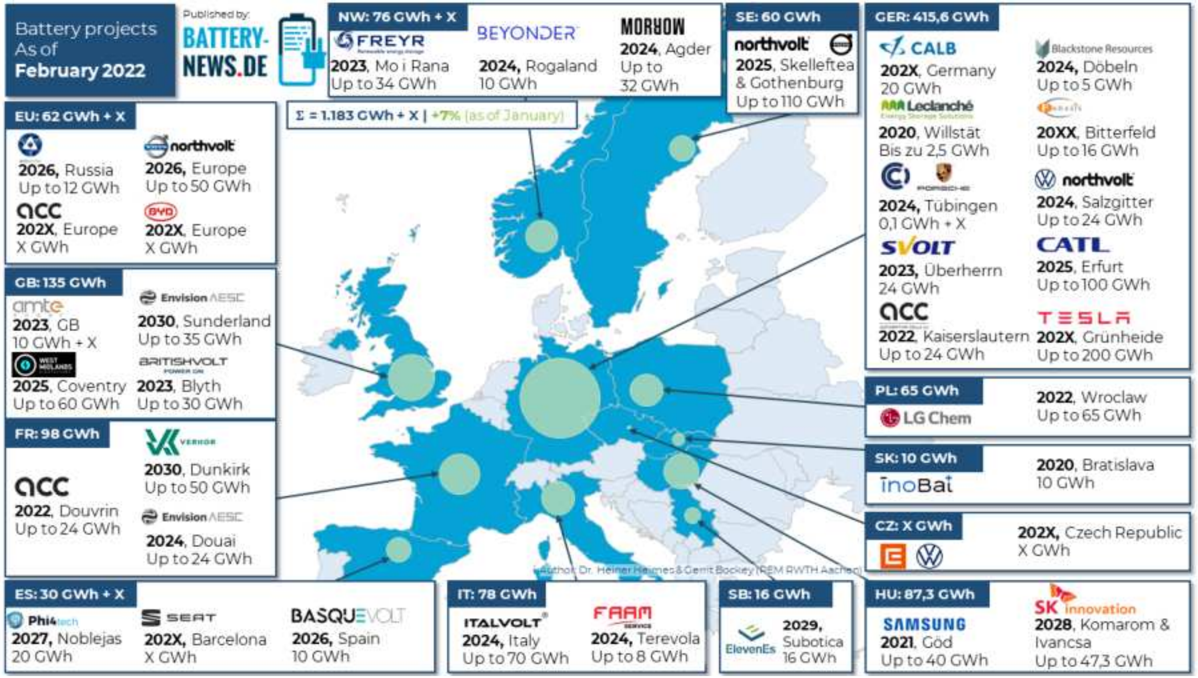
Coating Machinery GmbH

Li-ion Giga fab projects in Europe



Key Trends | Costs

Overview on battery tech

Battery price decline slows down due to rising commodity prices. China has lowest pack price globally.

Pack prices fell by only 6% from 2020 – 2021 compared to 13% from 2019 – 2020.

Prices were low for the first 6 month of 2021, then started to **increase** in the second half due to supply chain pressures.

Price increases: Since September, Chinese producers have raised LFP prices by 10 – 20%. Average pack prices could rise to **$135/kWh in 20**22

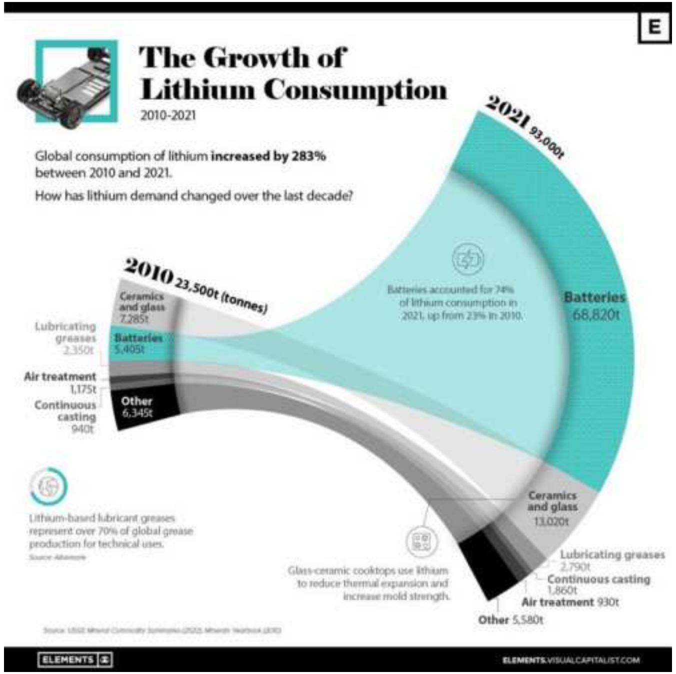
Regional differences:

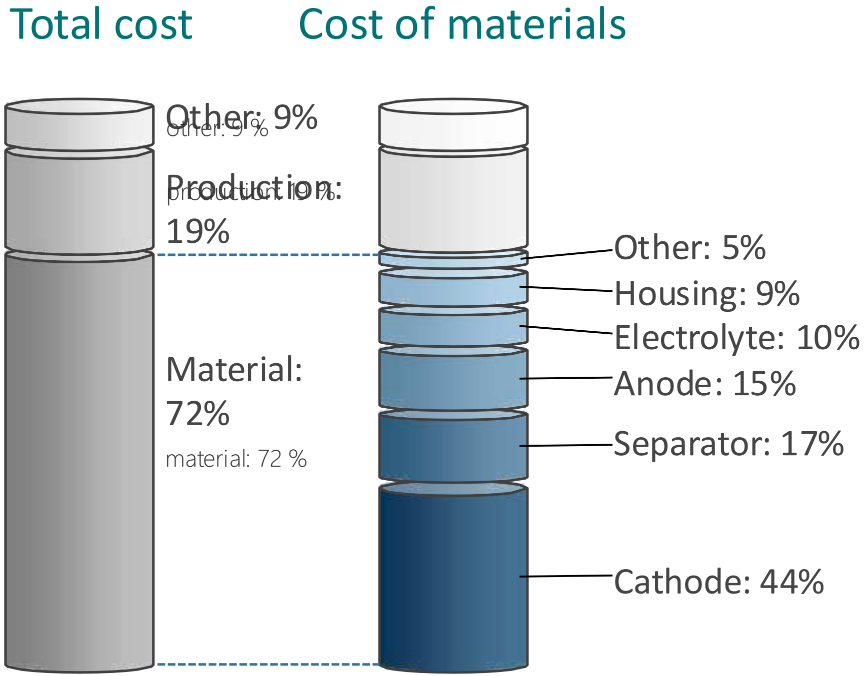
- ✓ China has the cheapest battery pack prices ($1117kWh)
- ✓ U.S. pack price ($155/kWh, 40% higher than China
- ✓ EU pack price ($177/kWh, 60% higher than China)

Source: Bloomberg, BNEF Battery Price Survey

Factors Decreasing Price	Factors Increasing Price
✓ Adoption of low-cost cathode chemistry LFP (On average, LFP cells are ~30% cheaper than NMC cells in 2021) ✓ Decreased use of Co in Ni-based cathodes	✓ Rising commodity prices (Li, Co, Ni) ✓ Increased costs for key materials (e.g. electrolytes)

Materials





Source: Bloomberg, BNEF Battery Price Survey

Investment | Capital Raised in Material Innovation

Cathode Material & Technology — Total Raised: $280.59M

LYTEN | GREATPOWER | Li-S Energy | MITRACHEM | Conamix | volexion | ALTRIS

Capital Raised To Date: **Cathode Material & Technology: $280.59M**

Anode Materials & Technology — Total Raised: $2.01B

SILA	$933.51M
enovix	$414.28M
ENEVATE	$192.36M
amprius	$191.90M
	$140.99M
Nanoscale Components	$35.07M
ADVANO	$23.77M
sionic energy	$23.19M
ECELLIX	$4.00M
LeydenJar	$29.06M
E-magy	$6.05M
CENATE	$5.00M
SICONA	$3.80M
BSG 佰思格	$1.55M
GRAPHITE	$1.50M

Solid-state and Li-metal — Total Raised: $2.32B

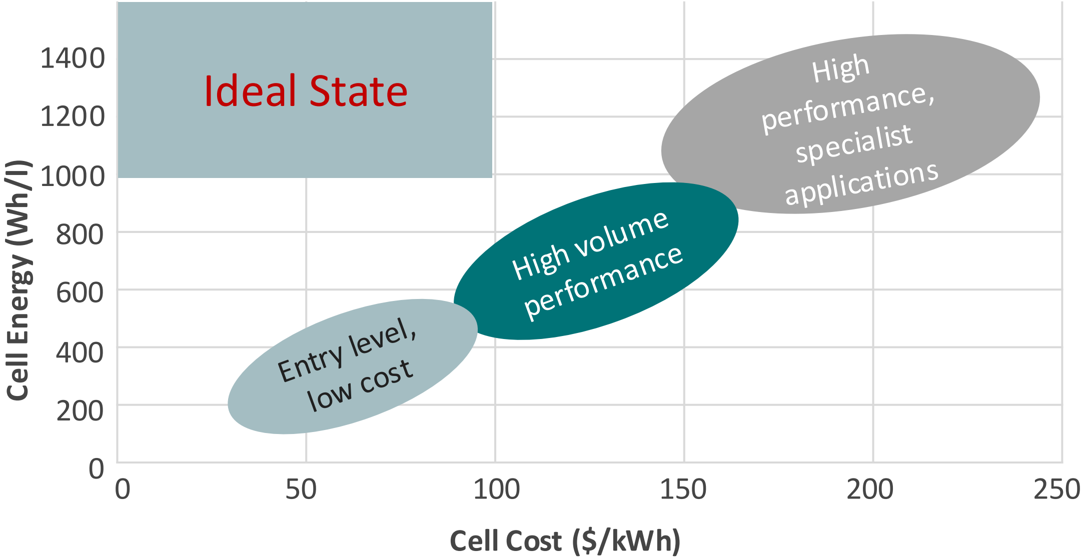
ProLogium	$823.00M
SES	$520.50M
Solid Power	$358.13M
Sion Power	$290.35M
CYMBET	$104.50M
WELION 卫蓝新能源	$78.13M
Factorial	$53.71M
BRIGHTVOLT	$42.50M
SEPION	$18.75M
Prieto Battery	$18.45M
LionVolt	$6.10M
Solivis	$3.96M
INTECELLS	$3.00M
SOELECT INC	$2.30M

*Companies listed according to Pitchbook with disclosed fundraising deal in year 2021

Source: Data from Pitchbook, Market Map by BatteryBits

Key Trends | Automotive OEM Solutions

The automotive industry is converging around 3 types of battery solutions, but OEMs differ on specific solutions.



Entry level low cost				
LFP	Na-ion	Mn-rich	Na-Ni-Cl	NFA

High volume performance					
NCA	NMC	NCMA	eLNO	Gr-Si Blend Anodes	Mn-rich

High performance, specialist application			
Ultra-High Ni Blends	Silicon Anodes	Lithium Metal Anodes	Solid State Electrolyte
Li-S	HV-Spinel Cathodes	Rapid Charge Anodes	Lithium Air

*Bubbles are to visualize overall trends and not intended to completely represent solutions

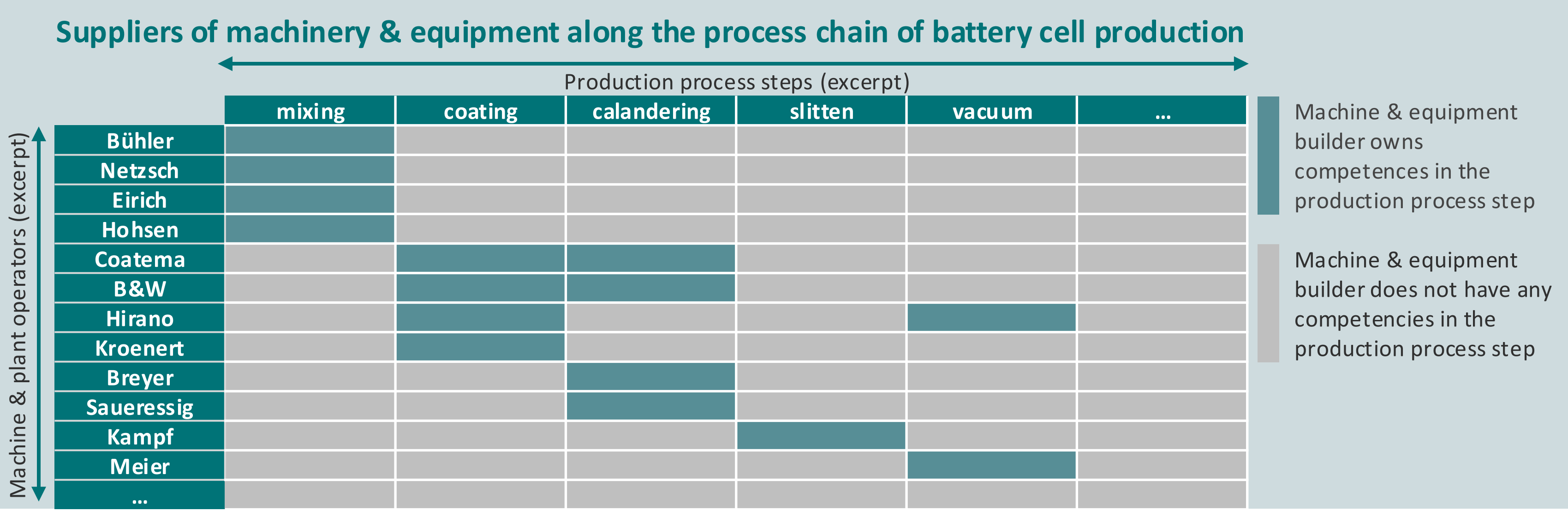
Source:

Battery equipment manufacturers in Europe

Equipment ma

Li-on developments – Equipment supply chain

A key challenge is to integrate the individual technologically diverse process steps into a robust production chain.



Source: RWTH Aachen University / PEM Datenbank für Maschinen & Anlagen in der Batteriezellproduktion

Coatema®
Coating Machinery GmbH

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

Premises, assumptions and data for an exemplary design of a battery cell factory

Product features

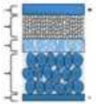
Performance characteristics
- ✓ 5,2 AH
- ✓ 3,68 V
- ✓ 290 Wh/kg
- ✓ 790 Wh/l

Cell format/ -dimensions/ -weight
- ✓ Cylindrical
- ✓ 21 mm diameter, 70 mm height
- ✓ 66 g

Cell chemistry
- ✓ Electrodes: Graphite vs. NMC622
- ✓ Electrolyte: EC:DMC + $LiPF_6$
- ✓ Seperator: Polyolefin base with ceramic coating

Cell design

Aluminum foil thickness	12 µm
Cathode coating thickness	71 µm
Seperator thickness	20 µm
Thickness of anode coating	82 µm
Thickness of copper foil	8 µm
Width of electrode	63 mm
Length of the electrode	863 mm



Production acceptance and machine data

Production capacities
- ✓ 14 GWh/a
- ✓ 731.600.000 Cells/a

Layer model
- ✓ 301 d/a, 3 layers/d, 8 h/layer

Machine data

Mixing
- ✓ Mixing volume: 300 l
- ✓ Mixing time: 45 min.

Coating and drying
- ✓ Coating width: 800 mm
- ✓ Coating speed: 30 m/min.

Calendering and slitting
- ✓ Calendering width: 800 mm
- ✓ Calendering speed: 100 m/Min.

Vacuum drying
- ✓ Coils / Dryer: 4
- ✓ Drying time: 24 h

Attach contact flags
- ✓ Cells / welding machine: 6
- ✓ Welding duration / contact lug: 5 sek.

Winding
- ✓ Cells / Winding line: 2
- ✓ Winding time / cell: 2,6 sek.

Fill electrolyte
- Cells / Filling system: 500
- Filling time / cell: 840 sek.

Krimpen
- ✓ Cells / crimping plant: 8
- ✓ Crimping duration / cell: 3 sek.

Forming
- ✓ Cells / storage system: 4.500
- ✓ Forming time / cell: 15 h

Aging
- ✓ Cells / Charging system: 5 Mio.
- ✓ Aging duration / cell: 20,5 d

Testing and packing
- ✓ Cells / Charging system: 4.500
- ✓ Charging time / cell: 30 min.

Source: RWTH Aachen University / PEM Datenbank für Maschinen & Anlagen in der Batteriezellproduktion

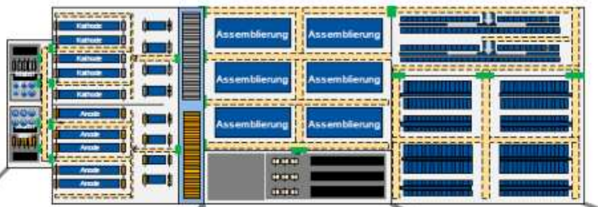
Coatema® Coating Machinery GmbH

Gigfab calculation

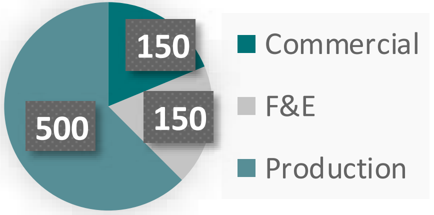
Exapmle design of a battery cell factory with an annual output of 14 GWh

Material requirement per year	
Material	**Amount**
Copper foil	3,3 kt
Aluminum foil	1,3 kt
Coating anode	11,9 kt
Coating cathode	16,9 kt
Electrolyte	5,1 kt
Seperator	95,1 km^2
Housing	731,6 mio.

Example of a layout for battery cell production



Personnel requirements



Electrodes production			Assembly of the cell			Forming the cell	
Machine / Plant	**Amount**		**Machine / Plant**	**Amount**		**Machine / Plant**	**Amount**
Mixer	3,3 kt		Contacting	28		Forming	398
Coater	1,3 kt		Winding	44		Aging	12
Dryer	11,9 kt		Filling electrode	56		Testing and packing	11,9 kt
Calender	16,9 kt		Crimping	13			
Slitter	5,1 kt		Clean / dry room	1			
Vacuum dryer	95,1 km^2						

Source: RWTH Aachen University / PEM Datenbank für Maschinen & Anlagen in der Batteriezellproduktion

3.

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

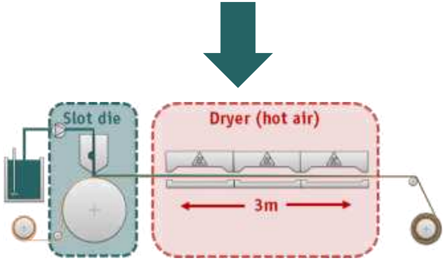
Upscaling of new battery tech

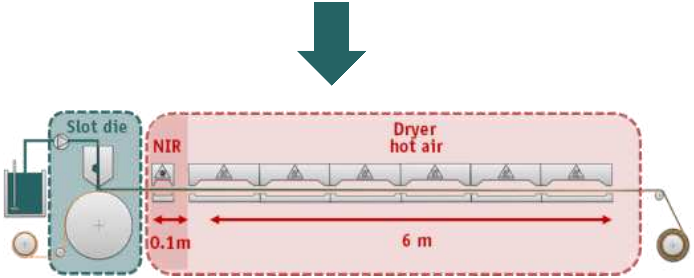
Coatema*2go* (Tabletop)

Smartcoater

Click&Coat® pilot line

Lab-scale R2S





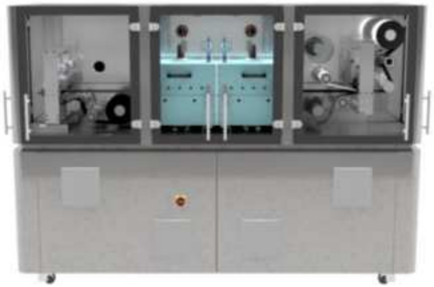
Transfer of parameters and processes in to equipment design

Coatema2go

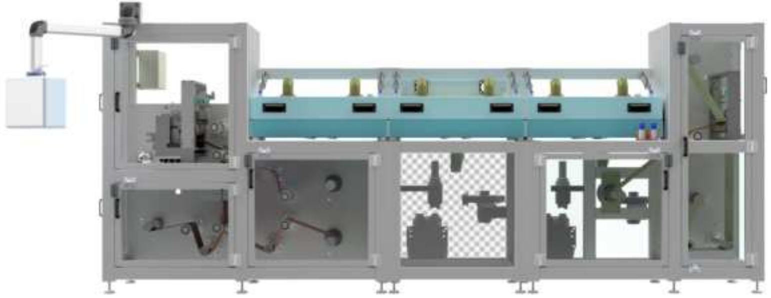
Easycoater

Easycoater Evolution

R2R lab systems



Test Solution R2R



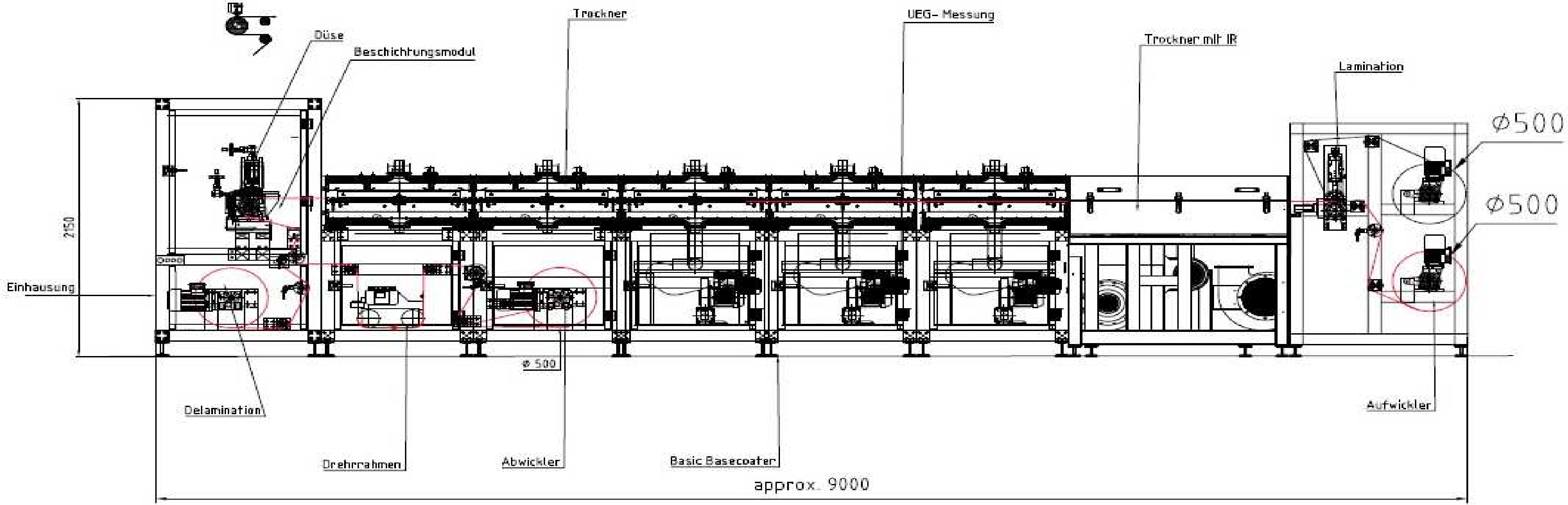
Basecoater R2R

Smartcoater R2R

The Basecoater

The Basecoater

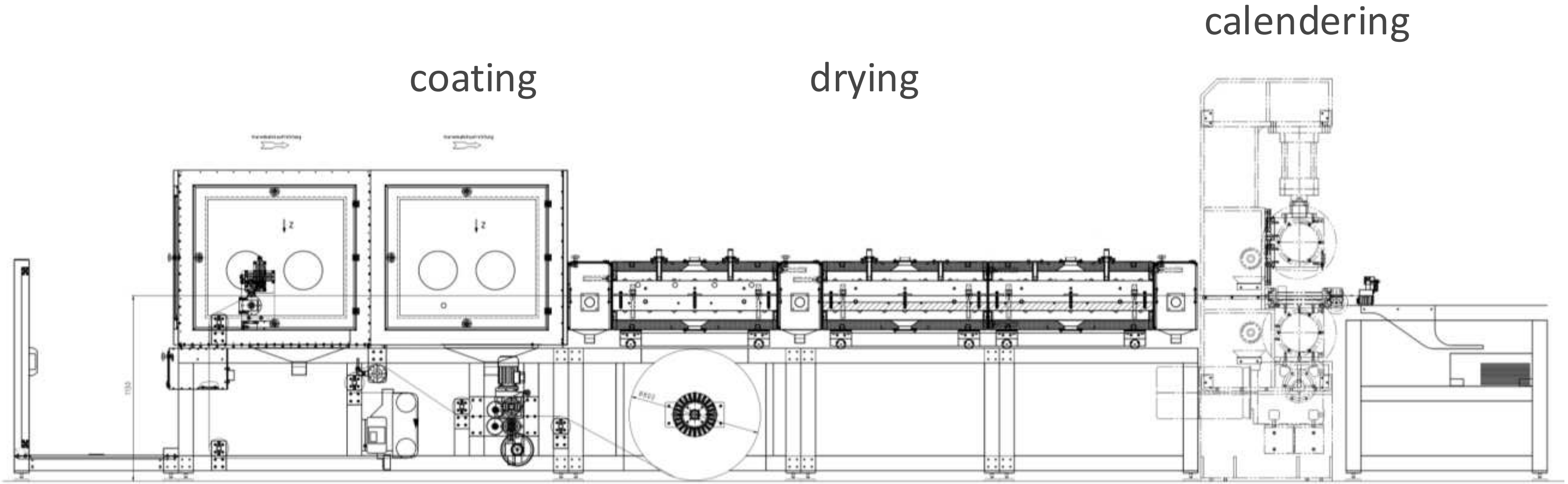
The Basecoater



Bespoke Basecoater battery equipment

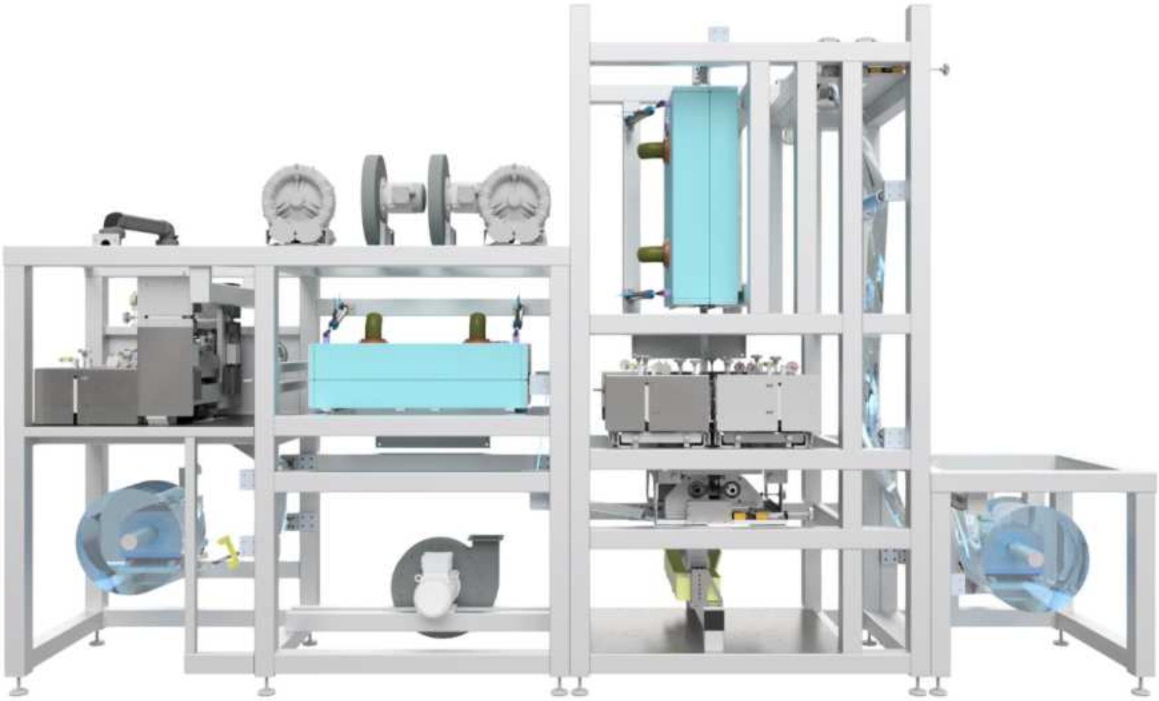
- ✓ Oxygen content < 3%
- ✓ Saturated solvents below LEL
- ✓ IR Drying
- ✓ $50m^3/h$ N_2 flow

Bespoke Basecoater battery equipment

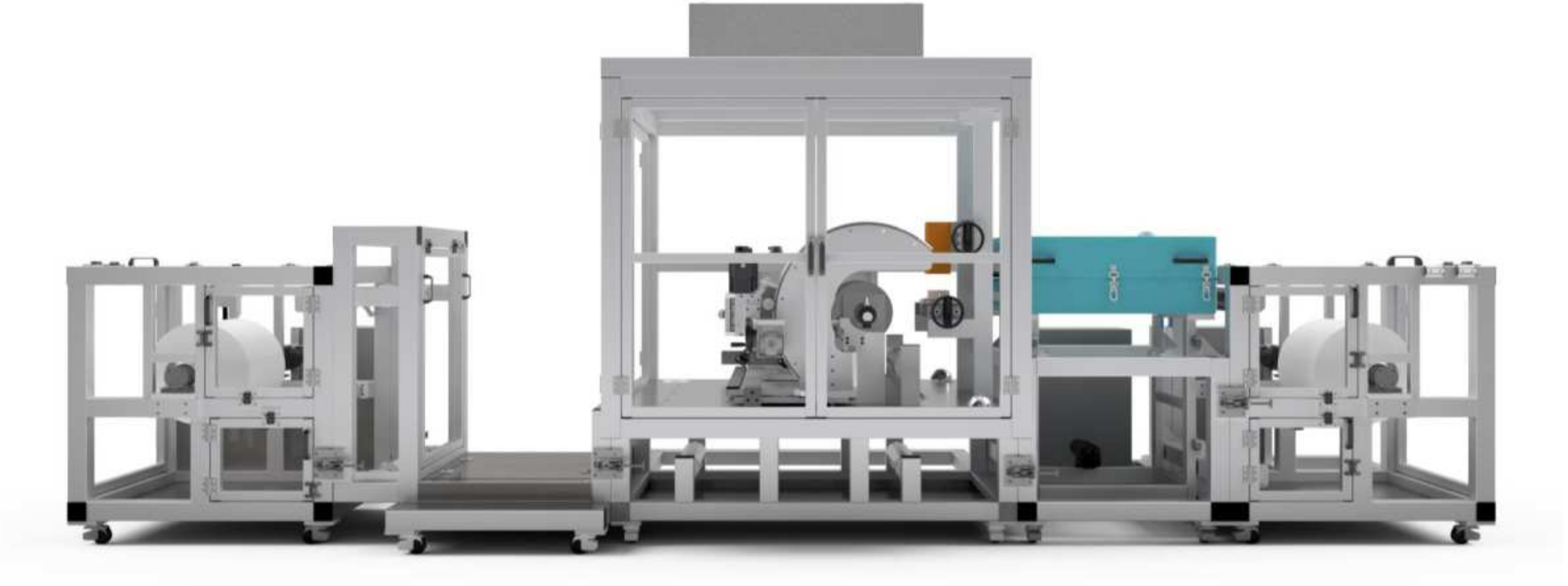


The Basecoa

The Basecoater

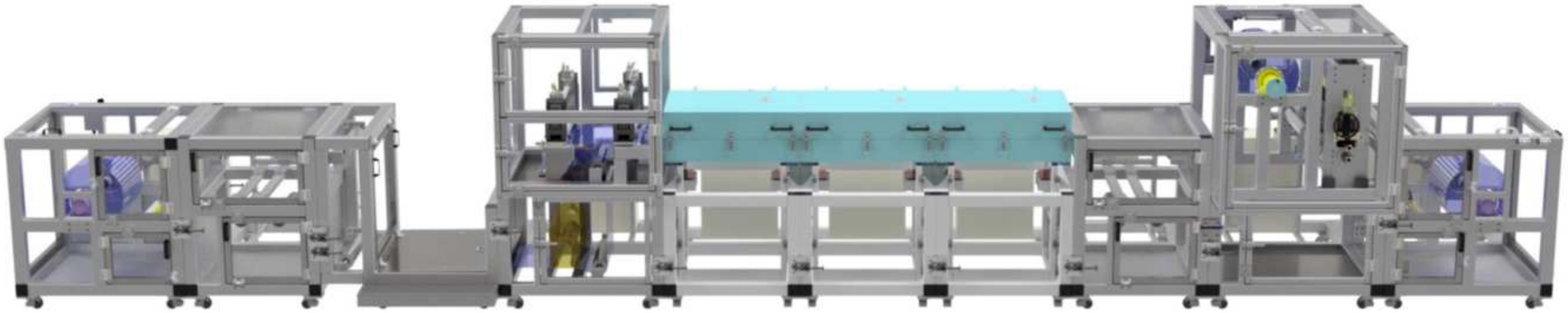


The Click&Coat™



The Click&Coat™

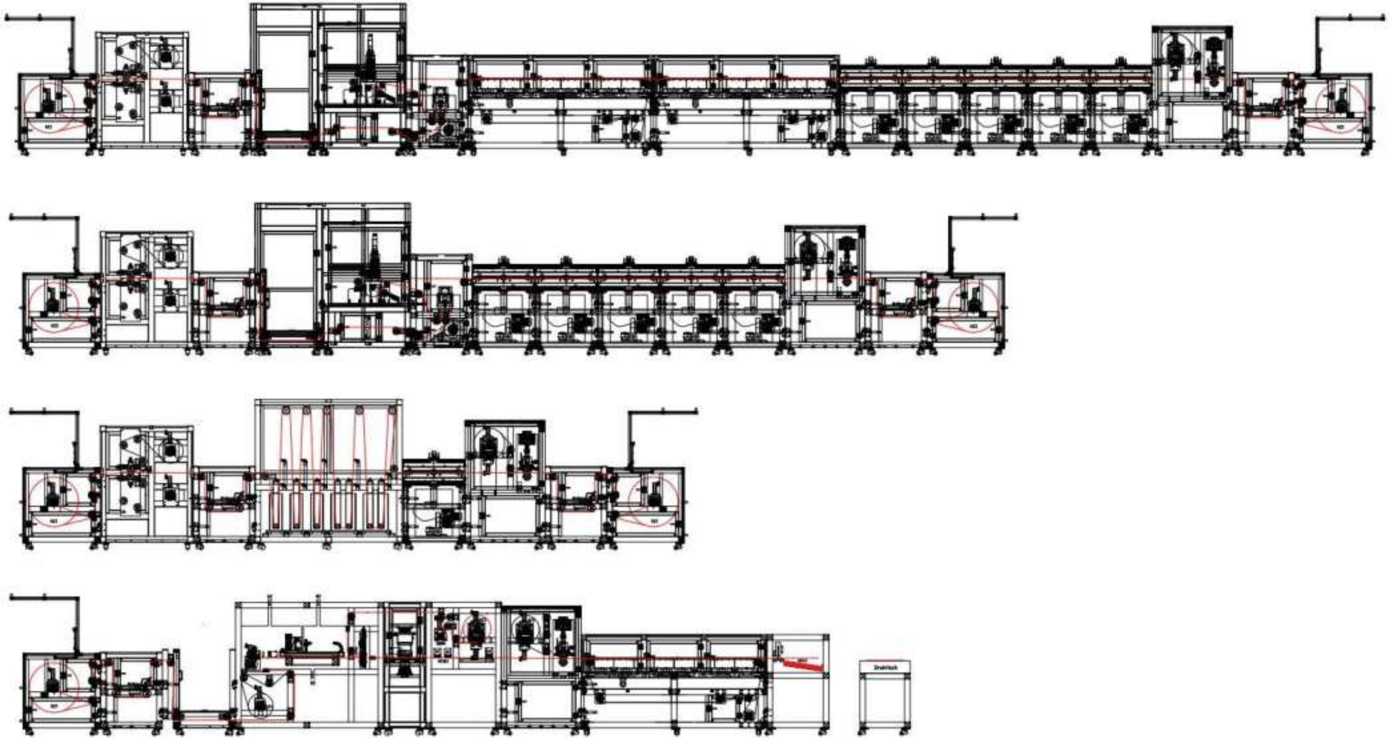
The Click&Coat^{TM}



The Click&Coat™

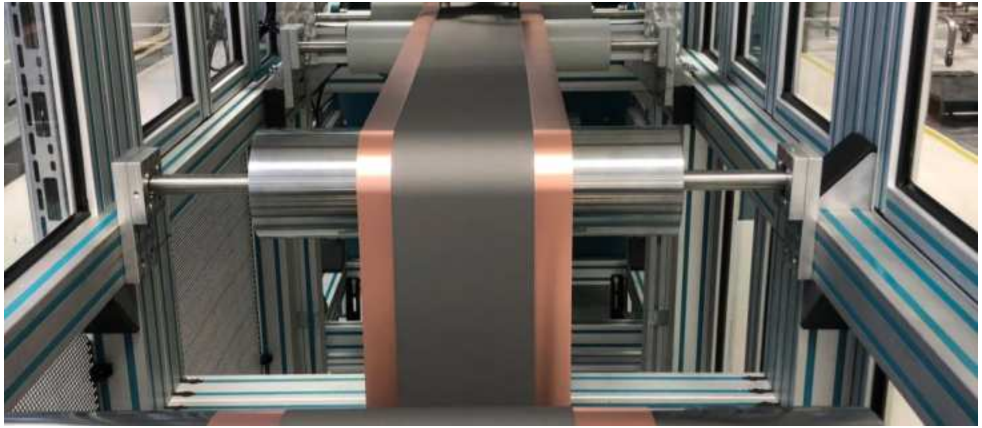
The Click&Coat™

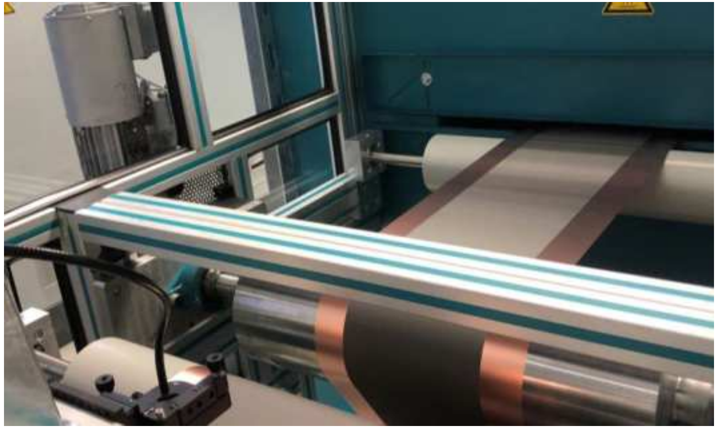
Specific battery equipment in Click&Coat™ layout

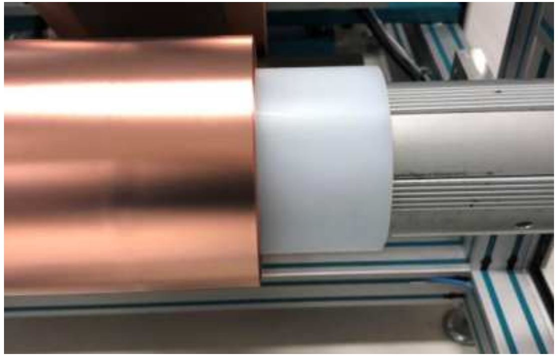


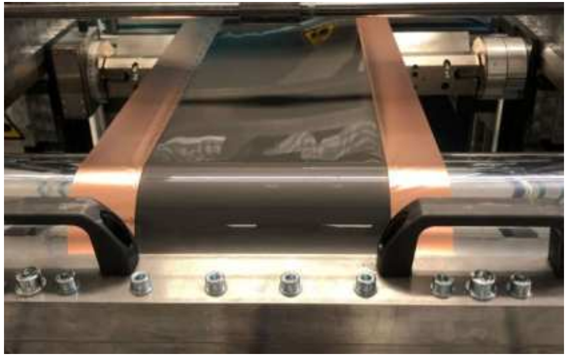
The Click&Coat™ in production scale

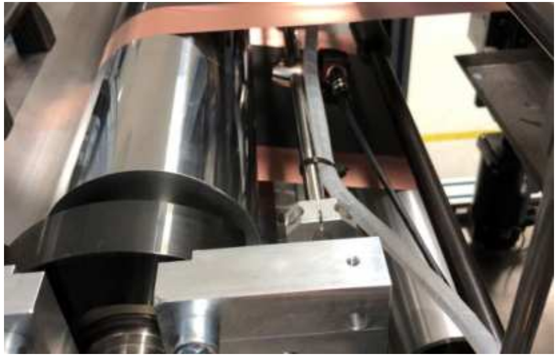
Today‘s equipment for batteries





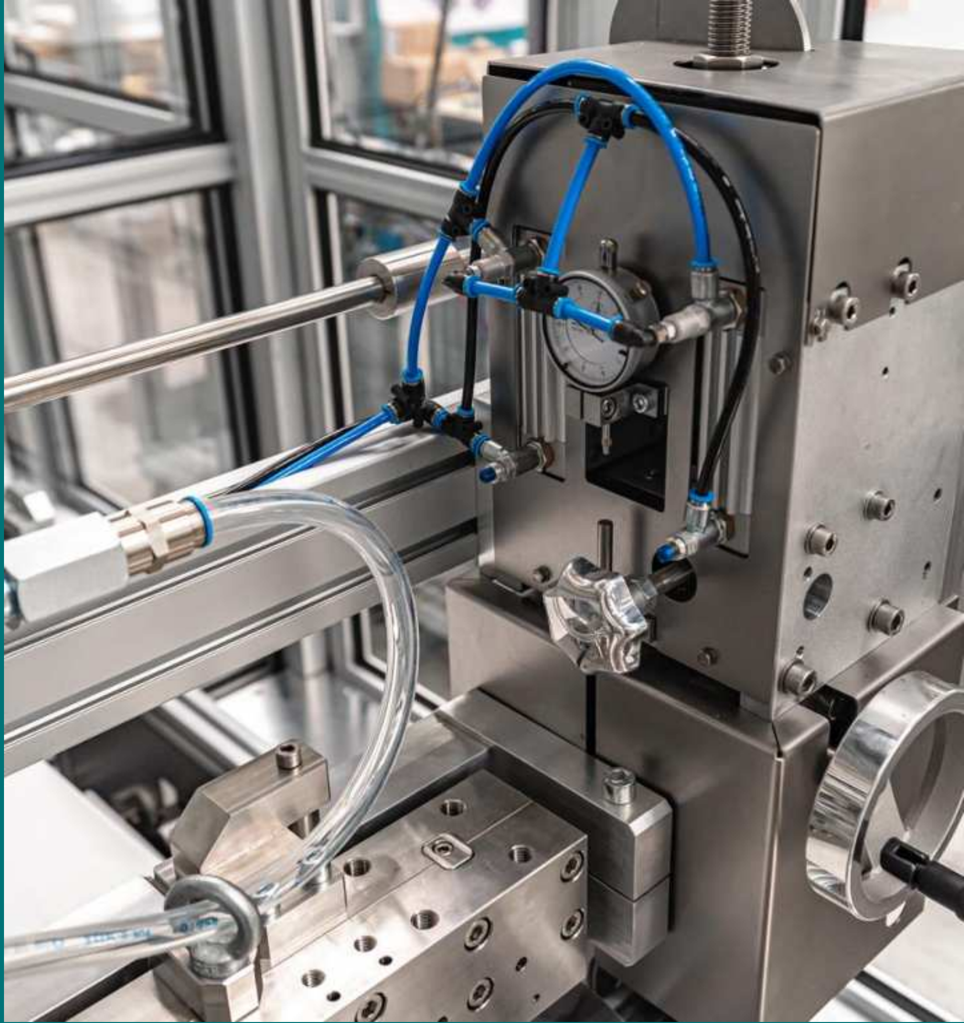




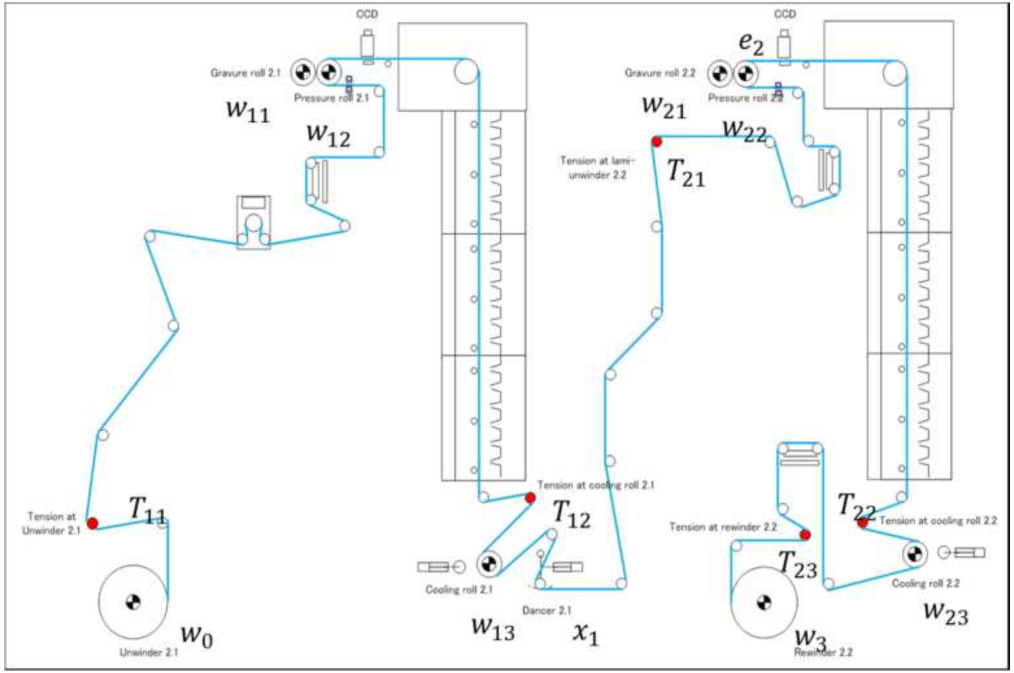


4.

Process control



R2R web process control



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

Integrated & inline processes

Surface treatment	Printing	Coating	Digital fabrication
Nano-imprint	Lamination	Encapsulation	Backend processes

Inline process accuracy integration

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

Edge guide control
- ✓ Different sensors
- ✓ Mechanical stress
- ✓ Data collection

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

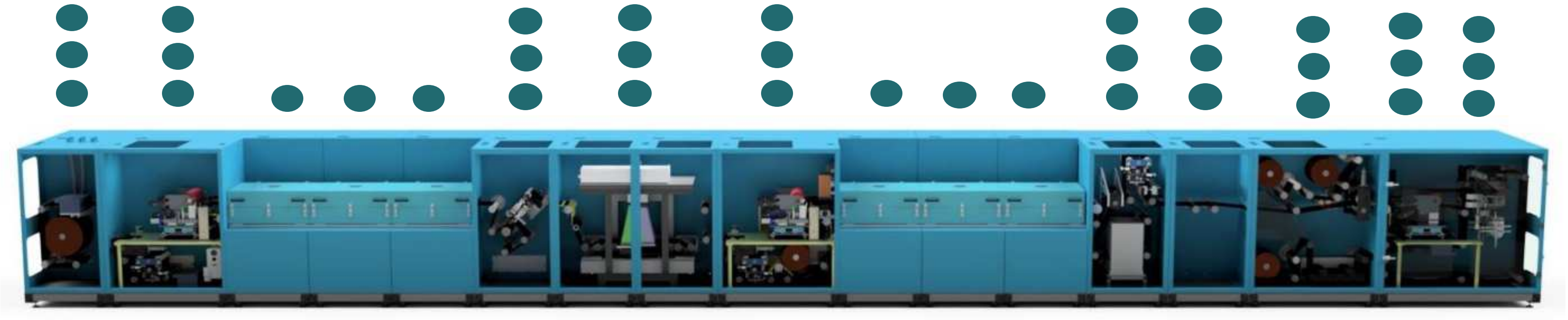
Registration control
- ✓ Camera
- ✓ Fiber optic
- ✓ Design of drives
- ✓ Algorithm control

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

Coatema®
Coating Machinery GmbH

Inline process integration and measuring points

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

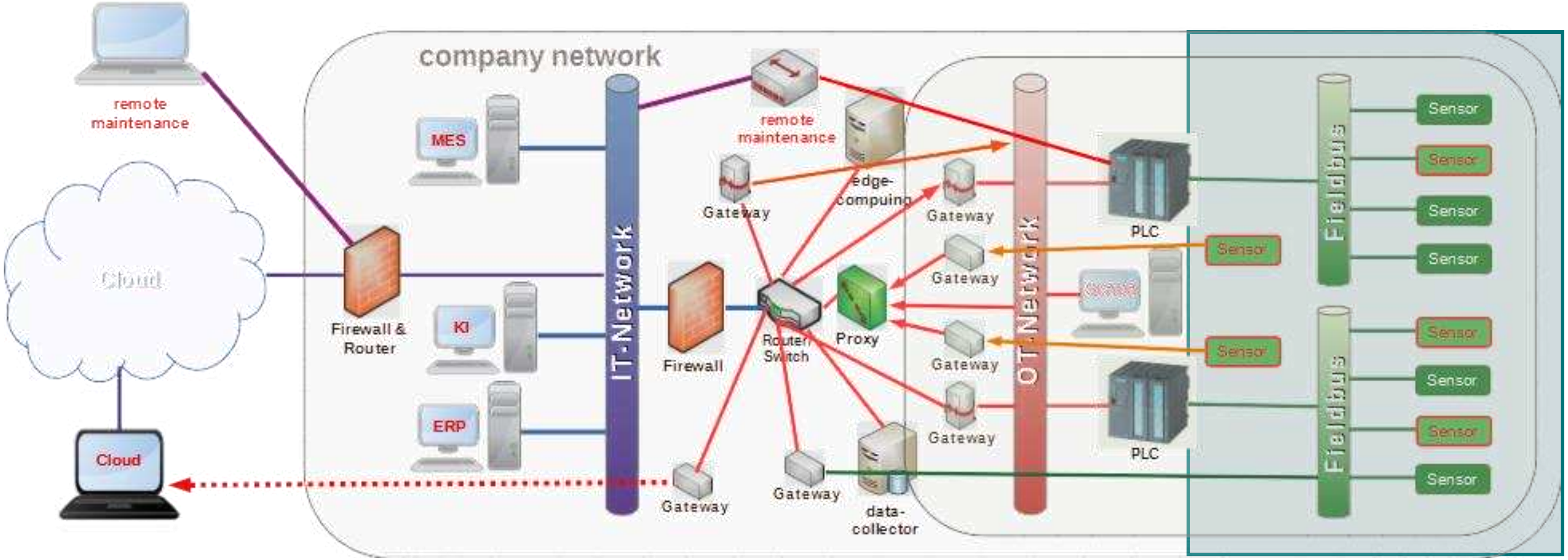


Unwinder | OET 4 Axis system | 3m dryers | ps laser | OET 4 Axis system | Ink jet | 3m dryers | IPL | In-line optical metrology (SE, Raman) | LBIC | Rewinder

- Number of measuring points
- Amount of measurements per time

oet
ORGANIC ELECTRONIC TECHNOLOGIES

Complexity introduced through connectivity

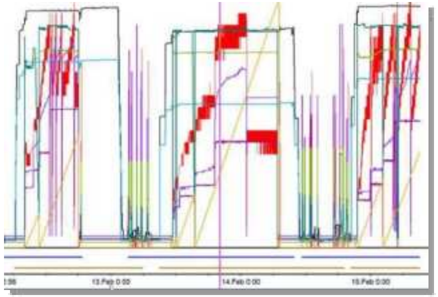


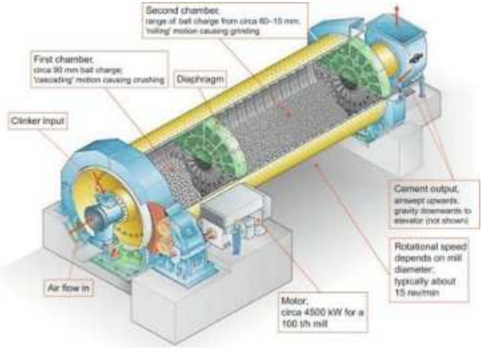
Heterogeneous connectivity landscape:
complex, prone for errors, multiple penetration points, difficult to maintain, ….

From lab 2 fab

Data generation in million of data points

Solution based approach





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

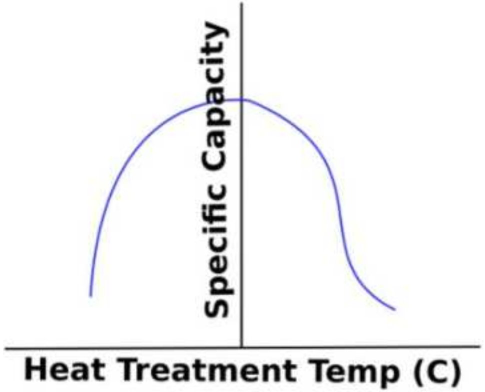
Detection
Analysis of specific system states (e.g. characteristic freequencies)

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

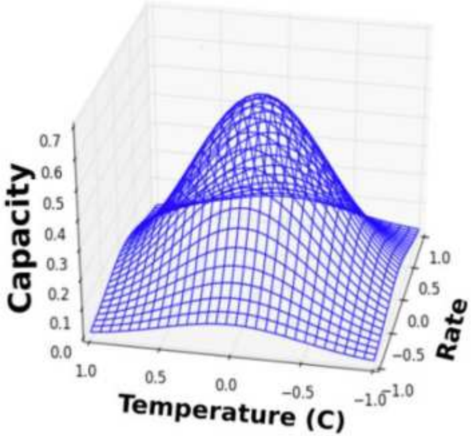
Prediction
Spare parts and maintenance (next service, service tasks, …)

Control
Maintaining productivity (e.g. increasing viscosity)

Understanding the data



A



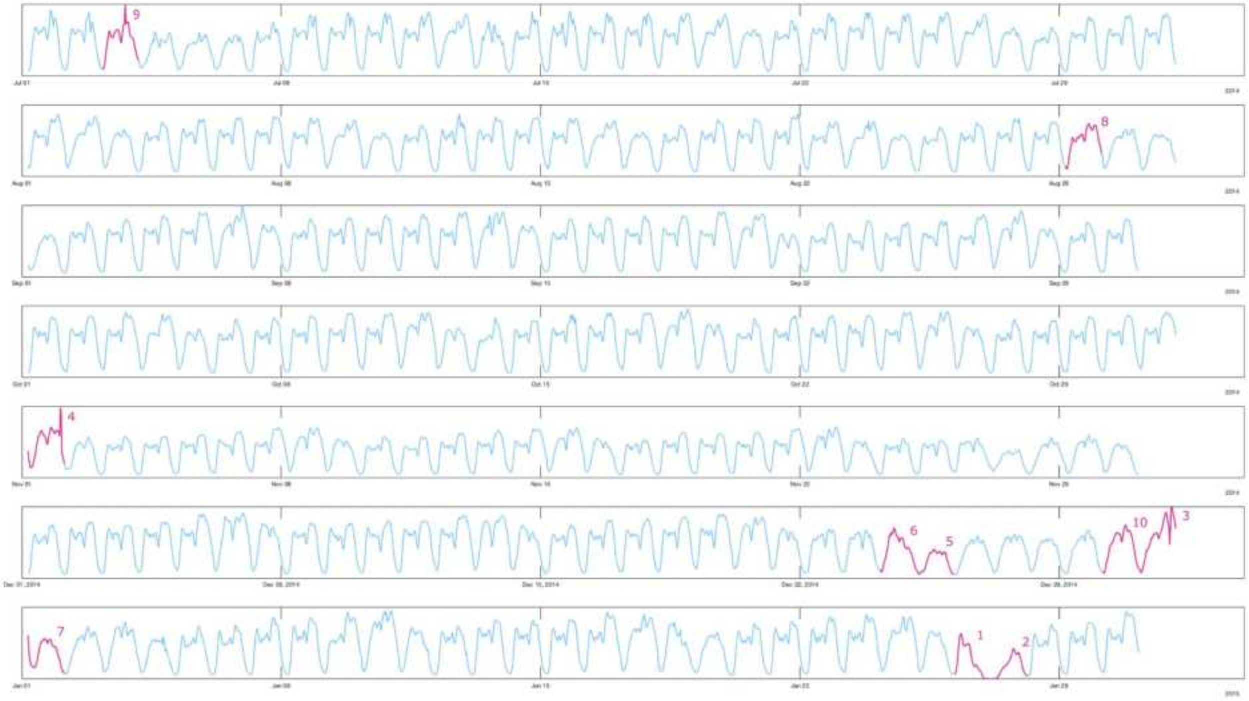
B

Target of all the efforts:

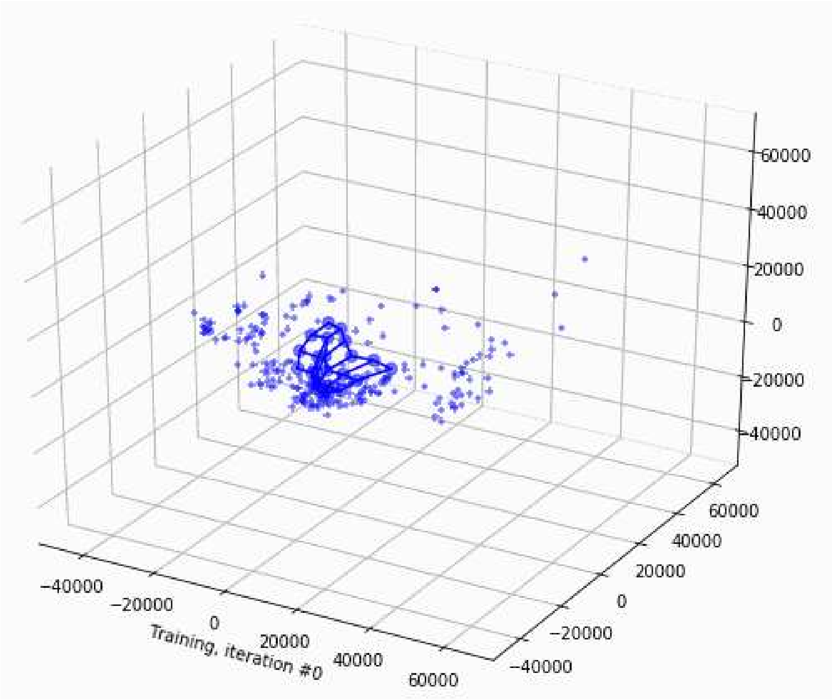
Finding the parameters which will lead to failure

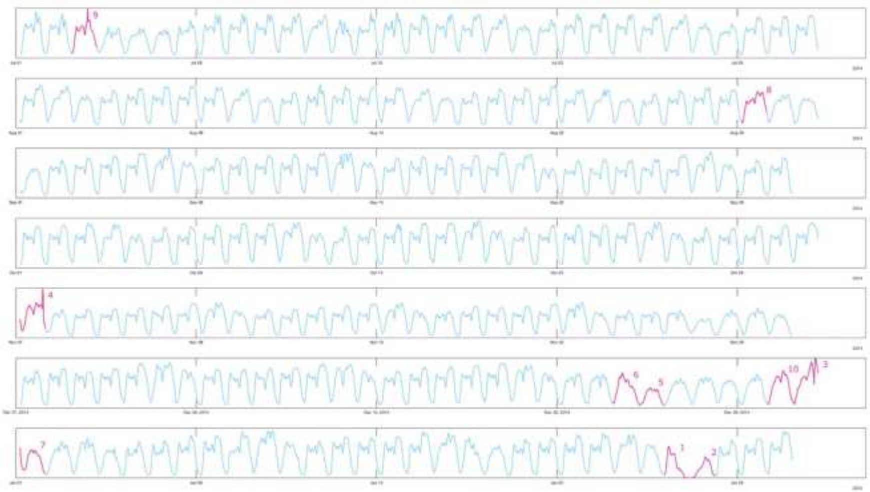
Reducing the number of parameters to be controlled

Automatic anomaly detection for time series



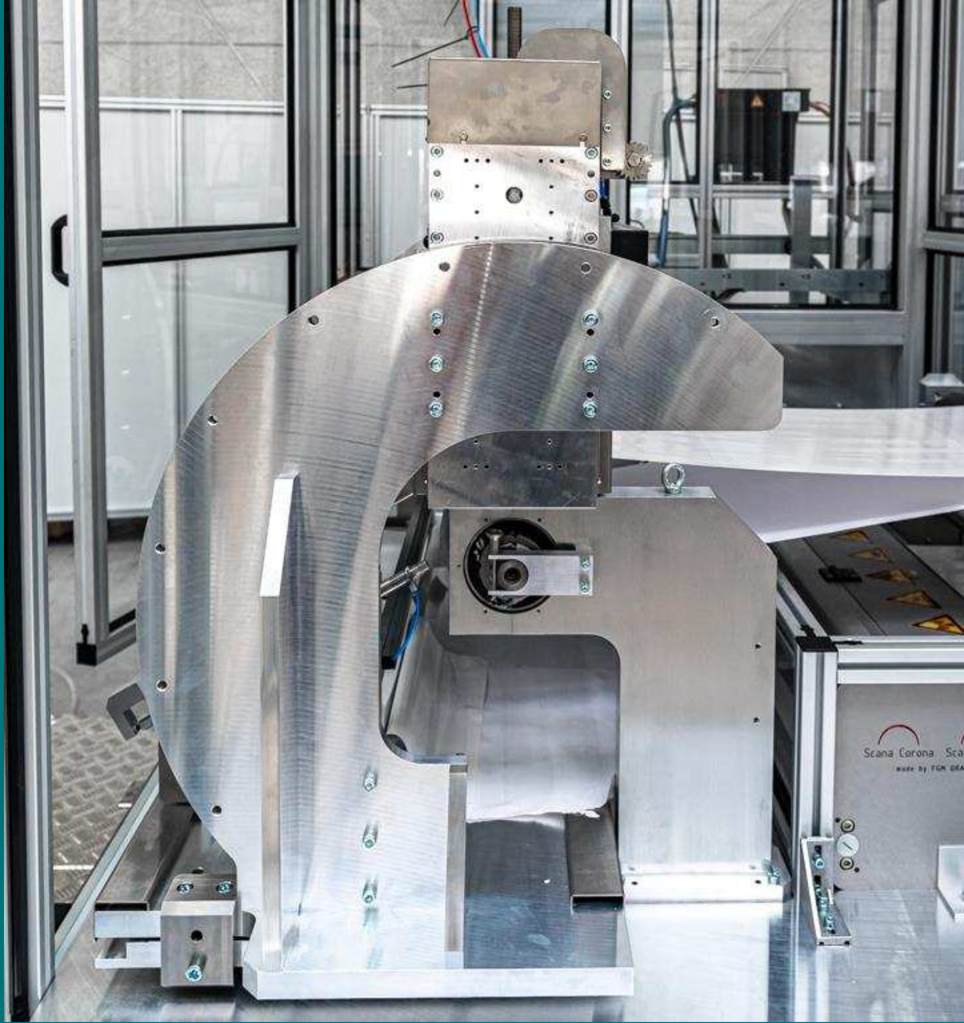
… what the algorithm is doing





5.

Coating systems



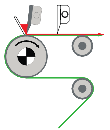
Coating parameters

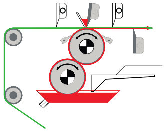
Coating chemistry	Coating processes	Process control	Drying
✓ Rheology ✓ Viscosity ✓ Viscoelasticity ✓ Type of solvents ✓ Solid content ✓ Van der Waals force ✓ Sheer ratio ✓ Adhesion/Cohesion	✓ Coating systems ✓ Single or multilayer coatings ✓ Direct coatings ✓ Transfer (indirect) coatings ✓ Substrate 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

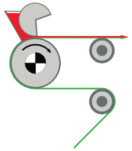
Processes – definition of coating systems

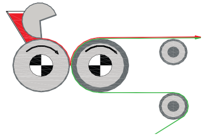
Category of coating methods	Examples of coating methods belonging to the category	Characteristics
Self-metered	✓ Dip roll ✓ Nip forward roll ✓ Reverse roll	✓ Wet thickness is determined by the conditions of the coating meniscus
Doctored	✓ Mayer rod ✓ Blade / Knife ✓ Air knife ✓ Dip & scrape	✓ Post applicator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

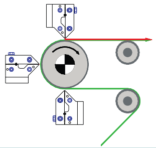
Coating systems

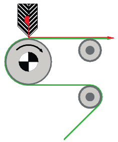

Knife system

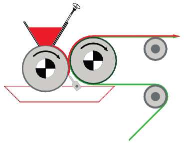

Double side coating system

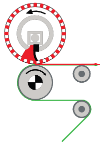

Commabar system

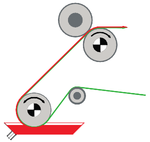

Reverse commabar system

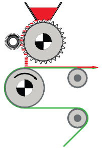

Slot die system

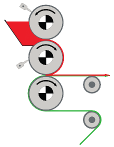

Curtain coating system

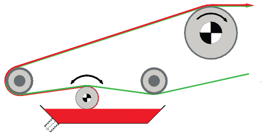

Case knife system

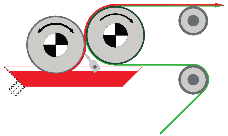

Rotary screen system

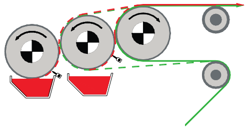

Dipping system (Foulard)

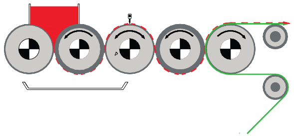

Powder scattering system


Reverse roll coating system

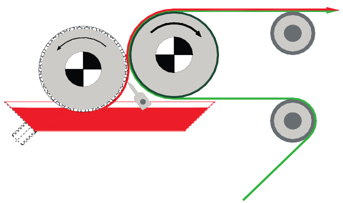

Micro roller coating system


2-roller coating system

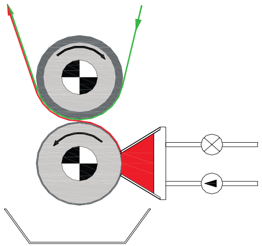

3-roller combi coating system


5-roller coating system

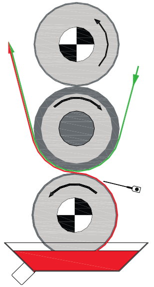
Printing systems



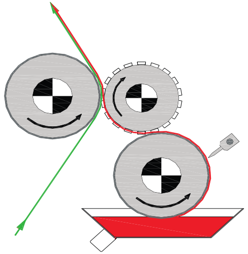
Engraved roller system



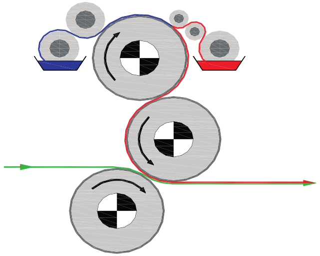
Gravure roller system



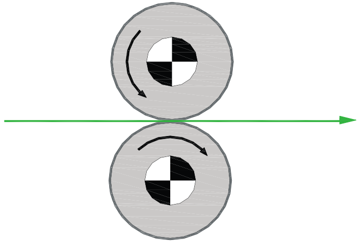
Gravure indirect system



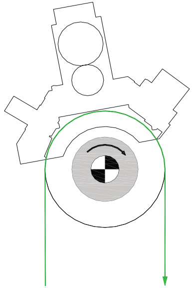
Flexography system



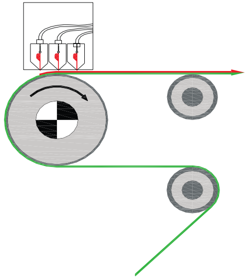
Offset lithography system



Hot embossing system

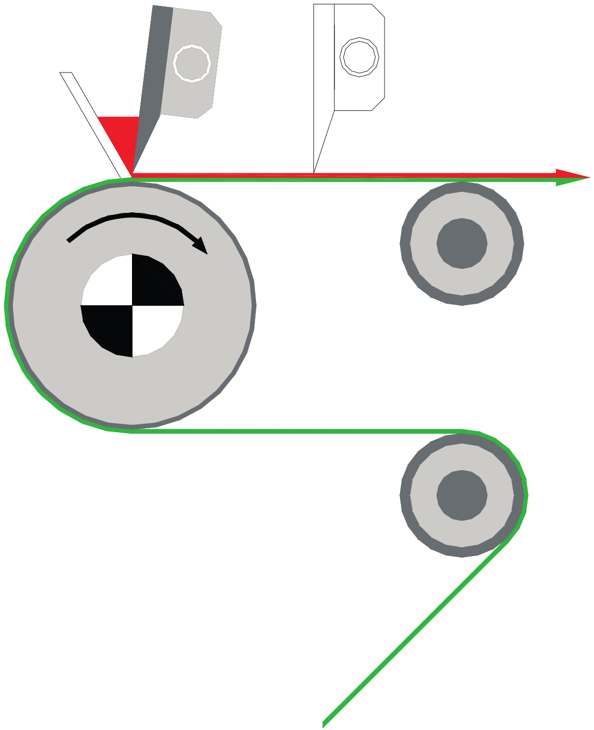


Nanoimprint system



Inkjet system

Knife coating



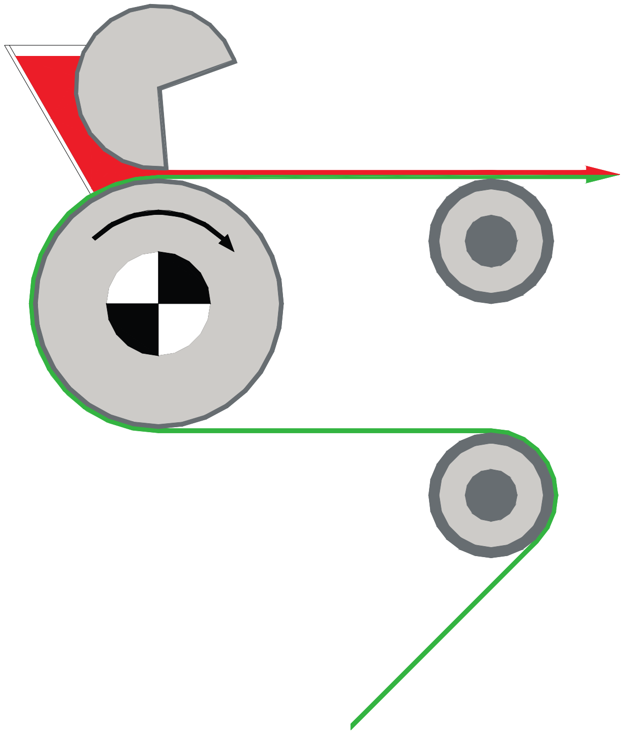
Variation of the coating weight

- ✓ 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



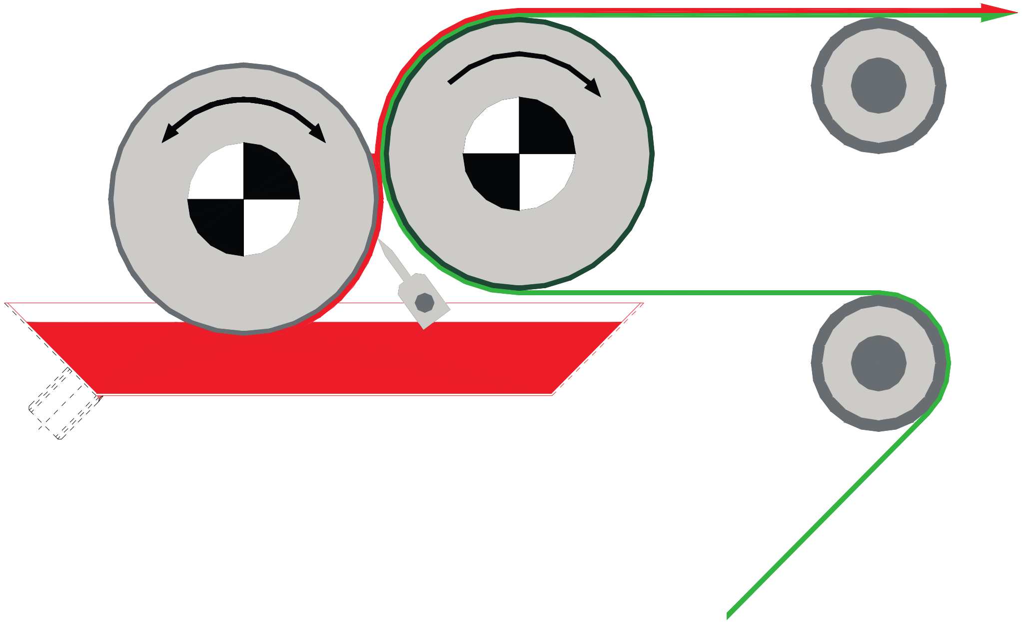
Variation of the coating weight

- ✓ Air knife
  5 – 6 to 1.250 g/m^2

Range of viscosity

- ✓ Paste
  5 – 6 to 60 g/m^2
- ✓ Foam
  10 000 – 25 000 mPas

Gravur coating



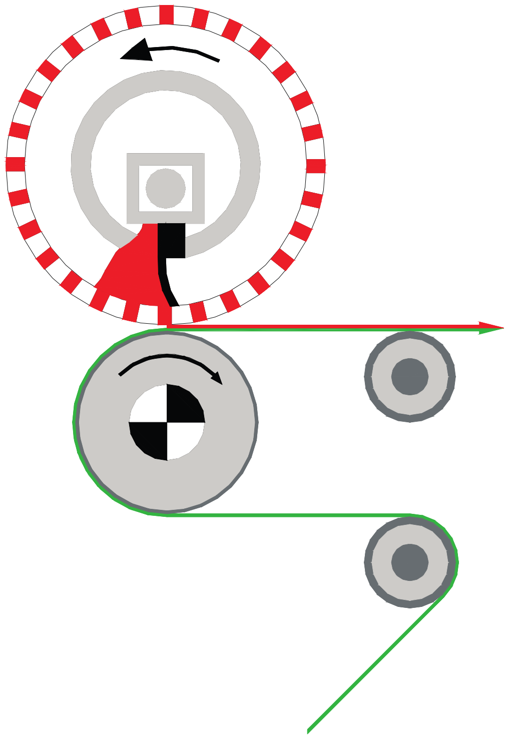
Variation of the coating weight

✓ 2 – 200 g/m^2

Range of viscosity

✓ 1 – 15 000 mPas

Rotary screen coating



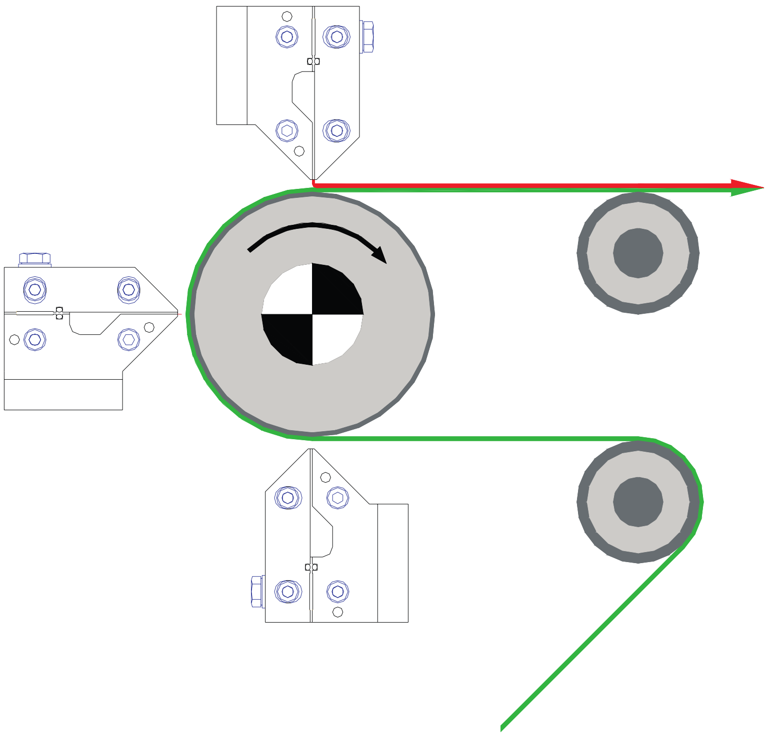
Variation of the coating weight

- ✓ 10 – 300 g/m2

Range of viscosity

- ✓ Paste
  10 000 – 80 000 mPas
- ✓ Paste
  10 000 – 25 000 mPas

Slot die coating



Variation of the coating weight

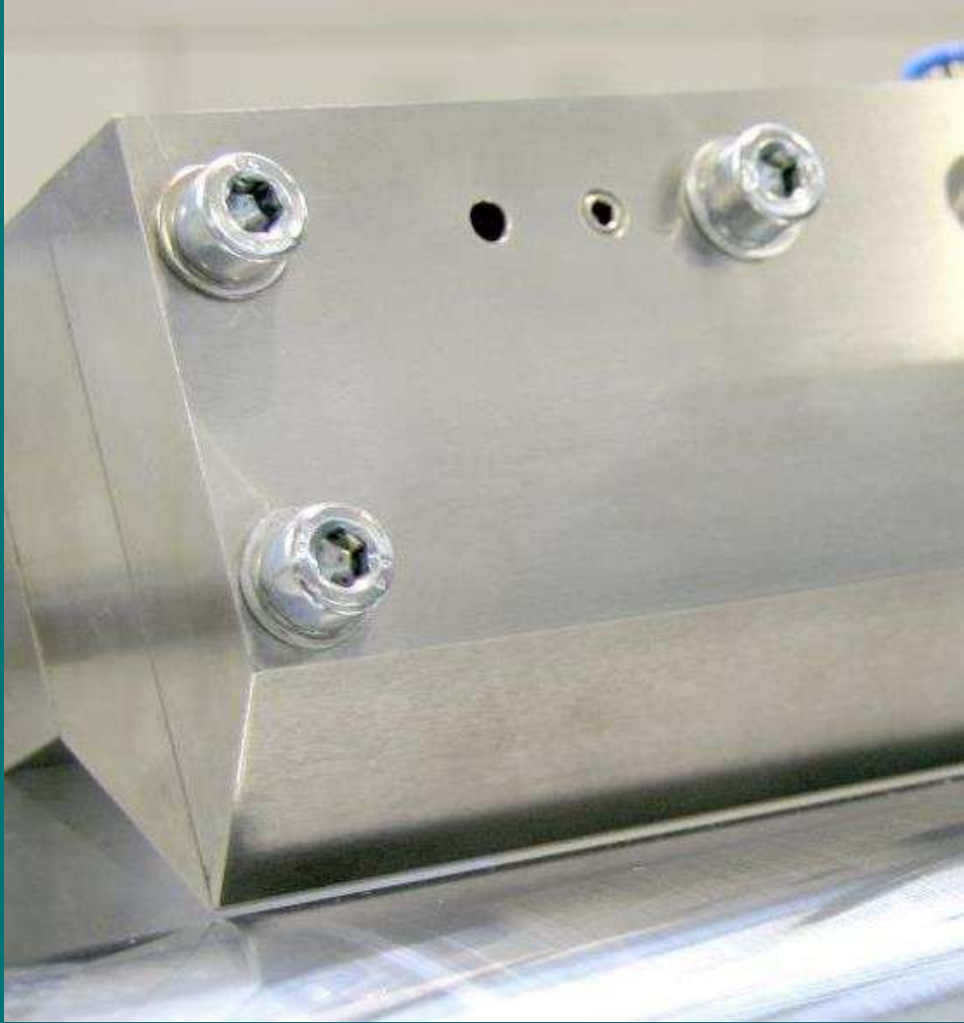
✓ 1 – 200 g/m²

Range of viscosity

✓ 1 – 30 000 mPas

6.

Slot die coating for batteries

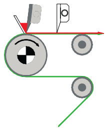


Coating parameters

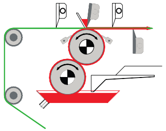
Ink properties	Coating processes	Process control	Drying
✓ Rheology ✓ Viscosity ✓ Viscoelasticity ✓ Type of solvents ✓ Solid content ✓ Van der Waals force ✓ Sheer ratio ✓ Adhesion/Cohesion	✓ $\boxed{\text{Coating systems}}$ ✓ Single or multilayer coatings ✓ Direct coatings ✓ Transfer (indirect) coatings ✓ 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

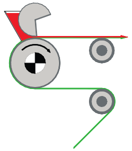
Coating systems



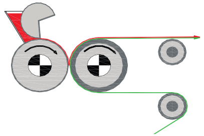
Knife system



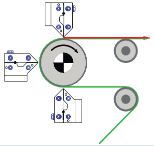
Double side coating system



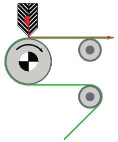
Commabar system



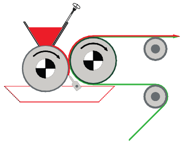
Reverse commabar system



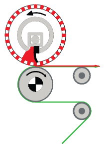
Slot die system



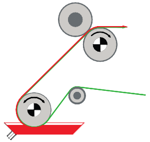
Curtain coating system



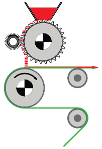
Case knife system



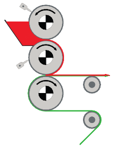
Rotary screen system



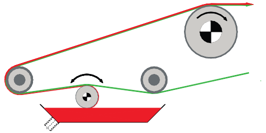
Dipping system (Foulard)



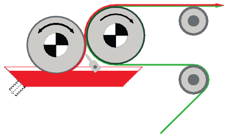
Powder scattering system



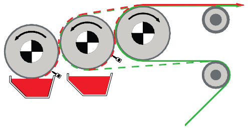
Reverse roll coating system



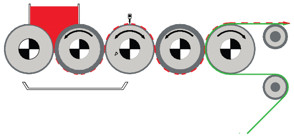
Micro roller coating system



2-roller coating system

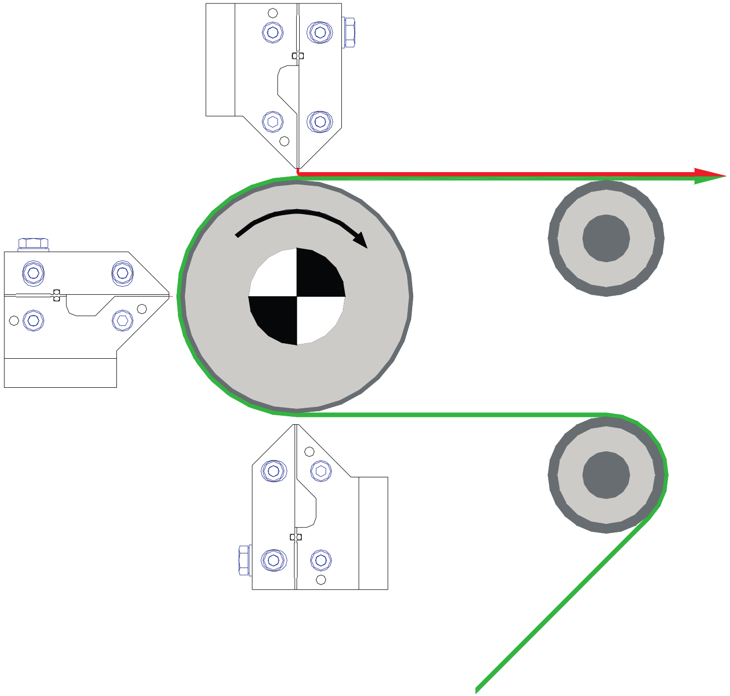


3-roller combi coating system



5-roller coating system

Basics of slot die coating – range of parameters



Coating speed
- ✓ 0.1 – >1000 m/min

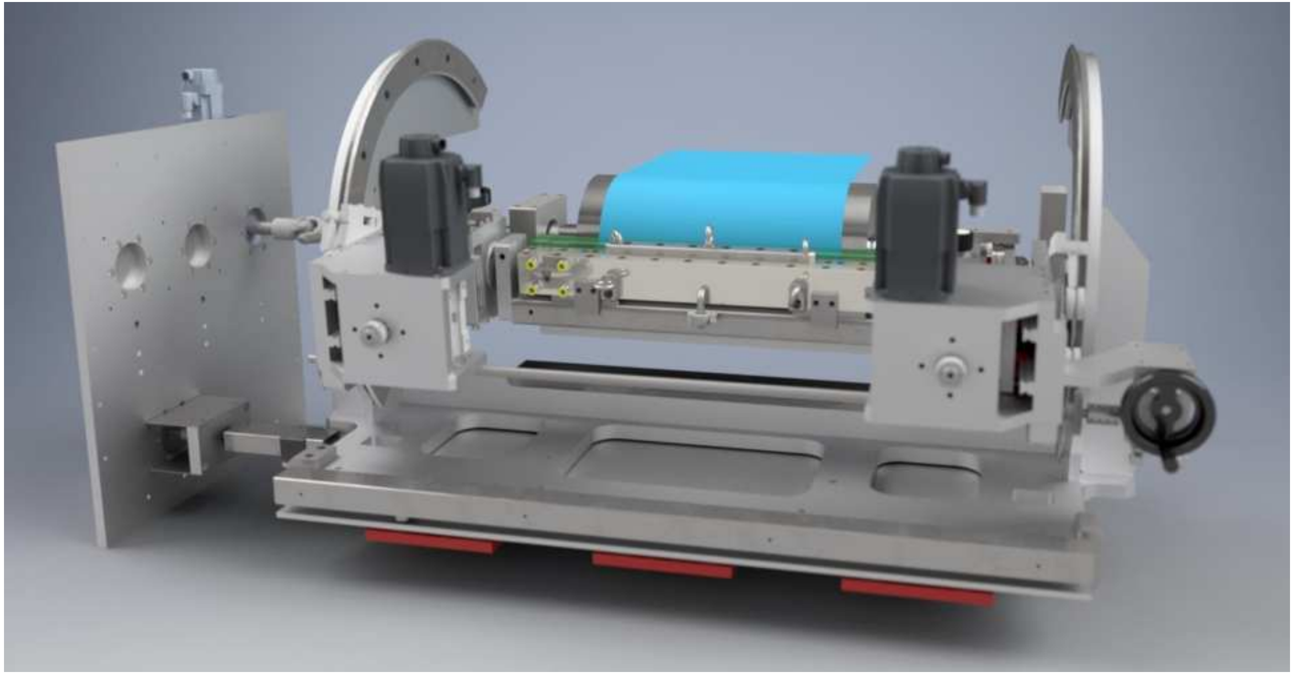
Ink viscosity
- ✓ 1 – 300 000 mPas

Layer thickness (dry)
- ✓ 0.1 – >200 µm

Coating accuracy
- ✓ <1% (2 – 5%)

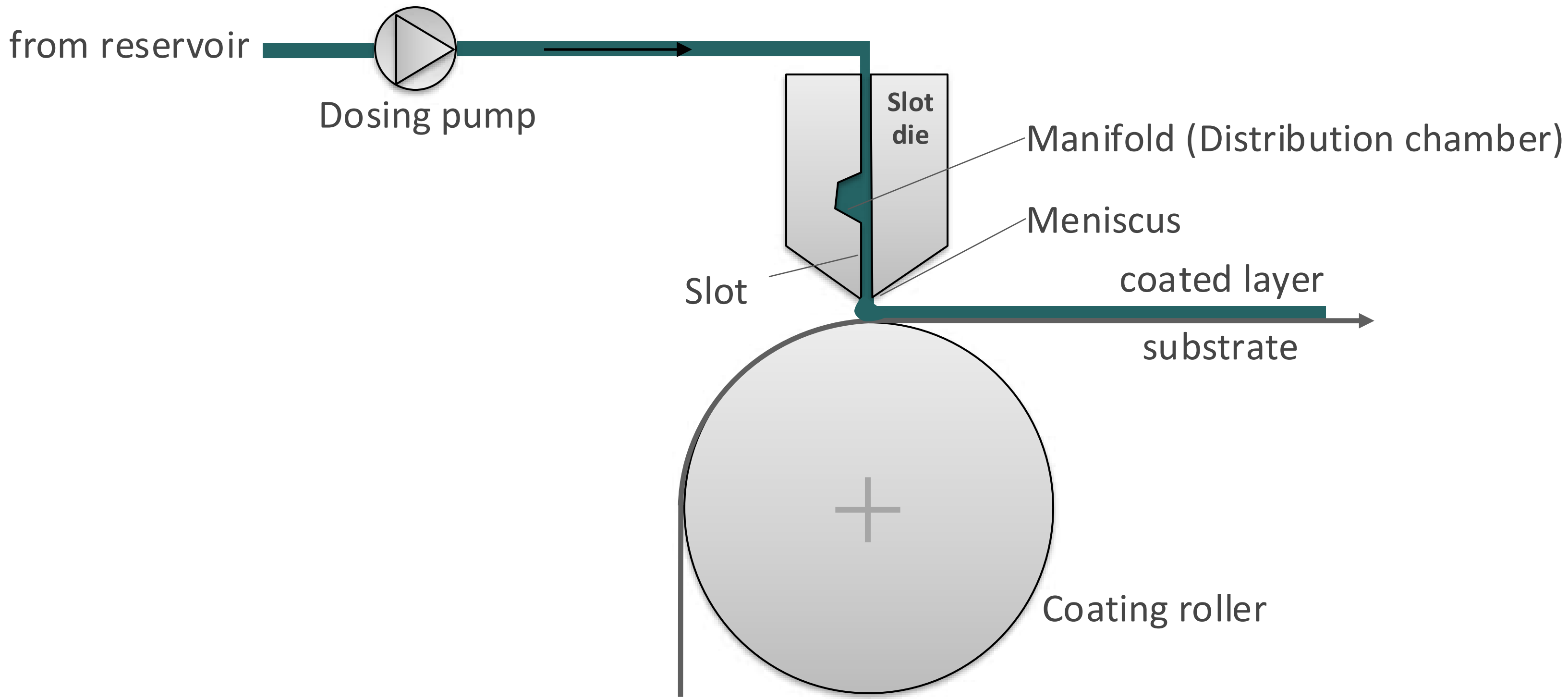
Coating width
- ✓ up to approx. 3 m

Basic principle

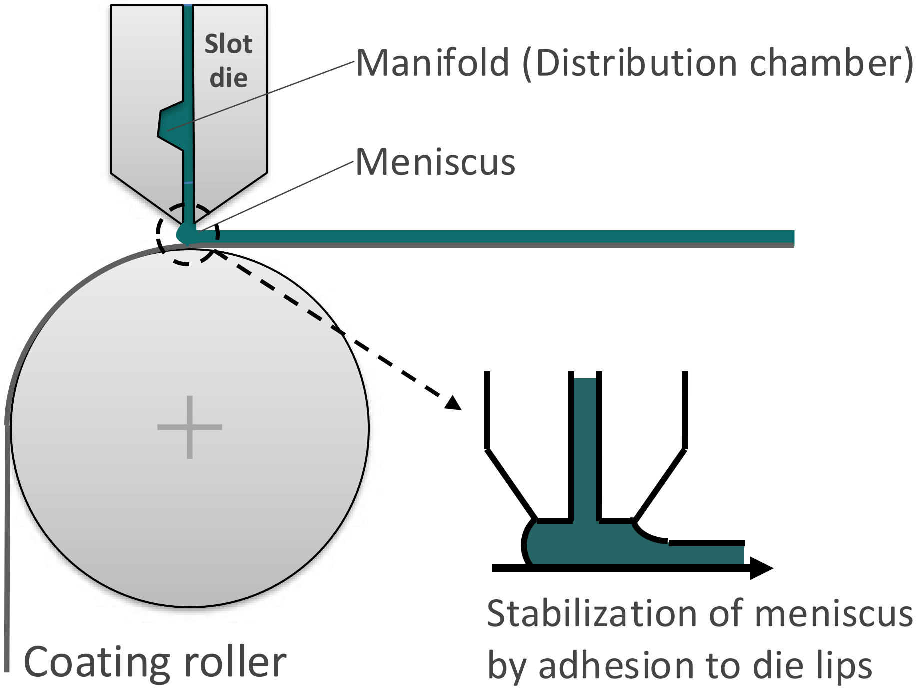


Basic principle

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
- ✓ Preferrably for low coating speed

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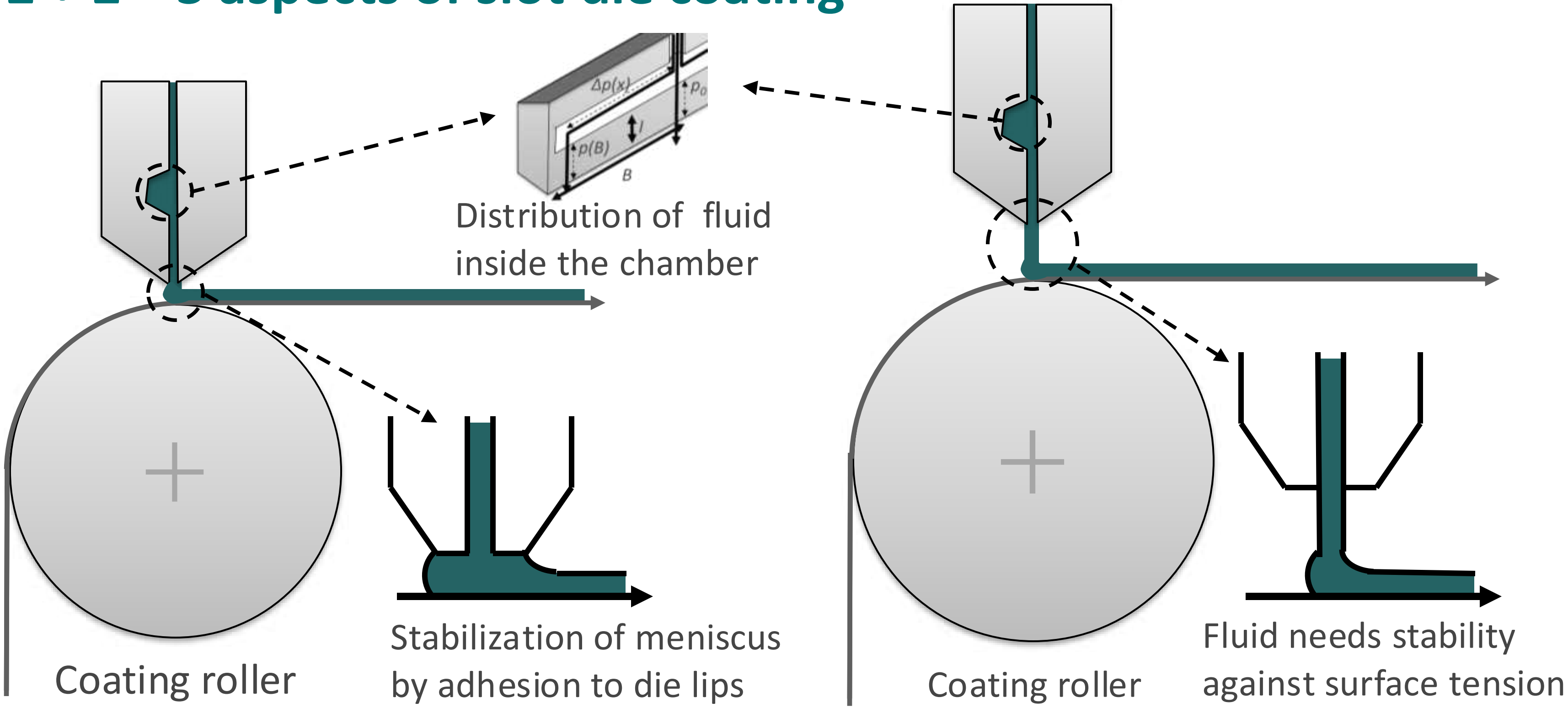
2 + 2 = 3 aspects of slot die coating



Theoretical background – „Basic“ fluid dynamics for advances geometries

Slot die coating for batteries

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

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.

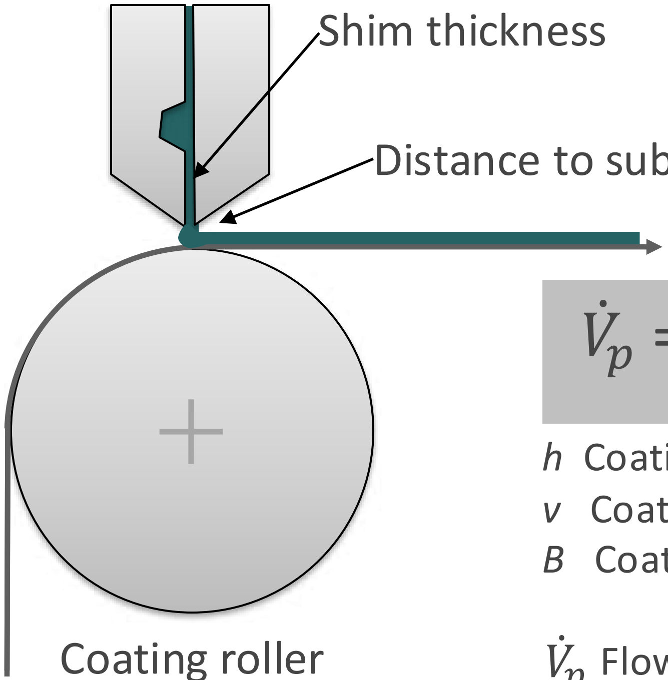
Can be done by appropriate computer programs.

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

Navier-Stokes-equations (equations of motion for incompressible fluids, ρ = const)

Δ, ∇= differential operators

Theoretical background



Slot die coating for batteries

$$\dot{V}_p = B \cdot v \cdot h$$

h Coating thickness wet
v Coating speed
B Coating width

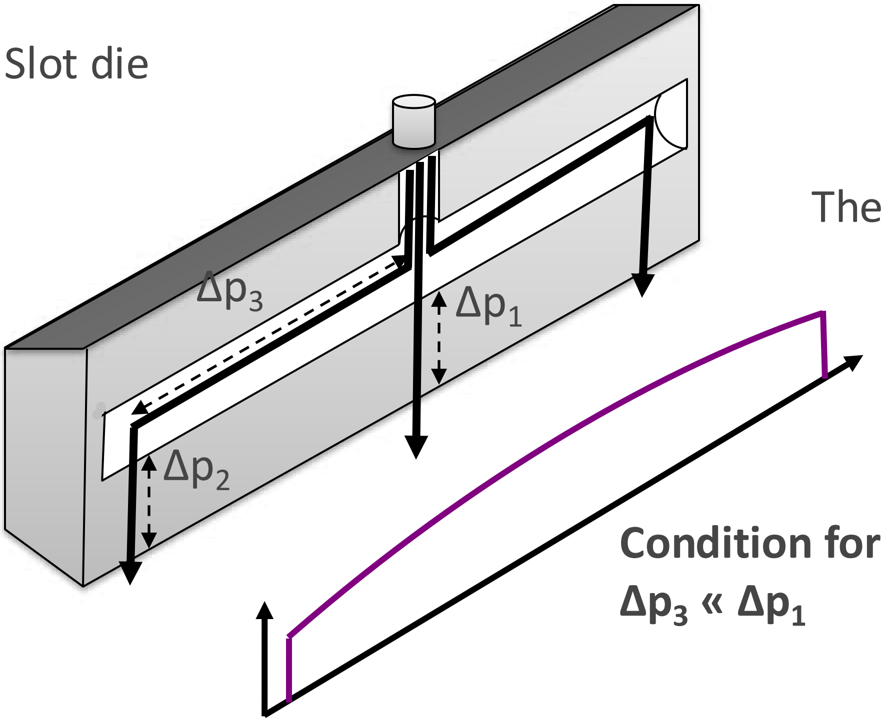
$\dot{V}_p$ Flow rate of the pump

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?

Slot die

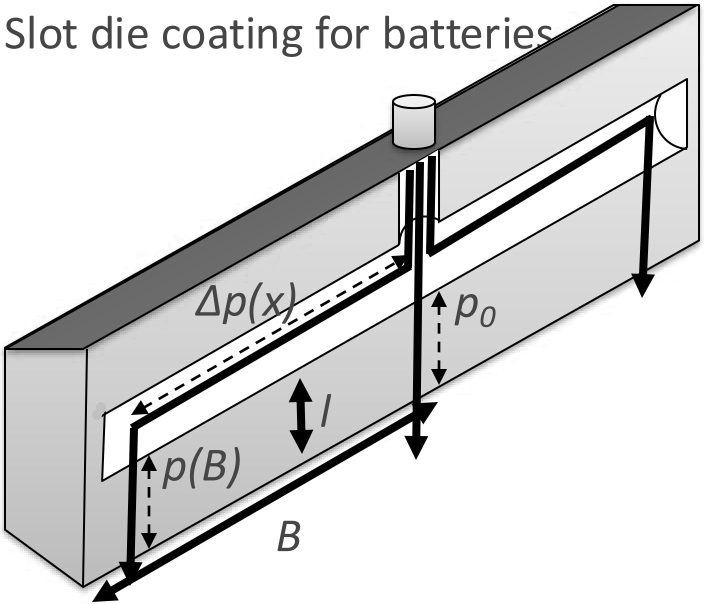


Theoretical thickness profile

Condition for good profile
$\Delta p_3 \ll \Delta p_1$

Fluids in the manifold: 1.5D approximation

Slot die coating for batteries



Pressure drop Δp(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:

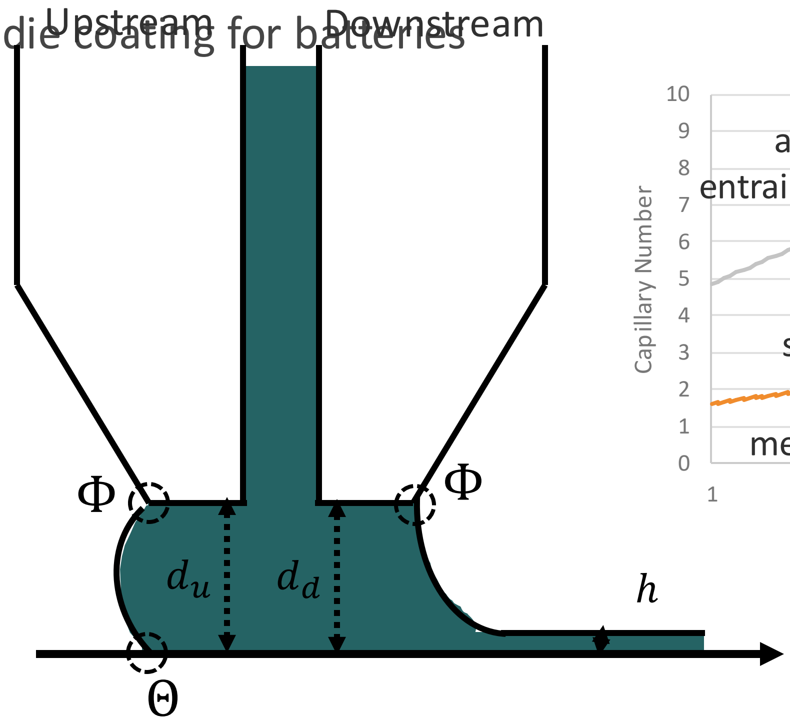
$$h(x) = \frac{B \cdot h_0}{\lambda} \cdot \frac{\cosh \frac{W-x}{\lambda}}{\sinh \frac{W}{\lambda}}$$

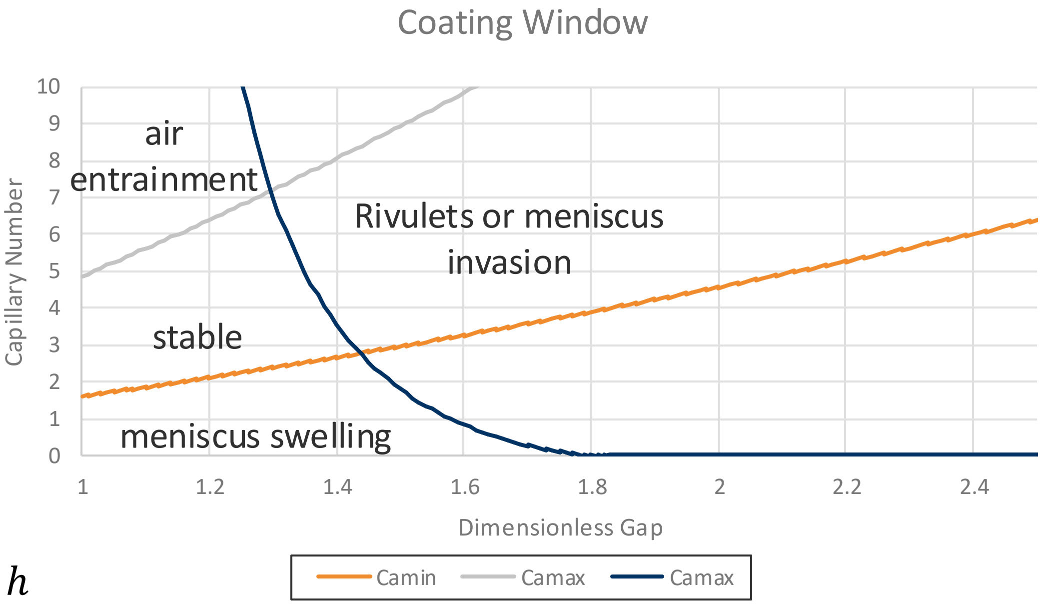
$$\lambda = \sqrt{\frac{3\pi \cdot l \cdot r^4}{2\delta^3}}$$

„slot die geometry parameter“

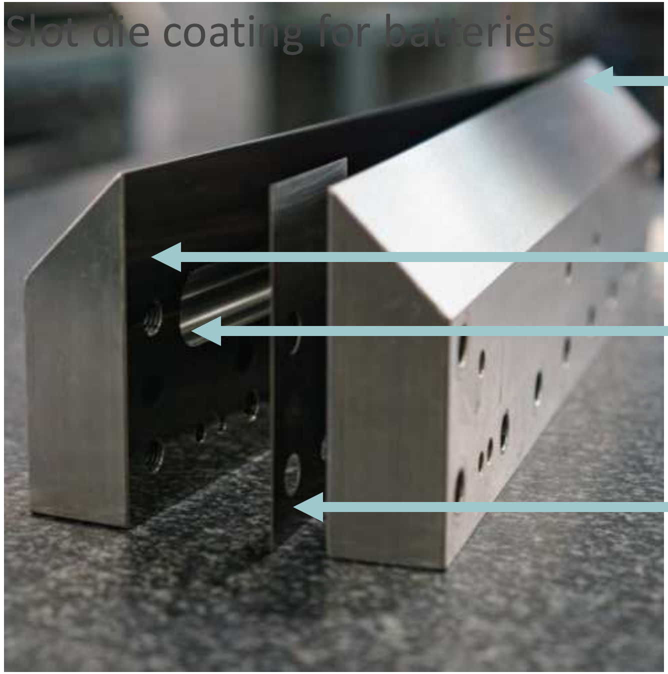
Calculation of the meniscus stability

Slot die coating for batteries





Coatema standard layout – one design among many available



Lips

Slot area

Manifold

Shim

Improving the coating profile

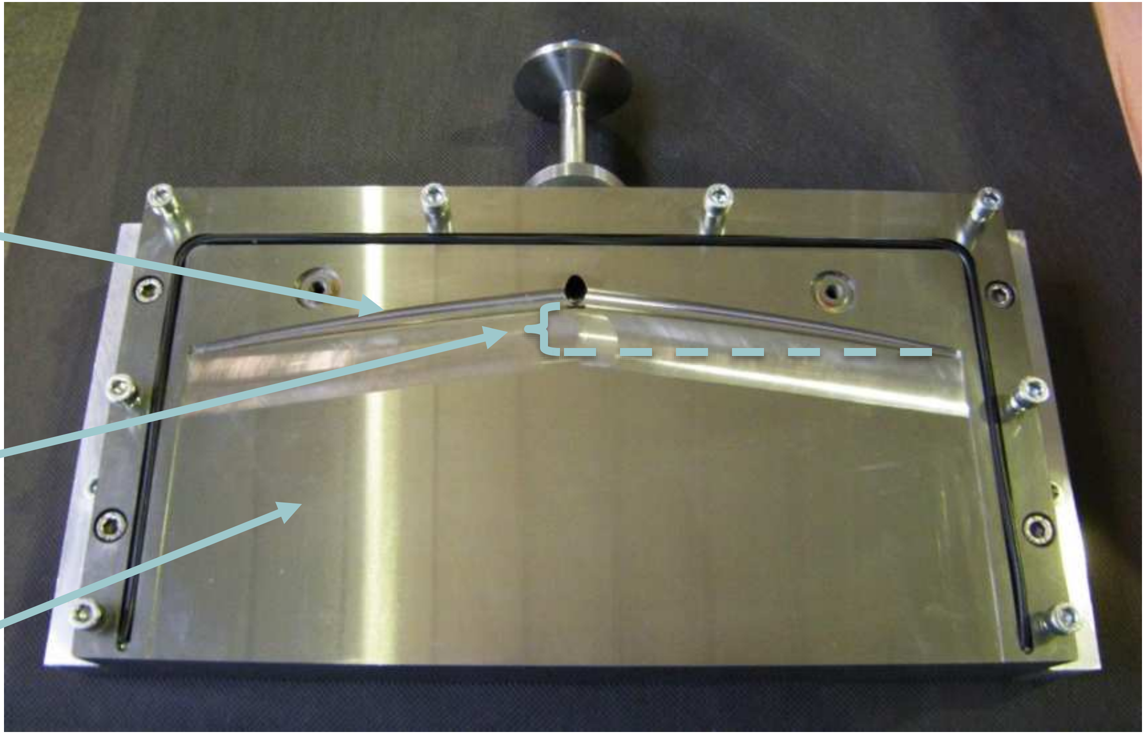
- ✓ Large manifold, long slot area, highly parallel lips (standard)
- ✓ Coat hanger design
  - ✓ Profile is compensated by a tilted manifold
  - ✓ Conical manifold cross section to keep flow speed constant (optional to prevent precipitation)
  - ✓ Works perfect for adequate rheology only
- ✓ Slot width adjustment
  - ✓ Slot width is locally narrowed or widened to adjust the local flow resistence
  - ✓ 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



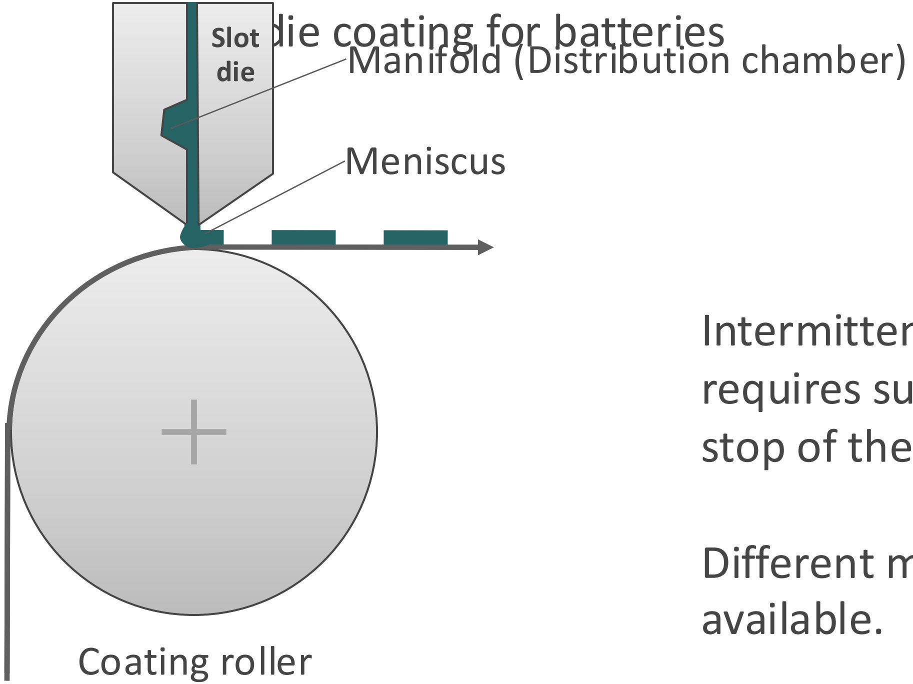
Increasing homogeneity: The last 1 % automatized

iesComputerized
adjustment of
slot width
or gap width

Slot width:
for uniformity

Gap width:
for very small
coating windows

Structured coating – crossweb stripes (intermittent)

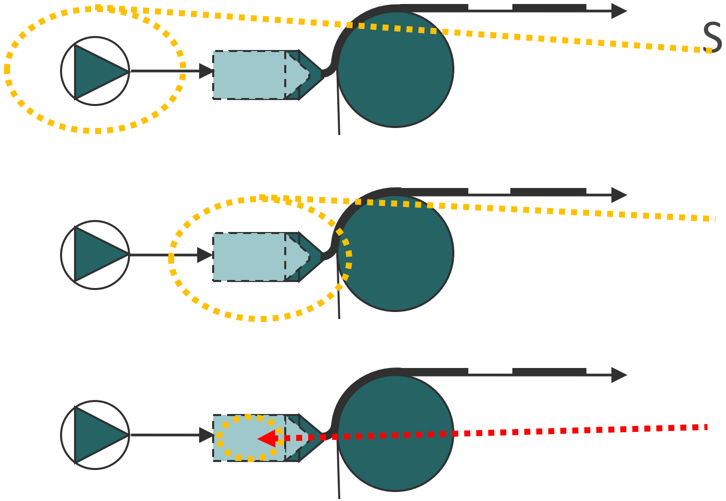


Intermittent coating requires sudden start / stop of the fluid flow.

Different methods are available.

Standard techniques for intermittent coating

Slot die coating for batteries



Pump:
stop – reverse – restart

Slot die body:
move back – move forth to minimum gap – move back to working gap (wedge procedure)

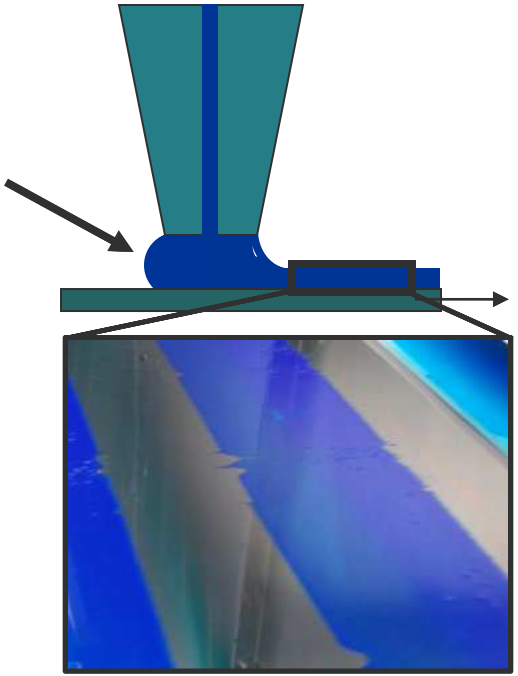
Slot die internal:
stop and redirect the flow by shutters and valves. Pump flow continues, die flow stops.

All 3 techniques (single or in combination) work quite well, if the viscosity is rather high and the required edge defintion 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

- ✓ Mensicus 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



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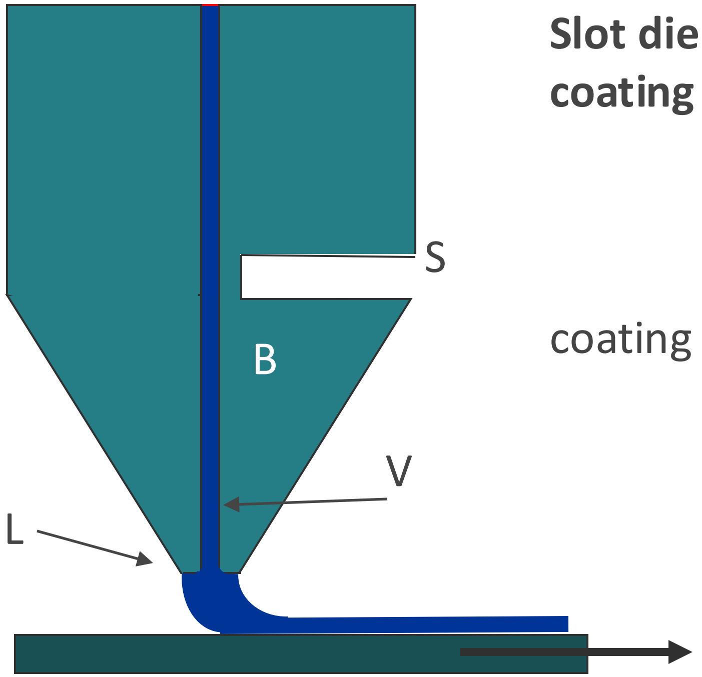
Structured coating – the switching slot die lip



Slot die with movable lips:
coating mode

coating works as usual

L lip
V slot volume
B bendable lip
S bending slot

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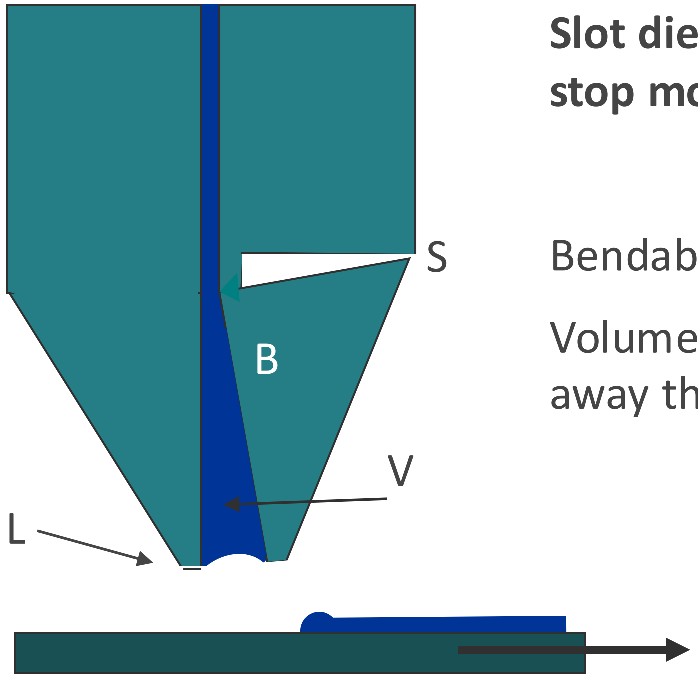
Structured coating – the switching slot die lip



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

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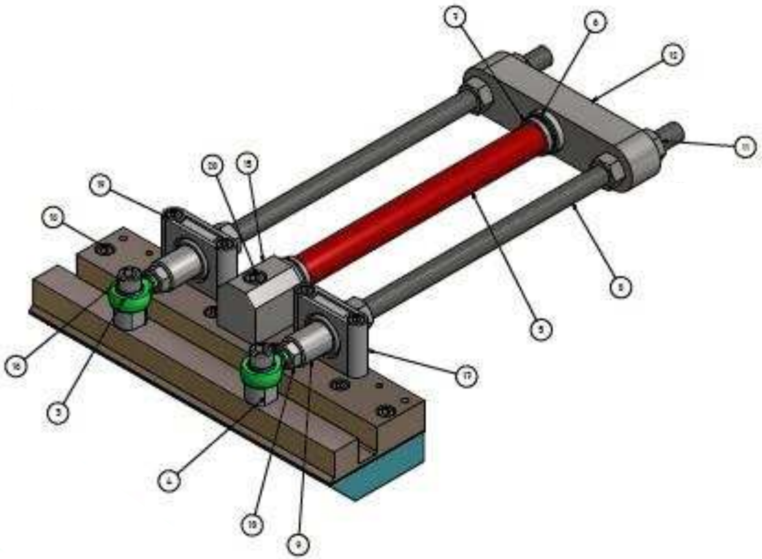
Structured coating – technical implementation with Piezo-Drive



Ext[illegible]ly fast action:
within few ms from coating to stop mode and vice versa

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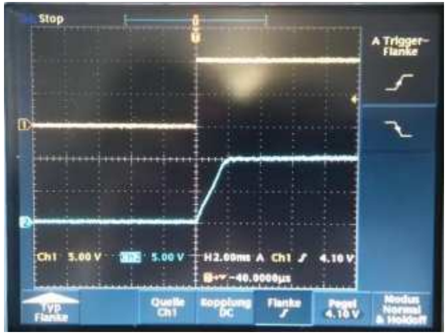
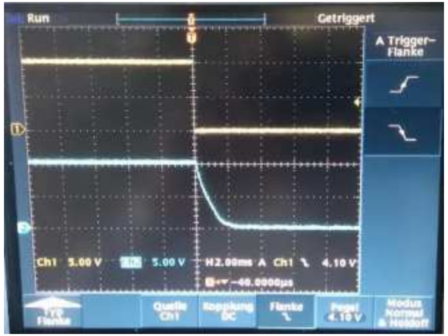
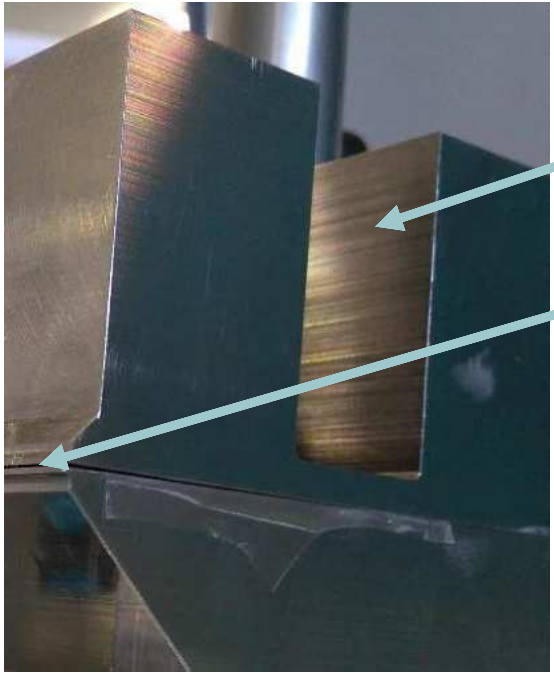
Control Voltage

Piezo Response





Structured coating – technical implementation with bendable lips

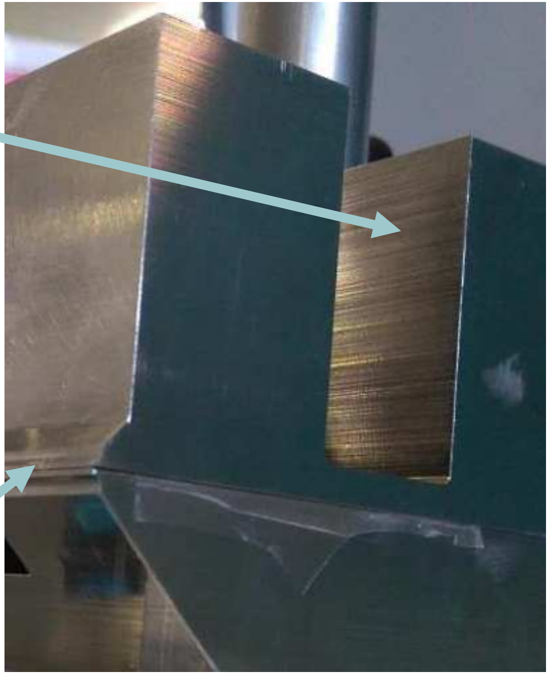


Bending slot

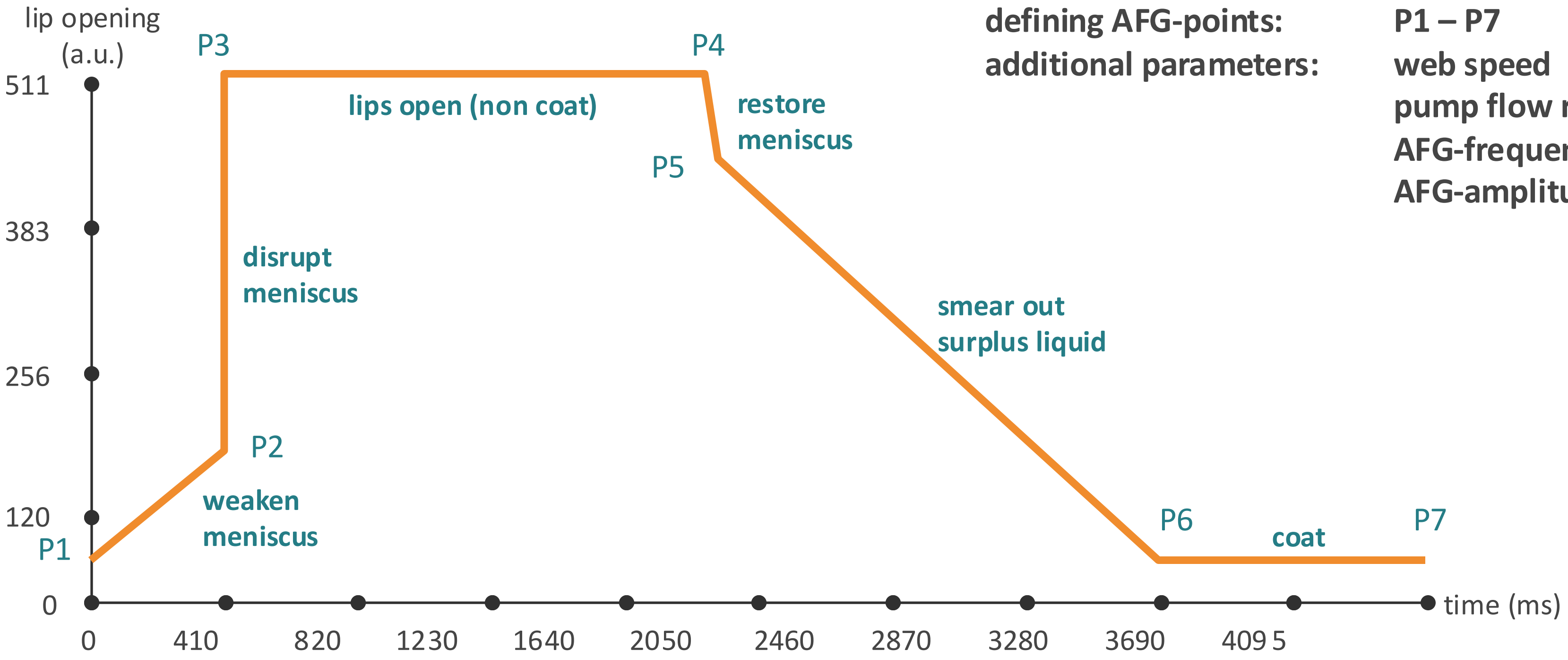
Lips open

Difference is 300 µm only

Lips closed



Structured coating – stages of lip motion



defining AFG-points: **P1 – P7**

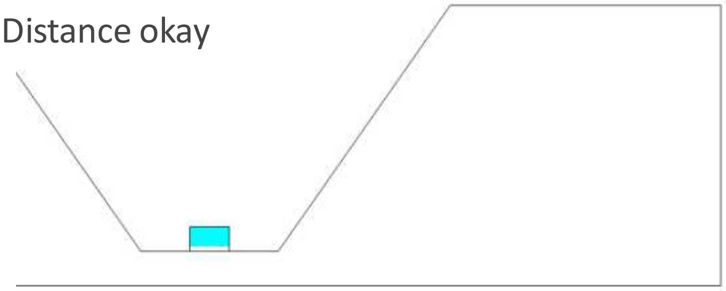
additional parameters:
- **web speed**
- **pump flow rate**
- **AFG-frequency**
- **AFG-amplitude**

Simulation of anode Coating

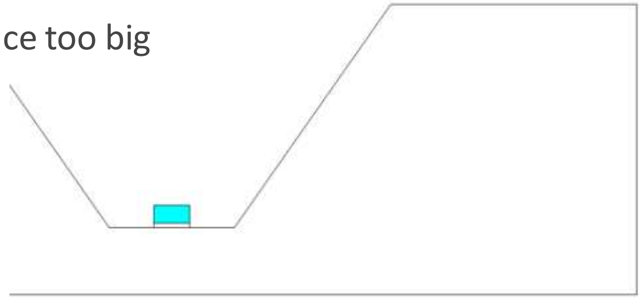
Slot-die Chamber

- ✓ 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

Distance okay



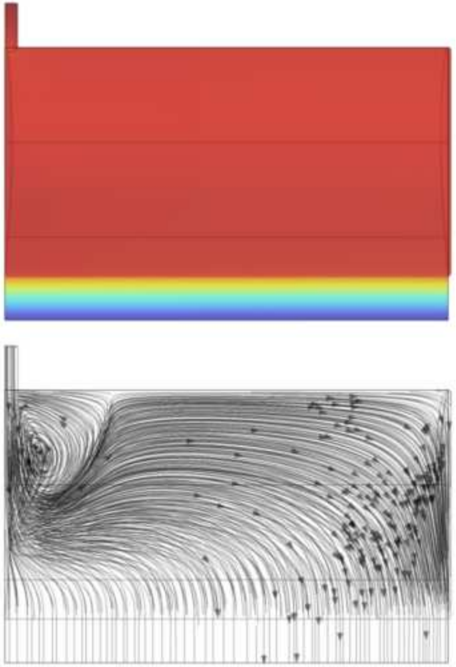
Distance too big



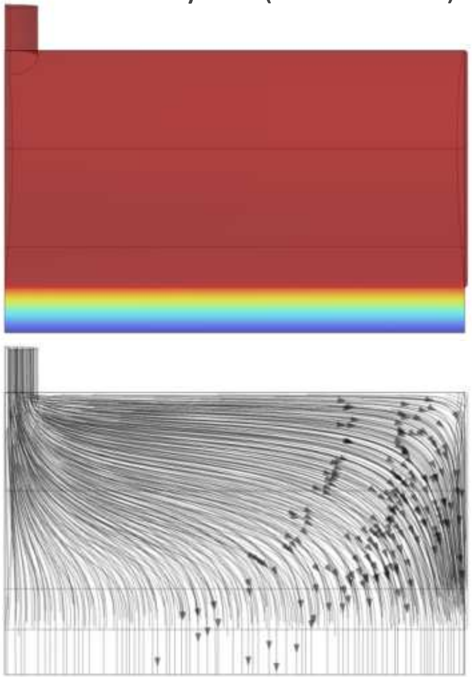
Streamlines and pressure distribution

Slot die Chamber

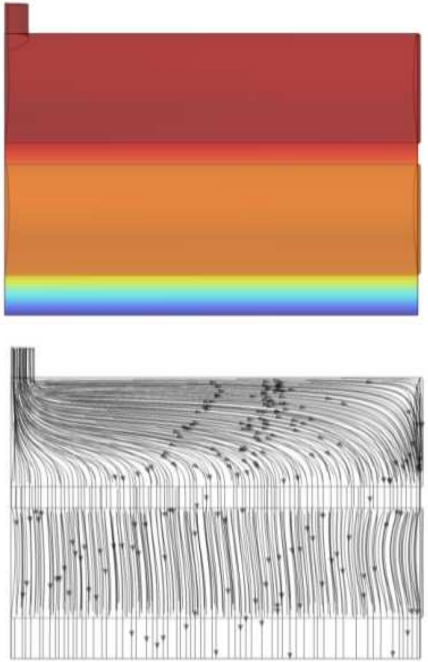
Single Chamber with too small inlet (4mm)



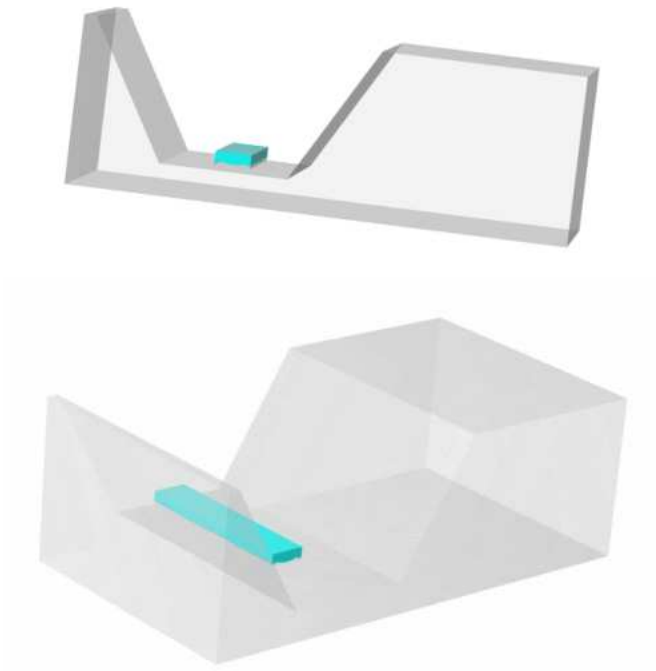
Single Chamber with correct chamber layout (10mm inlet)

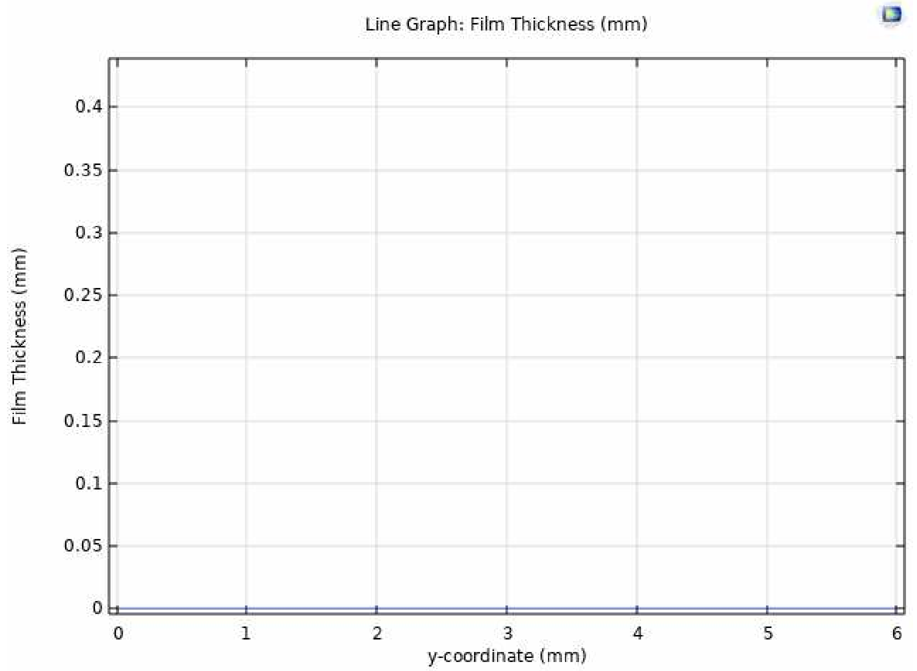


Dual chamber slot die (8mm inlet same dead volume)



Meniscus makes or breaks homogeneity





7.

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 ✓ 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

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

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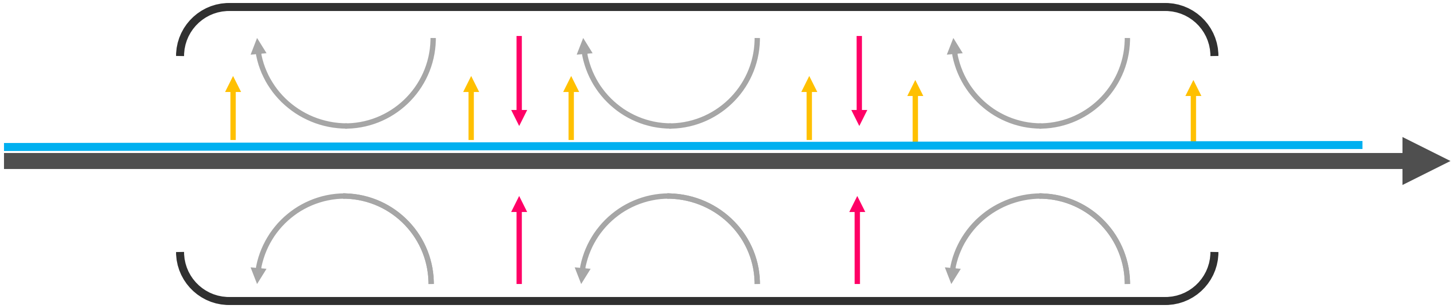
Introduction thermal drying – As general as possible(!?)



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

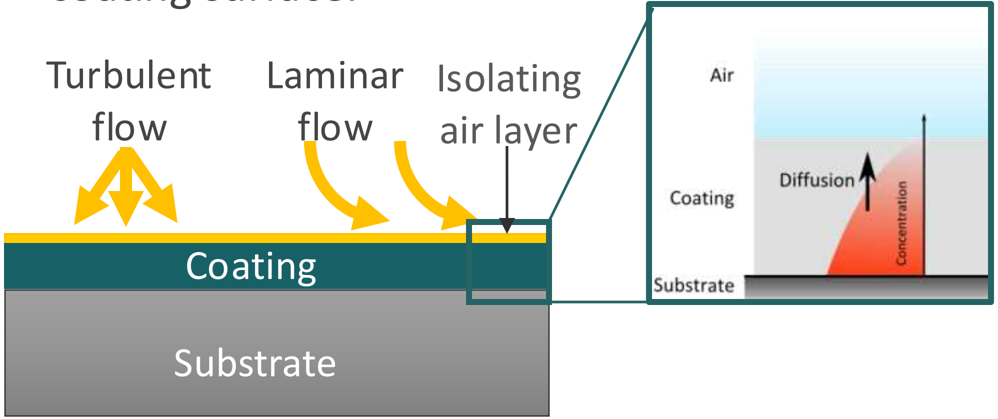
Substrate
Coating
Heat transfer
Evaporating solvent
Solvent vapor transfer

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.

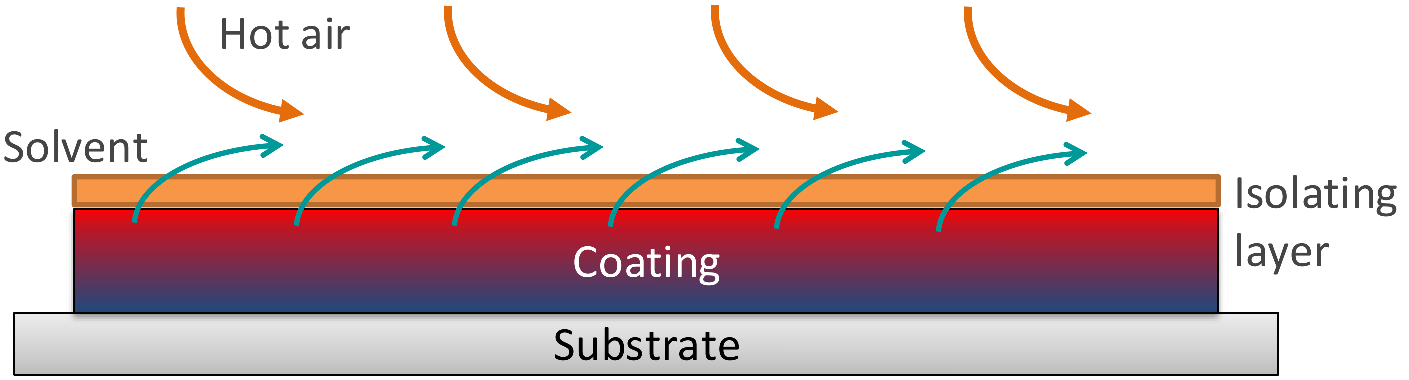


Usually there is a trade-off:

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 – 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.

Dryer 1	Dryer 2
Temperature 1 Airflow 1	Temperature 3 Airflow 3
Temperature 2 Airflow 2	Temperature 4 Airflow 4

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-Proponol	60	97	20	112	750	2.8	23.0
2-Proponol	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

Industrial drying systems

Coatema slot nozel and circulation dryer on small scale

Industrial drying systems

Coatema slot nozel and circulation dryer on small scale

Drytec Click&Coat™ dryer prinziple

Drying technologies

Industrial drying systems

Coatema slot nozel and circulation dryer on small scale

Industrial drying systems

Coatema slot nozel and circulation dryer on small scale

Industrial drying systems

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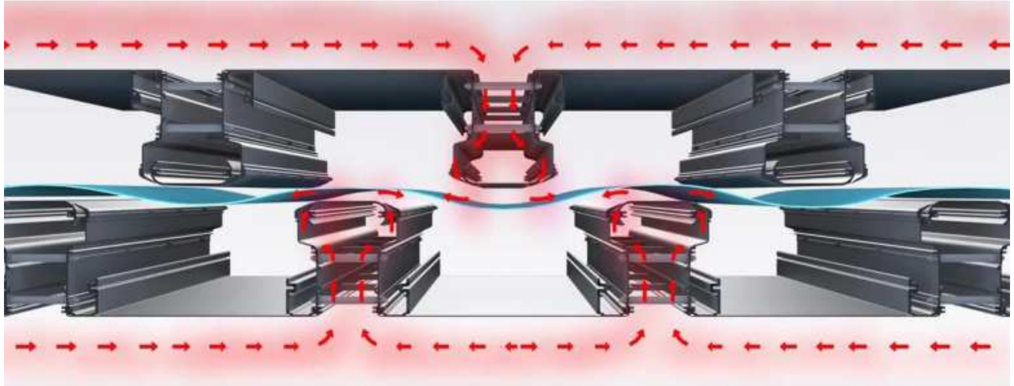
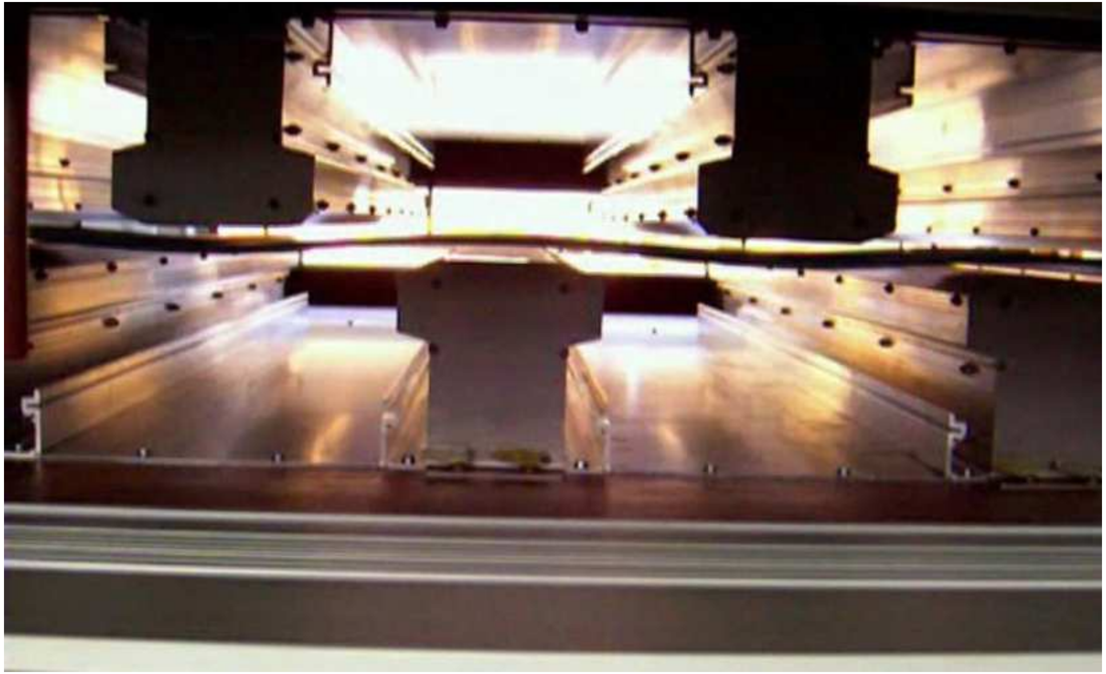
Drying technologies



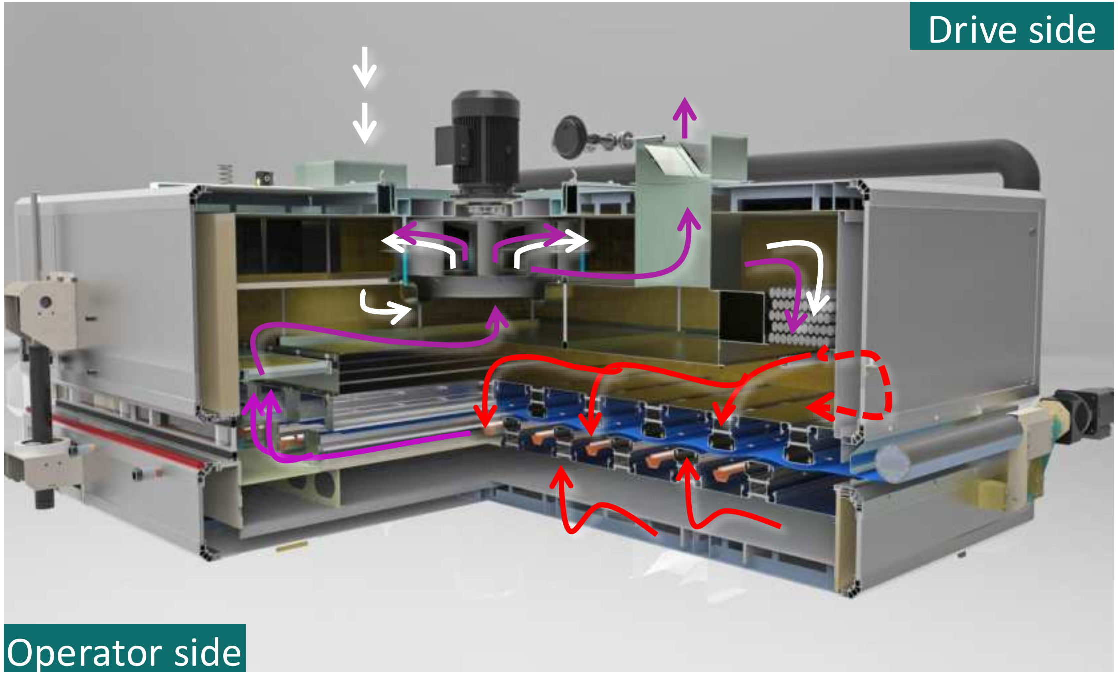
Drying topics – drying technologies: HighDry HD500



Web behaviour in a flowtation dryer

Click on the picture to show the video

Drying topics – drying technologies: HighDry HD500



Air flow air inlet (cold)

Air flow heated air (hot)

Air flow reverse

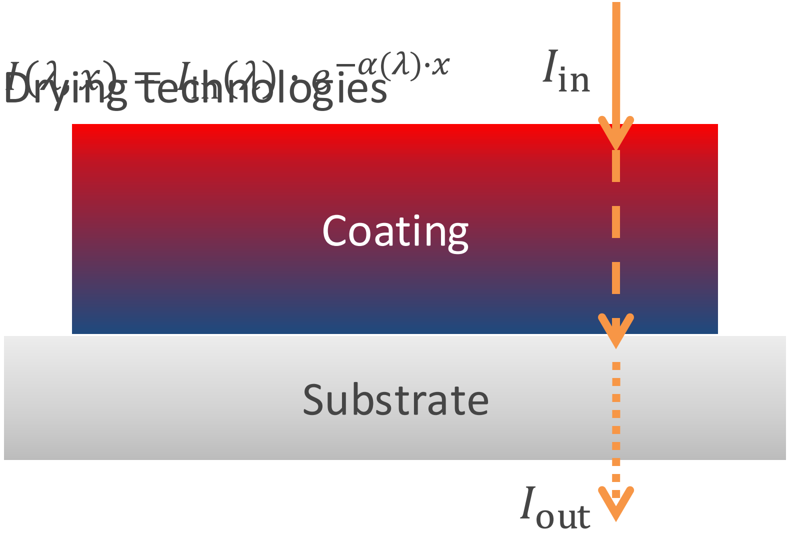
Clear arrows

Click „Air distribution“ to show air flow direction

Basics mass + heat transfer: (N)IR technology

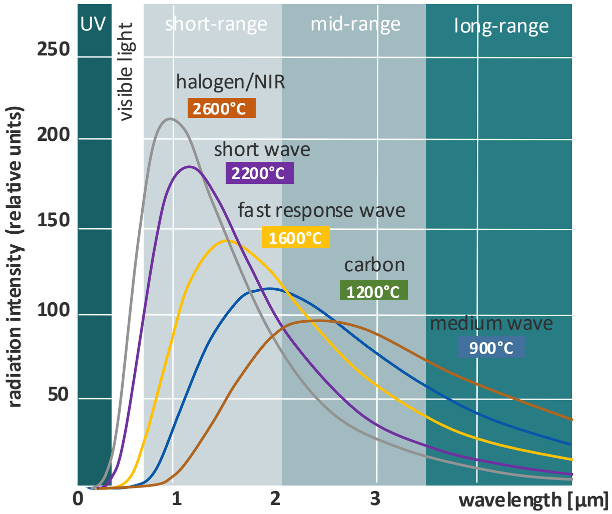
Drying Technologies

$$I(\lambda, x) = I_{in}(\lambda) \cdot e^{-\alpha(\lambda) \cdot x}$$



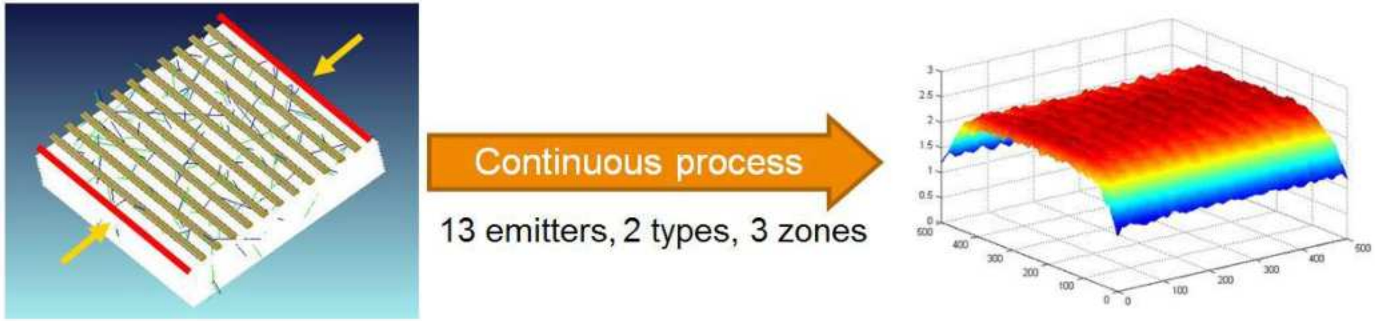
$I_{in}(\lambda)$ Intensity in
I_{out} Intensity out
$\alpha(\lambda)$ Absorption coefficient
d Layer thickness

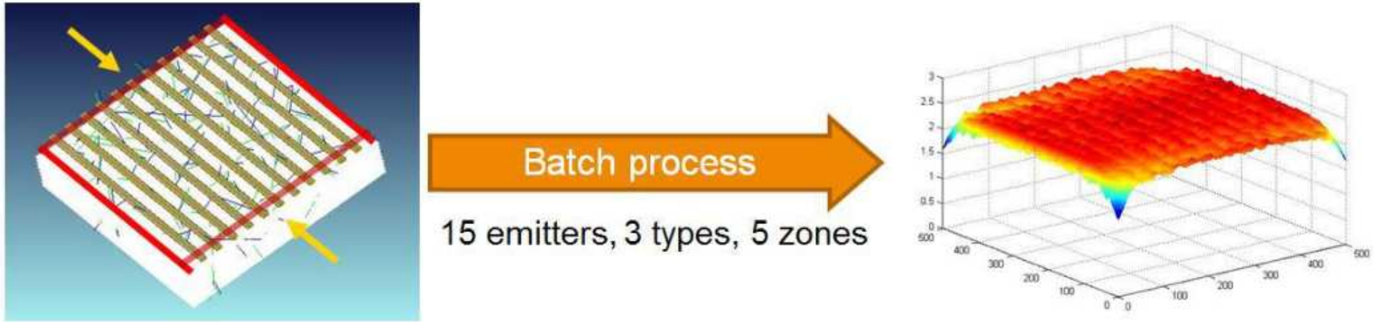
High absorption	Optimum absorption	Low absorption



Relative intensity of radiators at different wavelengths

IR / NIR Drying – Infrared drying

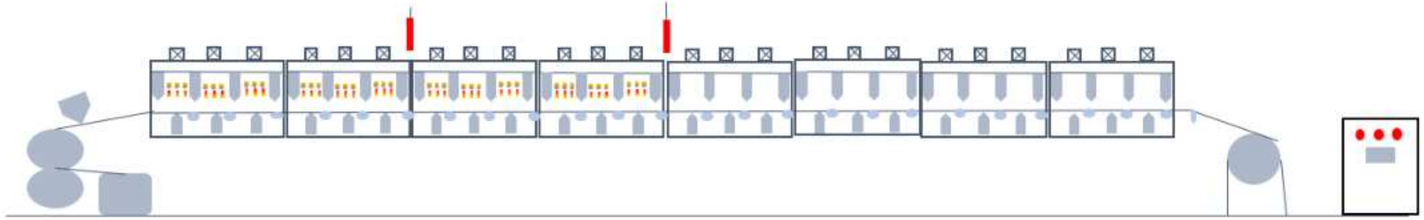


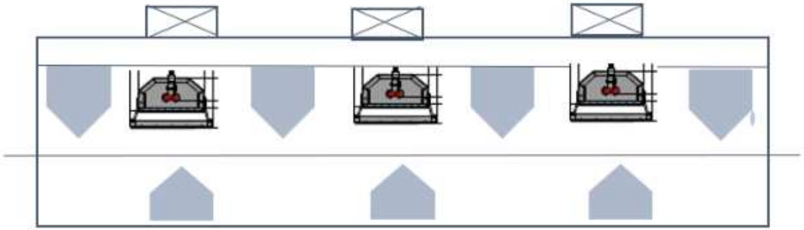


Source: Heraeus Noblelight

IR / NIR Drying – Infrared drying

Layout





Hotair oven: 50m (10 zone)

IR at first 25m (5 zone) for boost

Heating distance : 100mm

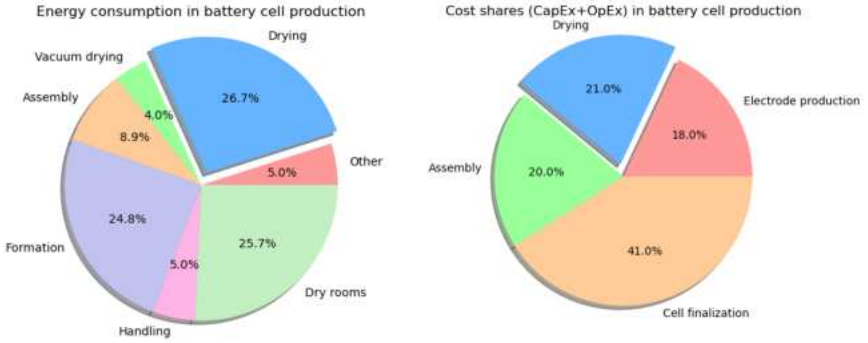
Qty of IR : 60 *3.1Kw = 186Kw

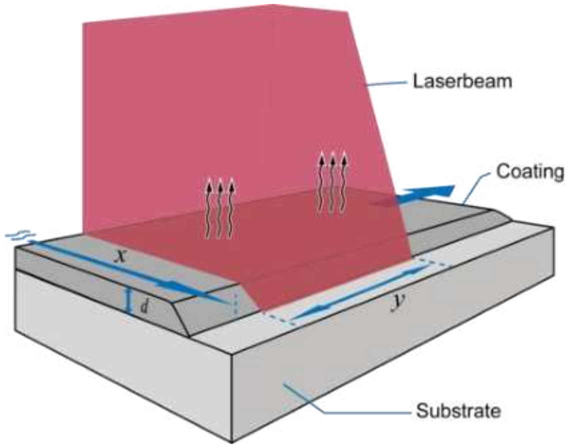
Source: Heraeus Noblelight

Laser drying

Drying technologies

- ✓ Typically, a high-power laser, such as a diode laser or a fiber laser, is used for this purpose.
- ✓ The laser passing through the optics is directed at a large.
- ✓ The absorbed laser energy rapidly heats the solvent in the slurry, causing it to evaporate.
- ✓ The quick drying might help preventing the formation of cracks or defects in the electrode.
- ✓ Laser drying is **more energy-efficient** compared to traditional drying.
- ✓ Laser drying can be adapted for use in high-volume battery manufacturing processes.





Source: laserline

[1] Degen et al. (*Life cycle assessment of the energy consumption and GHG emissions of state-of-theart automotive battery cell production*) 2022
[2] Küpper et al. (*The future of battery production for electric vehicles*) 2018

Important factors laser drying

Laser System: The laser should be capable of delivering the necessary energy for solvent evaporation without damaging the electrode material.

Temperature Control: Implement temperature control systems within the drying chamber to ensure that the slurry is dried at the suitable temperature.

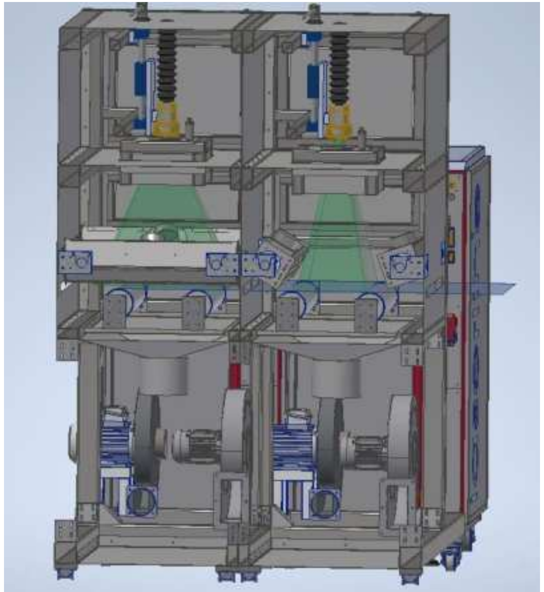
Gas Atmosphere: Consider the use of inert gases or controlled atmospheres within the drying chamber to prevent unwanted reactions or oxidation of the electrode materials during the drying process.

Monitoring and Control: Incorporate sensors and monitoring systems to continuously measure key parameters such as temperature, humidity, and laser power.

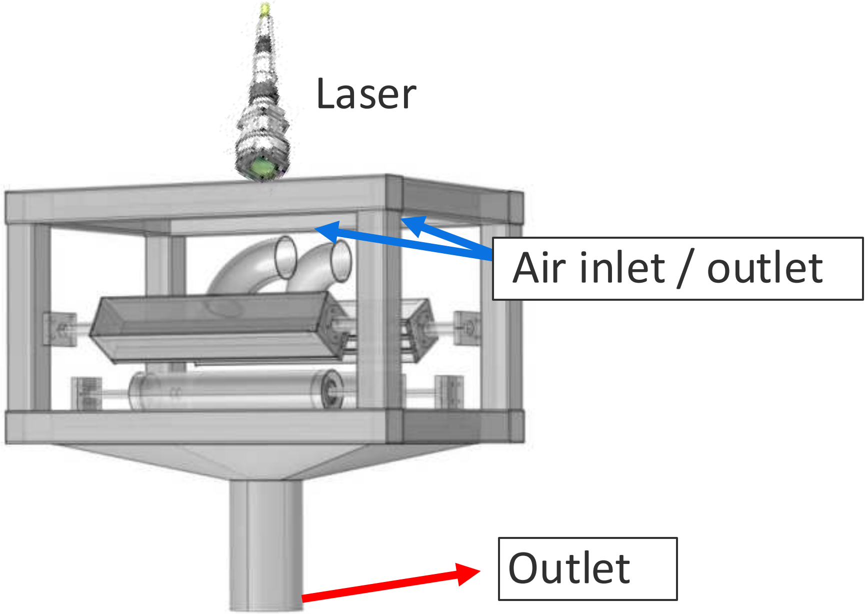
Drying Chamber: Design a drying chamber that allows for precise control of temperature, airflow, humidity, etc. to assure a **uniform and efficient drying.**

Laser dryer

Coatema's design

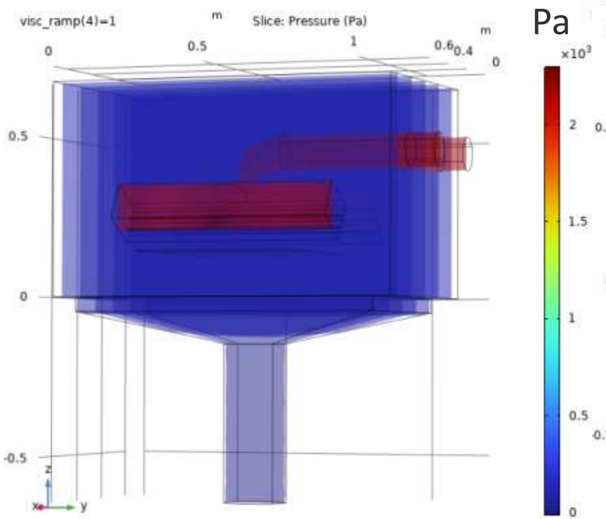


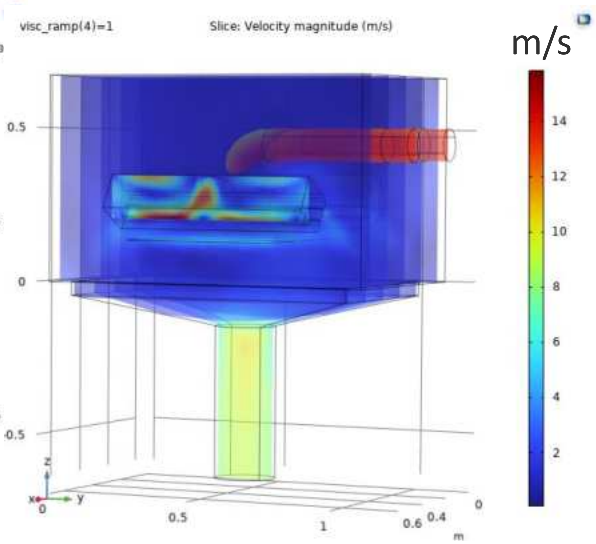
Geometry used for simulation

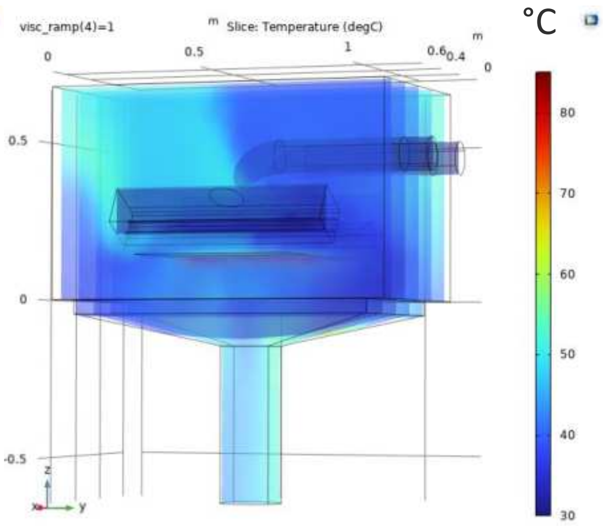


Web speed 30m/min, in -x direction

Pressure | **Air velocity** | **Temperature**

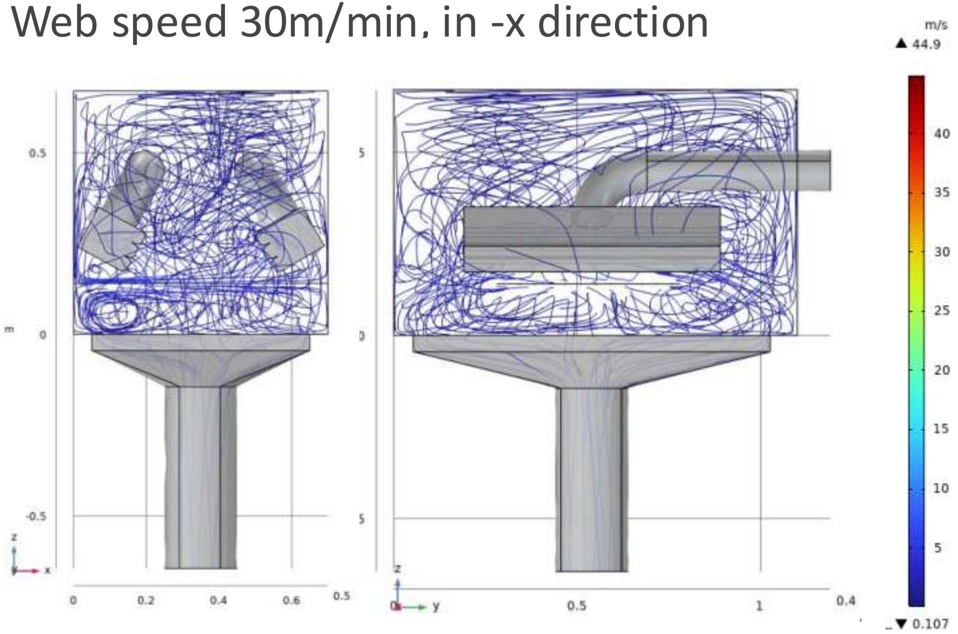




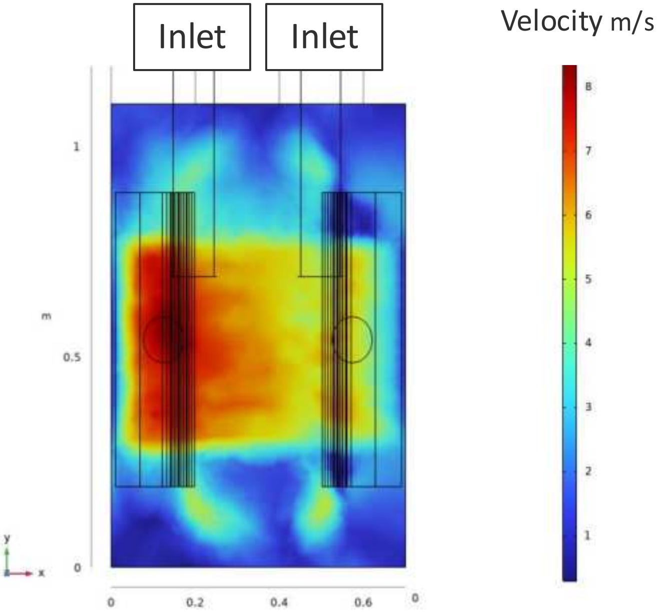


Airflow in 3D, testing different design possibilities

#1: 2 inlets, 1 outlet
Web speed 30m/min, in -x direction

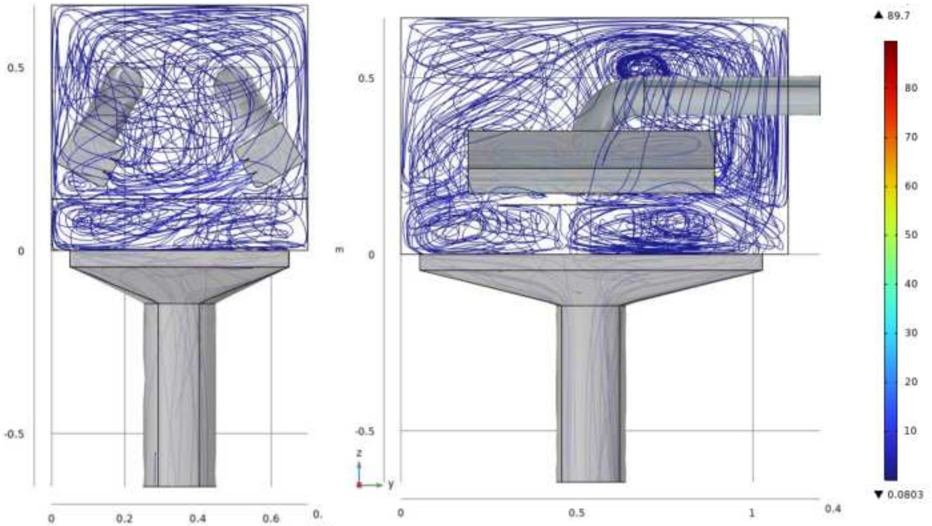


Volumetric air inflow~ 300 m3/hr

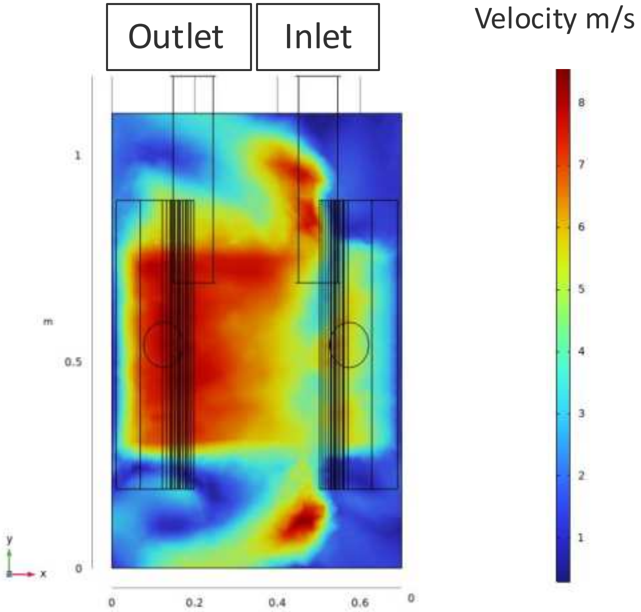


Airflow in 3D, testing different design possibilities

#2: 1 inlet , 2 outlets
Web speed 30m/min, in -x direction

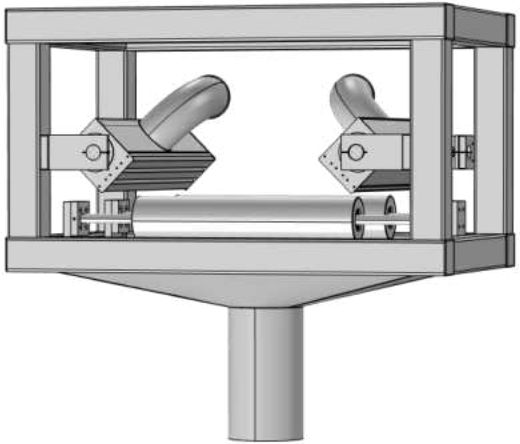


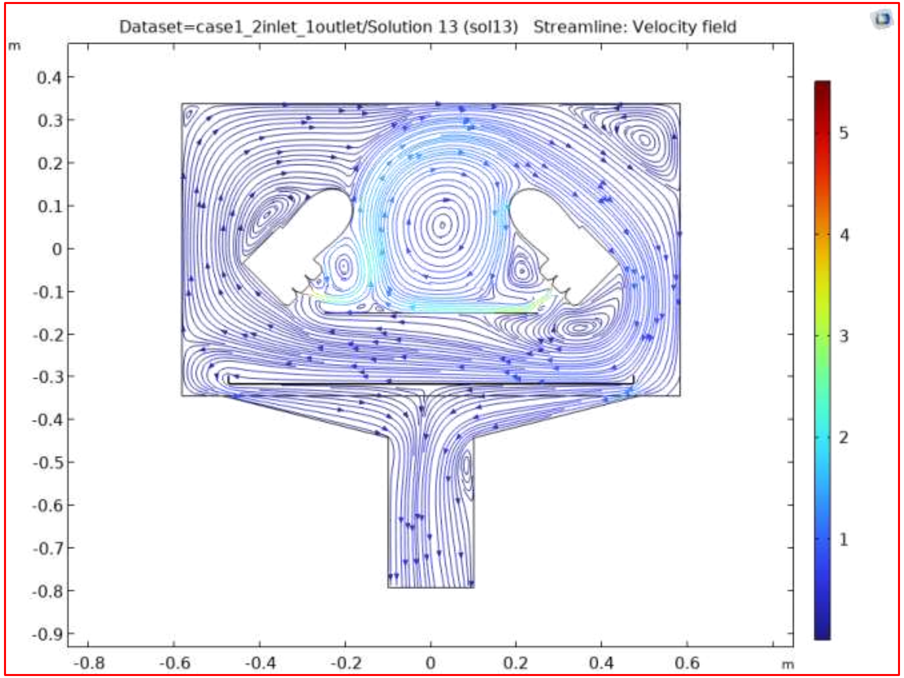
Web speed 30m/min, in +x direction



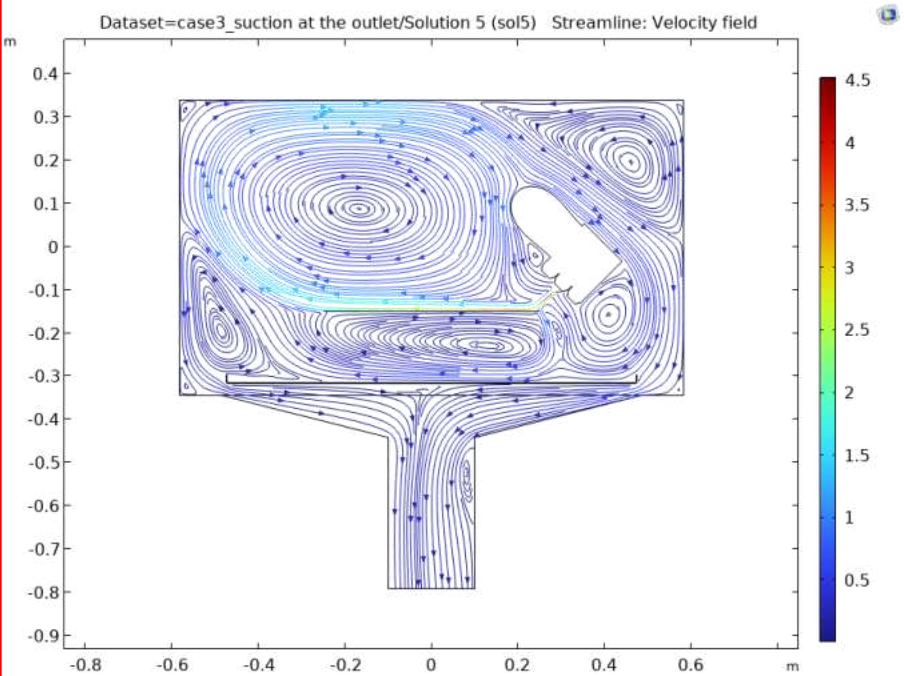
Airflow in 3D, testing different design possibilities

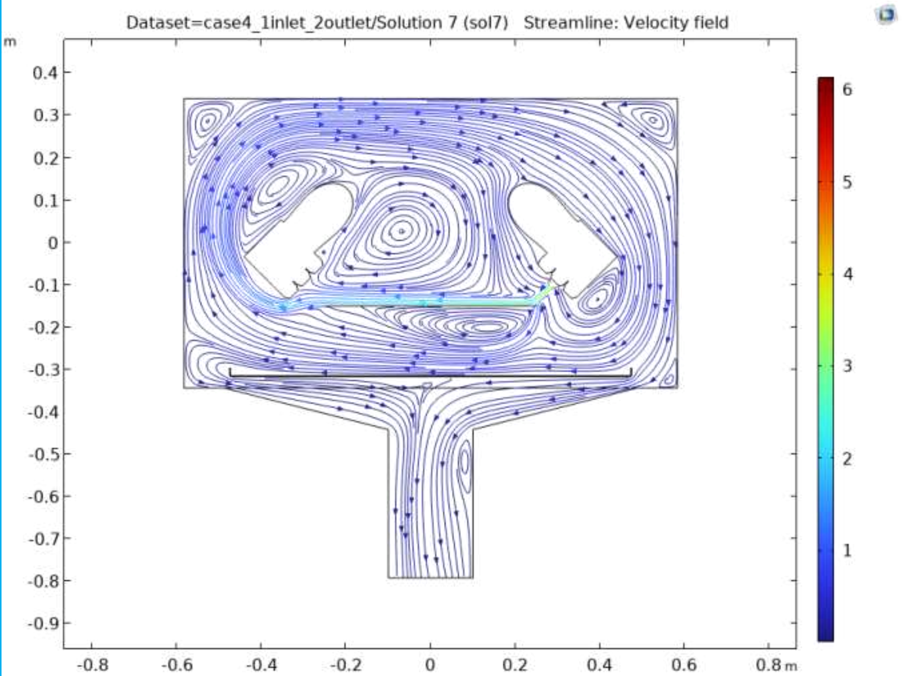
- ✓ The air is blown in a transverse direction to the web
- ✓ 280 mm x 350 mm laser area





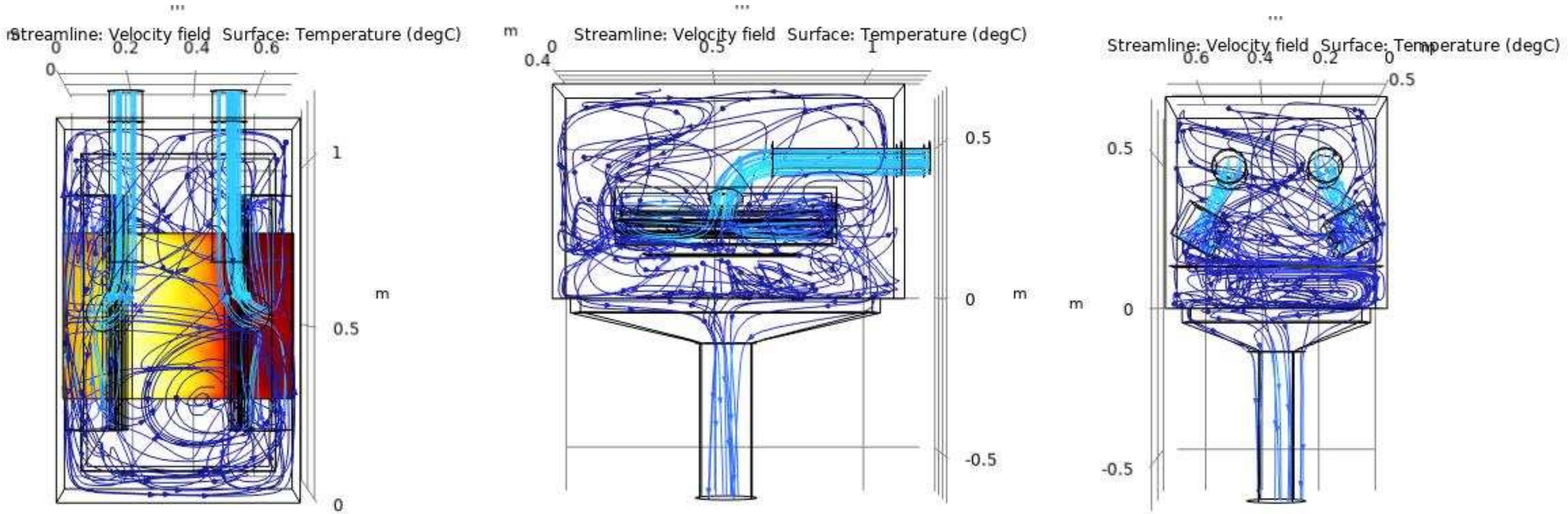
Airflow in 3D, testing different design possibilities





Airflow in 3D, testing different design possibilities

Temperature distribution on the moving web when the laser shines with a homogeneous energy density on an area of 350 mm x 280 mm

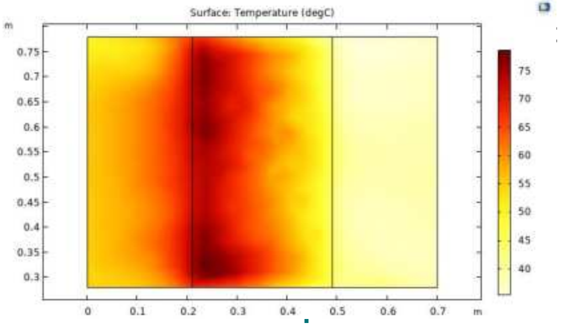


Airflow in 3D, testing different design possibilities

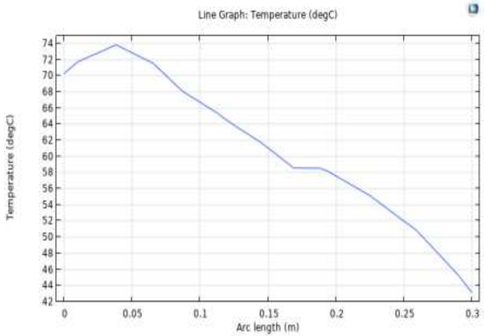
Drying technologies

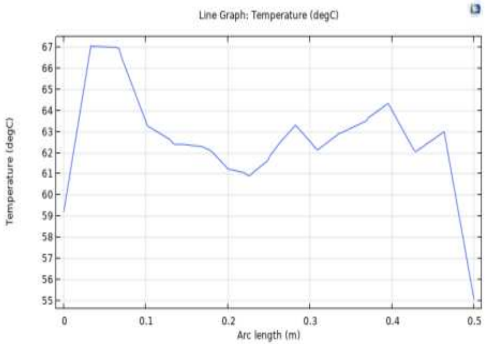
Evaporation is not included in the model!

From Simulation

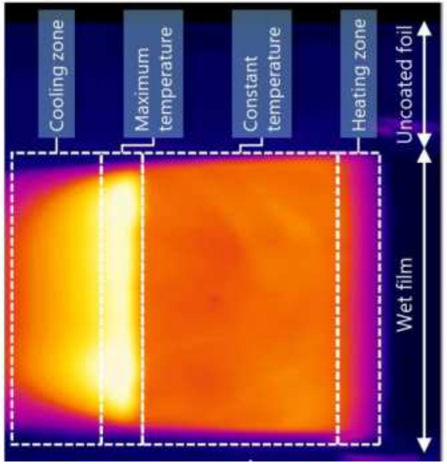


Direction of web





From thermographic camera



Thermographic analysis of the laser drying process

8.

Calendering

Technologies & processes – Calendering Tech

Layout

- ✓ Tabeltop calender system
- ✓ S2S calender with support tables
- ✓ R2R calender

Width / Speed / temp

- ✓ 100 mm -2.000 mm
- ✓ 0.1 – 30m/min
- ✓ 20C – 400C

Pressure range from tons to N / cm

- ✓ Pneumatic pressure up to 10 tons / 2.500 n/cm

  (roller width 400mm)
- ✓ Hydraulic pressure up to
- ✓ 120 tons / 10.00 n/cm
- ✓ (roller width 600mm)

Features

- ✓ Motoric gap adjustment
- ✓ Crossing
- ✓ Heating
- ✓ Sleeve technology
- ✓ Different roller surfaces

Markets

- ✓ Battery
- ✓ Fuel Cell
- ✓ Prepreg
- ✓ Thermal imprint
- ✓ Membranes
- ✓ Textil

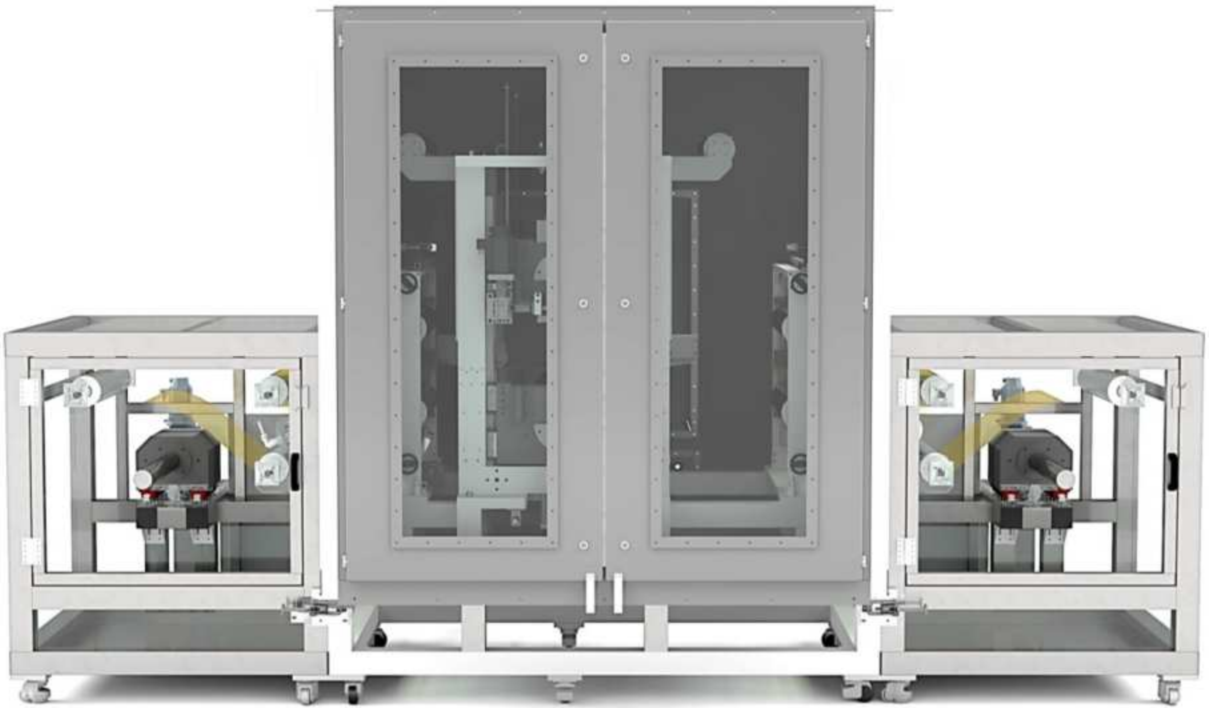
Coating calendering equipment

Calendering systems from:

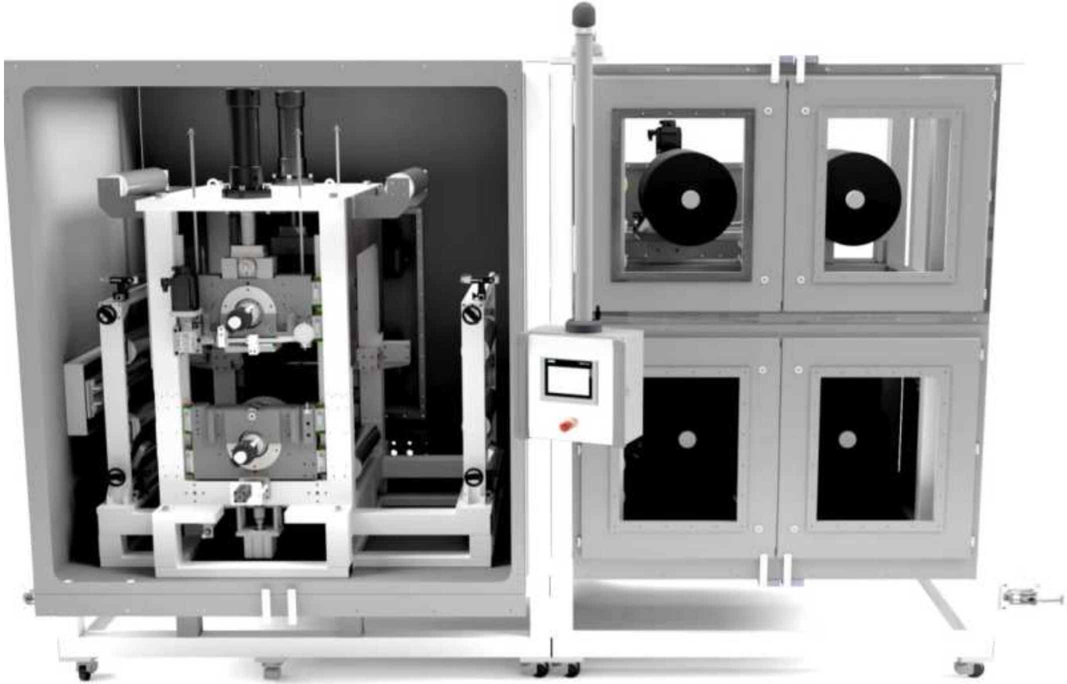
- ✓ 100 mm – 2.000 mm
- ✓ 5t to 120t
- ✓ S2S or R2R with integrated quality control and under inert atmosphere as option
- ✓ Inline calender in coating lines

Calendering R2R Click&Coat™ 500 mm

Calendering R2R Click&Coat™ – Inert enclosure 500 mm

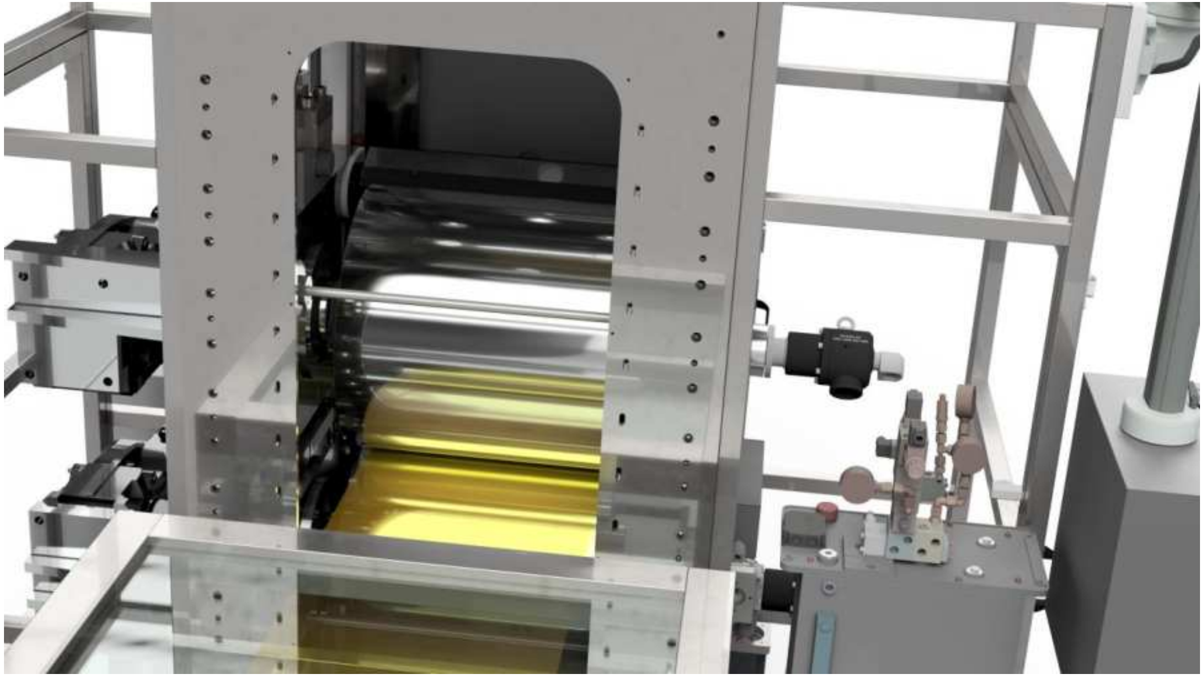


Calendering R2R Click&Coat™ – Inert enclosure for thermal imprint 500 mm working width



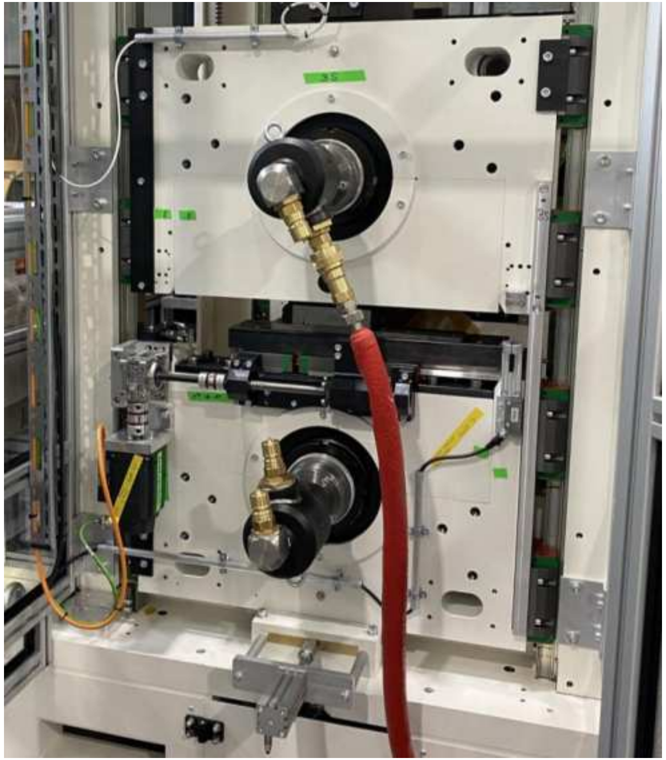
Calendering 60t / Coatema R&D centre system

Calendering 60t / Coatema R&D centre system



Calendering

Calendering



Calendering

Calendering

Calendering

Calendering

Calendering

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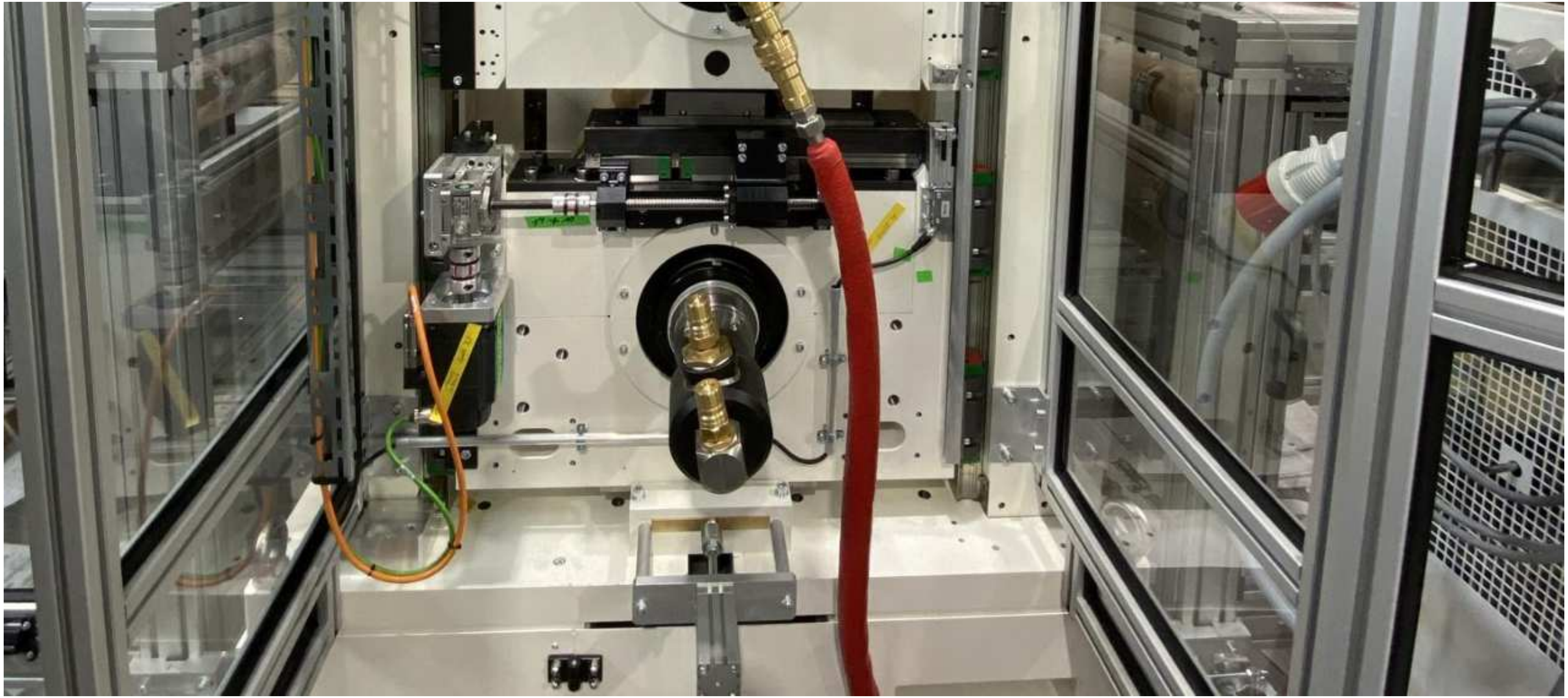
Calendering



Production scale / Integration in a coating line

Production scale / +/- 1µ accuracy on 2.000 mm

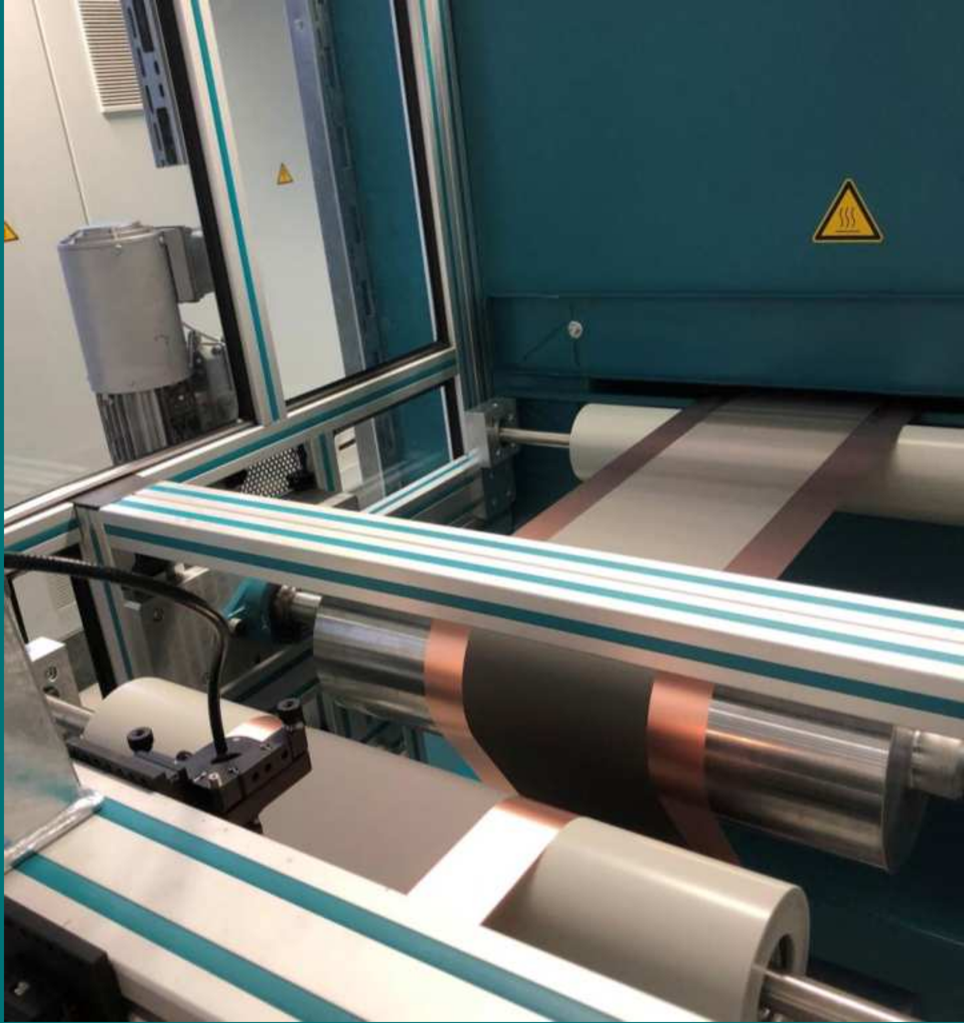
Production scale / +/- 1µ accuracy on 2.000 mm

Summary

- ✓ Coatema is providing calendering systems in all sizes and dimensions
- ✓ From 2 tons to 120 tons and from 23C to 400C temperature
- ✓ 100 mm up to 2.000 mm working width
- ✓ UV Nanoimprint and thermal nanoimprint with sleeve technology
- ✓ High performance rollers with Xcrossing and different surface qualities
- ✓ The calendering can also be integrated in Coatema coating lines
- ✓ Quality inline control and precise tension measurement for each size available
- ✓ Slitting can be integrated

9.

Battery production lines

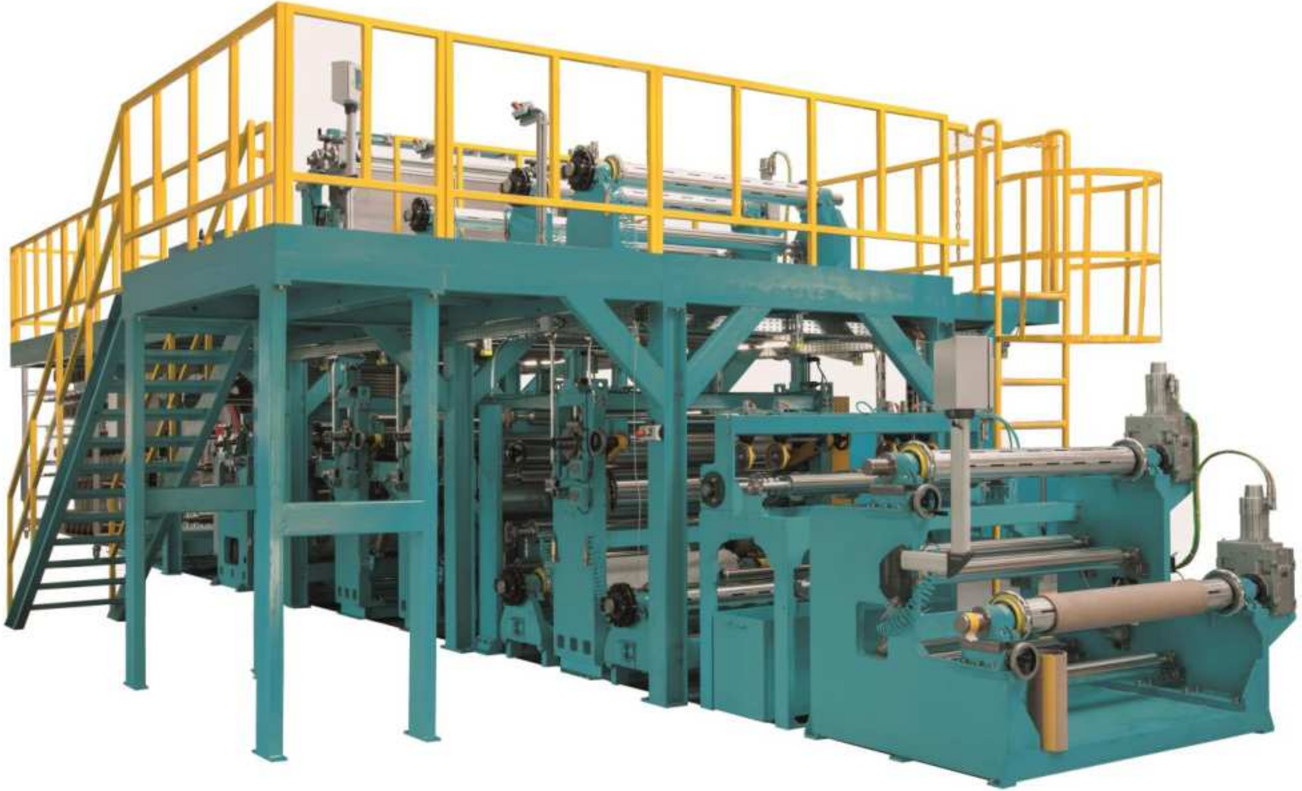


Production line for batteries

Production line

Production line

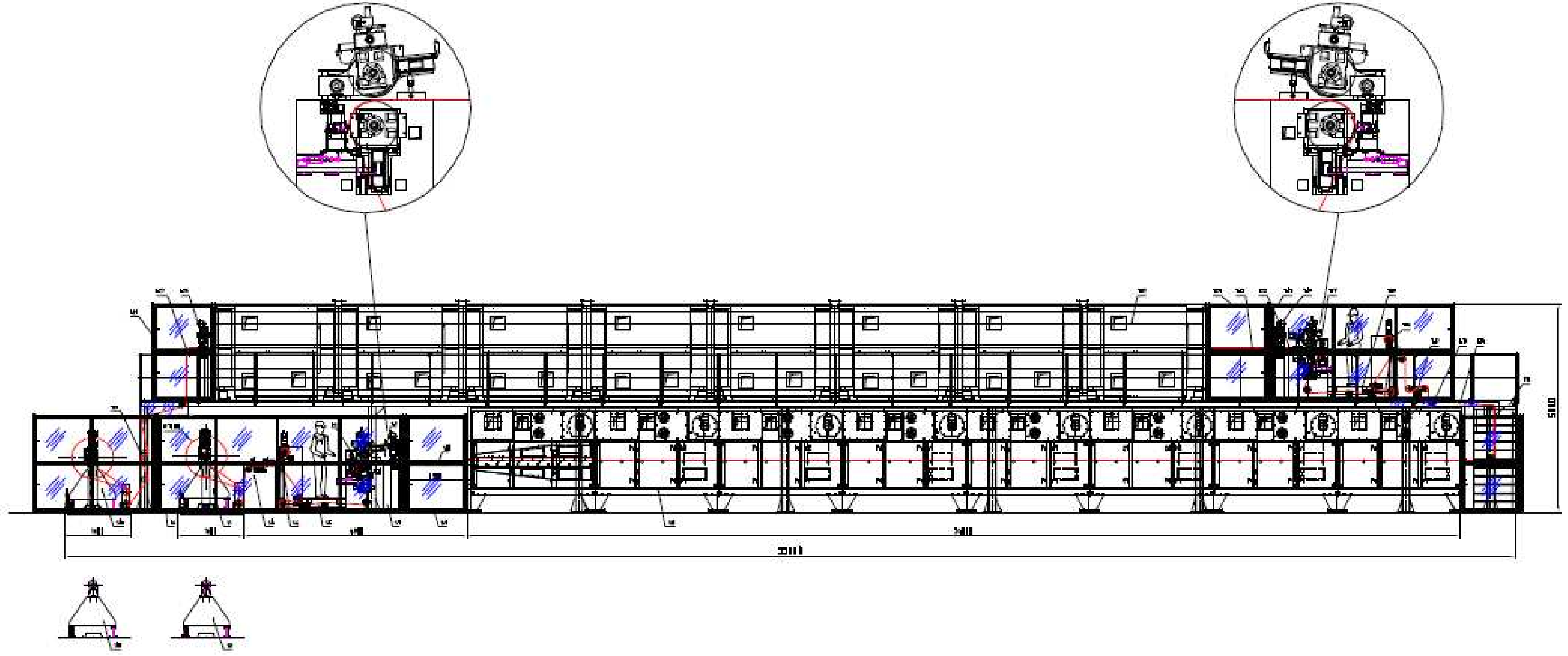
Production line



Production line

Production line

Coatema battery fab concept



10.

Summary

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 Comission
- ✓ 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

Download broschures & presentations

Coatema

Thank you

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