



# Coating solutions for batteries lab 2 fab concept

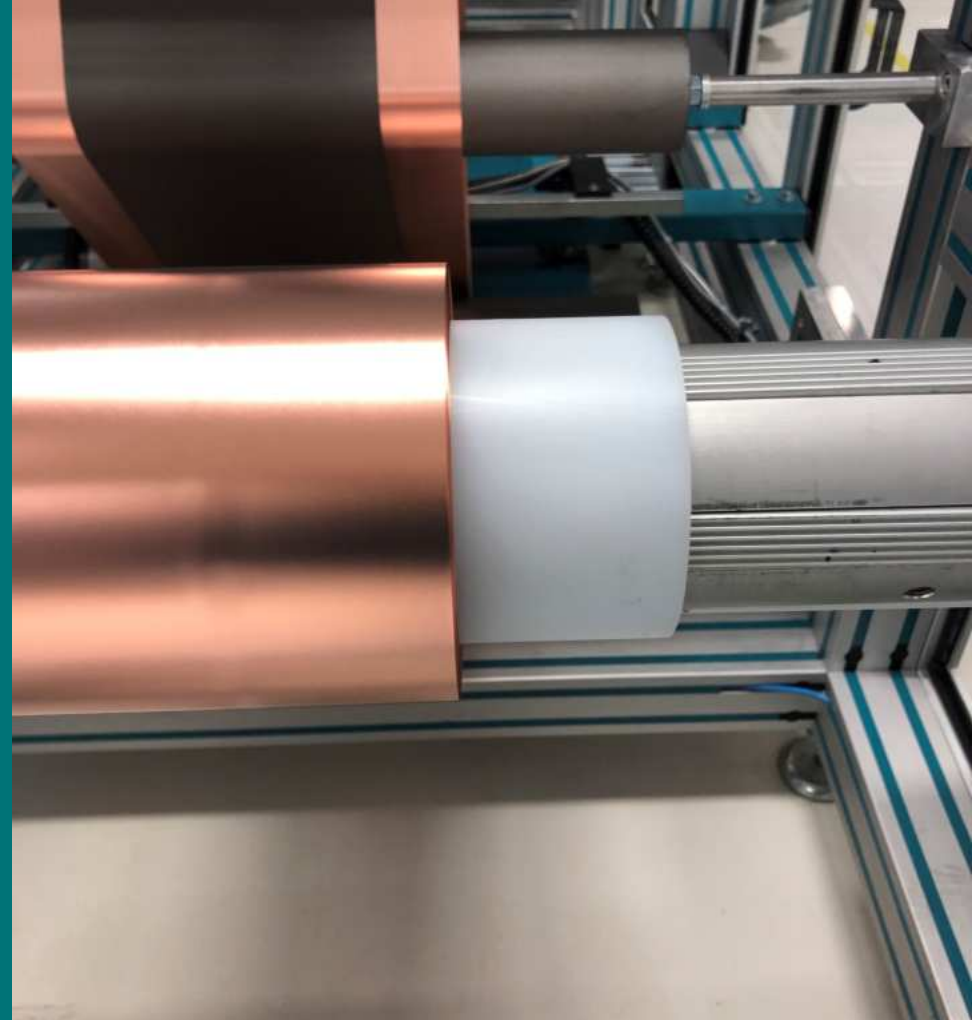
***Coatema***

13/03/2024

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



# Introduction



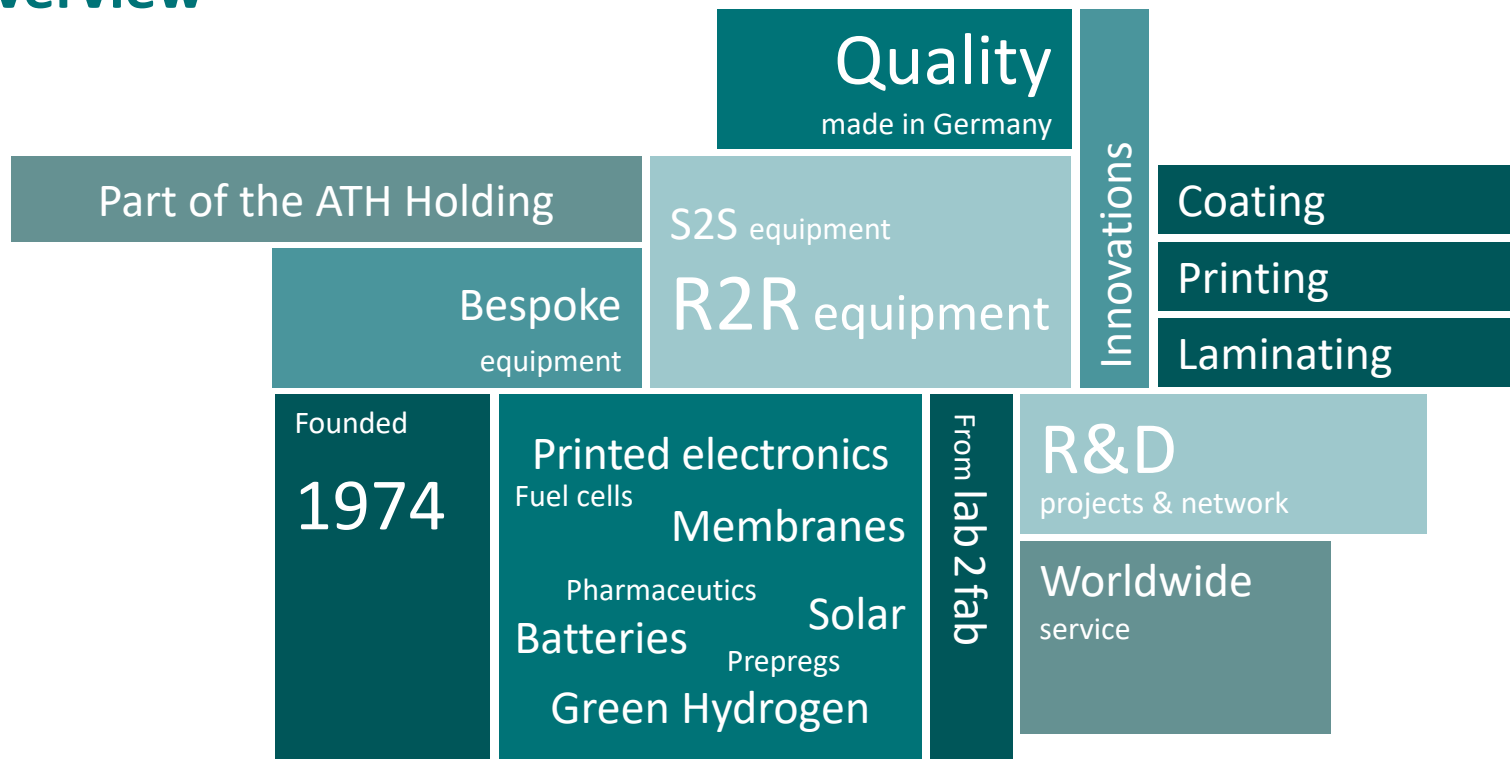
# Thomas Kolbusch, Director Sales, Marketing, Technology, VP



**Thomas  
Kolbusch**

COATEMA Coating  
Machinery GmbH

## 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

## Coatema equipment platform strategy for lab2fab



**Lab**

- ✓ State-of-the-art research and development equipment
- ✓ Sheet-to-sheet to roll-to-roll systems on small 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

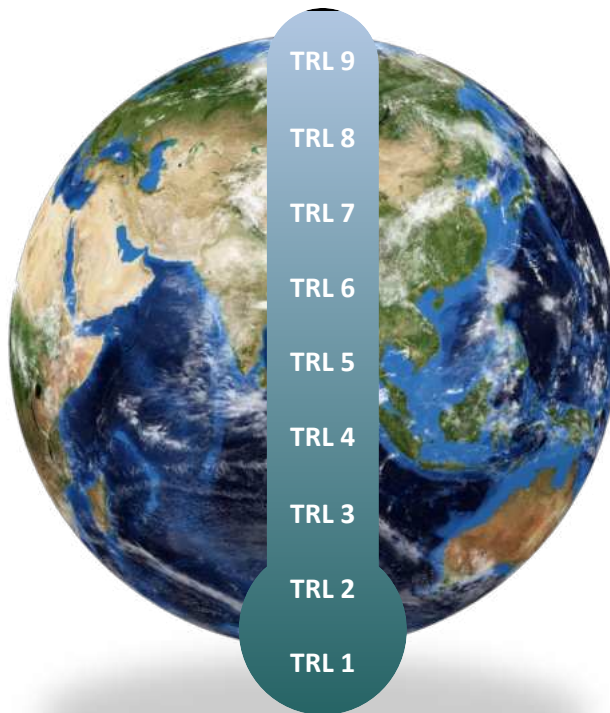
## Our markets – Coatema focus areas

Green Hydrogen

Fuel cells

Batteries

Solar



Sustainability

Digital fabrication

Printed  
electronics

The next thing

## 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

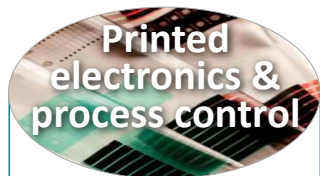
# Introduction – R&D centre



## R&D customers



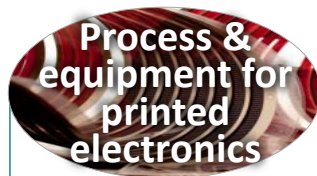
## R&D projects overview 2022 – 2024



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

### NOUVEAU PROJECT

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



R2R production line for OPV solar with integrated backend



Development of near-field electro hydrodynamic nanowire printing



Implementation of laser drying processes for lithium-ion battery production



R2R process optimization for solid state batteries



Plasmonically enhanced photocatalysis for wastewater treatment

### RetroWin

R2R Process and machinery development for retrofit window films for lower production costs



The WaterProof project aims at developing an electrochemical process that converts CO<sub>2</sub> emission



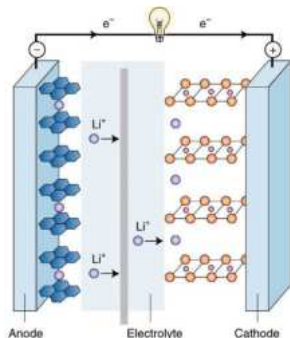
Creating an open-innovation testbed for sustainable packaging

# 2.

## Battery markets



## Li-Ion Battery – Overview



### Application Scale



### Time Horizon



### Classification

Intercalation Battery

↳ Li-Ion Battery

- ✓ Cyclability
- ✓ Efficiency
- ✓ Lifetime

### Conclusion

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

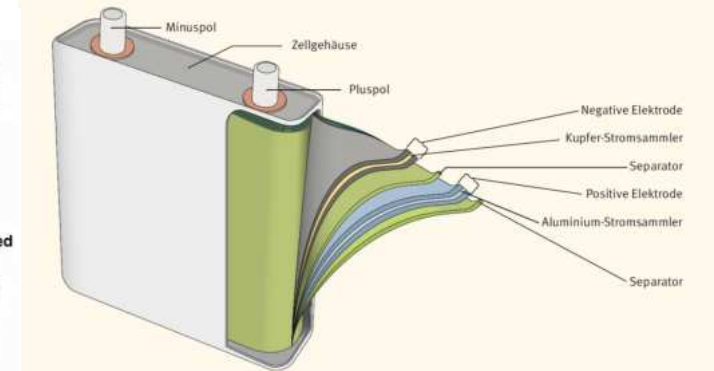
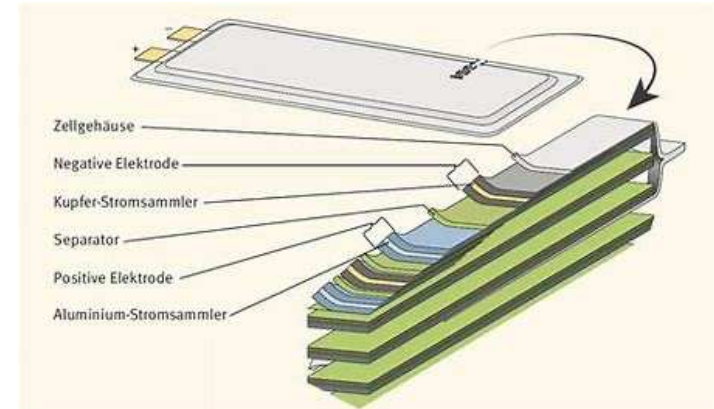
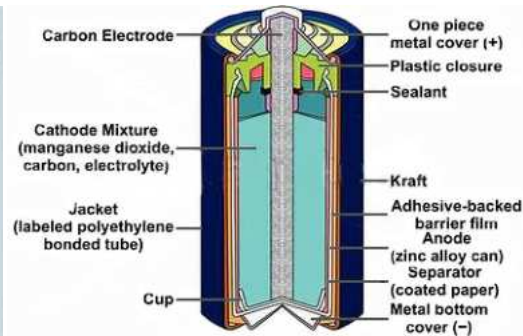
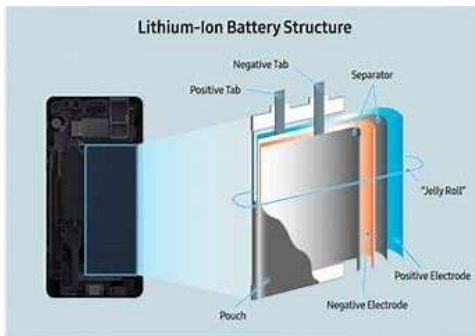
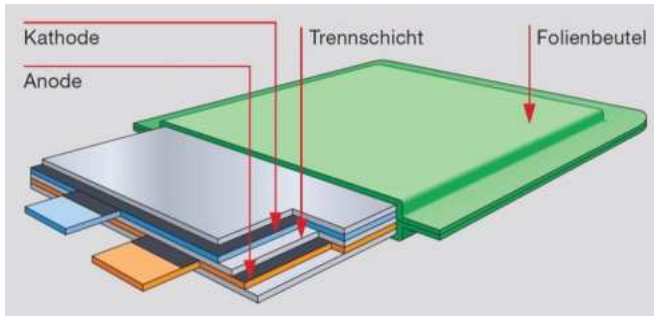
### Advantages & Disadvantages

- ✓ Energy density
- ✓ Safety
- ✓ Cost

### 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 %

## 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
VERBOR	POUCH
Gotion	PRISMATIC
SARASIS	POUCH
Envision AESC	POUCH

Source: Public Information

**CHART OF THE WEEK**

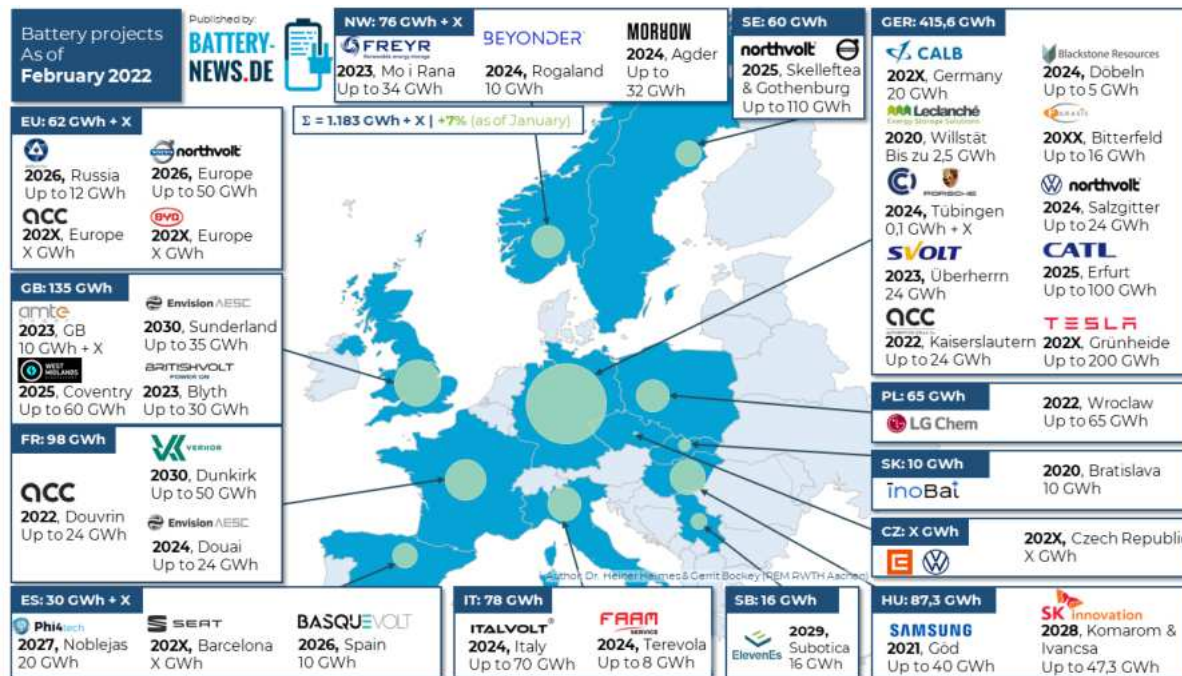
**EUROPEAN ELECTRIC VEHICLE CELL SUPPLY CHAIN SUMMARY**

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OEM	Cathode Type	Format	Some Key Suppliers
Ford	NMC	Pouch	LG Chem SK Innovation
Renault Nissan Mitsubishi	NMC	Pouch	VERBOR 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



## Key Trends | Costs

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

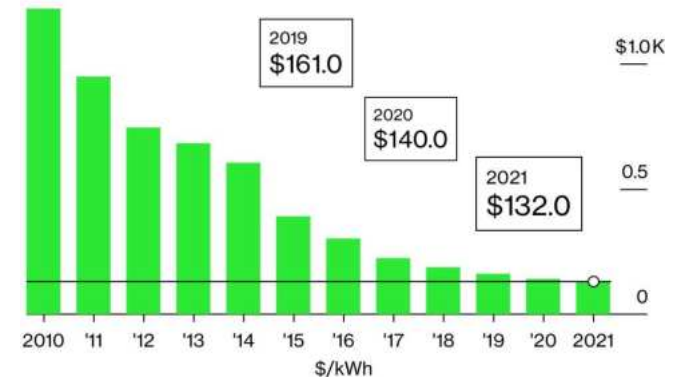
Pack prices fell by only 6% from 2020 – 2021 compared to 13% from 2019 – 2020. Prices were low for the first 6 month of 2021, then started to **increase** in the second half due to supply chain pressures.

**Price increases:** Since September, Chinese producers have raised LFP prices by 10 – 20%. Average pack prices could rise to **\$135/kWh in 2022**

### Regional differences:

- ✓ China has the cheapest battery pack prices (\$111/kWh)
- ✓ U.S. pack price (\$155/kWh, 40% higher than China)
- ✓ EU pack price (\$177/kWh, 60% higher than China)

**Battery Pack Prices**



Source: BloombergNEF

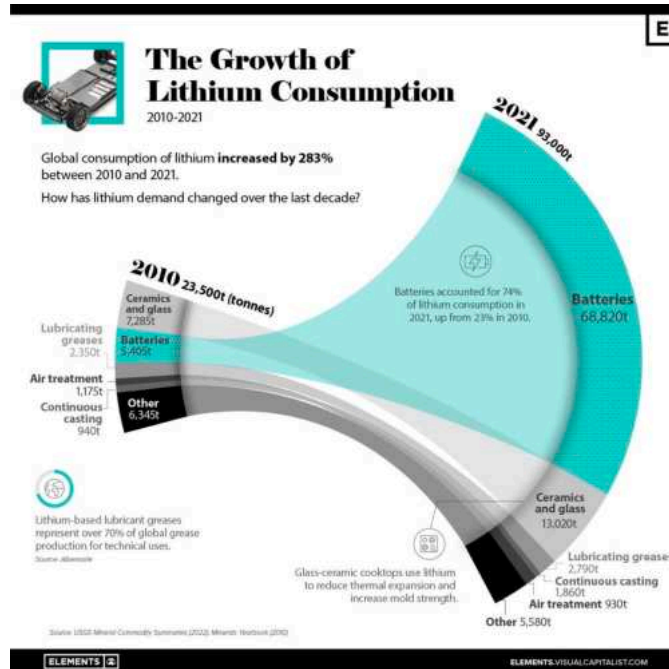
### Factors Decreasing Price

- ✓ 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

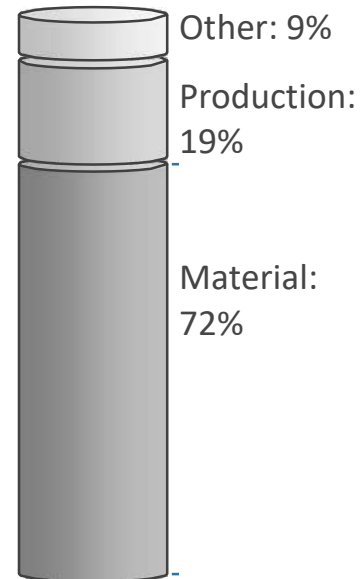
### Factors Increasing Price

- ✓ Rising commodity prices (Li, Co, Ni)
- ✓ Increased costs for key materials (e.g. electrolytes)

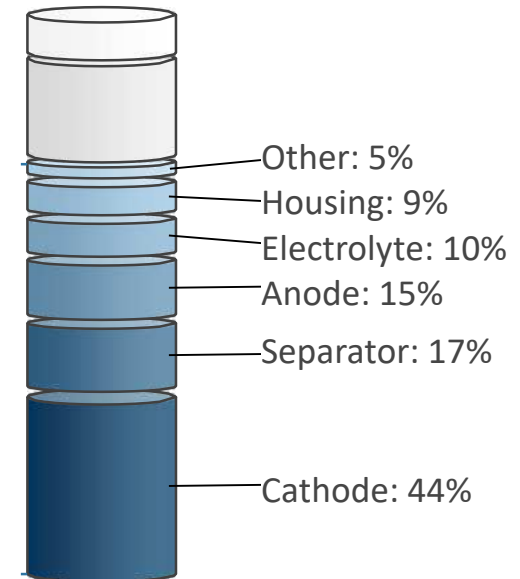
## Materials



### Total cost

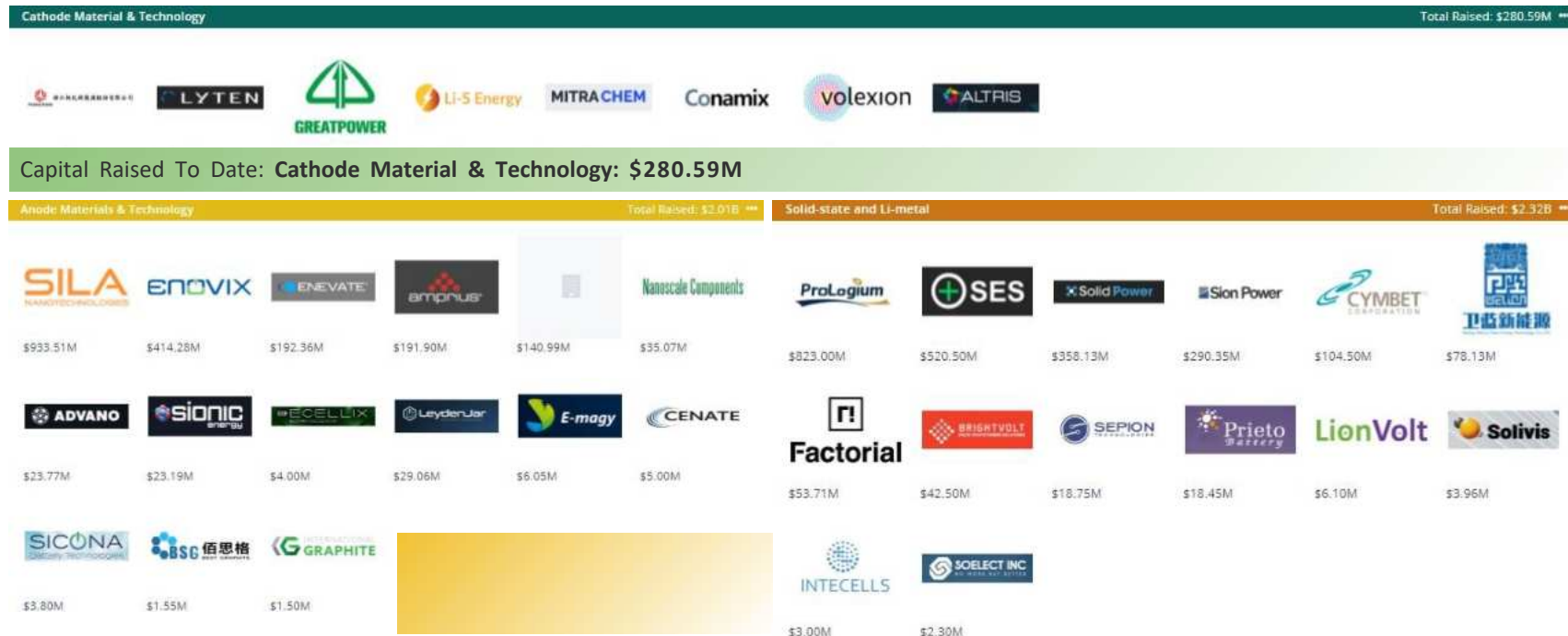


### Cost of materials



Source: Bloomberg, BNEF Battery Price Survey

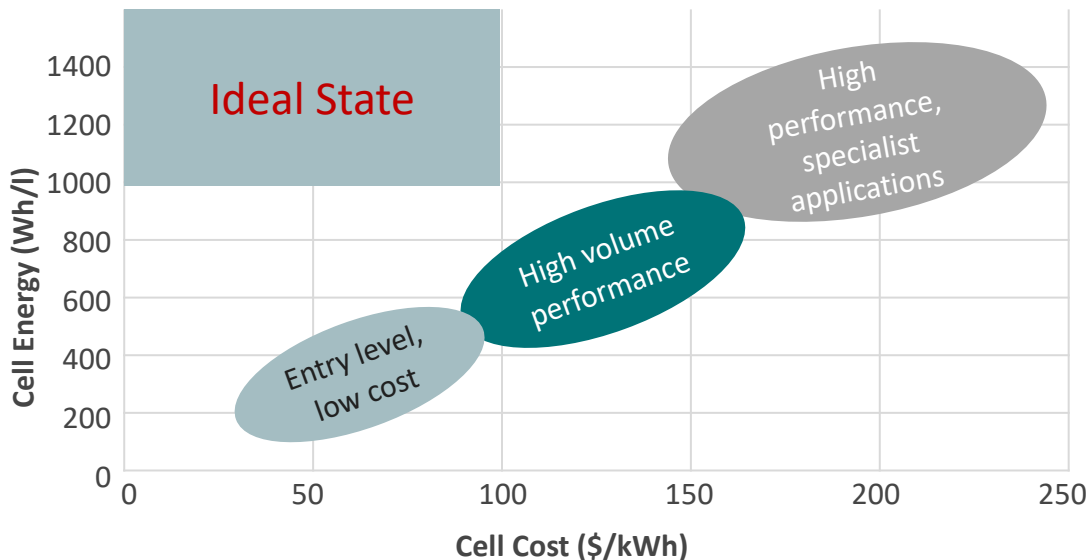
## Investment | Capital Raised in Material Innovation



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

## 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
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### High volume performance

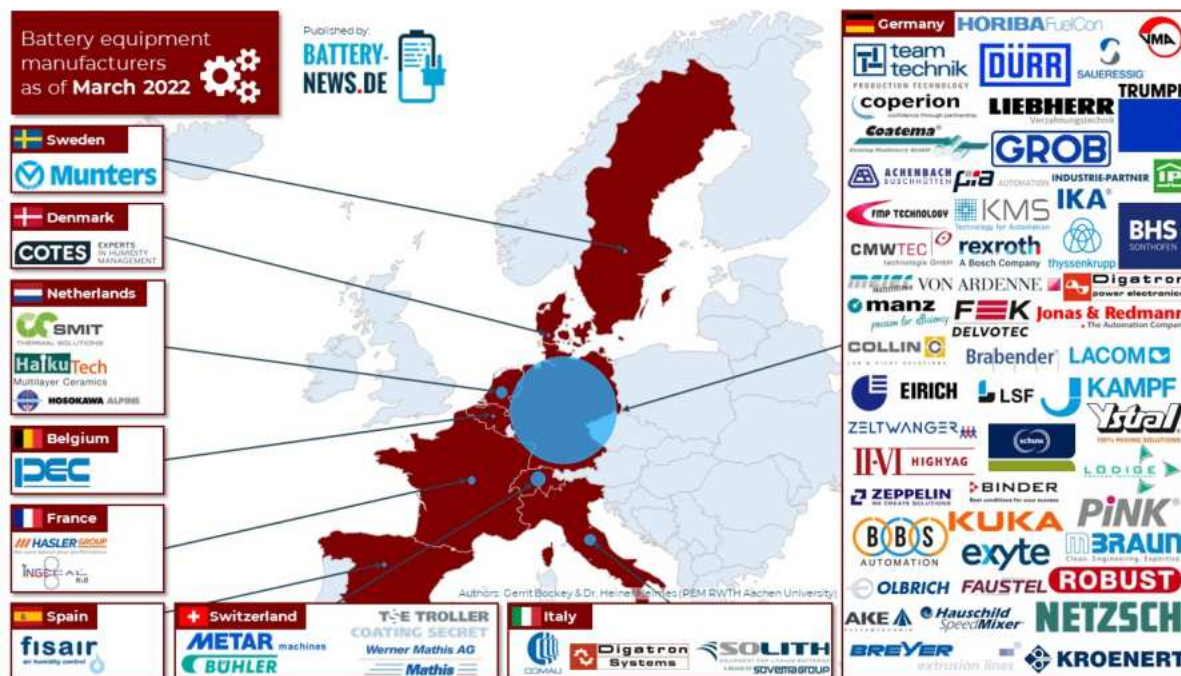
NCA	NMC	NCMA	eLNO	Gr-Si Blend Anodes	Mn-rich
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### High performance, specialist application

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

## Battery equipment manufacturers in Europe



## Li-on developments – Equipment supply chain


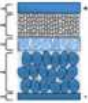
A key challenge is to integrate the individual technologically diverse process steps into a robust production chain.

**Suppliers of machinery & equipment along the process chain of battery cell production**

		Production process steps (excerpt)					
		mixing	coating	calendering	slitten	vacuum	
Machine & plant operators (excerpt)	Bühler						Machine & equipment builder owns competences in the production process step
	Netzsch						
	Eirich						
	Hohsen						
	Coatema						Machine & equipment builder does not have any competencies in the production process step
	B&W						
	Hirano						
	Kroenert						
	Breyer						
	Saueressig						
	Kampf						
	Meier						
	...						

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

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

Product features		Production acceptance and machine data		
<b>Performance characteristics</b> ✓ 5,2 AH ✓ 3,68 V ✓ 290 Wh/kg ✓ 790 Wh/l		<b>Production capacities</b> ✓ 14 GWh/a ✓ 731.600.000 Cells/a		<b>Layer model</b> ✓ 301 d/a, 3 layers/d, 8 h/layer
		<b>Machine data</b>		
		<b>Mixing</b> ✓ Mixing volume 300 l ✓ Mixing time 45 min.	<b>Coating and drying</b> ✓ Coating width 800 mm ✓ Coating speed 30 m/min.	<b>Calendering and slitting</b> ✓ Calendering width 800 mm ✓ Calendering speed 100 m/Min.
<b>Cell format/-dimensions/-weight</b> ✓ Cylindrical ✓ 21 mm diameter, 70 mm height ✓ 66 g		<b>Vacuum drying</b> ✓ Coils / Dryer 4 ✓ Drying time 24 h	<b>Attach contact flags</b> ✓ Cells / welding machine 6 ✓ Welding duration / contact lug 5 sek.	<b>Winding</b> ✓ Cells / Winding line 2 ✓ Winding time / cell 2,6 sek.
<b>Cell chemistry</b> ✓ Electrodes: Graphite vs. NMC622 ✓ Electrolyte: EC:DMC + LiPF6 ✓ Separator: Polyolefin base with ceramic coating		<b>Fill electrolyte</b> Cells / Filling system 500 Filling time / cell 840 sek.	<b>Krimpen</b> ✓ Cells / crimping plant 8 ✓ Crimping duration /cell 3 sek.	<b>Forming</b> ✓ Cells / storage system 4.500 ✓ Forming time / cell 15 h
<b>Cell design</b> Aluminum foil thickness 12 µm Cathode coating thickness 71 µm Separator 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		<b>Aging</b> ✓ Cells / Charging system 5 Mio. ✓ Aging duration / cell 20,5 d		
		<b>Testing and packing</b> ✓ Cells / Charging system 4.500 ✓ Charging time / cell 30 min.		

# Gigfab calculation

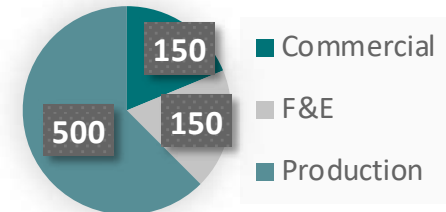
Exapmle design of a battery cell factory with an annual output of 14 GWh

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 <sup>2</sup>
Housing	731,6 mio.

Example of a layout for battery cell production



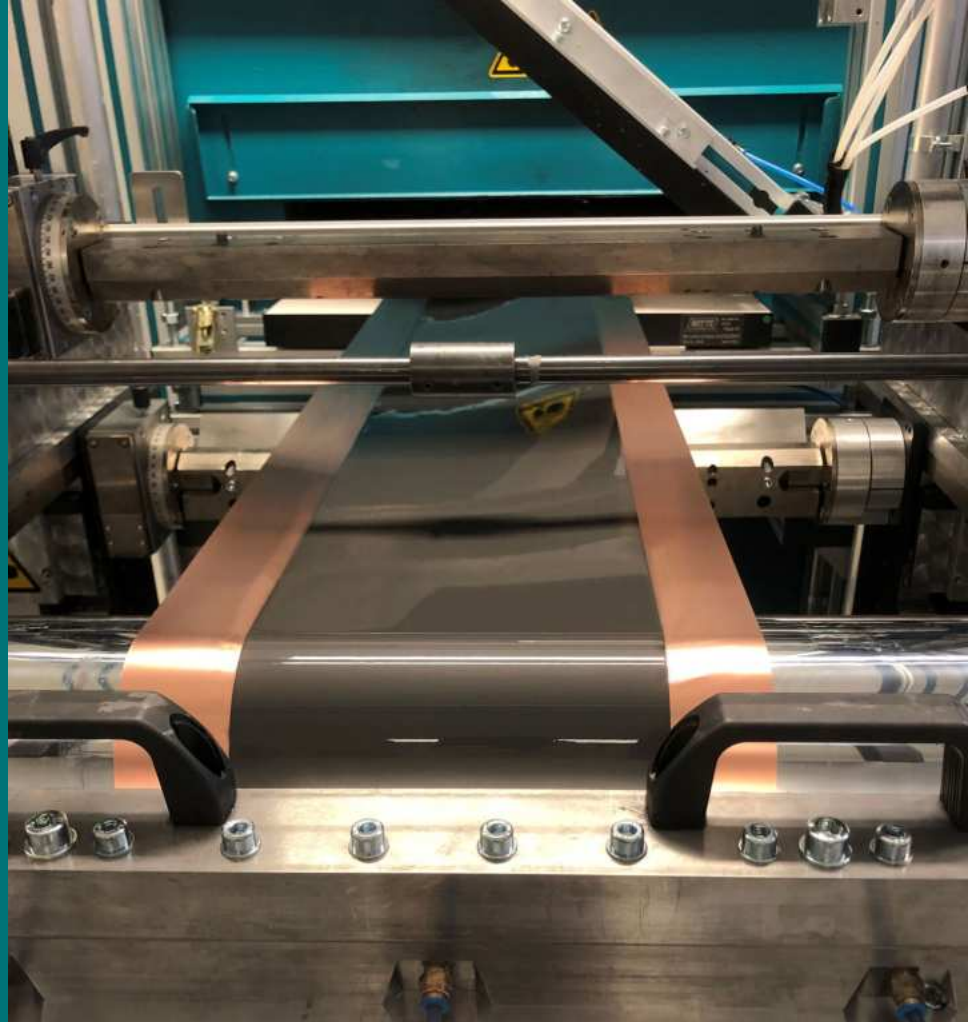
Personnel requirements



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 <sup>2</sup>				

# 3.

## 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



Today's equipment for batteries

## Proof of concept – Li-ion battery Project INTRES

Upscaling of new battery tech



*Test Solution 2S2 (Tabletop)*

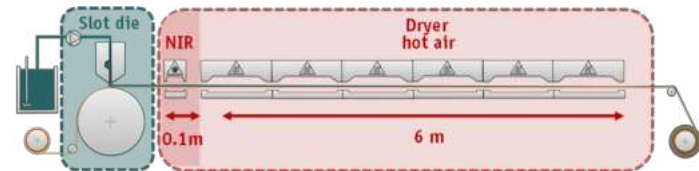
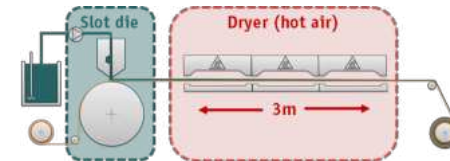


*Smartcoater*



*Click&Coat® pilot line*

Lab-scale R2S



Scale up for R2R processes

## Transfer of parameters and processes in to equipment design



Test Solution



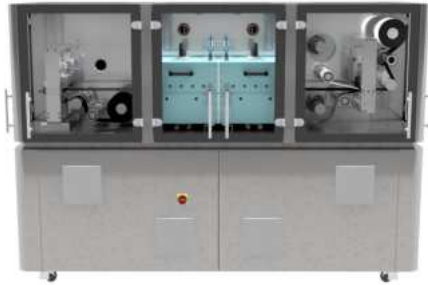
Easycoater



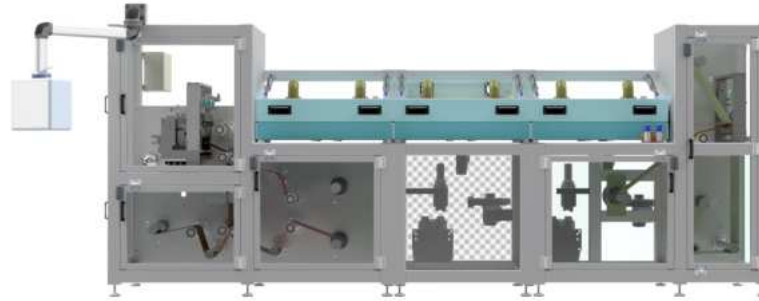
Easycoater Evolution

Scale up for R2R processes

## R2R lab systems



Test Solution R2R



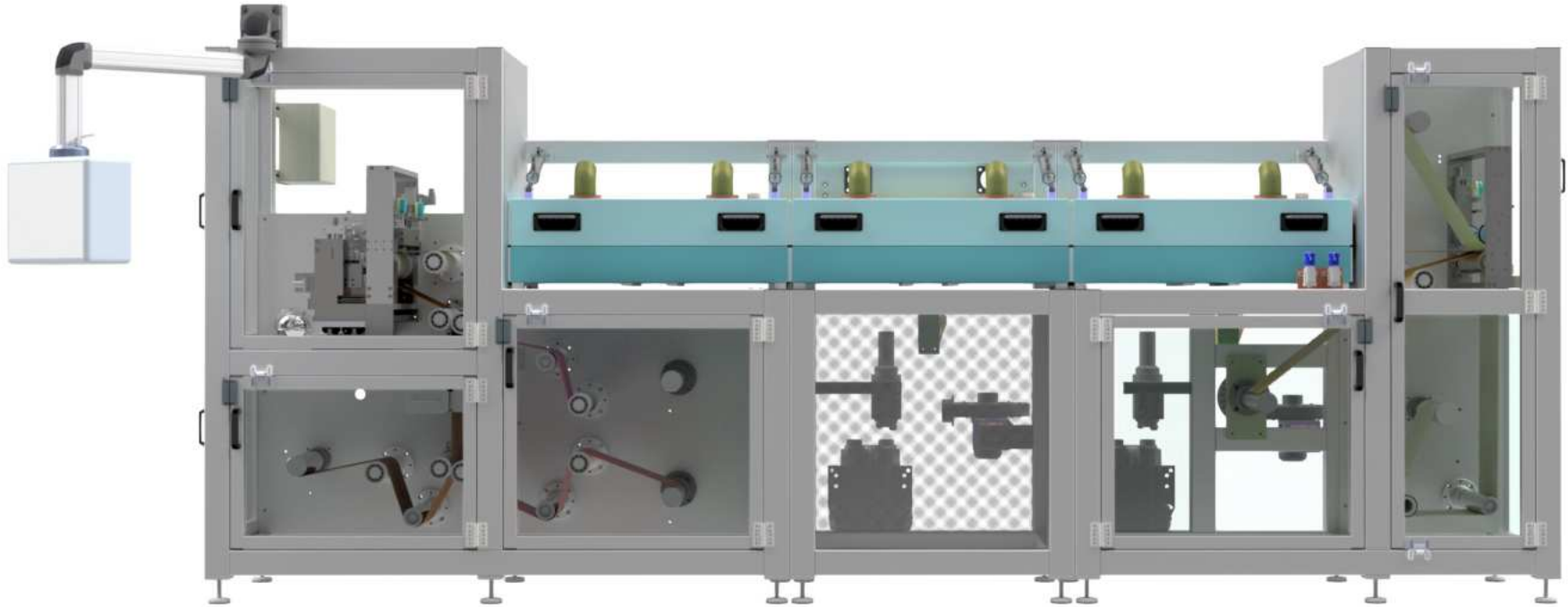
Basecoater R2R



Smartcoater R2R

Today's equipment for batteries

## The Basecoater



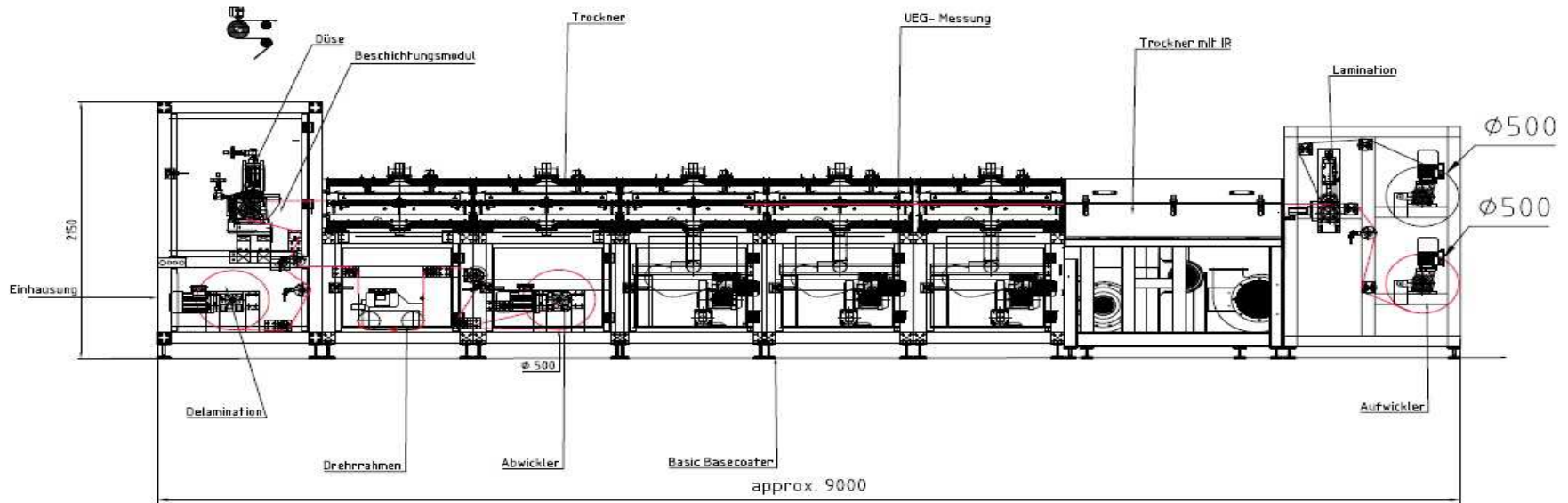
Today's equipment for batteries

## The Basecoater



Today's equipment for batteries

## The Basecoater



Today's equipment for batteries

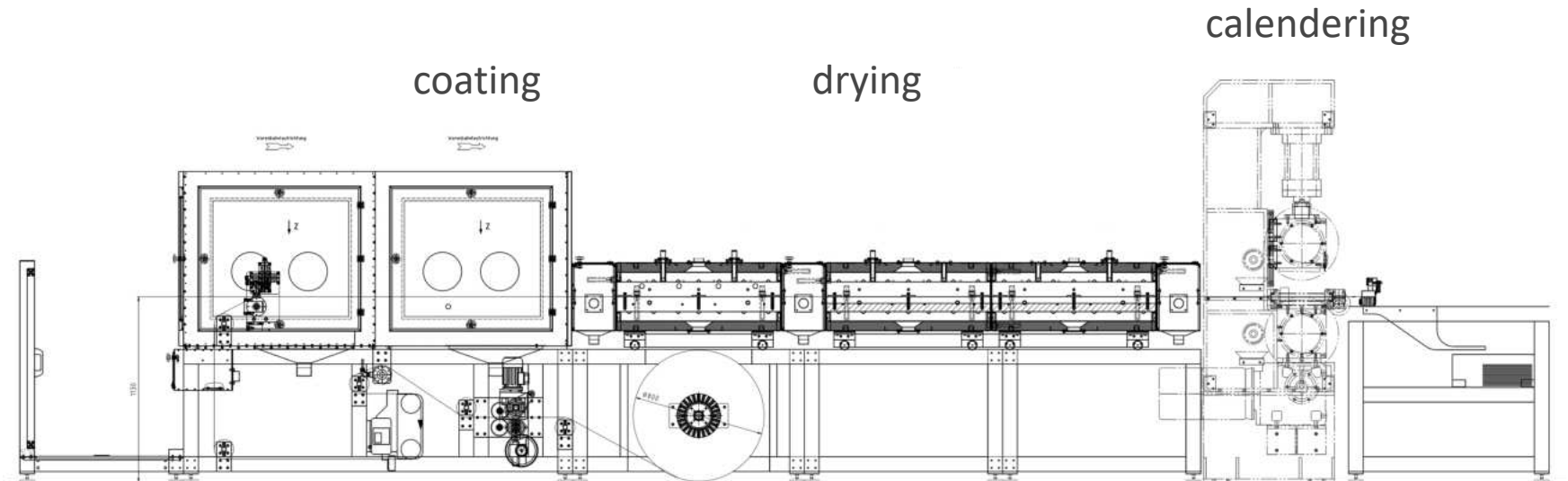
## Bespoke Basecoater battery equipment



- ✓ Oxygen content < 3%
- ✓ Saturated solvents below LEL
- ✓ IR Drying
- ✓ 50m<sup>3</sup>/h N<sub>2</sub> flow

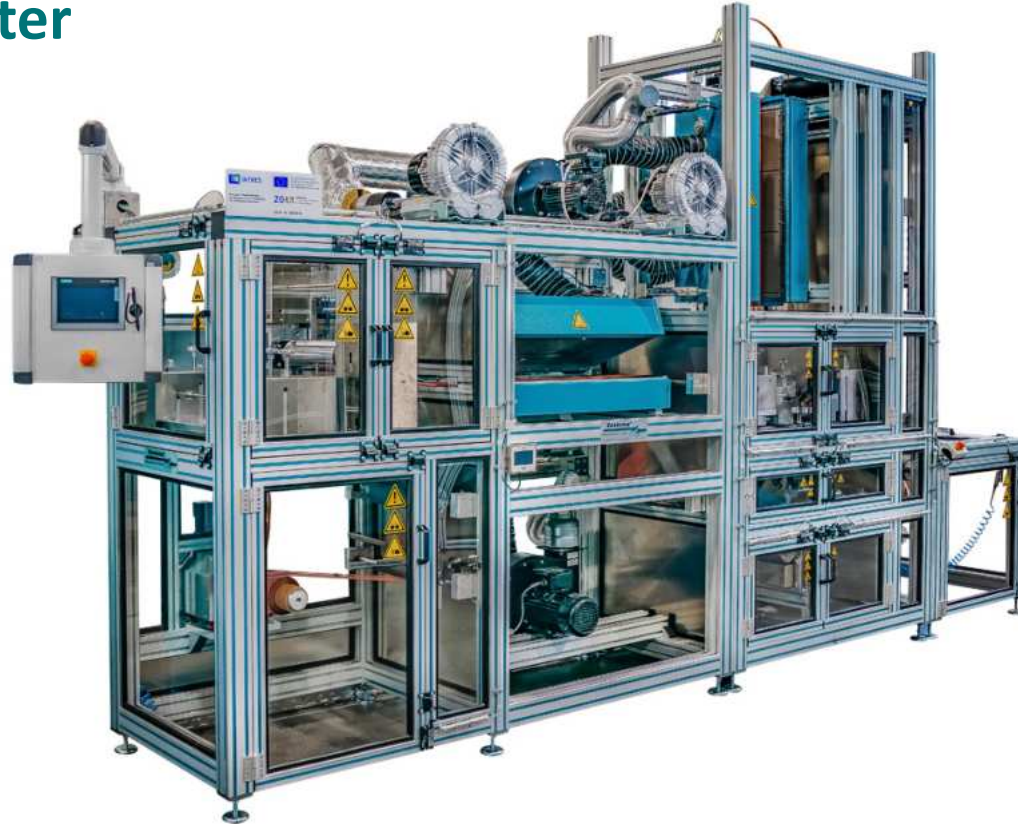
Today's equipment for batteries

## Bespoke Basecoater battery equipment



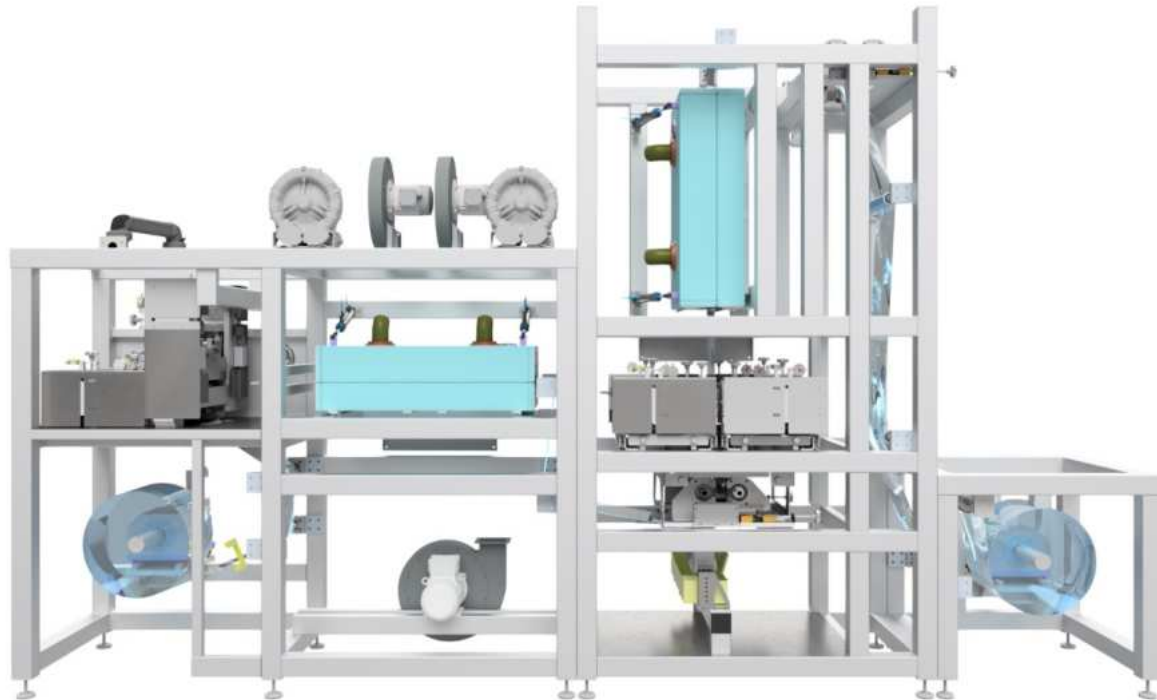
Today's equipment for batteries

## The Basecoater



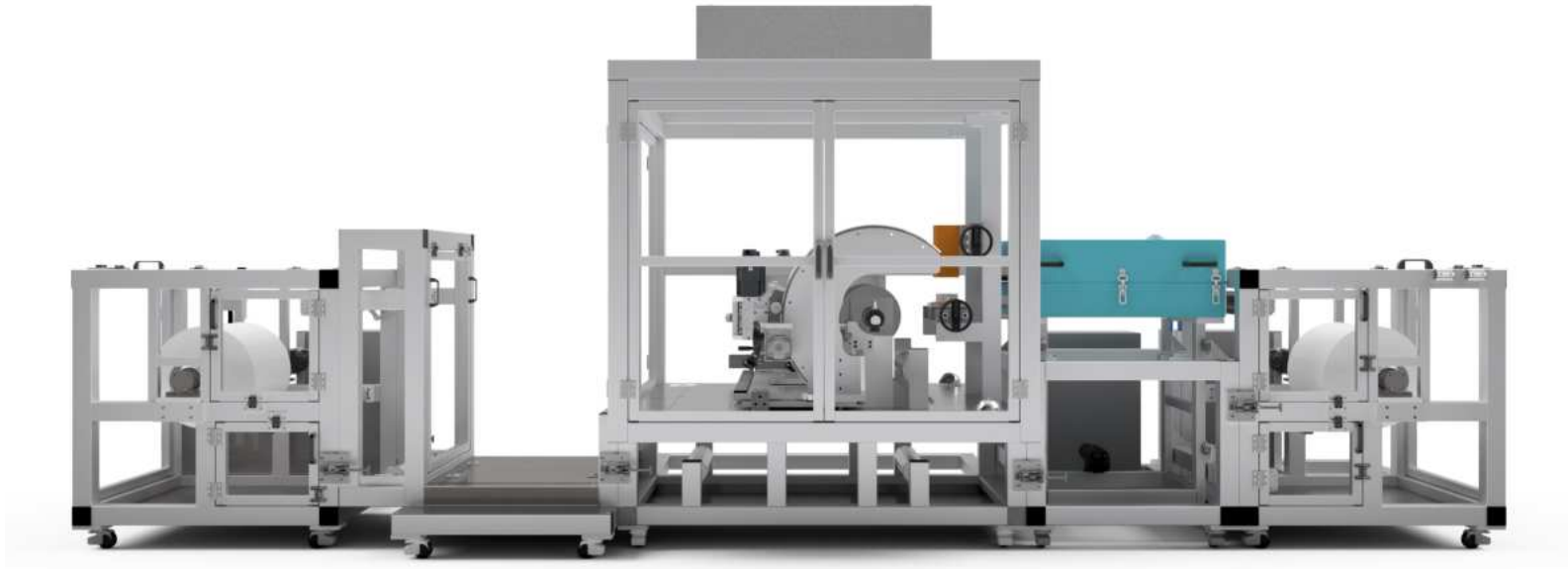
Today's equipment for batteries

## The Basecoater



Today's equipment for batteries

## The Click&Coat™



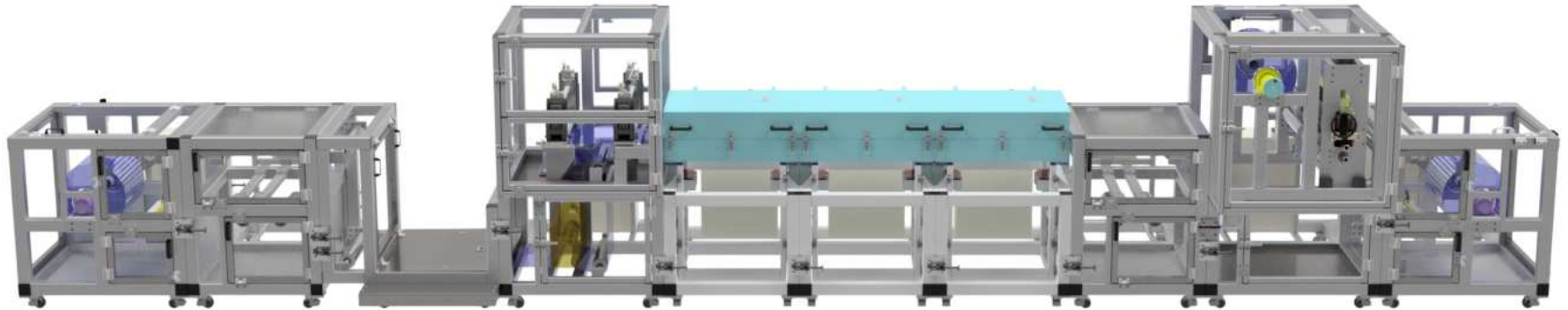
Scale up for R2R processes

## The Click&Coat™



Today's equipment for batteries

## The Click&Coat™



Today's equipment for batteries

## The Click&Coat™



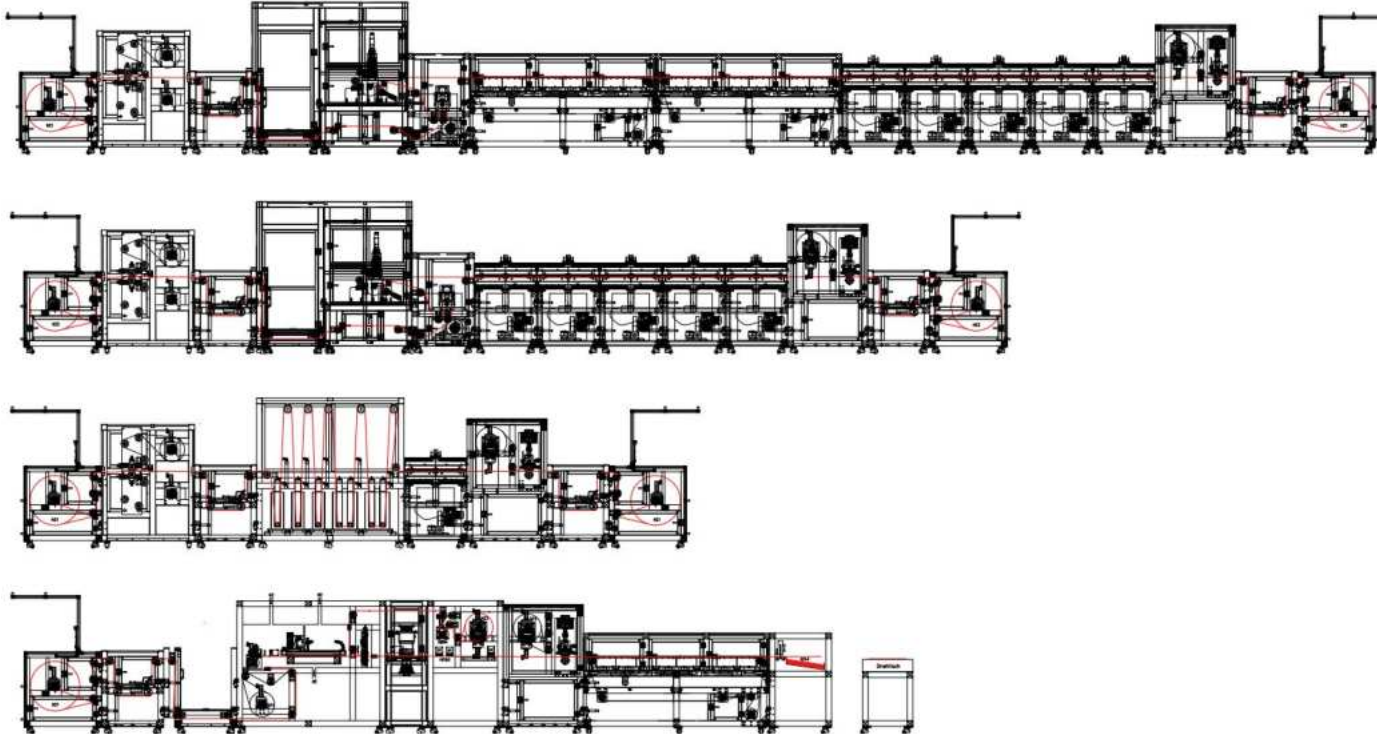
Today's equipment for batteries

## The Click&Coat™



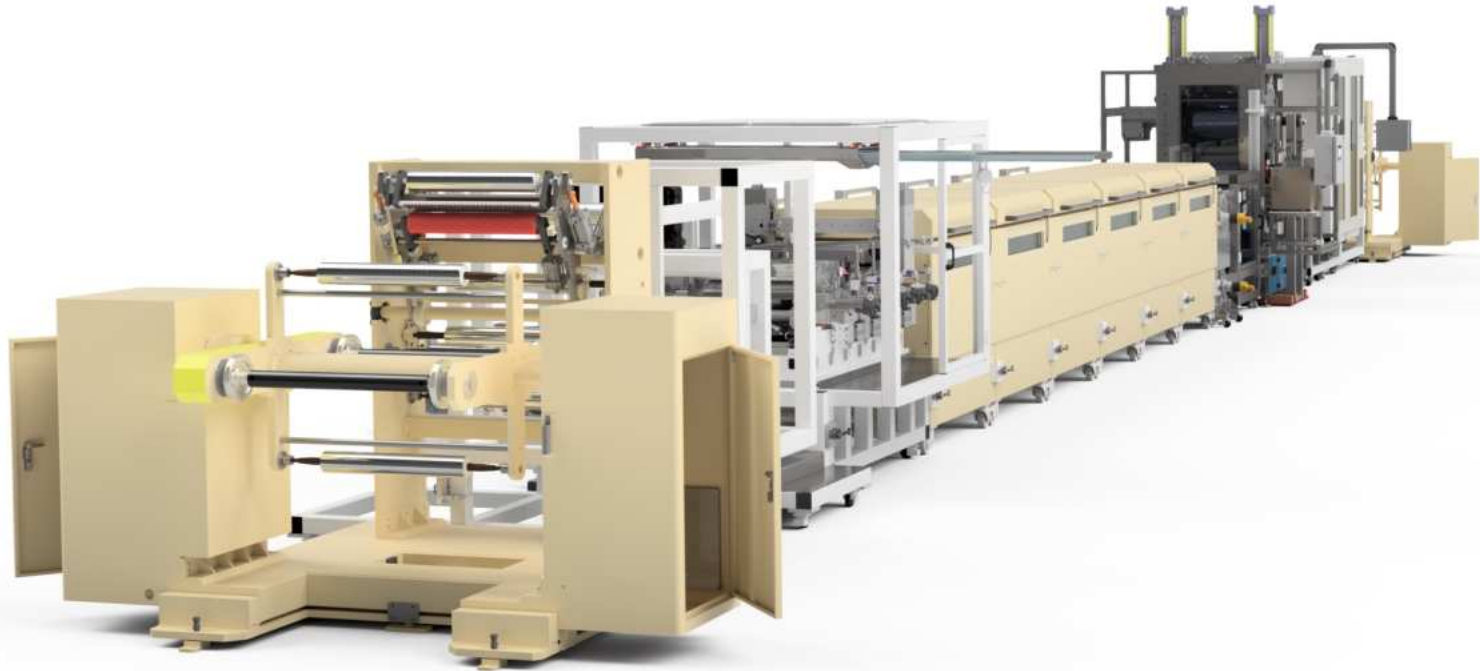
Today's equipment for batteries

## Specific battery equipment in Click&Coat™ layout

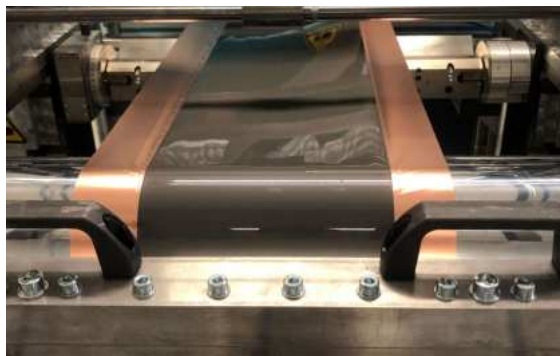
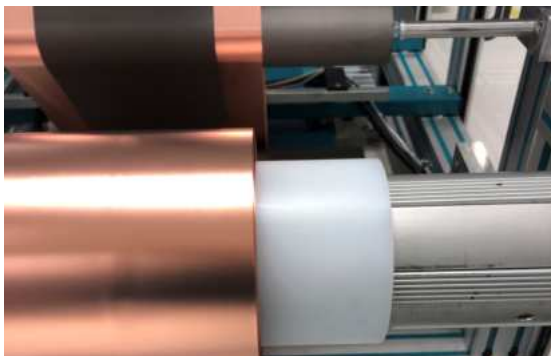
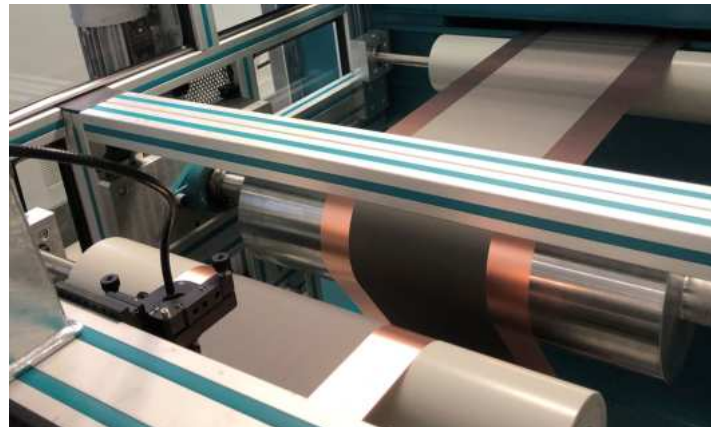
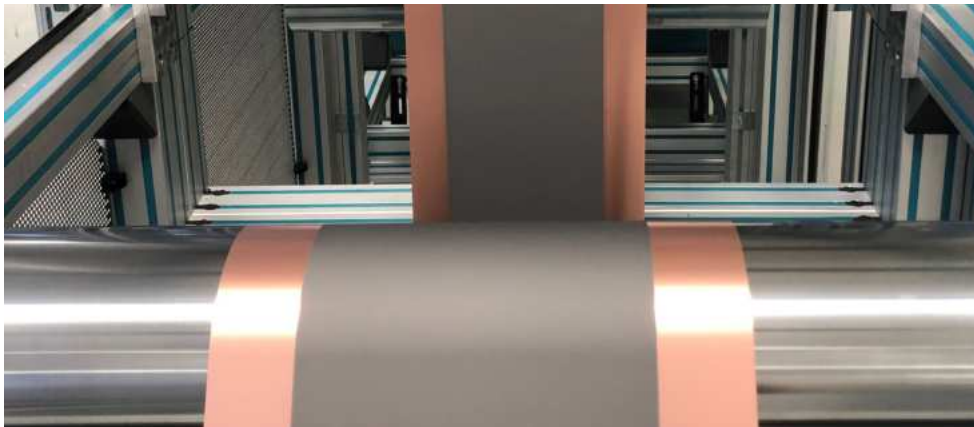


Today's equipment for batteries

## The Click&Coat™ in production scale

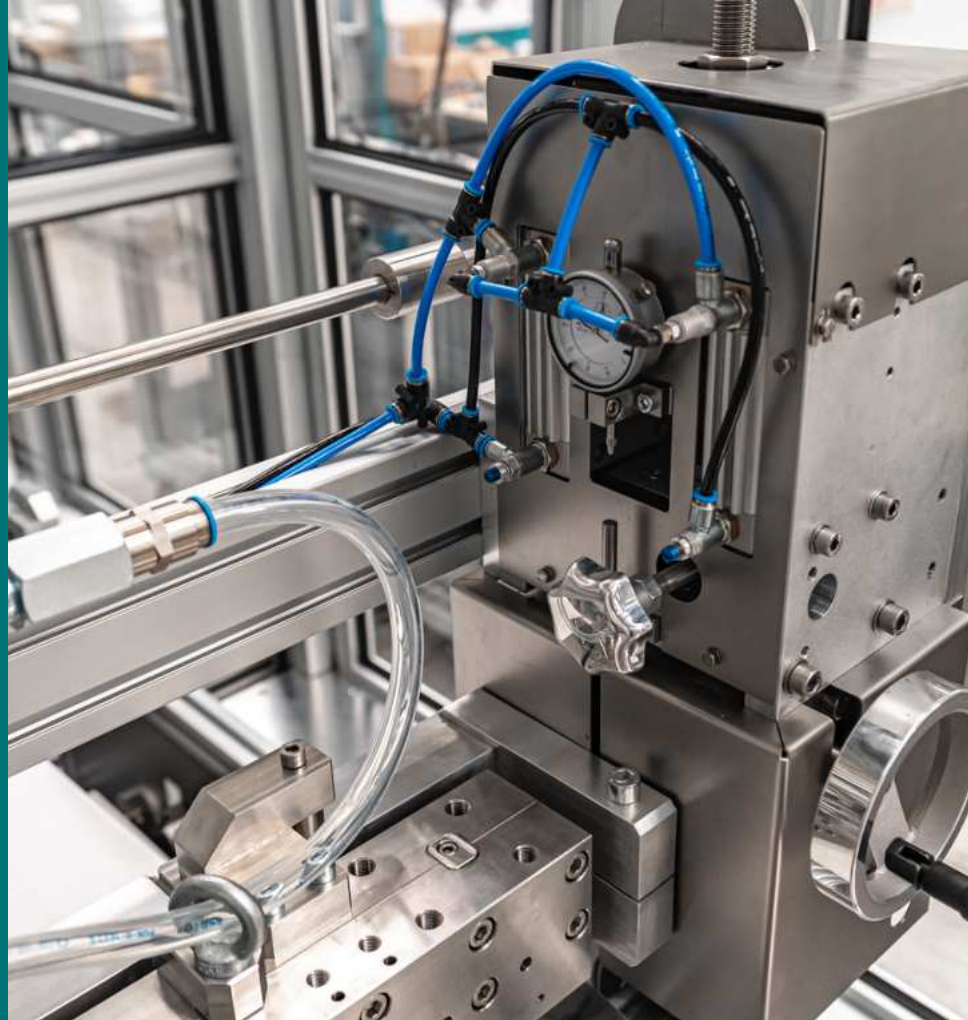


# Today's equipment for batteries



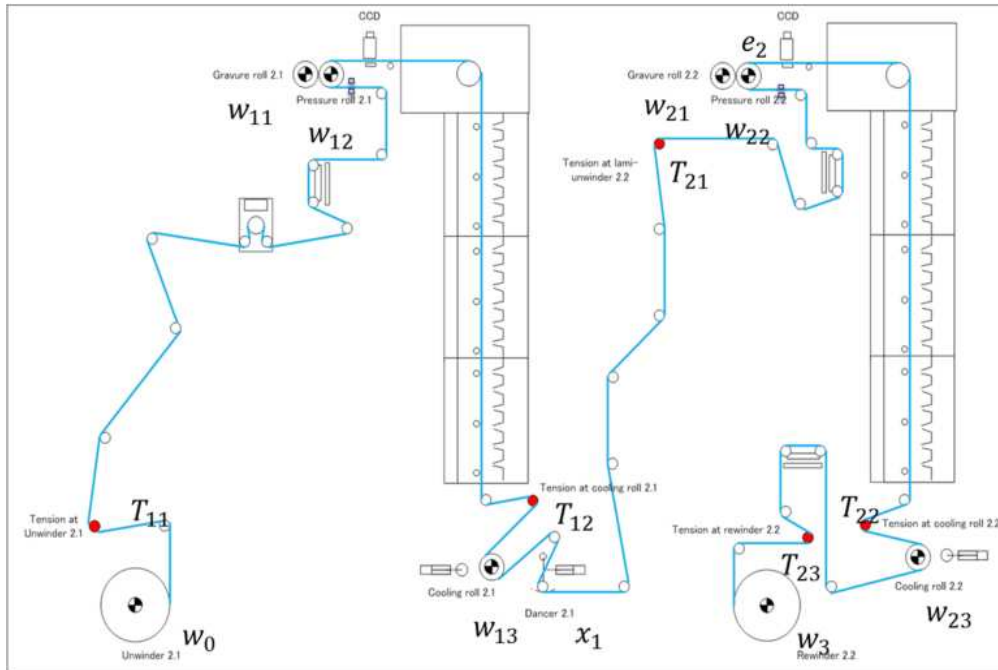
# 4.

## Process control



## The basic idea of R2R processes

# 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



## 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 intelligence

## Inline process integration and measuring points

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

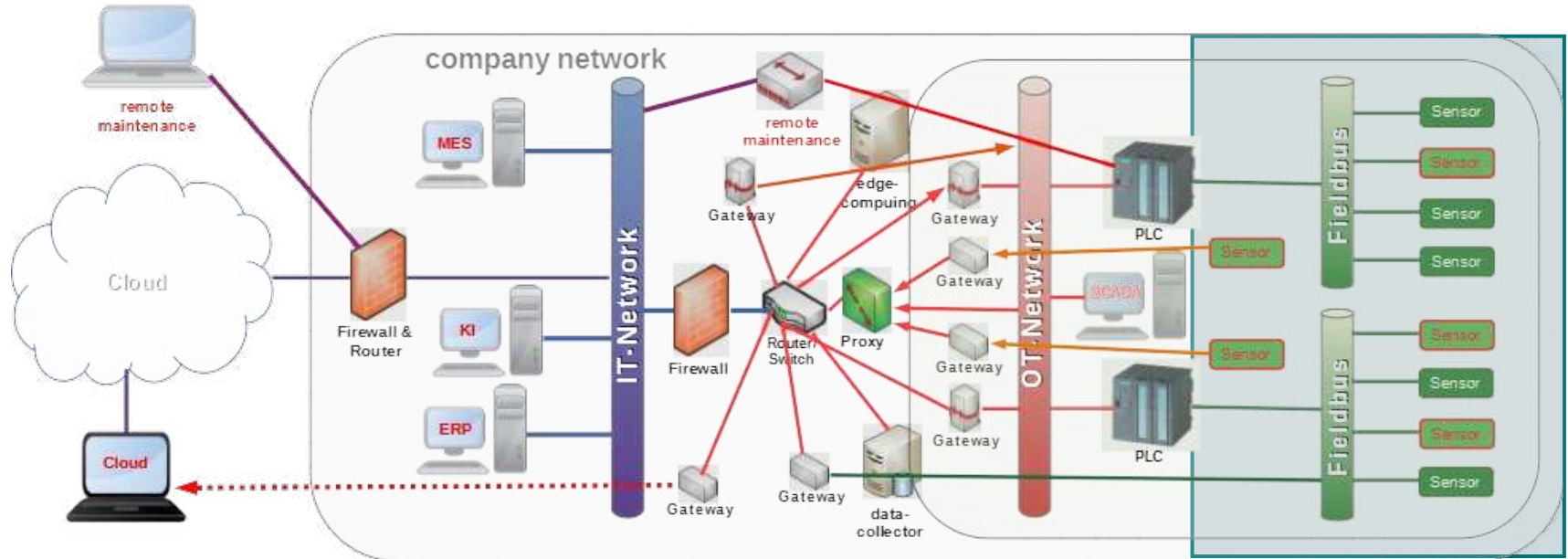


Unwinder	OET 4 Axis system	3m dryers	ps laser	OET 4 Axis system	Ink jet	3m dryers	IPL	In-line optical metrology (SE, Raman)	LBIC	Rewinder
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- Number of measuring points
- Amount of measurements per time



## Complexity introduced through connectivity



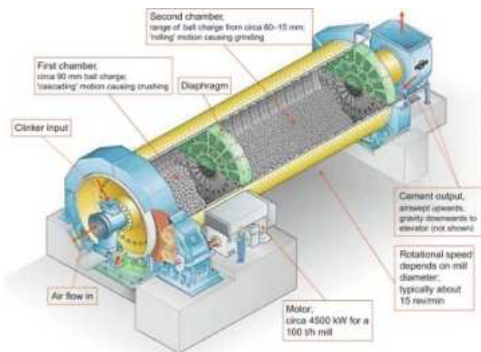
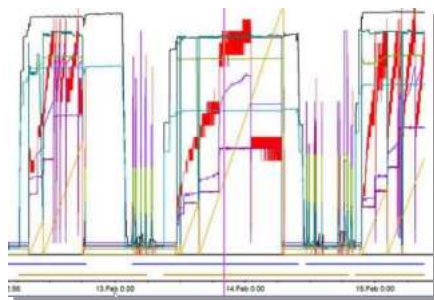
Heterogeneous connectivity landscape:  
complex, prone for errors, multiple penetration points, difficult to maintain, ....

## From lab 2 fab



Data generation in million of data points

## Solution based approach



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

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

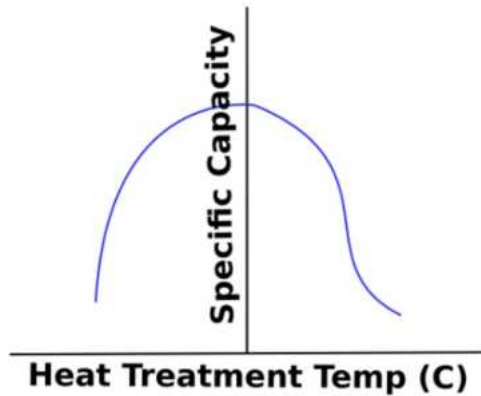


**Diagnostics**  
Root cause analysis (e.g. damaged bearings, clogged filter, ...)

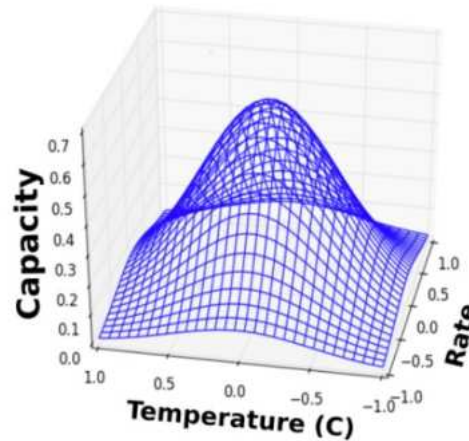
**Control**  
Maintaining productivity (e.g. increasing viscosity)

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

## Understanding the data



A



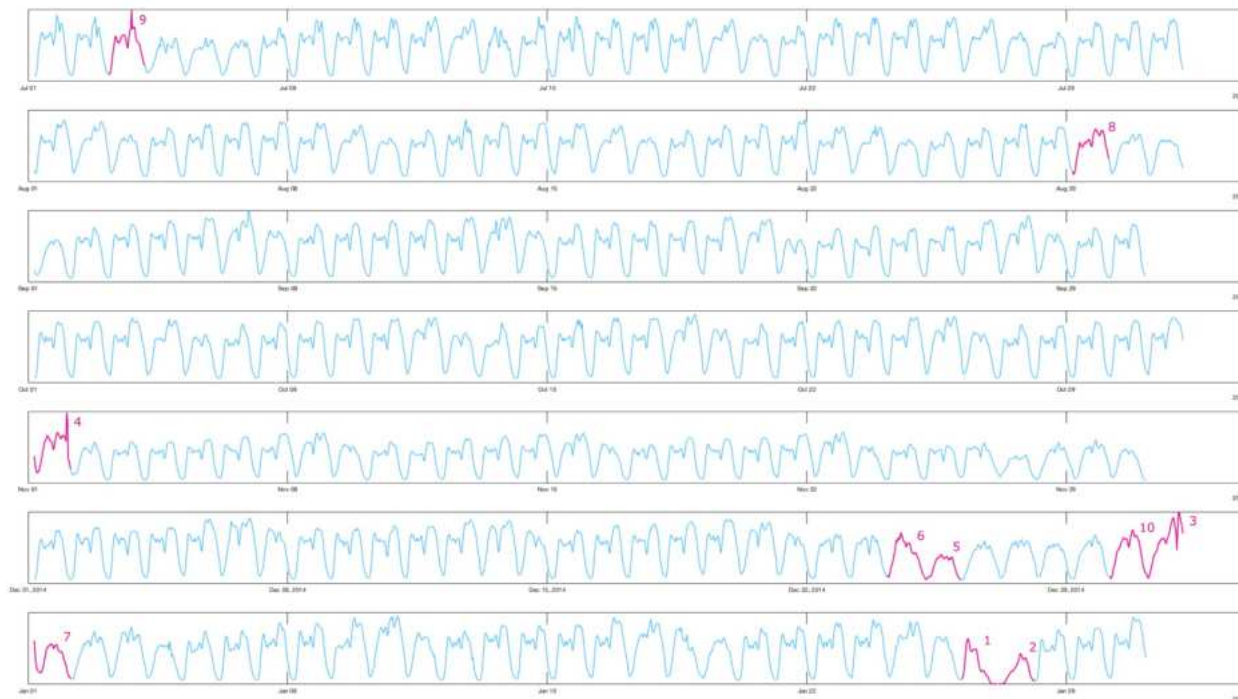
B

**Target of all the efforts:**

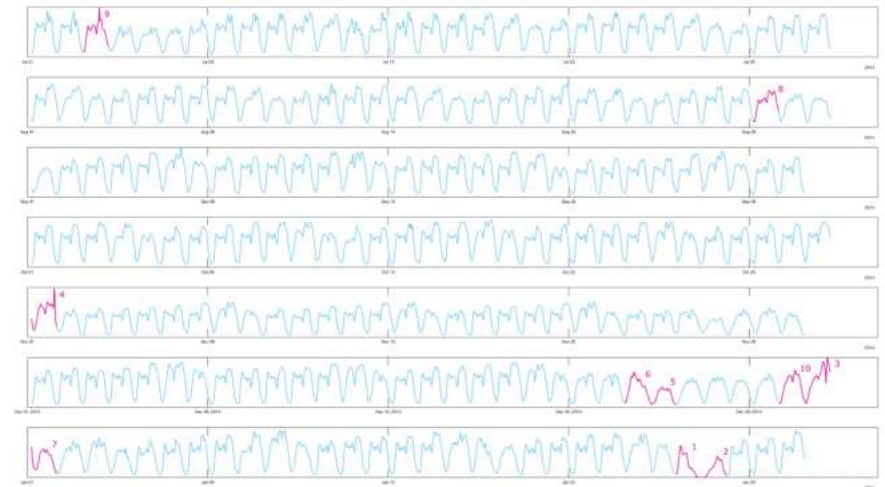
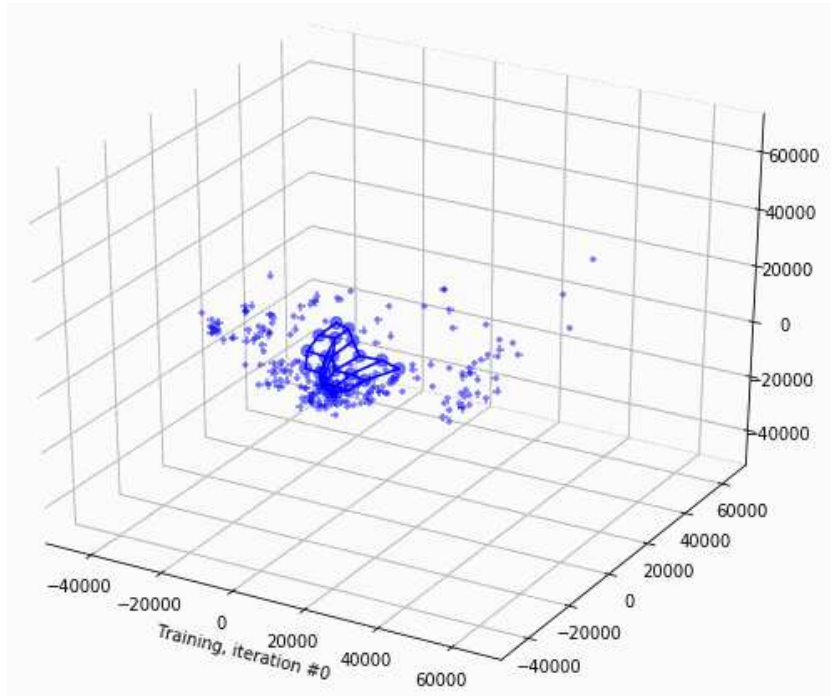
Finding the parameters  
which will lead to failure

Reducing the number of  
parameters to be controlled

## Automatic anomaly detection for time series



## ... what the algorithm is doing



# 5.

## Coating systems



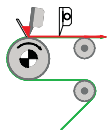
## Coating parameters

Coating chemistry	Coating processes	Process control	Drying
<ul style="list-style-type: none"> <li>✓ Rheology</li> <li>✓ Viscosity</li> <li>✓ Viscoelasticity</li> <li>✓ Type of solvents</li> <li>✓ Solid content</li> <li>✓ Van der Waals force</li> <li>✓ Shear ratio</li> <li>✓ Adhesion/Cohesion</li> </ul>	<ul style="list-style-type: none"> <li>✓ Coating systems</li> <li>✓ Single or multilayer coatings</li> <li>✓ Direct coatings</li> <li>✓ Transfer (indirect) coatings</li> <li>✓ Substrate speed</li> <li>✓ Layer thickness</li> <li>✓ Coating accuracy</li> </ul>	<ul style="list-style-type: none"> <li>✓ Process layout</li> <li>✓ Tension control system</li> <li>✓ Material guiding system</li> <li>✓ Inline parameter control</li> <li>✓ Quality control</li> </ul>	<ul style="list-style-type: none"> <li>✓ Convection drying</li> <li>✓ Contact drying</li> <li>✓ Infrared drying</li> <li>✓ Sintering</li> <li>✓ NIR</li> <li>✓ High frequency</li> <li>✓ UV crosslinking systems</li> </ul>
Substrate	Pretreatment	Environment	Finishing
<ul style="list-style-type: none"> <li>✓ Surface tension</li> <li>✓ Dimension stability</li> <li>✓ Surface structure</li> <li>✓ Contact angle</li> </ul>	<ul style="list-style-type: none"> <li>✓ Corona</li> <li>✓ Plasma</li> <li>✓ Cleaning</li> </ul>	<ul style="list-style-type: none"> <li>✓ Humidity</li> <li>✓ Temperature</li> <li>✓ Inert conditions</li> </ul>	<ul style="list-style-type: none"> <li>✓ Calendaring</li> <li>✓ Embossing</li> <li>✓ Slitting</li> </ul>

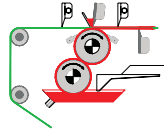
## Processes – definition of coating systems

Category of coating methods	Examples of coating methods belonging to the category	Characteristics
Self-metered	<ul style="list-style-type: none"><li>✓ Dip roll</li><li>✓ Nip forward roll</li><li>✓ Reverse roll</li></ul>	<ul style="list-style-type: none"><li>✓ Wet thickness is determined by the conditions of the coating meniscus</li></ul>
Doctored	<ul style="list-style-type: none"><li>✓ Mayer rod</li><li>✓ Blade / Knife</li><li>✓ Air knife</li><li>✓ Dip &amp; scrape</li></ul>	<ul style="list-style-type: none"><li>✓ Post applicator device determines the wet thickness</li></ul>
Pre-metered	<ul style="list-style-type: none"><li>✓ Slot die</li><li>✓ Slide curtain</li><li>✓ Spray</li></ul>	<ul style="list-style-type: none"><li>✓ All the ink fed into an applicator is transferred to the web</li></ul>

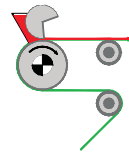
## Coating systems



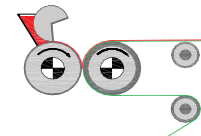
Knife system



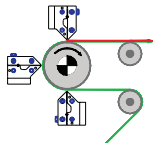
Double side coating system



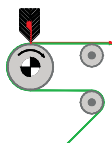
Commabar system



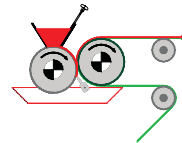
Reverse commabar system



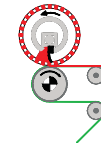
Slot die system



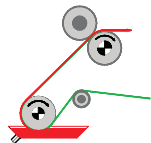
Curtain coating system



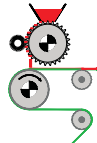
Case knife system



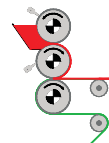
Rotary screen system



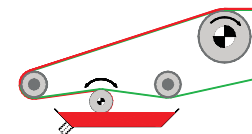
Dipping system (Foulard)



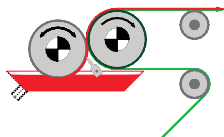
Powder scattering system



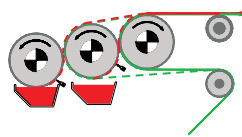
Reverse roll coating system



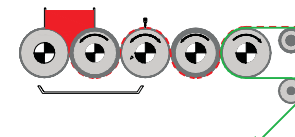
Micro roller coating system



2-roller coating system

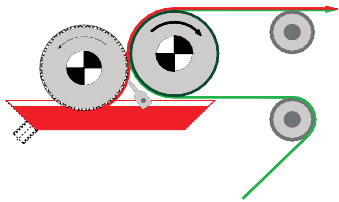


3-roller combi coating system

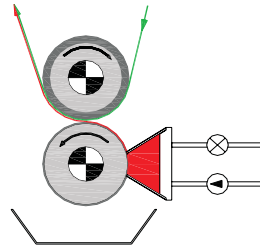


5-roller coating system

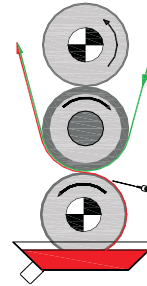
## Printing systems



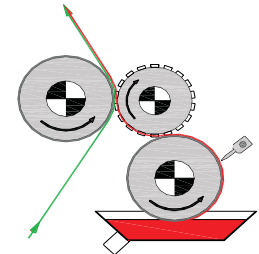
Engraved roller system



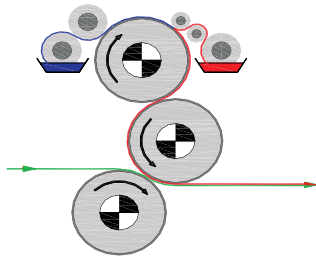
Gravure roller system



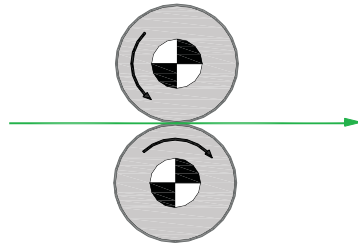
Gravure indirect system



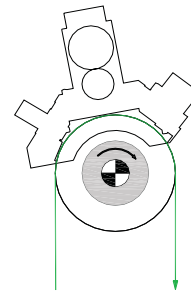
Flexography system



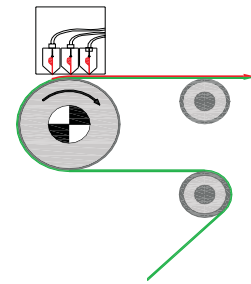
Offset lithography system



Hot embossing system

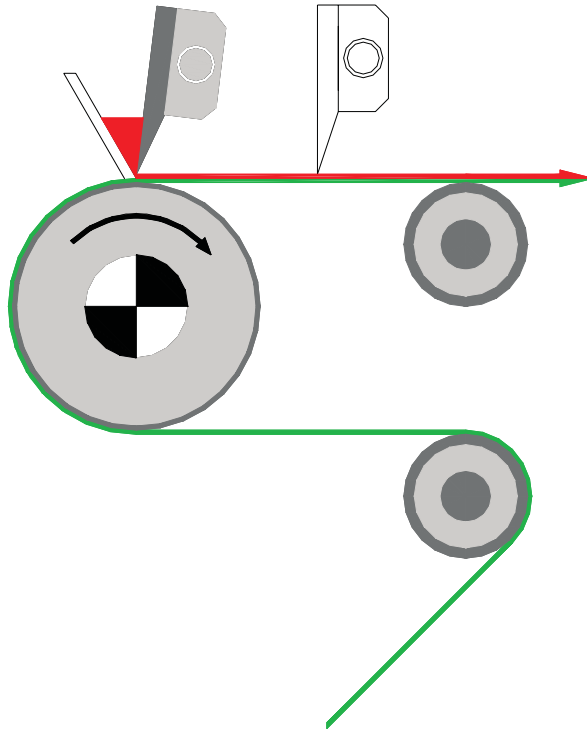


Nanoimprint system



Inkjet system

## Knife coating



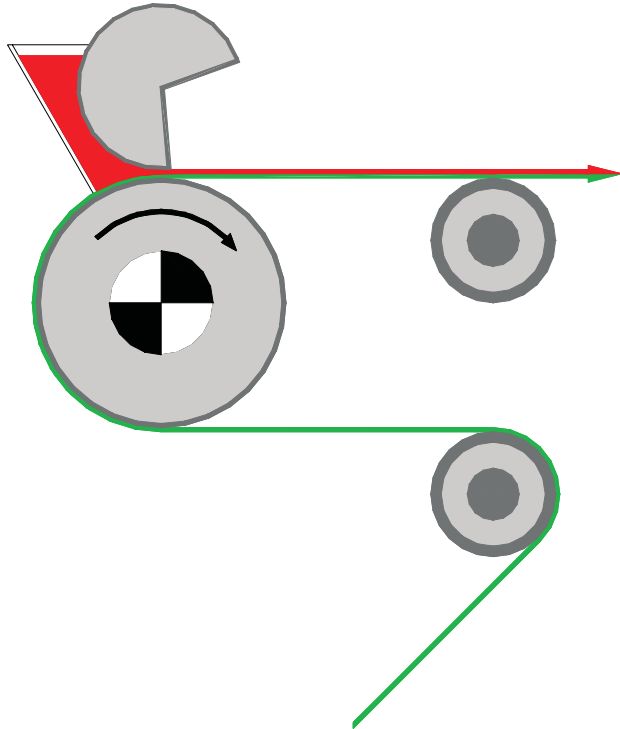
### Variation of the coating weight

- ✓ Roller knife  
10 – 1.250 g/m<sup>2</sup>
- ✓ Air knife 5 – 6 to 60 g/m<sup>2</sup>

### Range of viscosity

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

## Commabar coating



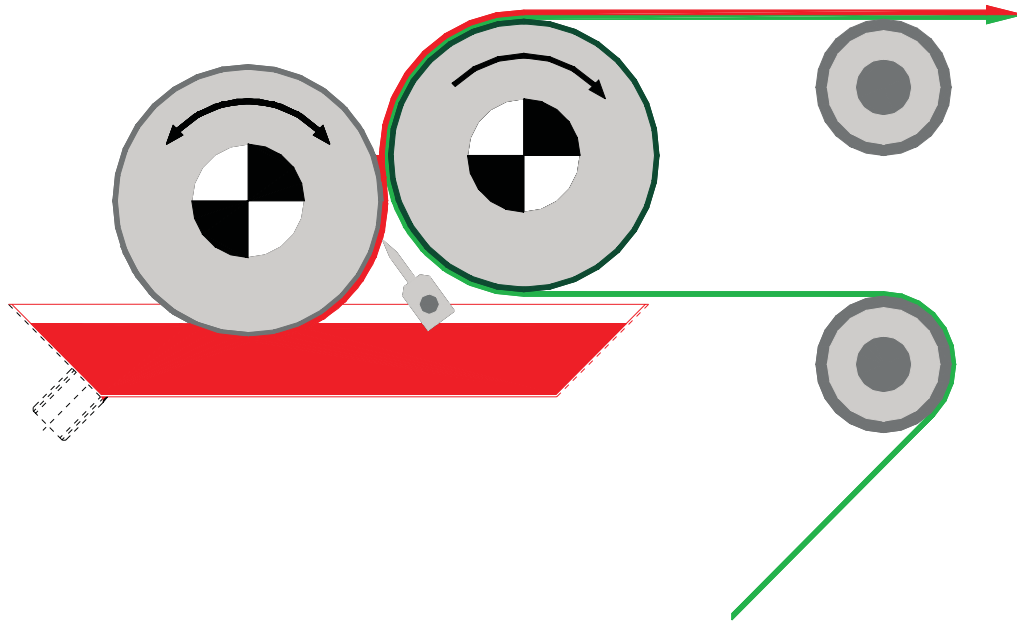
### Variation of the coating weight

- ✓ Air knife  
5 – 6 to 1.250 g/m<sup>2</sup>

### Range of viscosity

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

## Gravur coating



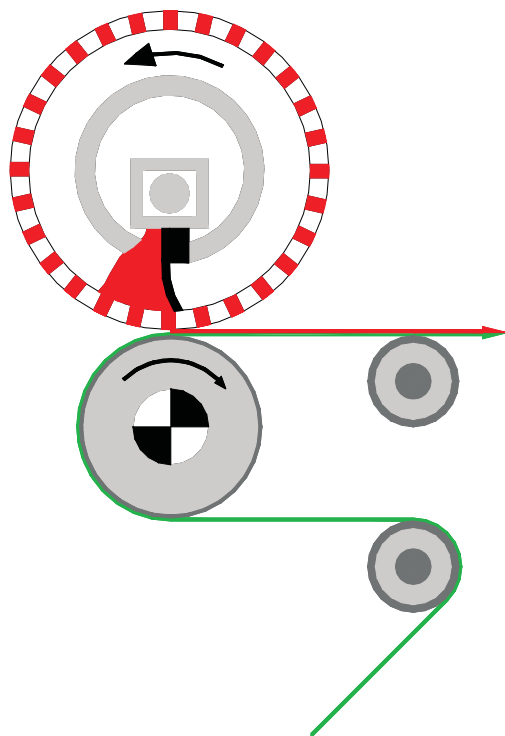
**Variation of the coating weight**

✓ 2 – 200 g/m<sup>2</sup>

**Range of viscosity**

✓ 1 – 15 000 mPas

## Rotary screen coating



### Variation of the coating weight

✓ 10 – 300 g/m<sup>2</sup>

### Range of viscosity

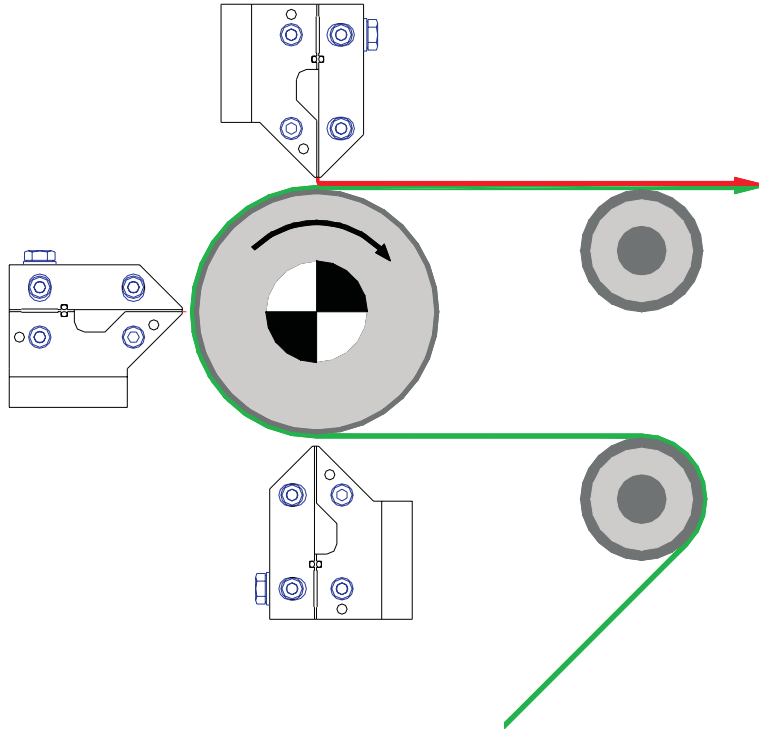
✓ Paste

10 000 – 80 000 mPas

✓ Paste

10 000 – 25 000 mPas

## Slot die coating



**Variation of the coating weight**

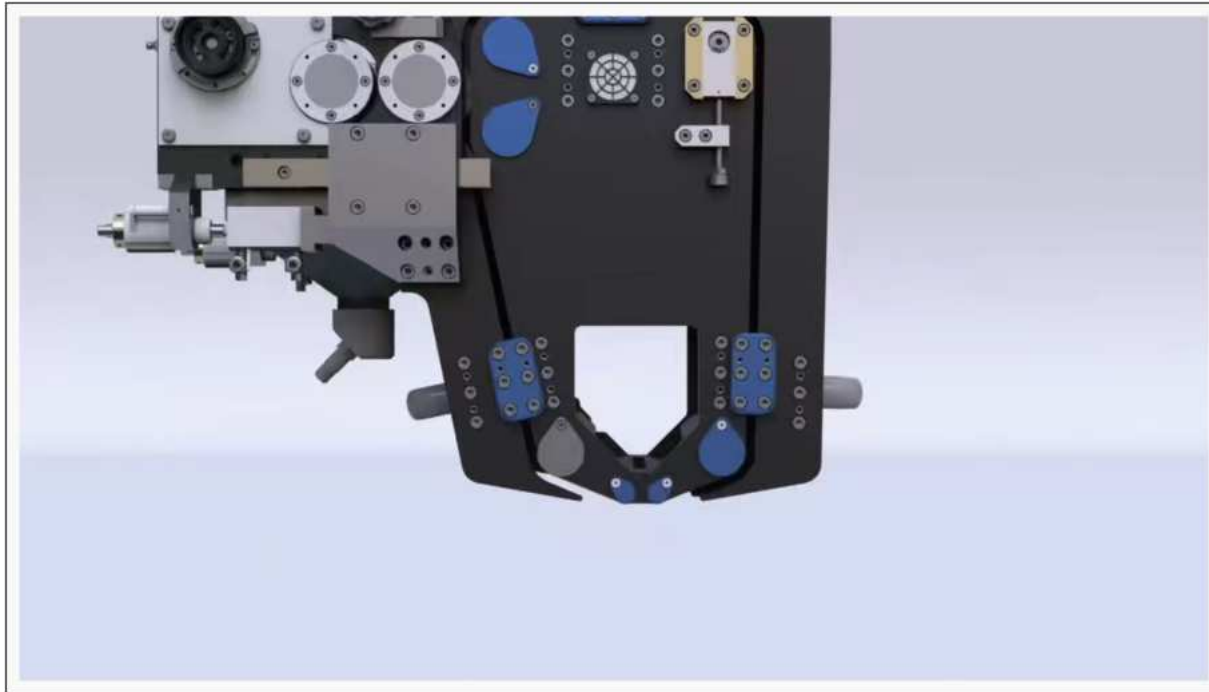
✓ 1 – 200 g/m<sup>2</sup>

**Range of viscosity**

✓ 1 – 30 000 mPas

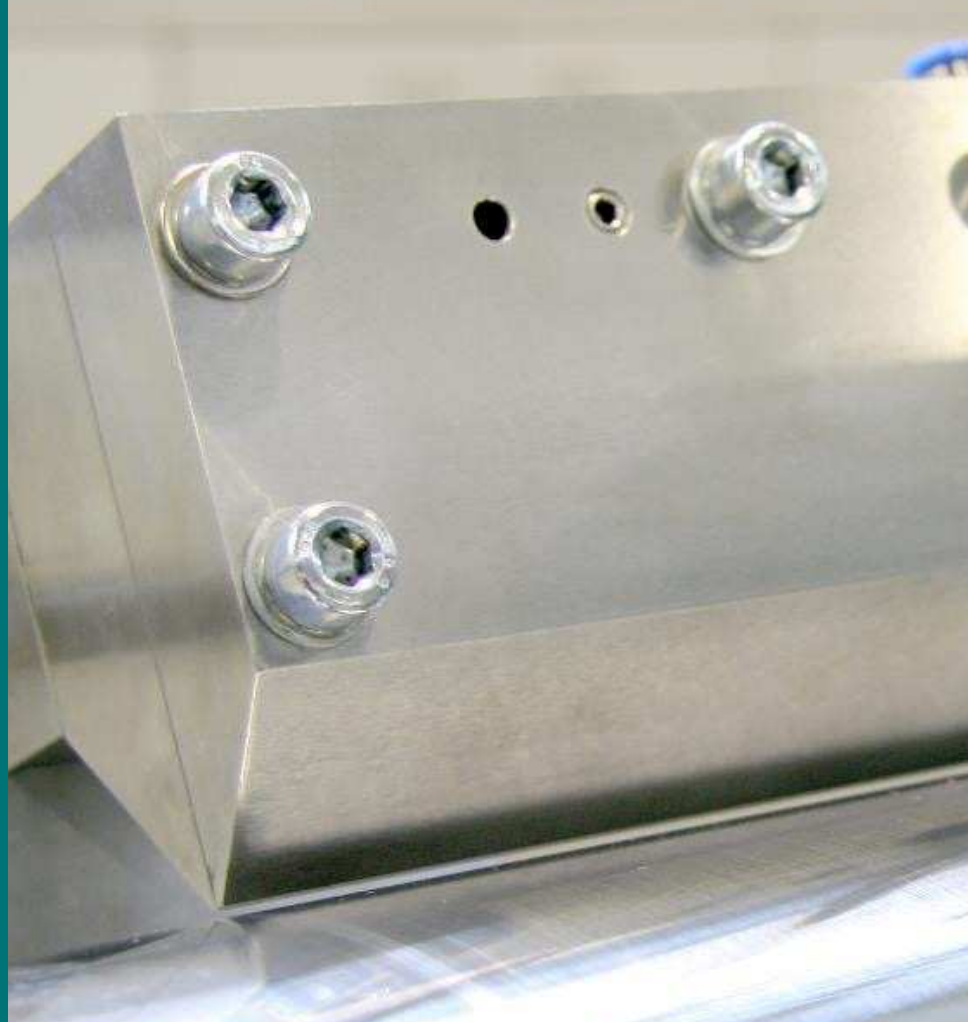


## LIFT technology for digital fabrication



# 6.

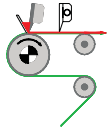
## Slot die coating for batteries



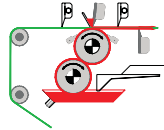
## Coating parameters

Ink properties	Coating processes	Process control	Drying
<ul style="list-style-type: none"> <li>✓ Rheology</li> <li>✓ Viscosity</li> <li>✓ Viscoelasticity</li> <li>✓ Type of solvents</li> <li>✓ Solid content</li> <li>✓ Van der Waals force</li> <li>✓ Sheer ratio</li> <li>✓ Adhesion/Cohesion</li> </ul>	<ul style="list-style-type: none"> <li>✓ Coating systems</li> <li>✓ Single or multilayer coatings</li> <li>✓ Direct coatings</li> <li>✓ Transfer (indirect) coatings</li> <li>✓ Substrate speed</li> <li>✓ Layer thickness</li> <li>✓ Coating accuracy</li> </ul>	<ul style="list-style-type: none"> <li>✓ Process layout</li> <li>✓ Tension control system</li> <li>✓ Material guiding system</li> <li>✓ Inline parameter control</li> <li>✓ Quality control</li> </ul>	<ul style="list-style-type: none"> <li>✓ Convection drying</li> <li>✓ Contact drying</li> <li>✓ Infrared drying</li> <li>✓ Sintering</li> <li>✓ NIR</li> <li>✓ High frequency</li> <li>✓ UV crosslinking systems</li> </ul>
Substrate	Pretreatment	Environment	Finishing
<ul style="list-style-type: none"> <li>✓ Surface tension</li> <li>✓ Dimension stability</li> <li>✓ Surface structure</li> <li>✓ Contact angle</li> </ul>	<ul style="list-style-type: none"> <li>✓ Corona</li> <li>✓ Plasma</li> <li>✓ Cleaning</li> </ul>	<ul style="list-style-type: none"> <li>✓ Humidity</li> <li>✓ Temperature</li> <li>✓ Inert conditions</li> </ul>	<ul style="list-style-type: none"> <li>✓ Calendaring</li> <li>✓ Embossing</li> <li>✓ Slitting</li> </ul>

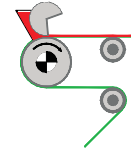
## Coating systems



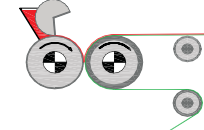
Knife system



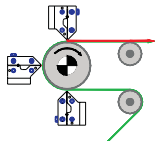
Double side coating system



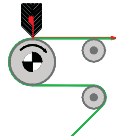
Commabar system



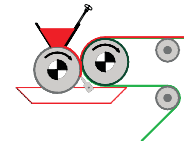
Reverse commabar system



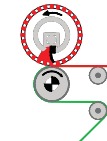
Slot die system



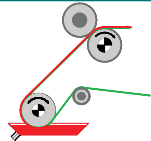
Curtain coating system



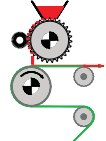
Case knife system



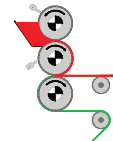
Rotary screen system



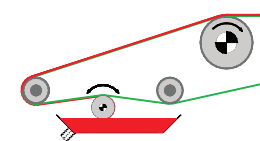
Dipping system (Foulard)



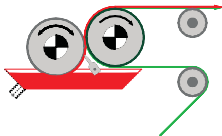
Powder scattering system



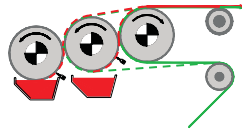
Reverse roll coating system



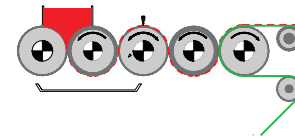
Micro roller coating system



2-roller coating system

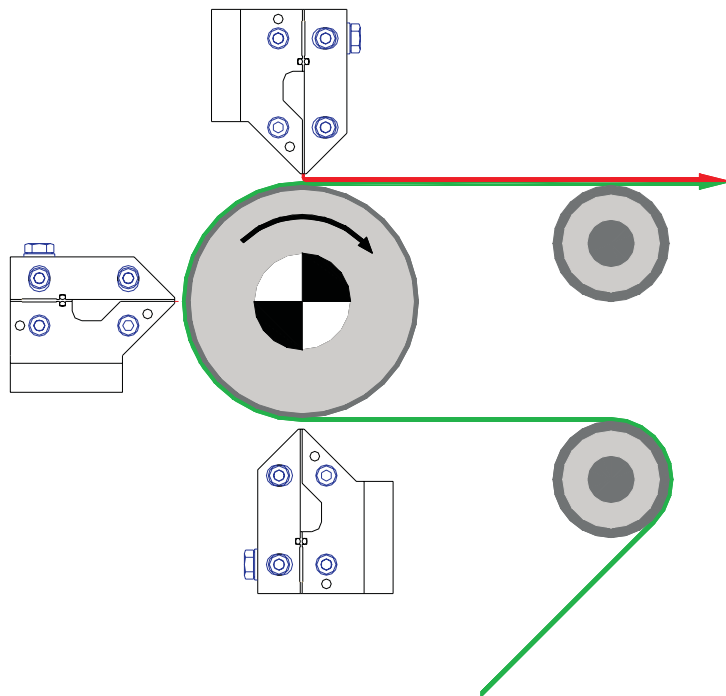


3-roller combi coating system



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  $\mu\text{m}$

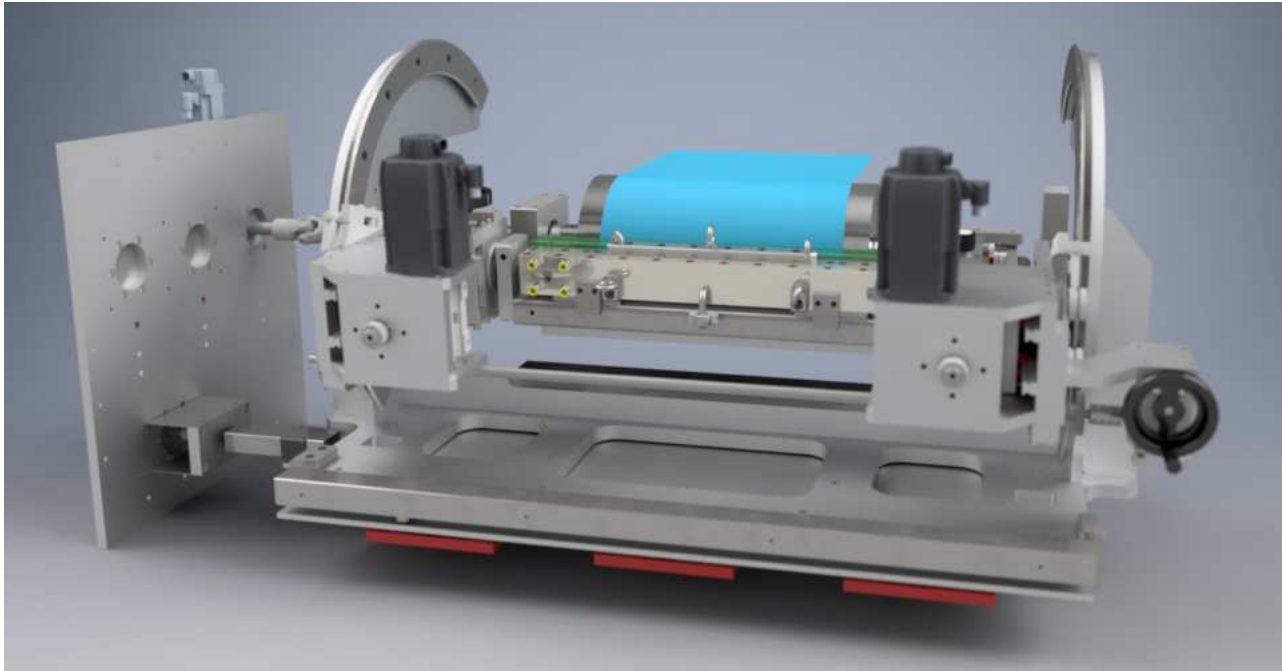
### Coating accuracy

✓ <1% (2 – 5%)

### Coating width

✓ up to approx. 3 m

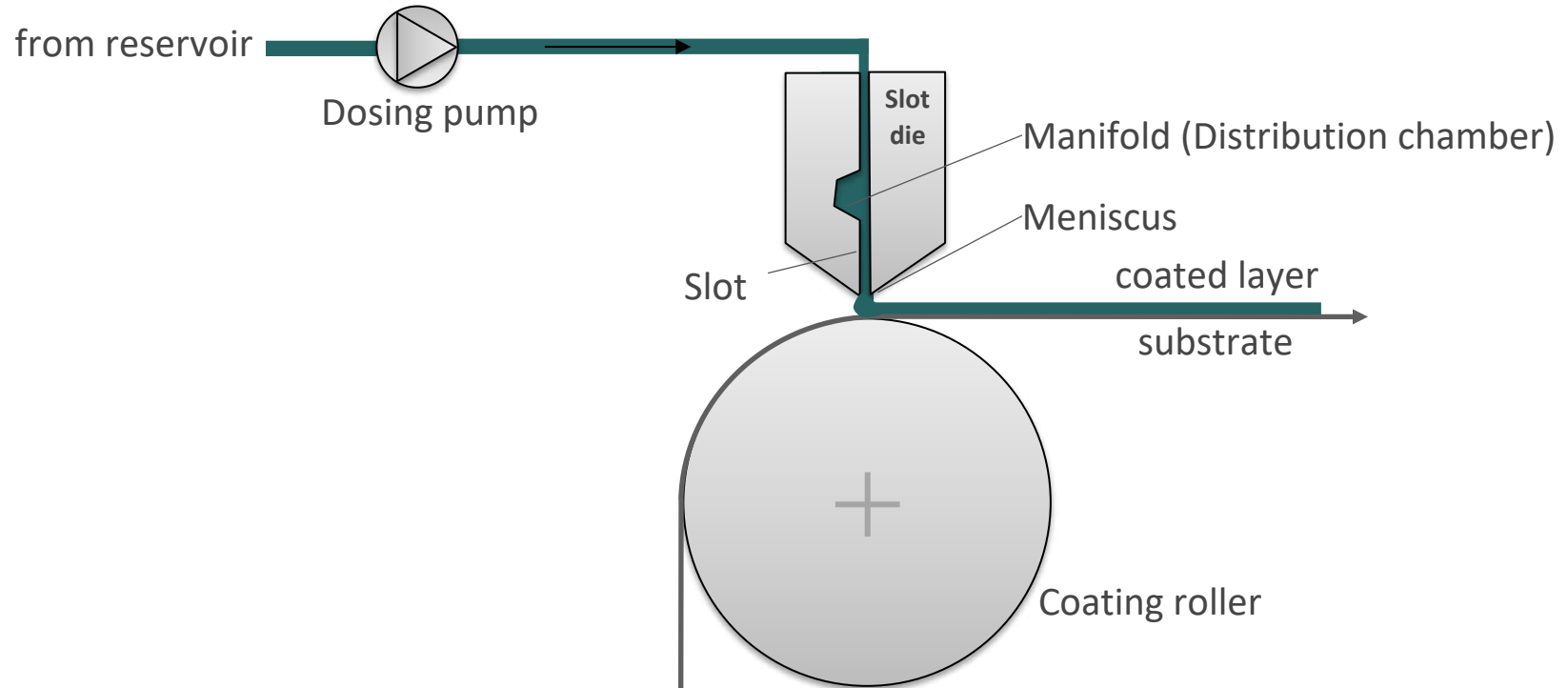
## Basic principle



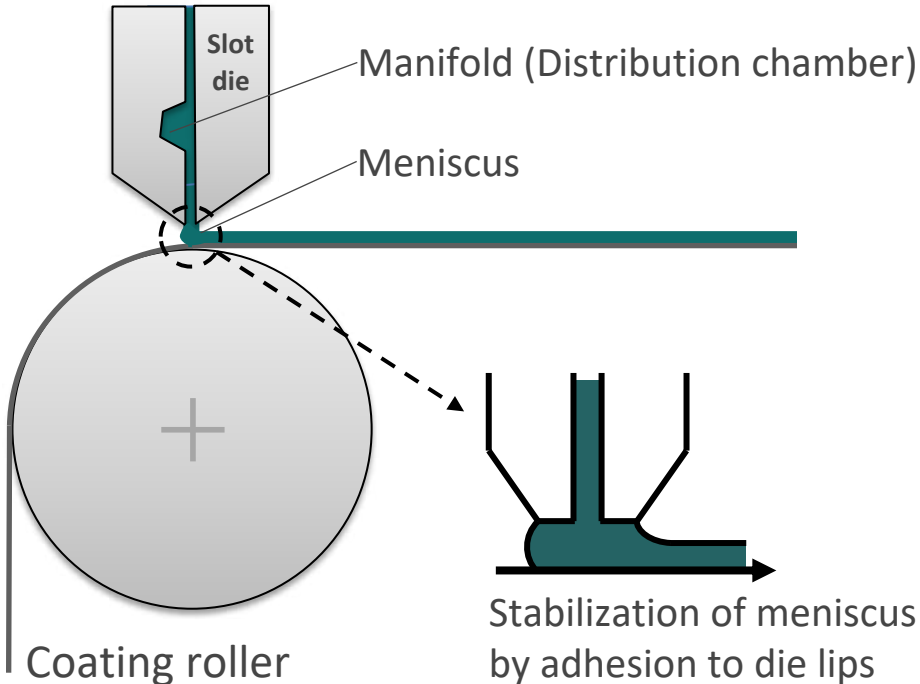
## Basic principle



## Basic principle

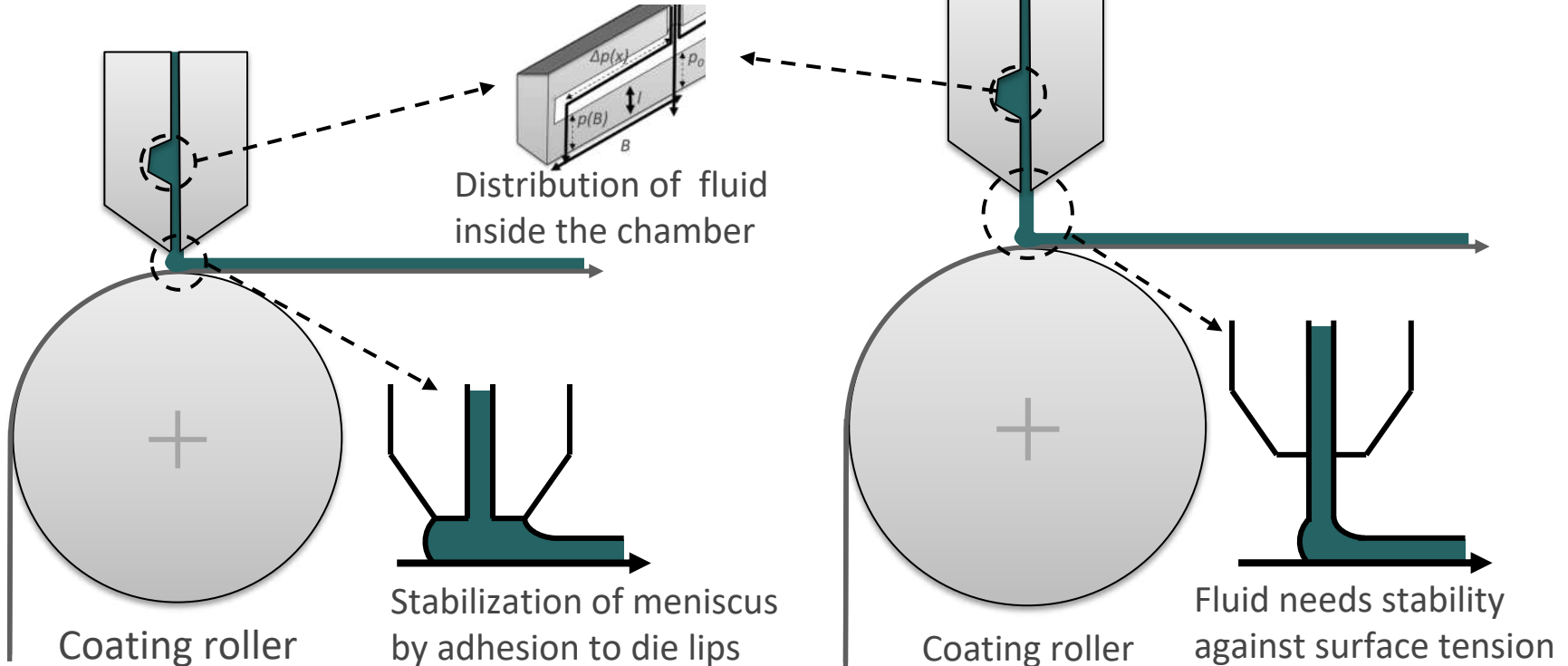


## Bead mode



- ✓ 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.

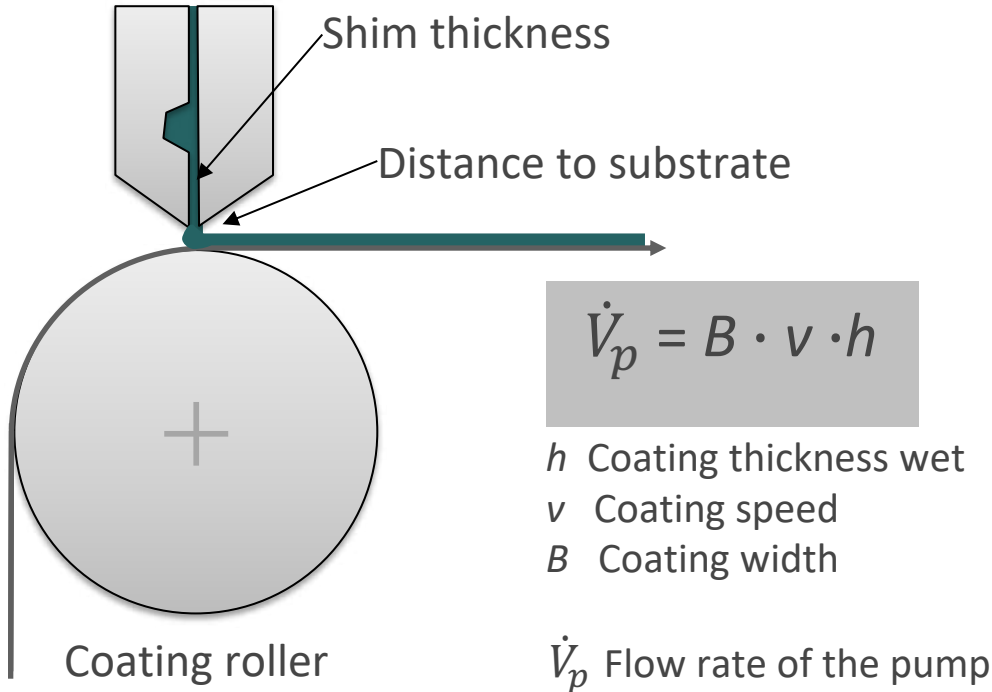
Can be done by appropriate computer programs.

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

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

$\Delta, \nabla$  = differential operators

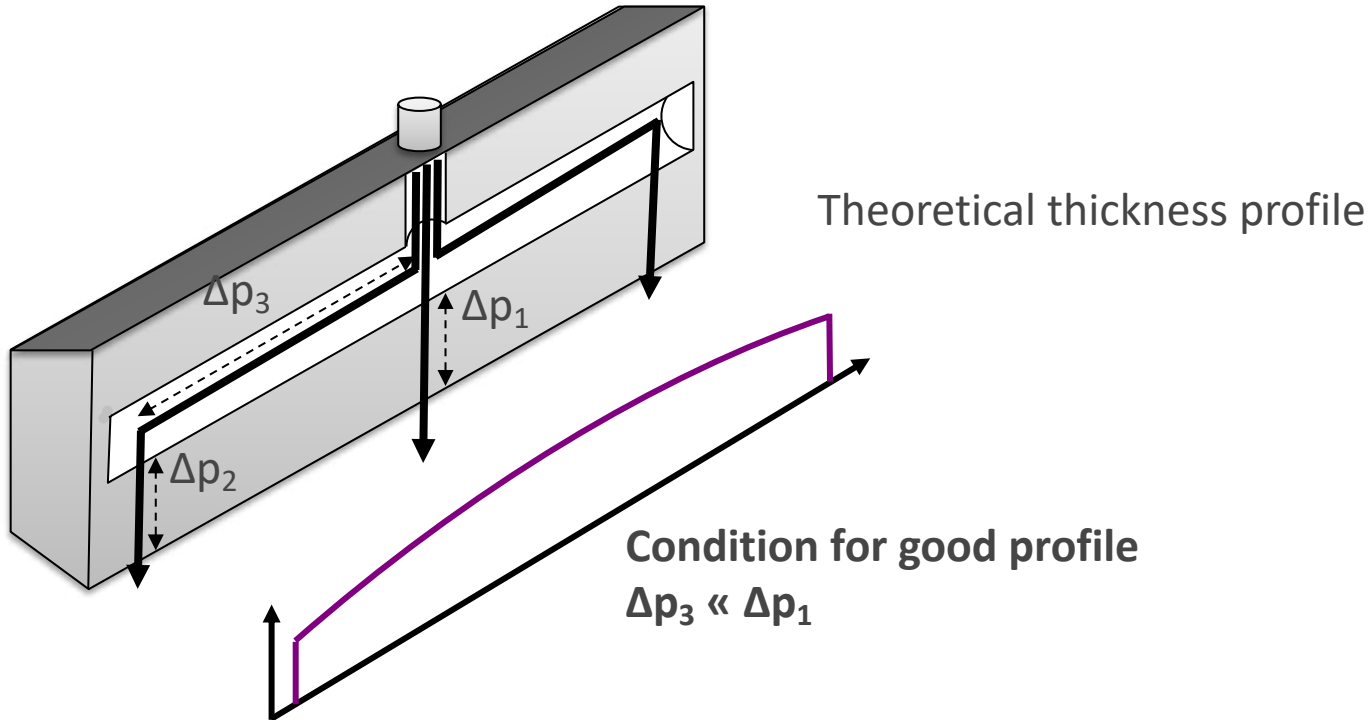
## Theoretical background



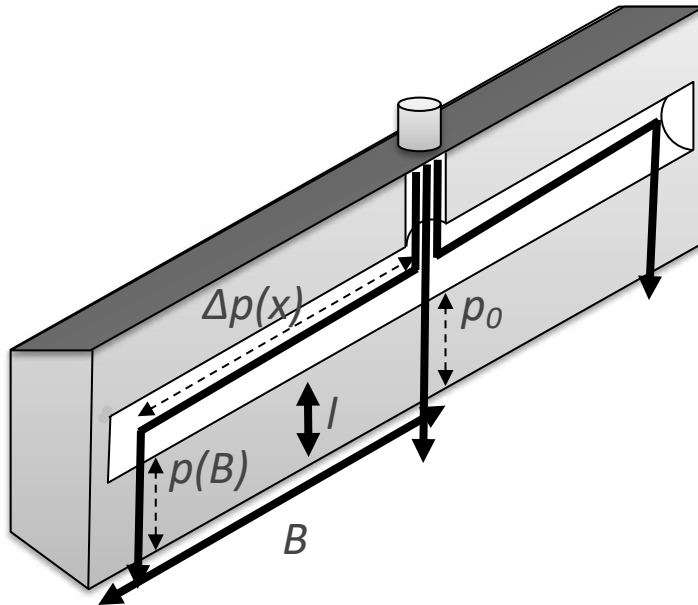
Contrary to a widespread misunderstanding the wet coating thickness does not depend on the shim thickness.

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:

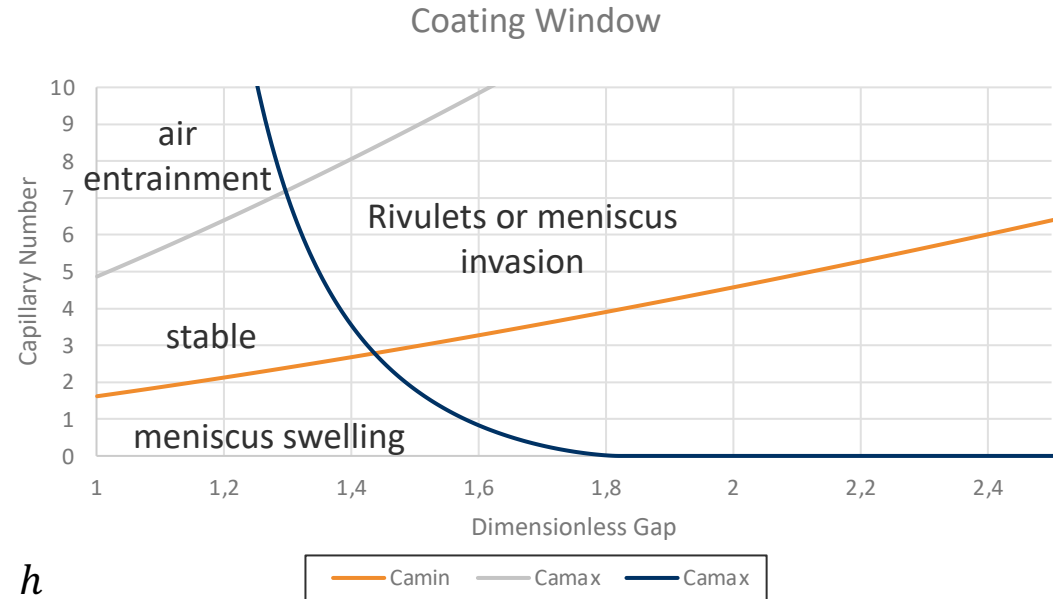
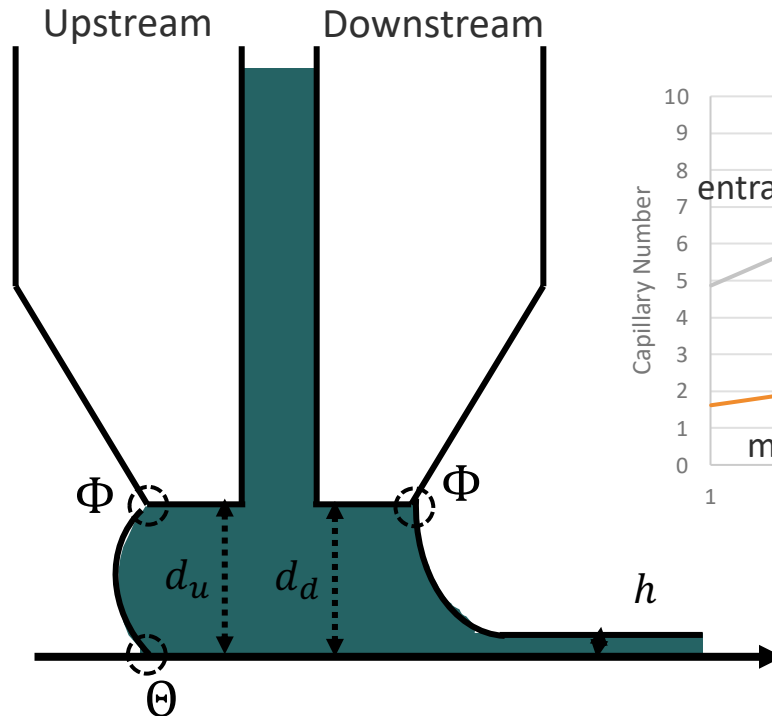
$$p(x) = p_0 \cdot \frac{\cosh \frac{W-x}{\lambda}}{\cosh \frac{W}{\lambda}}$$

Theoretical thickness profile:

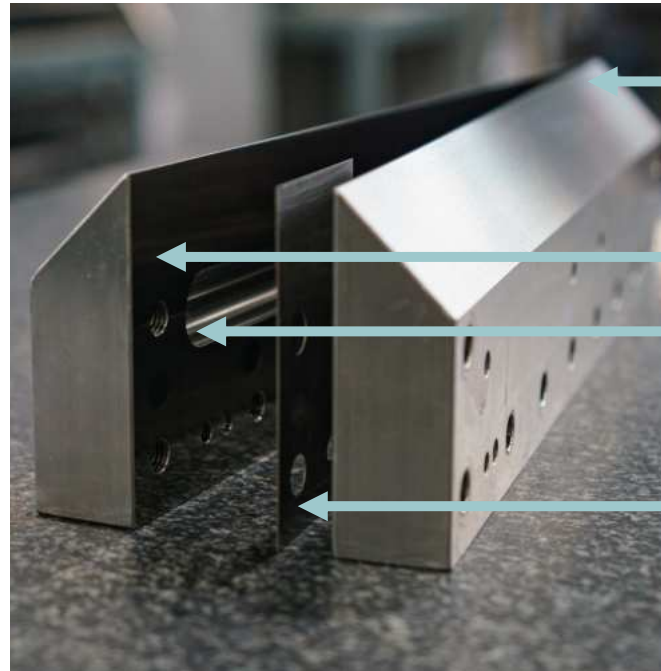
$$h(x) = \frac{B \cdot h_0}{\lambda} \cdot \frac{\cosh \frac{W-x}{\lambda}}{\sinh \frac{W}{\lambda}}$$

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

## 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 % automatized

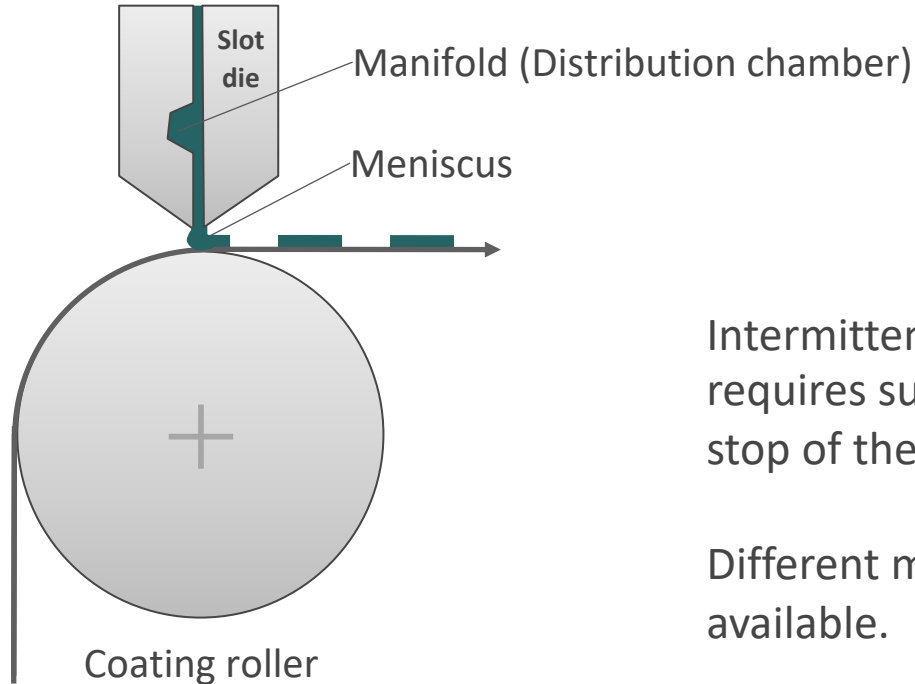


Computerized  
adjustment of  
slot width  
or gap width

Slot width:  
for uniformity

Gap width:  
for very small  
coating windows

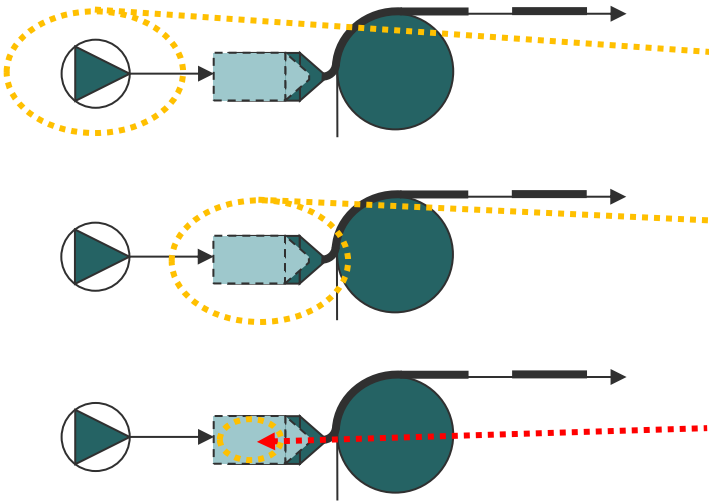
## Structured coating – crossweb stripes (intermittent)



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

Different methods are available.

## Standard techniques for intermittent coating



### **Pump:**

stop – reverse – restart

### **Slot die body:**

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

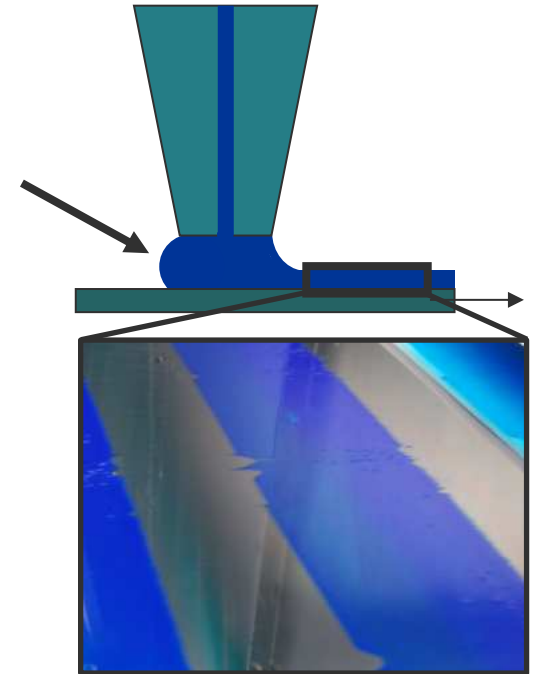
### **Slot die internal:**

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

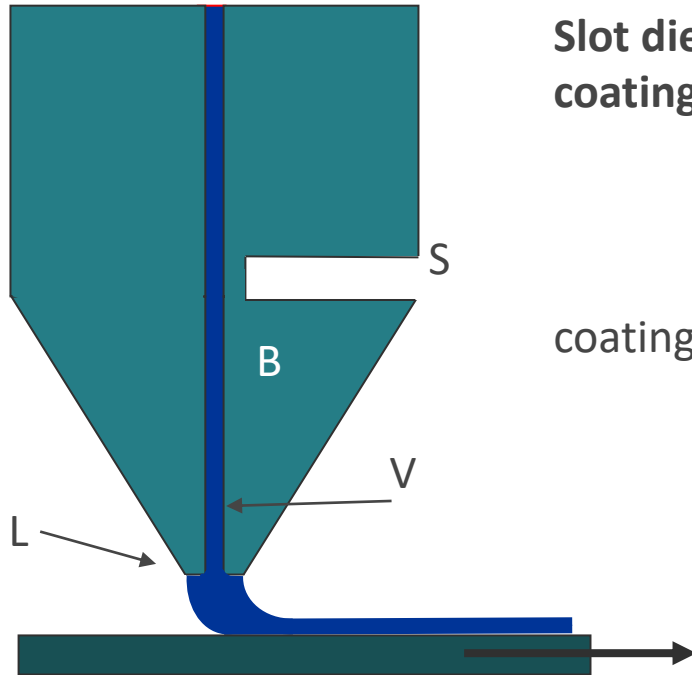
All 3 techniques (single or in combination) work quite well, if the viscosity is rather high and the required edge definition is not more precise than around 1 mm. All techniques may be combined with a vacuum pump upstream to stabilize the meniscus and suck away residual liquid.

## 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 – the switching slot die lip

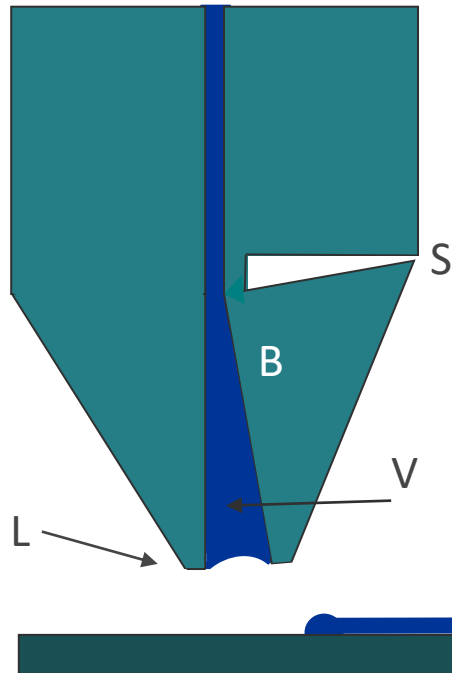


Slot die with movable lips:  
coating mode

coating works as usual

L lip  
V slot volume  
B bendable lip  
S bending slot

## Structured coating – the switching slot die lip



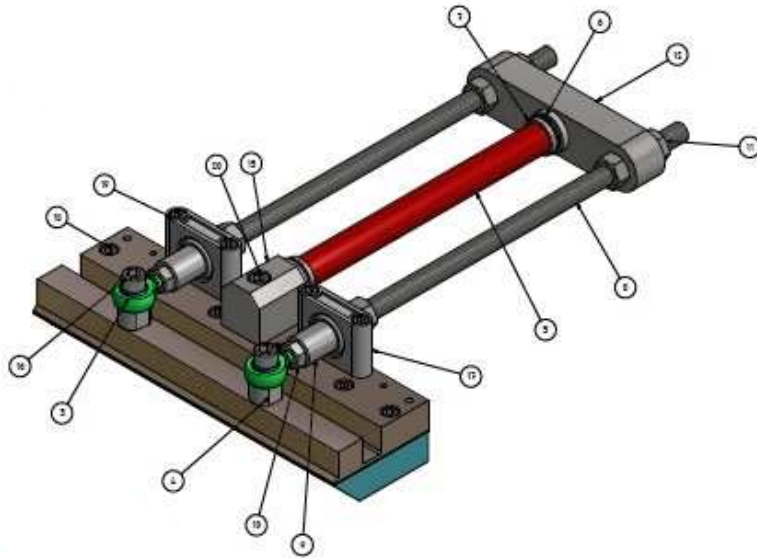
**Slot die with movable lips:  
stop mode**

Bendable lip B flips open

Volume V increases and sucks  
away the meniscus

L lip  
V slot volume  
B bendable lip  
S bending slot

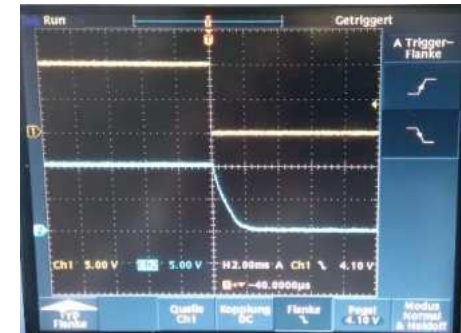
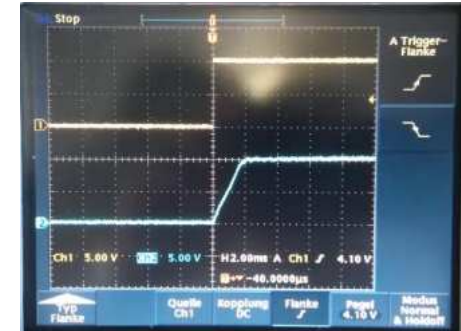
## Structured coating – technical implementation with Piezo-Drive



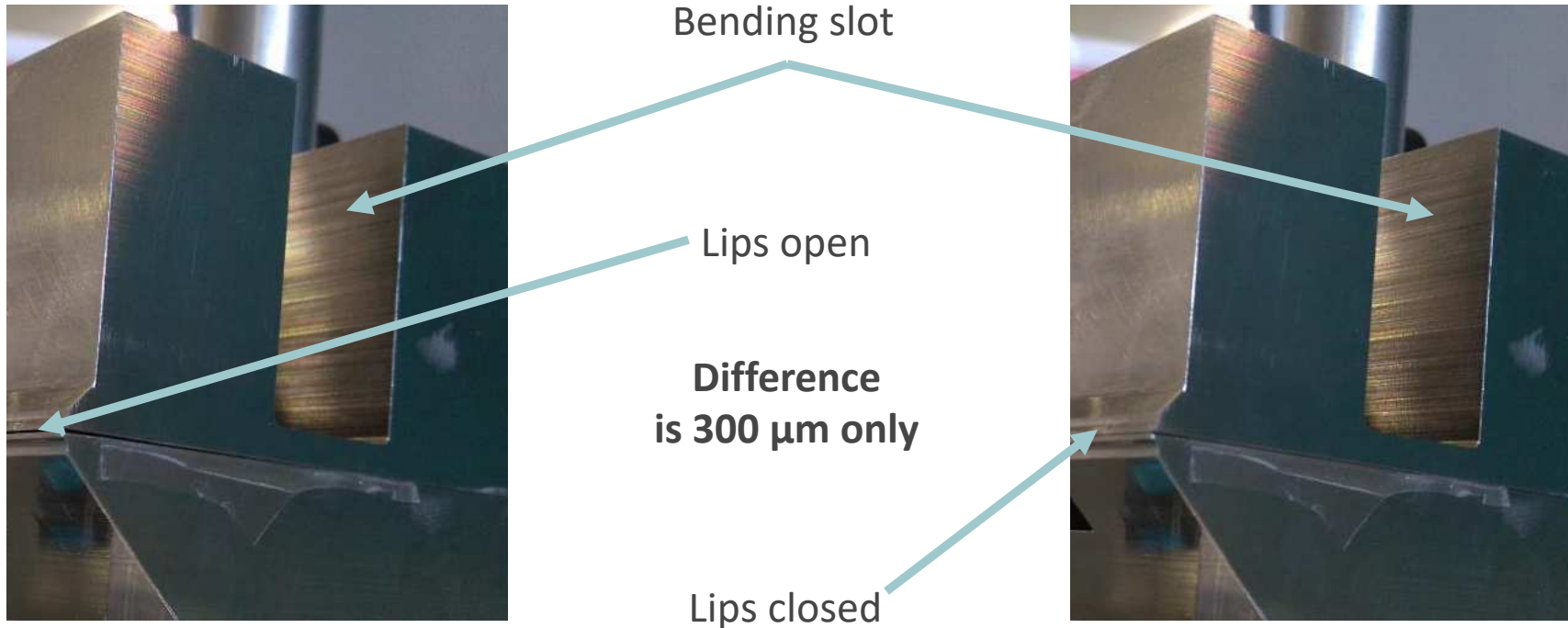
Extremely fast action:  
within few ms from coating to  
stop mode and vice versa

Control  
Voltage

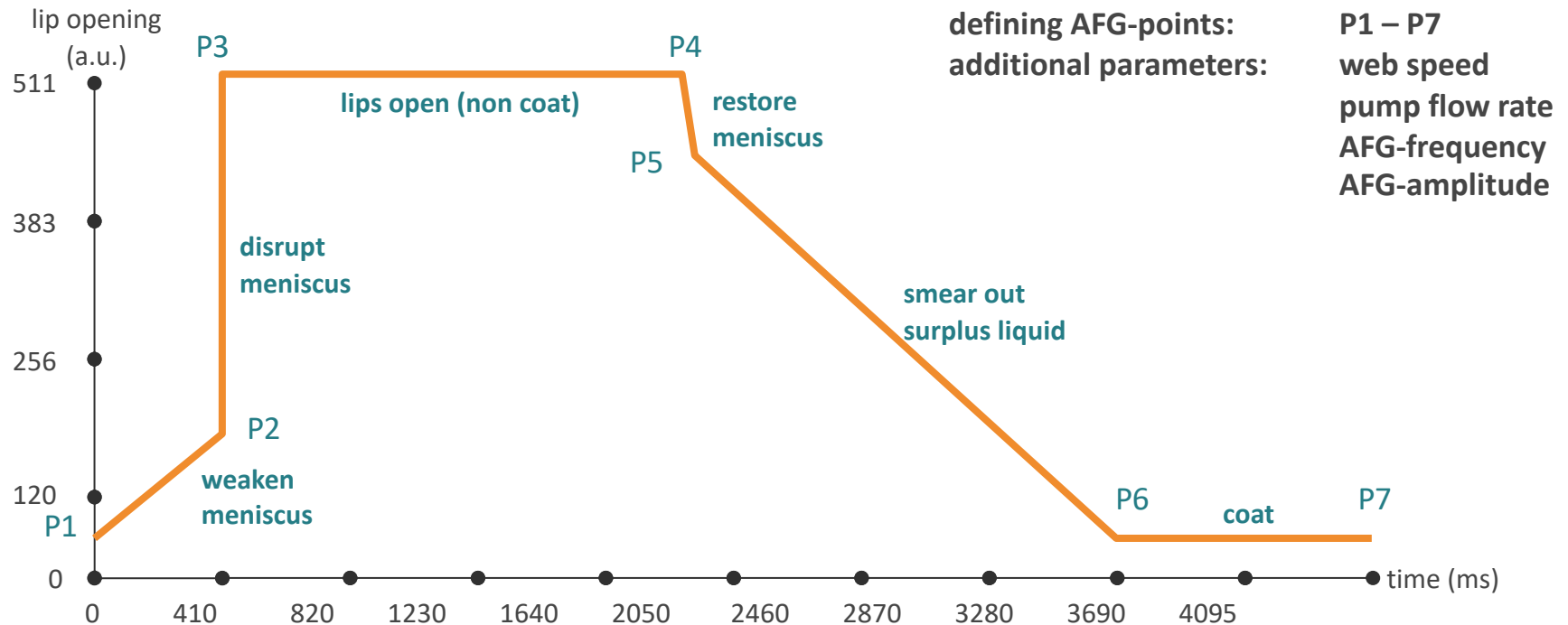
Piezo  
Response



## Structured coating – technical implementation with bendable lips

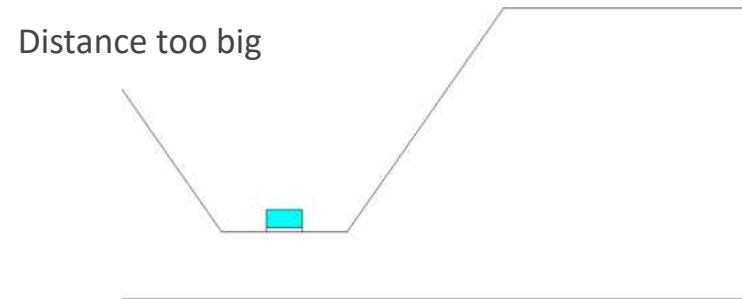
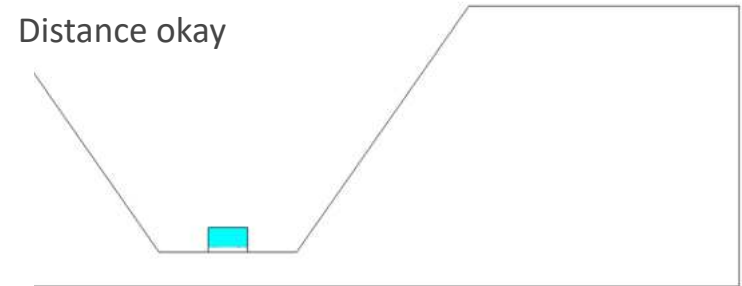


## Structured coating – stages of lip motion



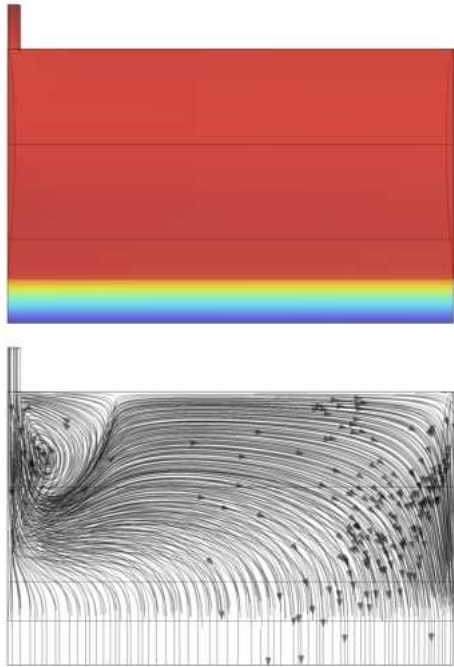
## Simulation of anode Coating

- ✓ 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

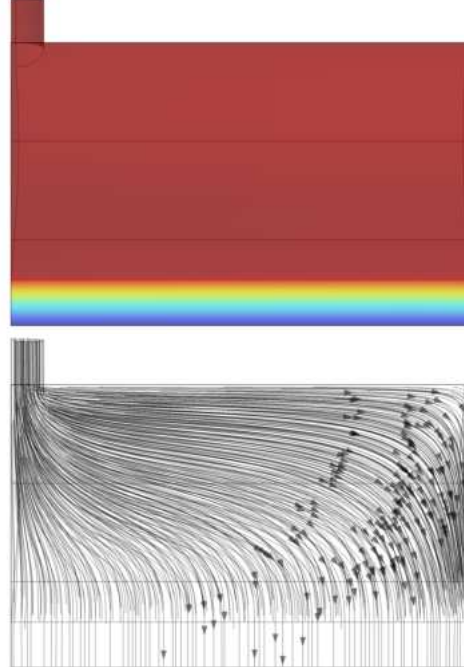


## Streamlines and pressure distribution

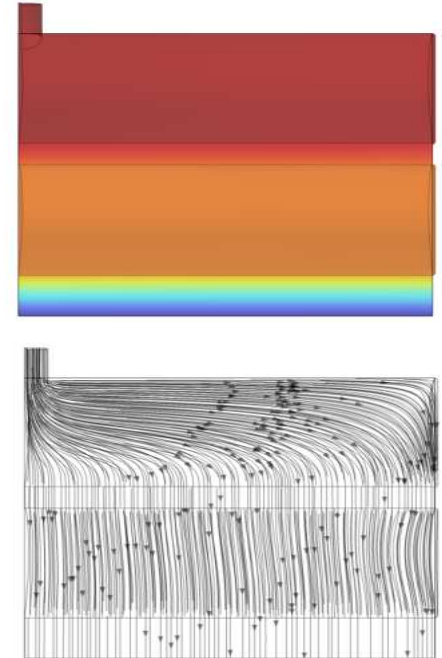
Single Chamber with too small inlet (4mm)



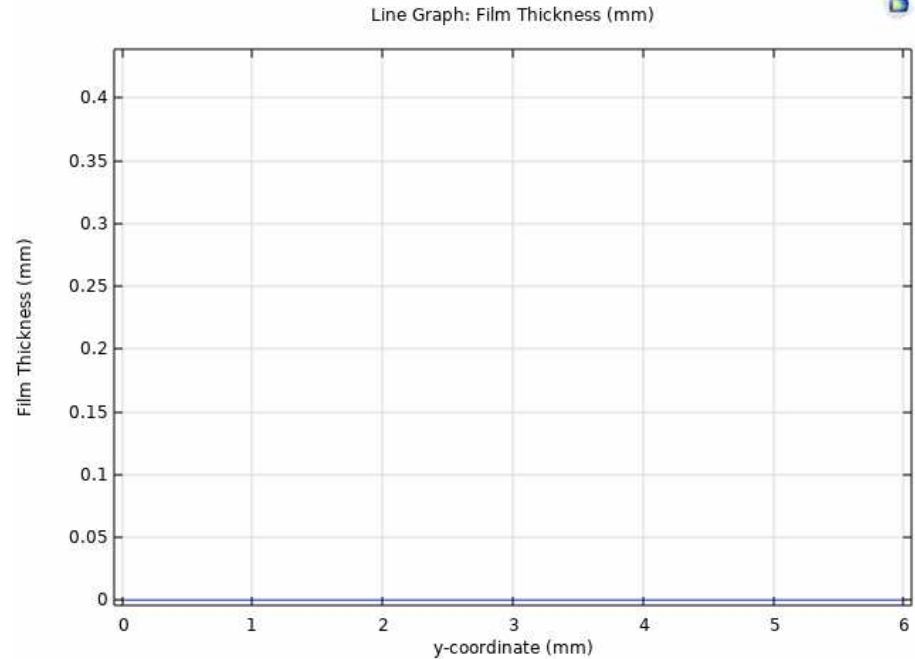
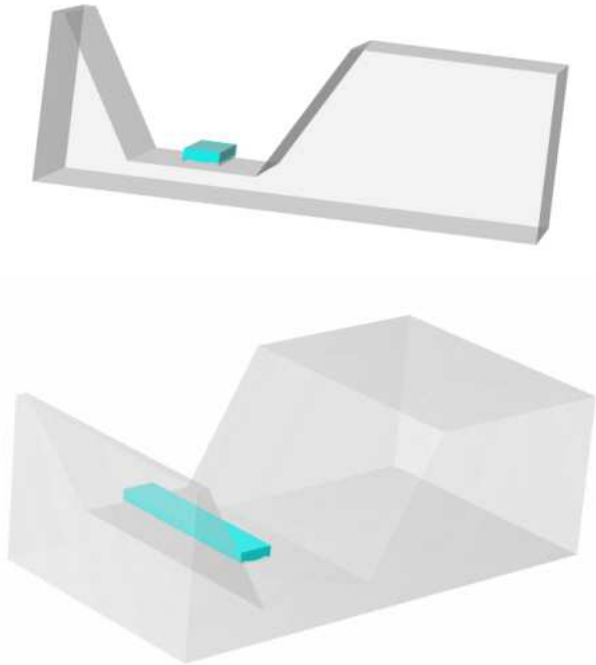
Single Chamber with correct chamber layout (10mm inlet)



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



## Meniscus makes or breaks homogeneity



# 7.

## Drying technologies



## Introduction thermal drying – Coating parameters

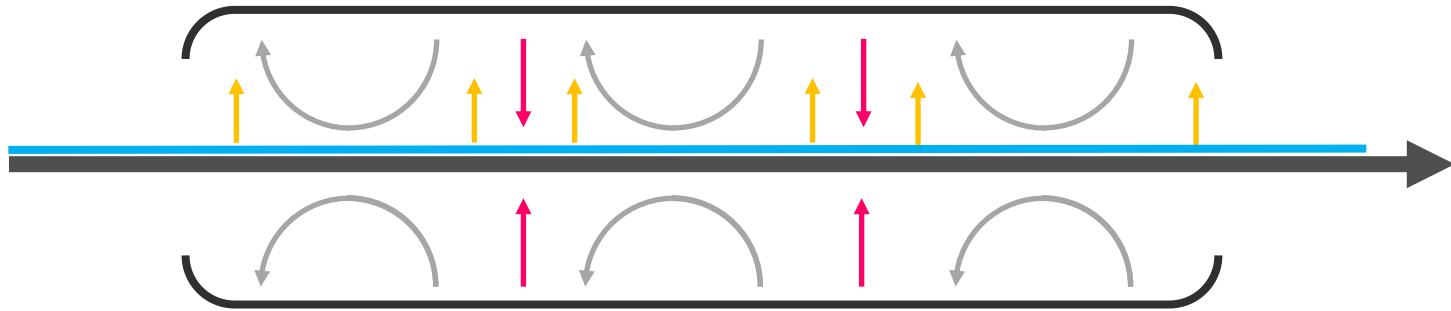
Coating chemistry	Coating processes	Process control	Drying
<ul style="list-style-type: none"> <li>✓ Rheology</li> <li>✓ Viscosity</li> <li>✓ Viscoelasticity</li> <li>✓ Type of solvents</li> <li>✓ Solid content</li> <li>✓ Van der Waals force</li> <li>✓ Sheer ratio</li> <li>✓ Adhesion/Cohesion</li> </ul>	<ul style="list-style-type: none"> <li>✓ Coating systems</li> <li>✓ Single or multilayer coatings</li> <li>✓ Direct coatings</li> <li>✓ Transfer (indirect) coatings</li> <li>✓ Substrate speed</li> <li>✓ Layer thickness</li> <li>✓ Coating accuracy</li> </ul>	<ul style="list-style-type: none"> <li>✓ Process layout</li> <li>✓ Tension control system</li> <li>✓ Material guiding system</li> <li>✓ Inline parameter control</li> <li>✓ Quality control</li> </ul>	<ul style="list-style-type: none"> <li>✓ Convection drying</li> <li>✓ Contact drying</li> <li>✓ Infrared drying</li> <li>✓ Sintering</li> <li>✓ NIR</li> <li>✓ High frequency</li> <li>✓ UV crosslinking systems</li> </ul>
Substrate	Pretreatment	Environment	Finishing
<ul style="list-style-type: none"> <li>✓ Surface tension</li> <li>✓ Dimension stability</li> <li>✓ Surface structure</li> <li>✓ Contact angle</li> </ul>	<ul style="list-style-type: none"> <li>✓ Corona</li> <li>✓ Plasma</li> <li>✓ Cleaning</li> </ul>	<ul style="list-style-type: none"> <li>✓ Humidity</li> <li>✓ Temperature</li> <li>✓ Inert conditions</li> </ul>	<ul style="list-style-type: none"> <li>✓ Calendaring</li> <li>✓ Embossing</li> <li>✓ Slitting</li> </ul>

## 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

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



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

Substrate

Coating

Heat transfer

Evaporating solvent

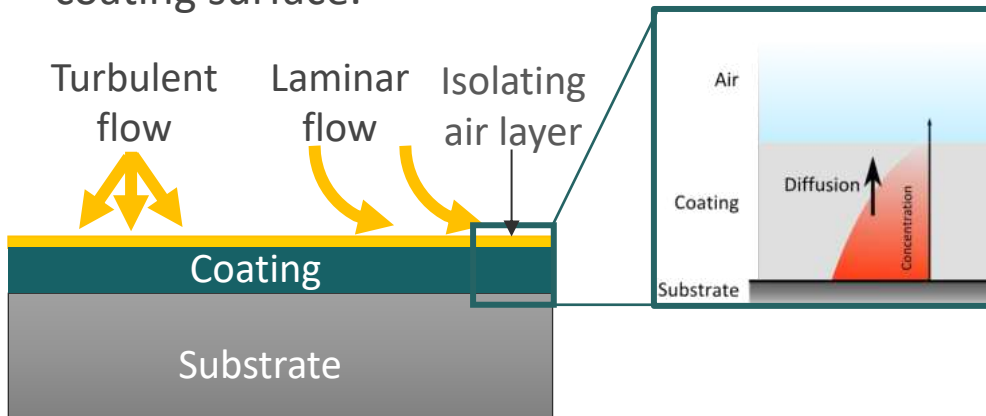
Solvent vapor transfer

**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.

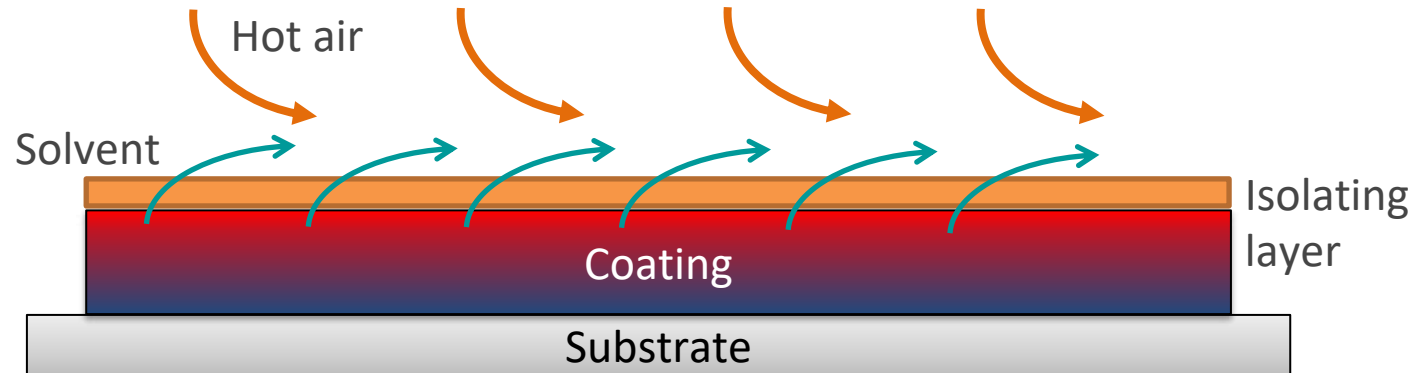


**Usually there is a trade-off:**

effective fast heat/mass transfer  
or  
gentle mild slow drying

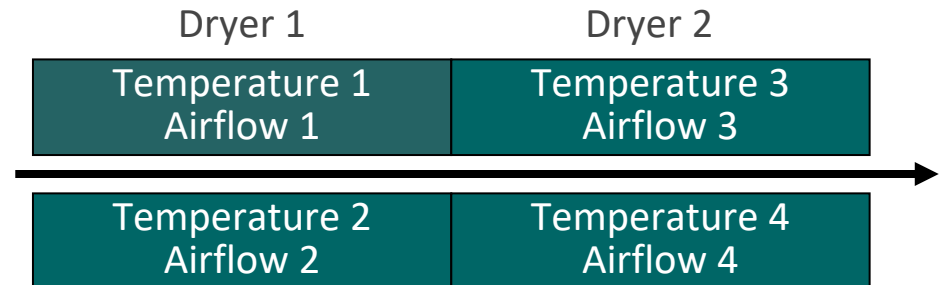
## Basics mass + heat transfer – Drying dynamics: Hot air drying

- ✓ 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.



## 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

## 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

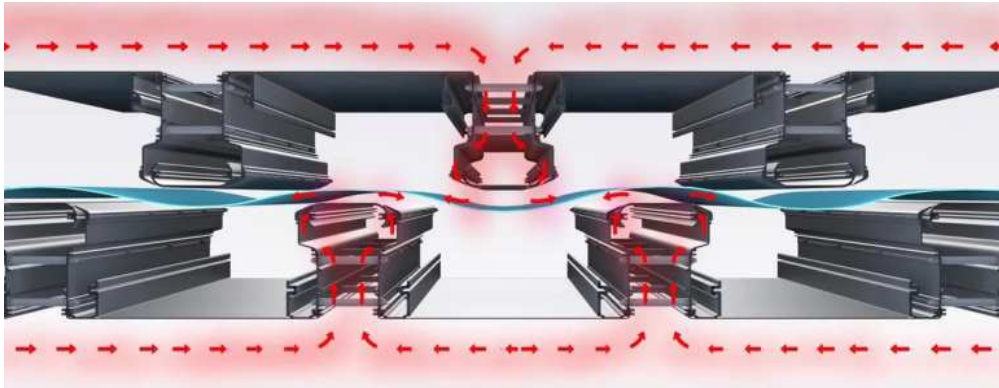


## Industrial drying systems

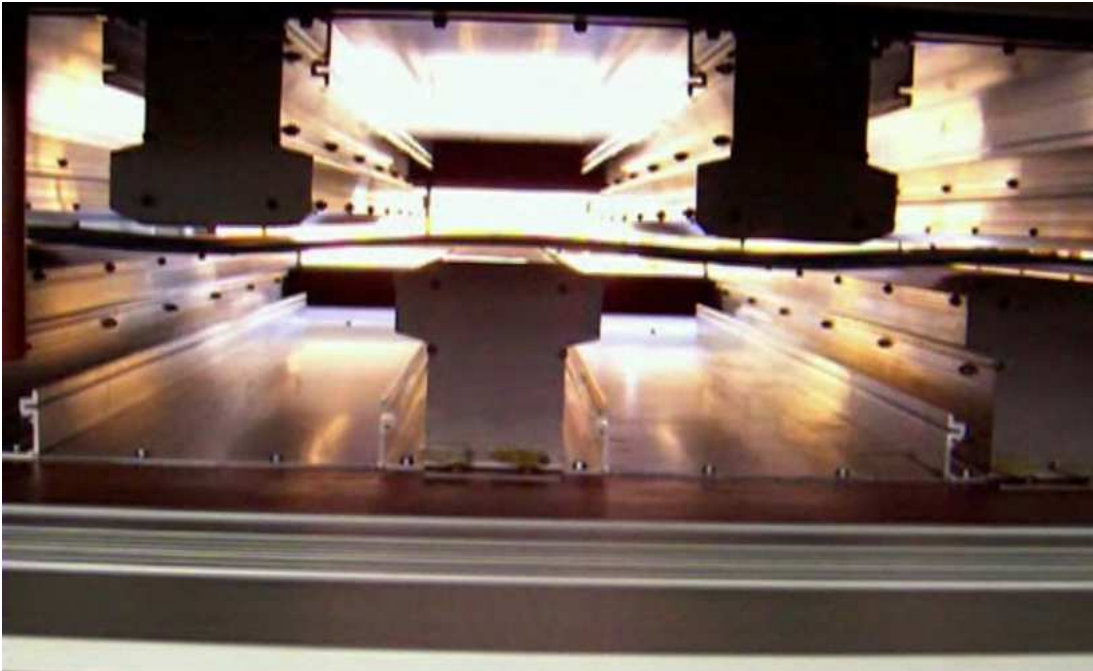
Coatema slot  
nozle and  
circulation  
dryer on small  
scale



## Drytec Click&Coat™ dryer principle



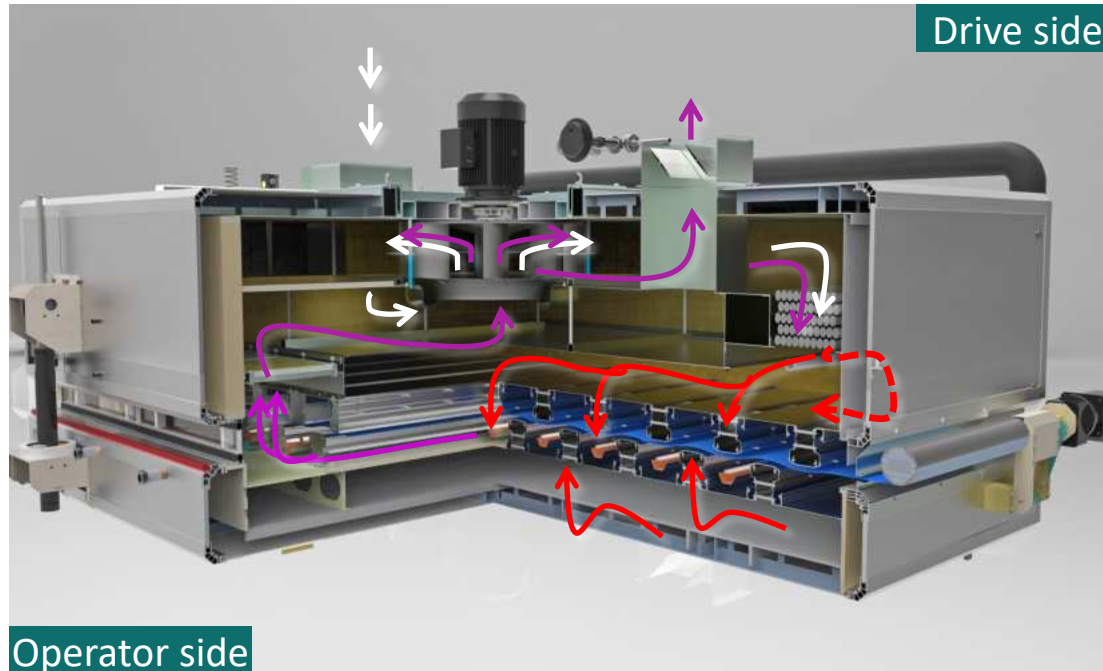
## Drying topics – drying technologies: HighDry HD500



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)

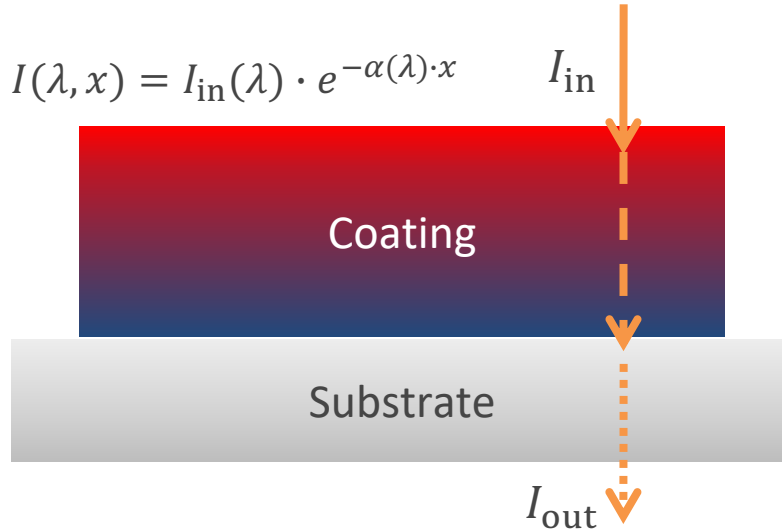
Air flow reverse

Clear arrows

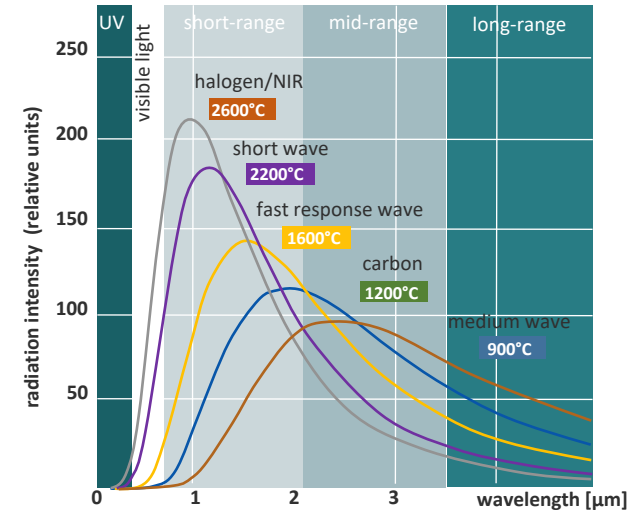
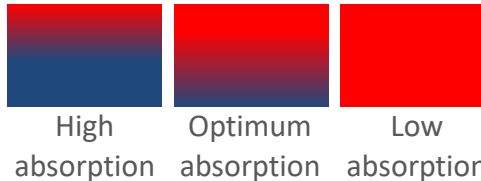
Click „Air distribution“ to  
show air flow direction

**DRYTEC**

## Basics mass + heat transfer: (N)IR technology

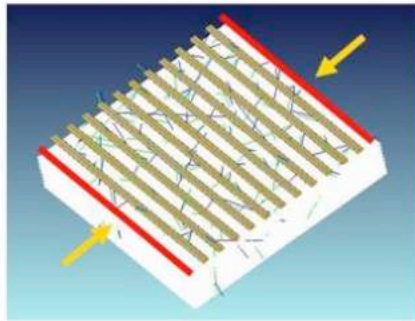


$I_{in}(\lambda)$  Intensity in  
 $I_{out}$  Intensity out  
 $\alpha(\lambda)$  Absorption coefficient  
 $d$  Layer thickness



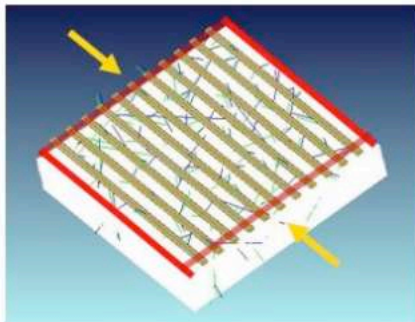
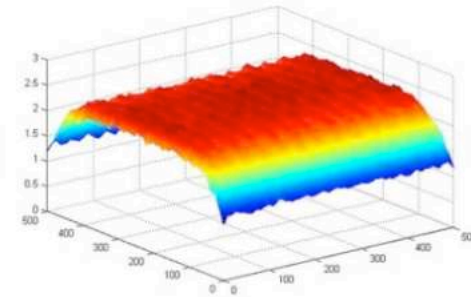
Relative intensity of radiators at different wavelengths

## IR / NIR Drying – Infrared drying



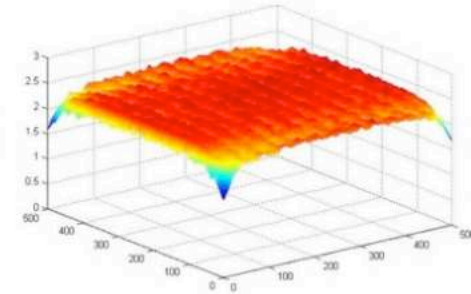
Continuous process

13 emitters, 2 types, 3 zones



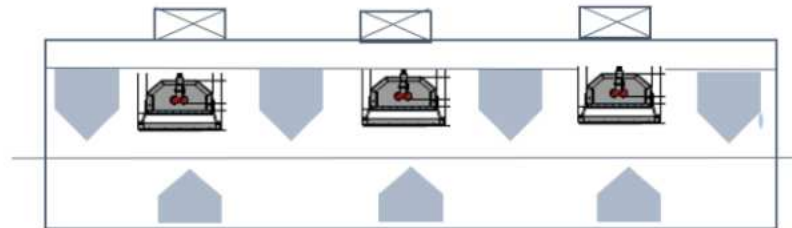
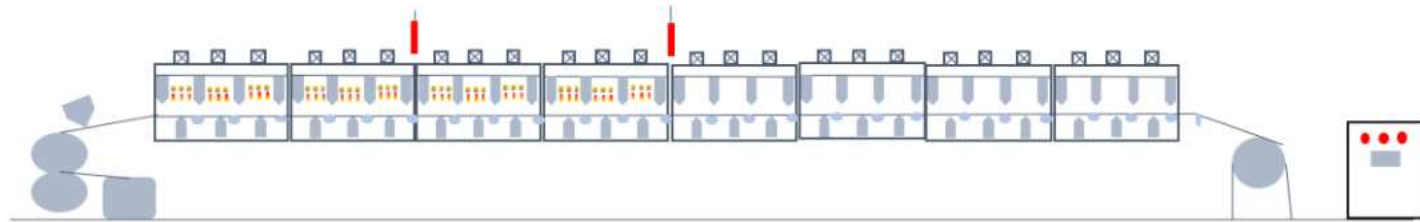
Batch process

15 emitters, 3 types, 5 zones



## IR / NIR Drying – Infrared drying

### Layout



Hotair oven: 50m ( 10 zone )

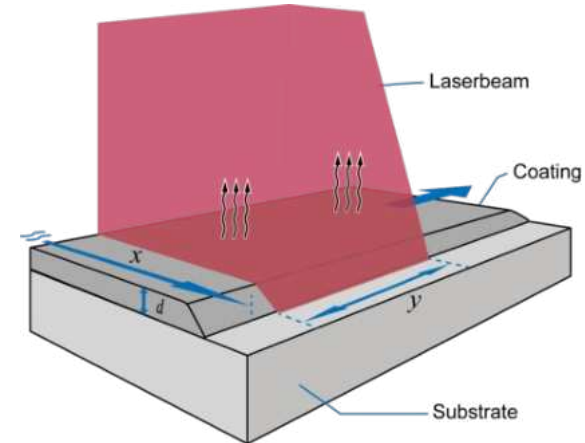
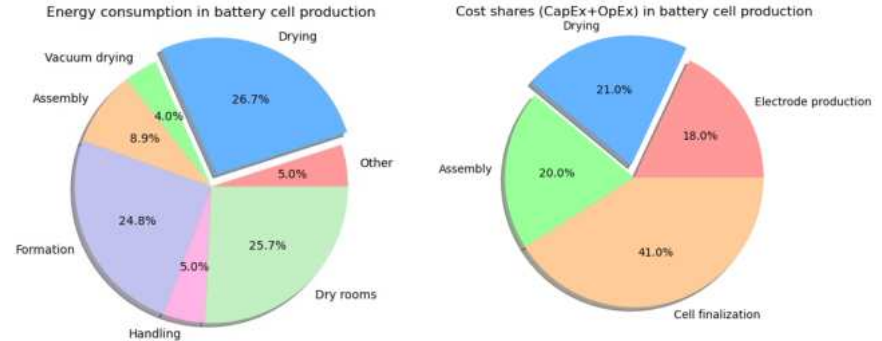
IR at first 25m (5 zone) for boost

Heating distance : 100mm

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

## Laser drying

- ✓ 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.



[1] DEGEN et al. (Life cycle assessment of the energy consumption and GHG emissions of state-of-the-art 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.

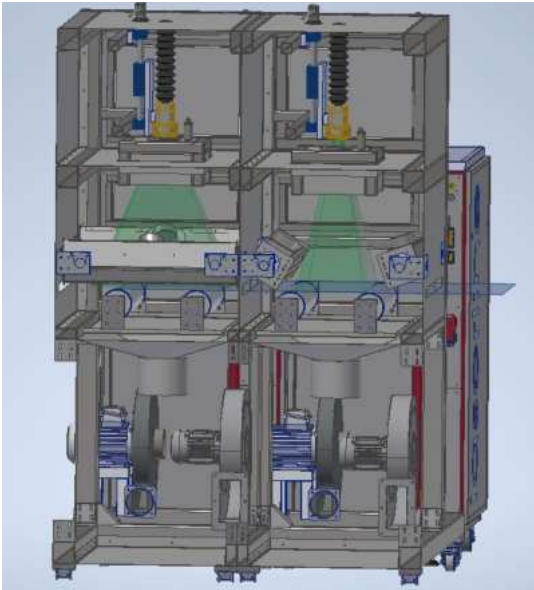
**Gas Atmosphere:** Consider the use of inert gases or controlled atmospheres within the drying chamber to prevent unwanted reactions or oxidation of the electrode materials during the drying process.

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

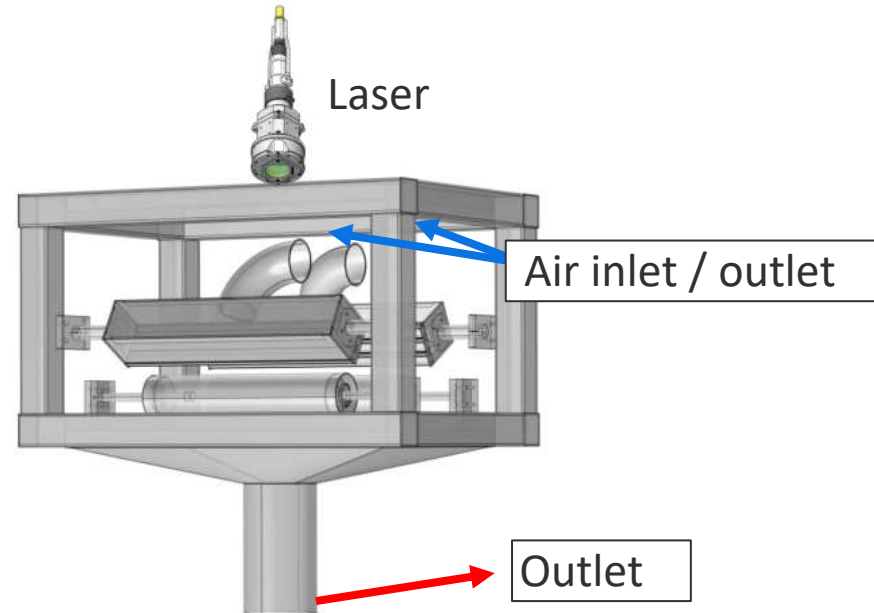
**Drying Chamber:** Design a drying chamber that allows for precise control of temperature, airflow, humidity, etc. to assure a **uniform and efficient drying**.

## Laser dryer

### Coatema's design

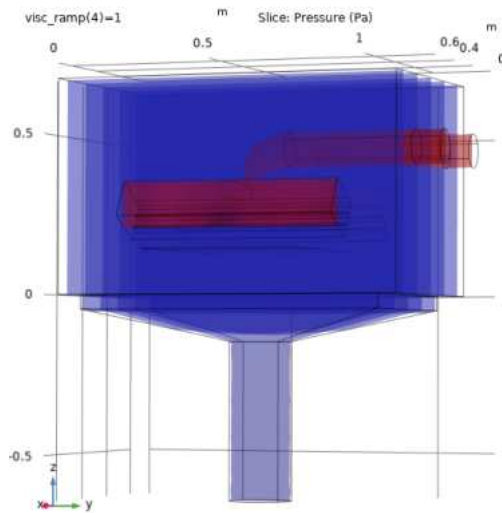


### Geometry used for simulation

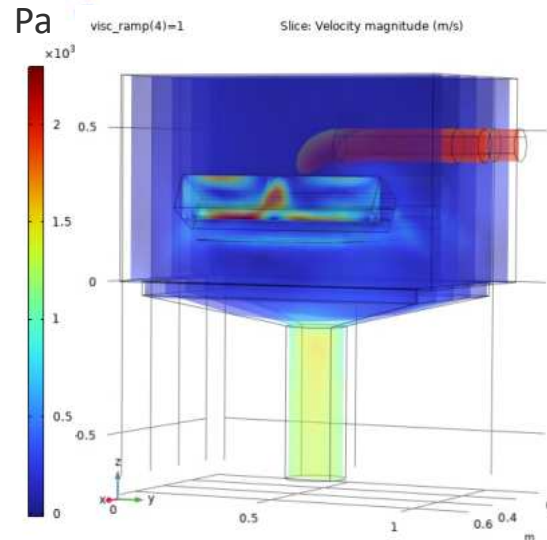


## Web speed 30m/min, in -x direction

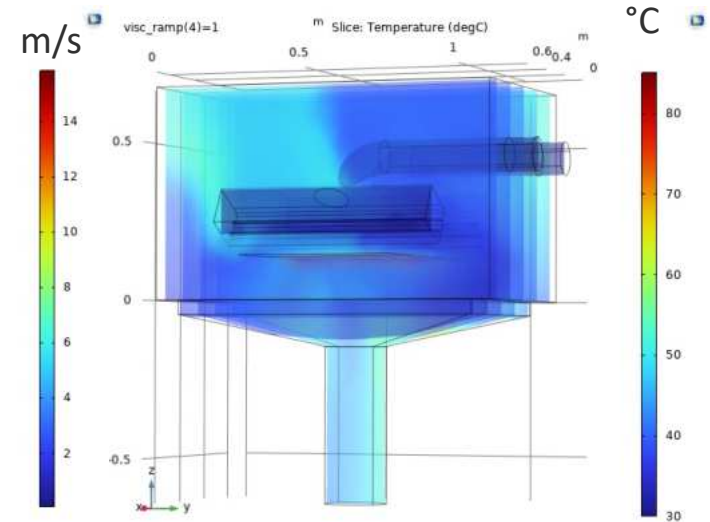
Pressure



Air velocity



Temperature

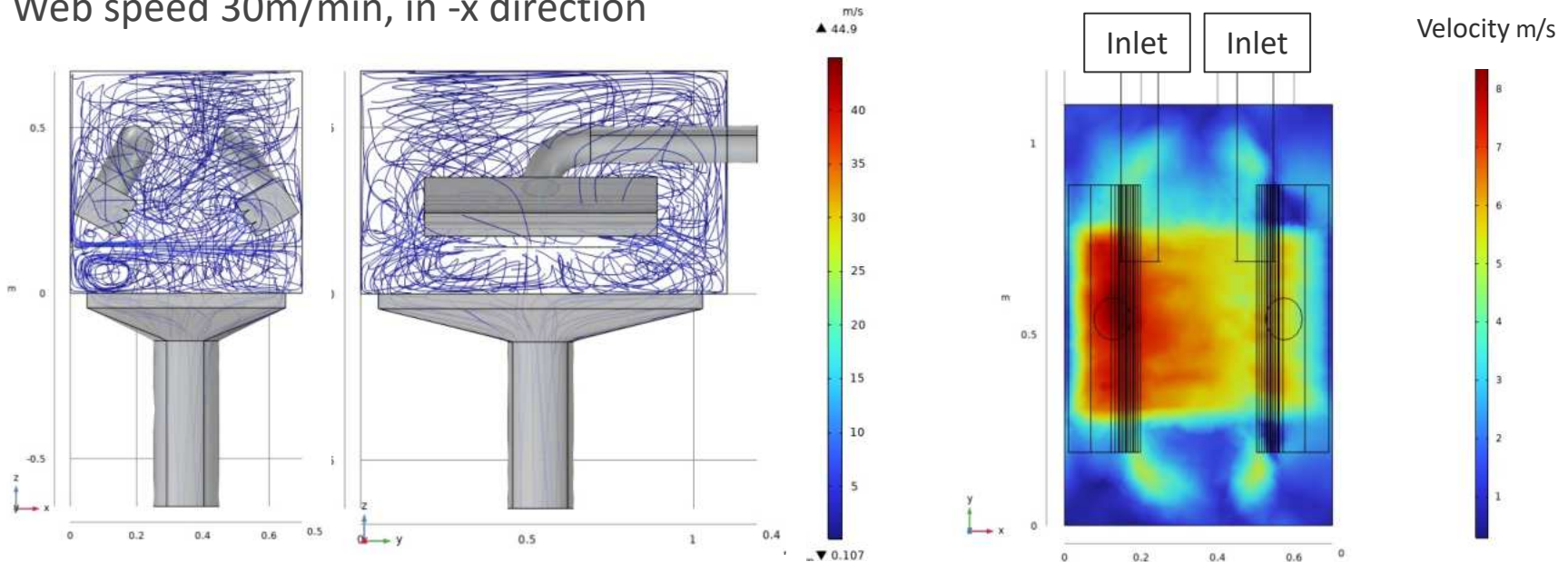


## Airflow in 3D, testing different design possibilities

#1: 2 inlets, 1 outlet

Web speed 30m/min, in -x direction

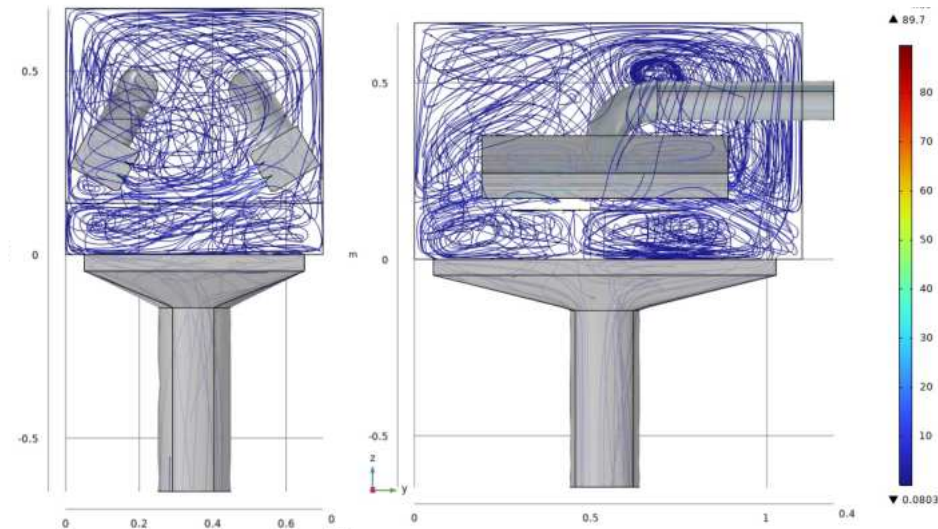
Volumetric air inflow ~ 300 m<sup>3</sup>/hr



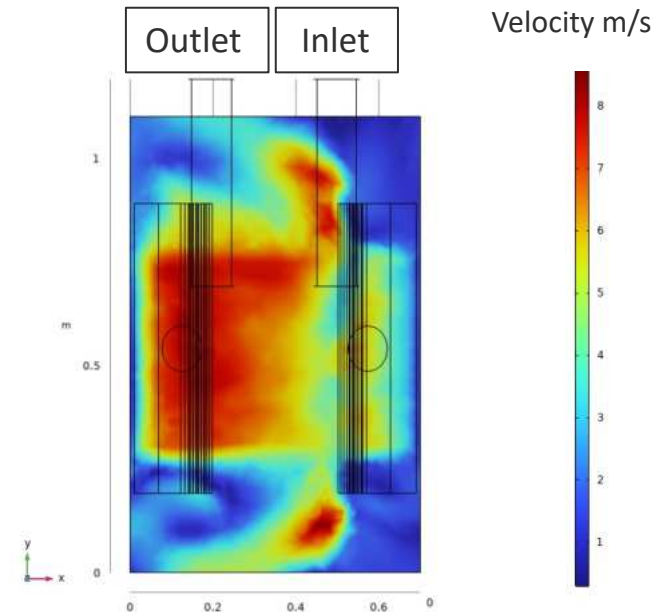
## Airflow in 3D, testing different design possibilities

#2: 1 inlet , 2 outlets

Web speed 30m/min, in -x direction

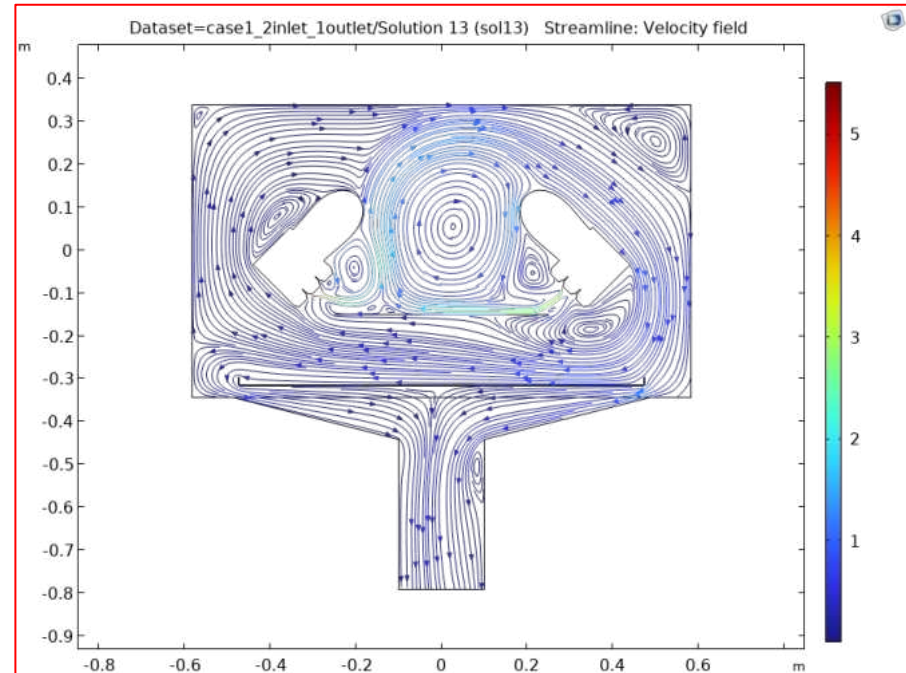
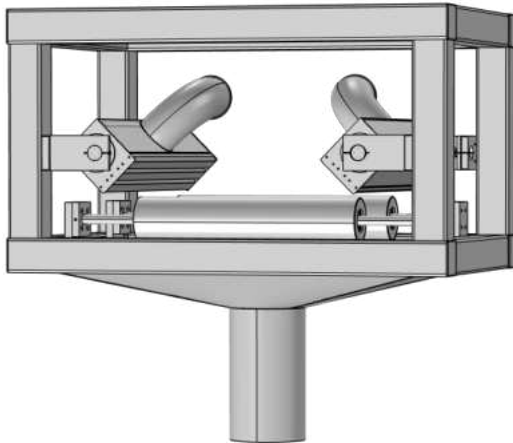


Web speed 30m/min, in +x direction

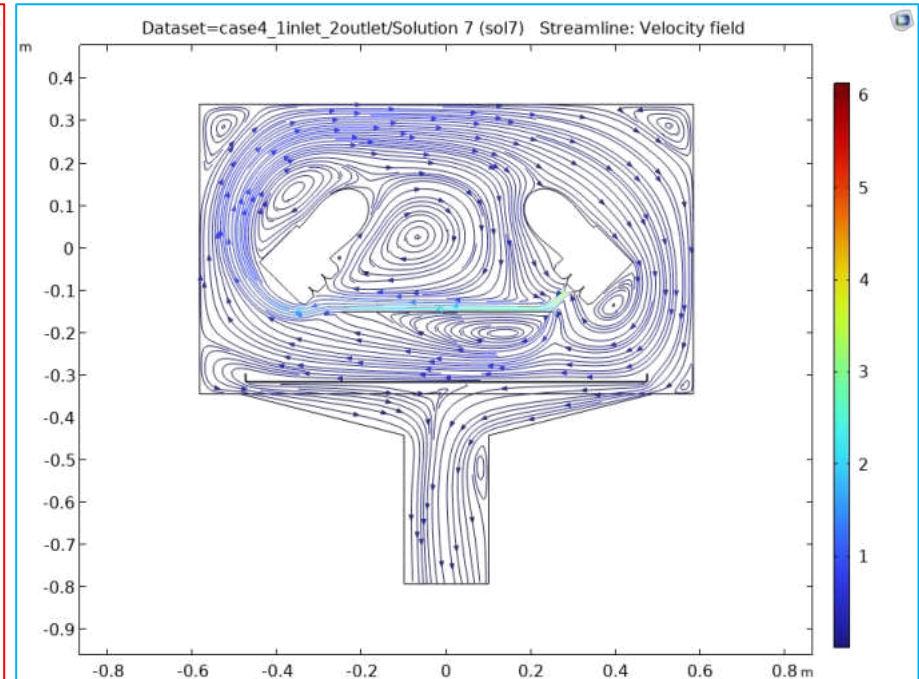
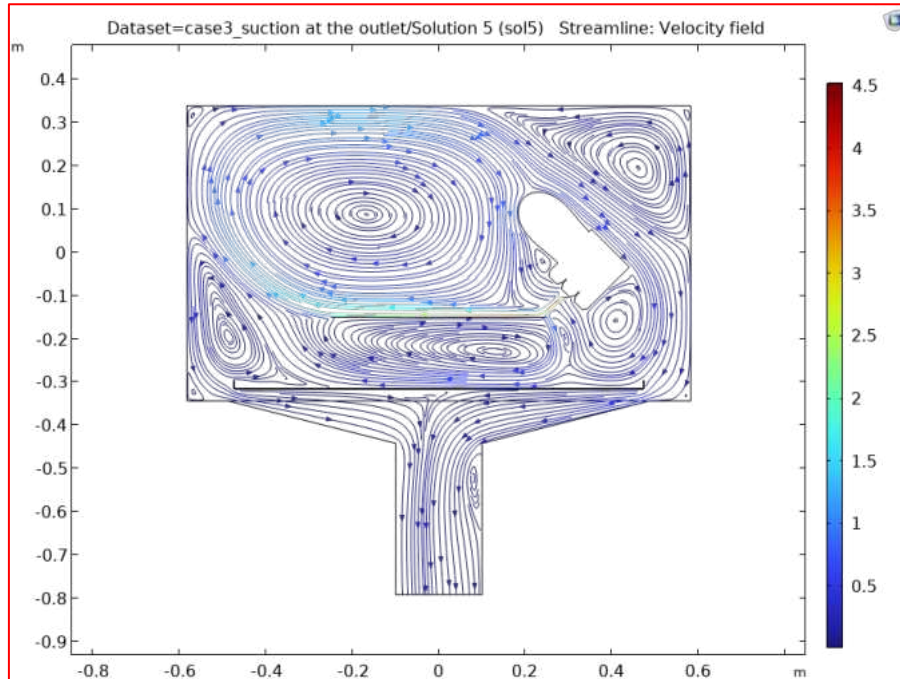


## Airflow in 3D, testing different design possibilities

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

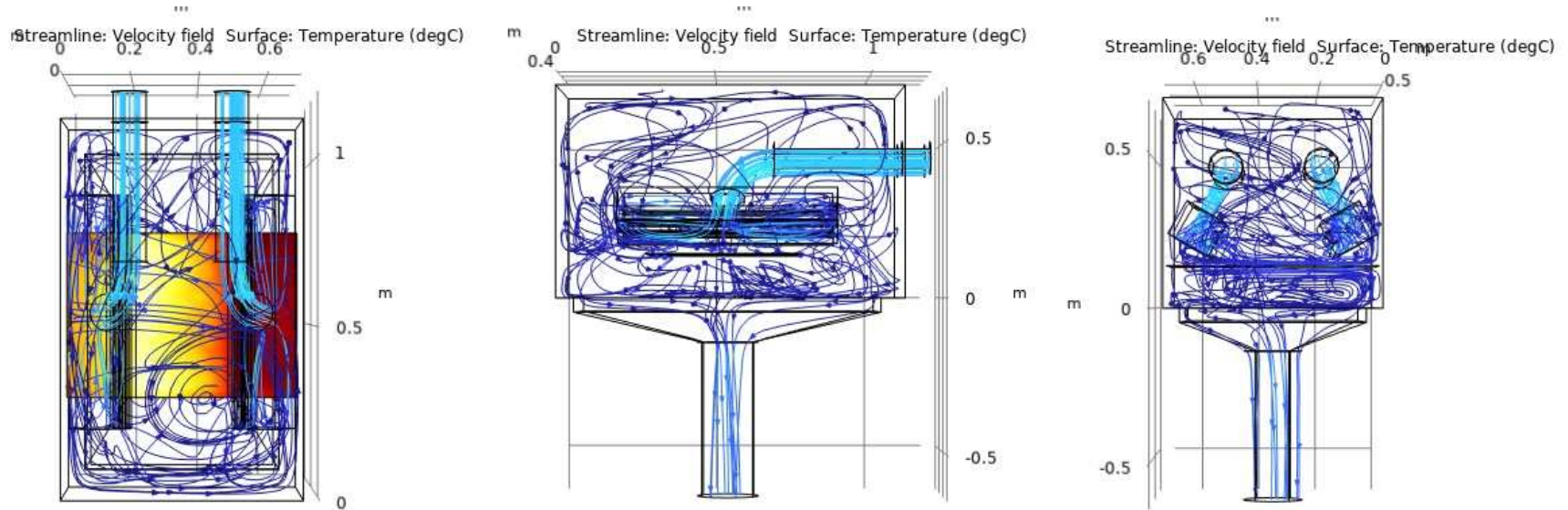


## Airflow in 3D, testing different design possibilities



## Airflow in 3D, testing different design possibilities

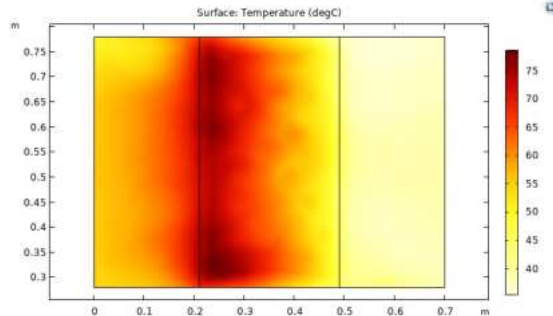
Temperature distribution on the moving web when the laser shines with a homogeneous energy density on an area of 350 mm x 280 mm



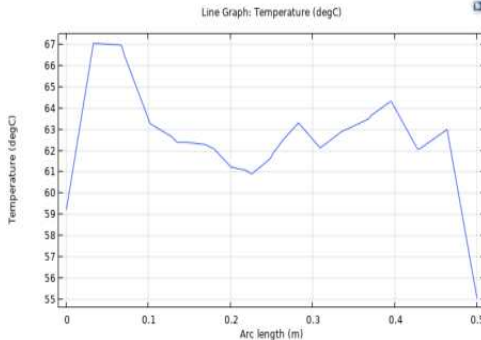
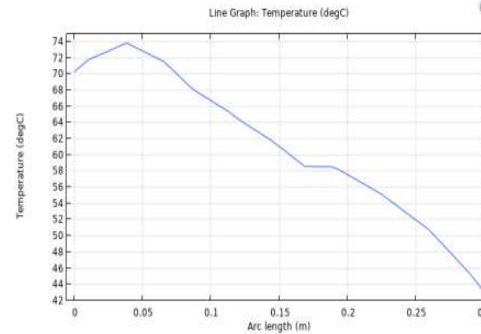
## Airflow in 3D, testing different design possibilities

Evaporation is not included in the model!

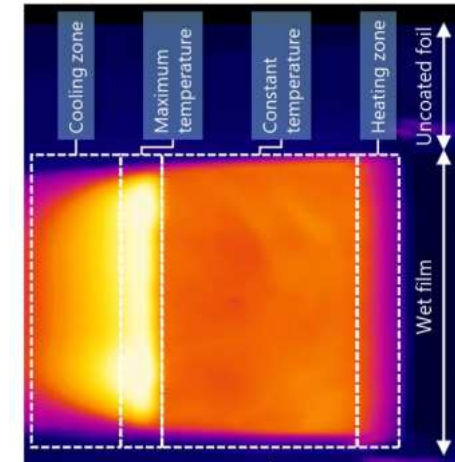
**From Simulation**



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

### Features

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

### Width / Speed / temp

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

### Markets

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

### 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)

## Coating calendering equipment

### Calendering systems from:

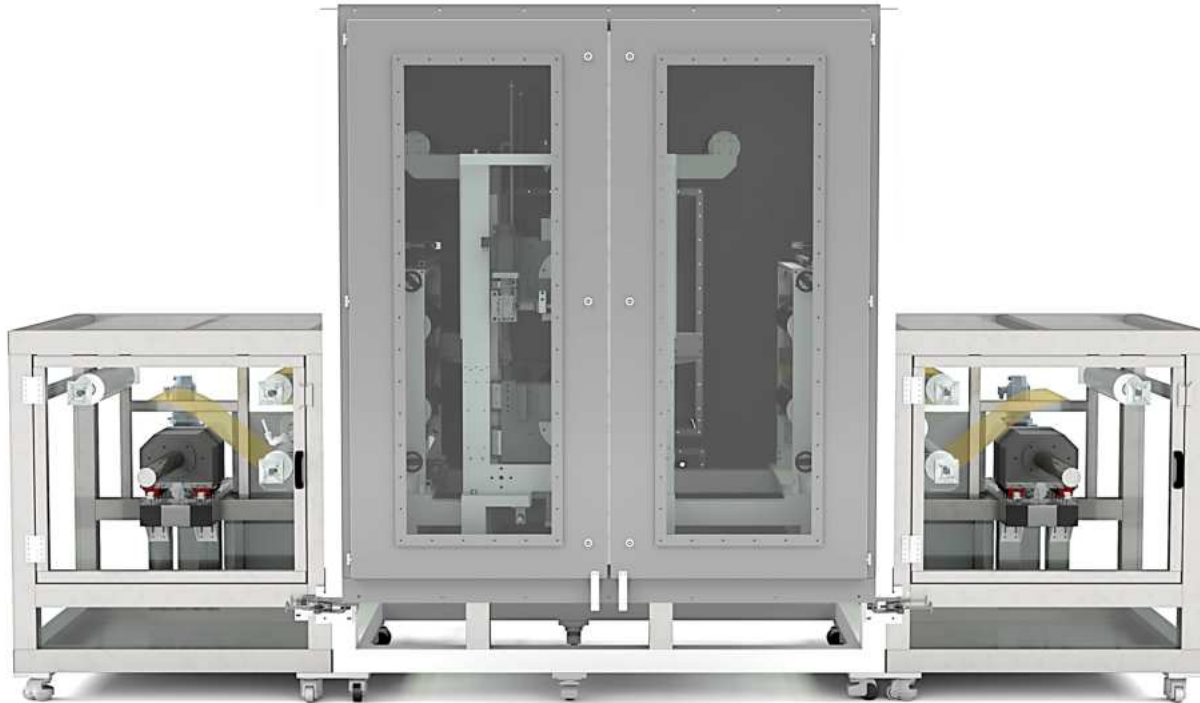
- ✓ 100 mm – 2.000 mm
- ✓ 5t to 120t
- ✓ S2S or R2R with integrated quality control and under inert atmosphere as option
- ✓ Inline calender in coating lines



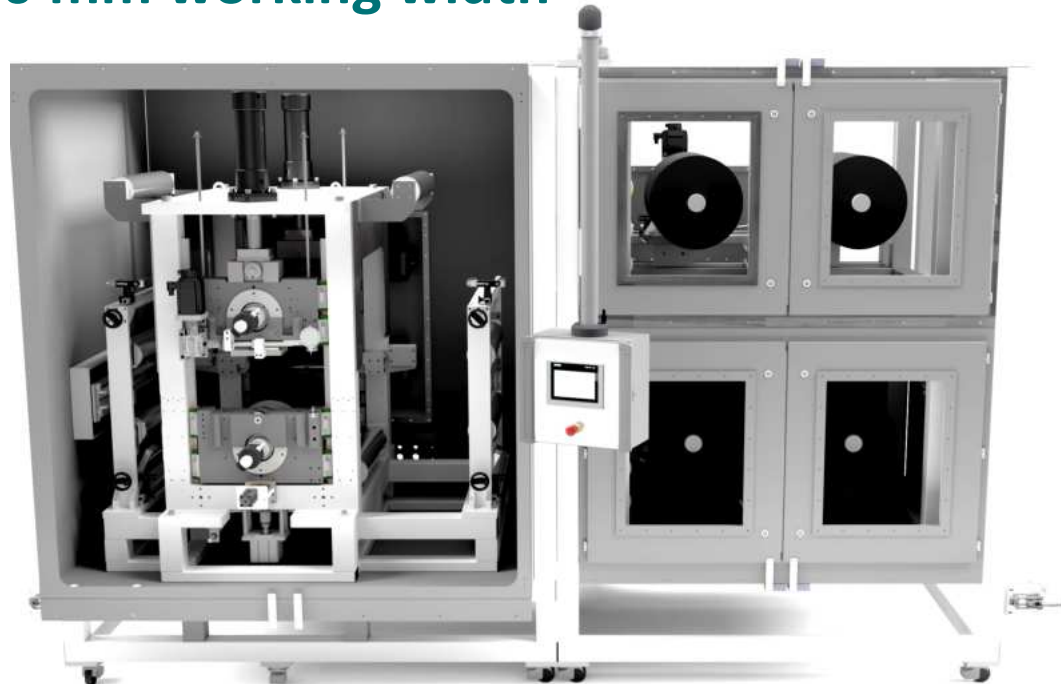
## Calendering R2R Click&Coat™ 500 mm



## Calendering R2R Click&Coat™ – Inert enclosure 500 mm



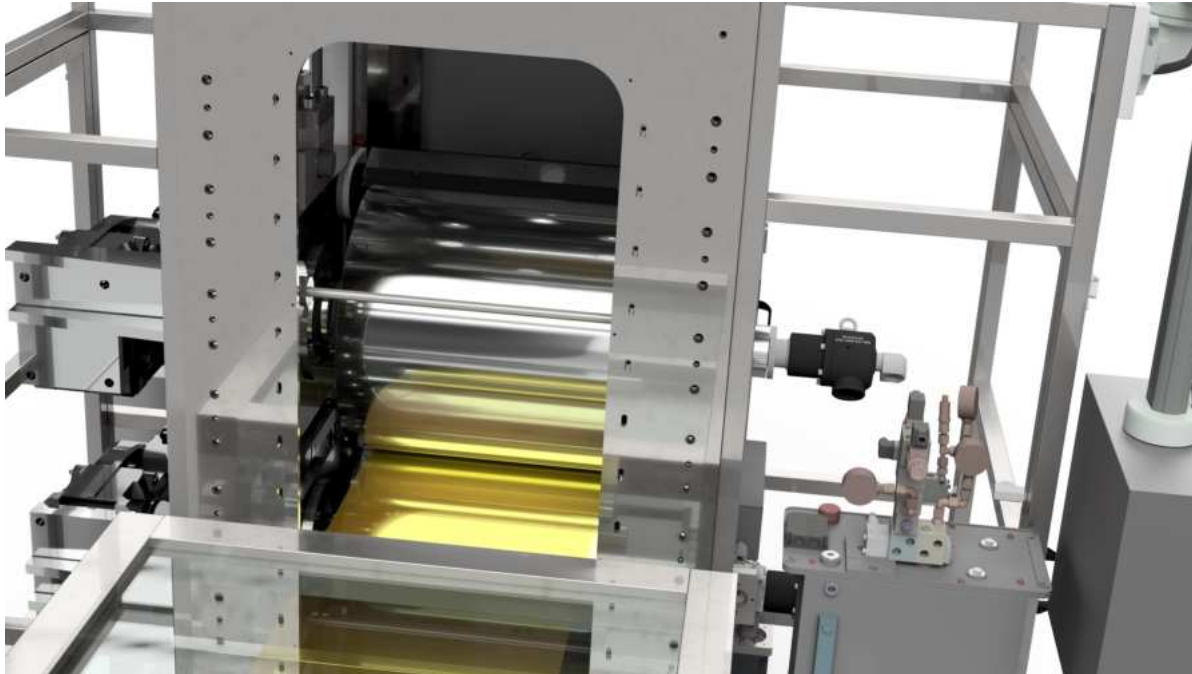
## Calendering R2R Click&Coat™ – Inert enclosure for thermal imprint 500 mm working width



## Calendering 60t / Coatema R&D centre system



## Calendering 60t / Coatema R&D centre system





# Calendering







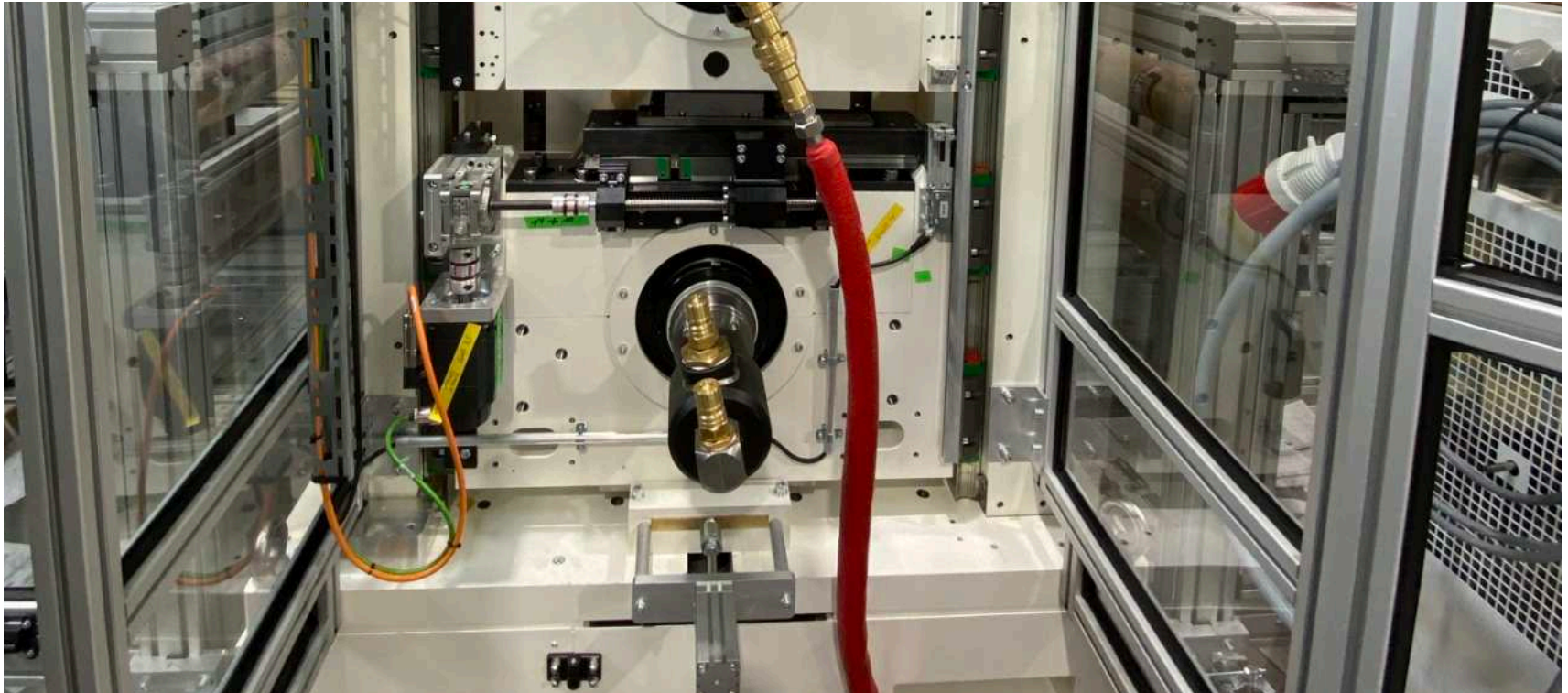






# Calendering





## Production scale / Integration in a coating line



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



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

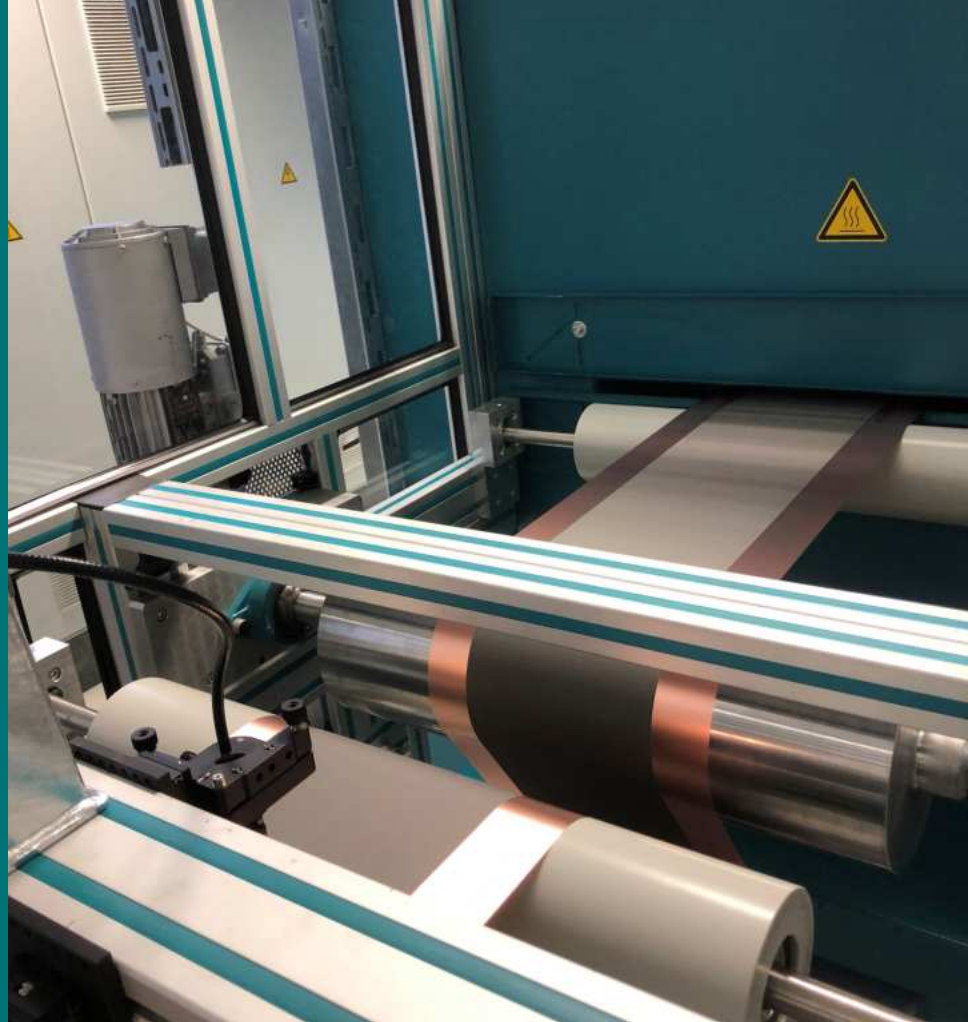


## Summary

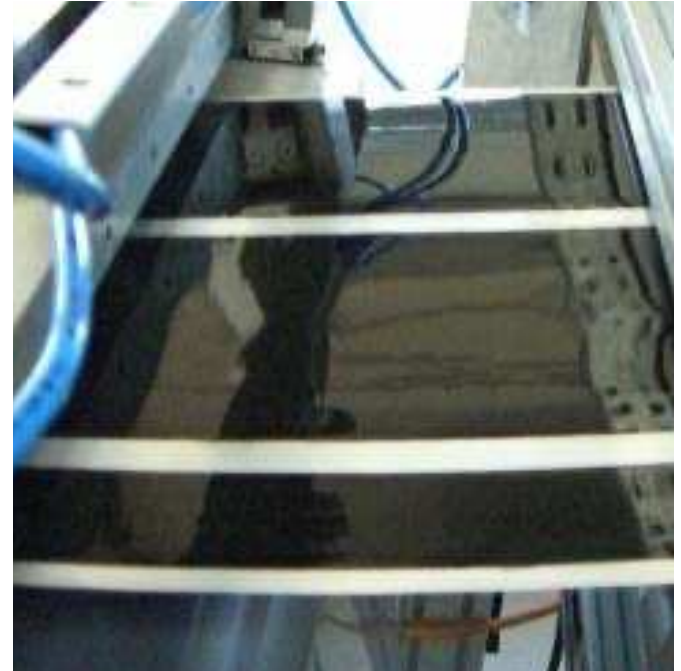
- ✓ Coatema is providing calendering systems in all sizes and dimensions
- ✓ From 2 tons to 120 tons and from 23C to 400C temperature
- ✓ 100 mm up to 2.000 mm working width
- ✓ UV Nanoimprint and thermal nanoimprint with sleeve technology
- ✓ High performance rollers with Xcrossing and different surface 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

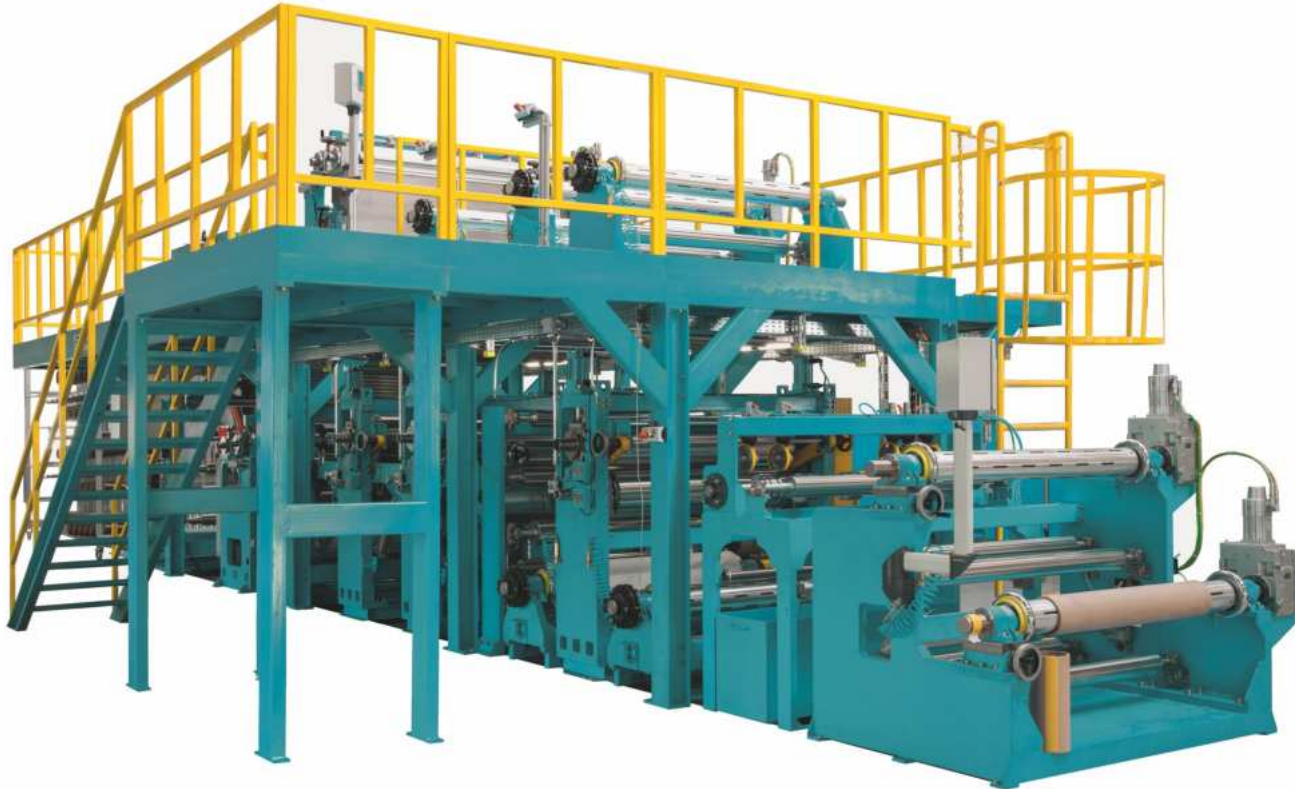


# Production line

## Production line



## Production line



## Production line

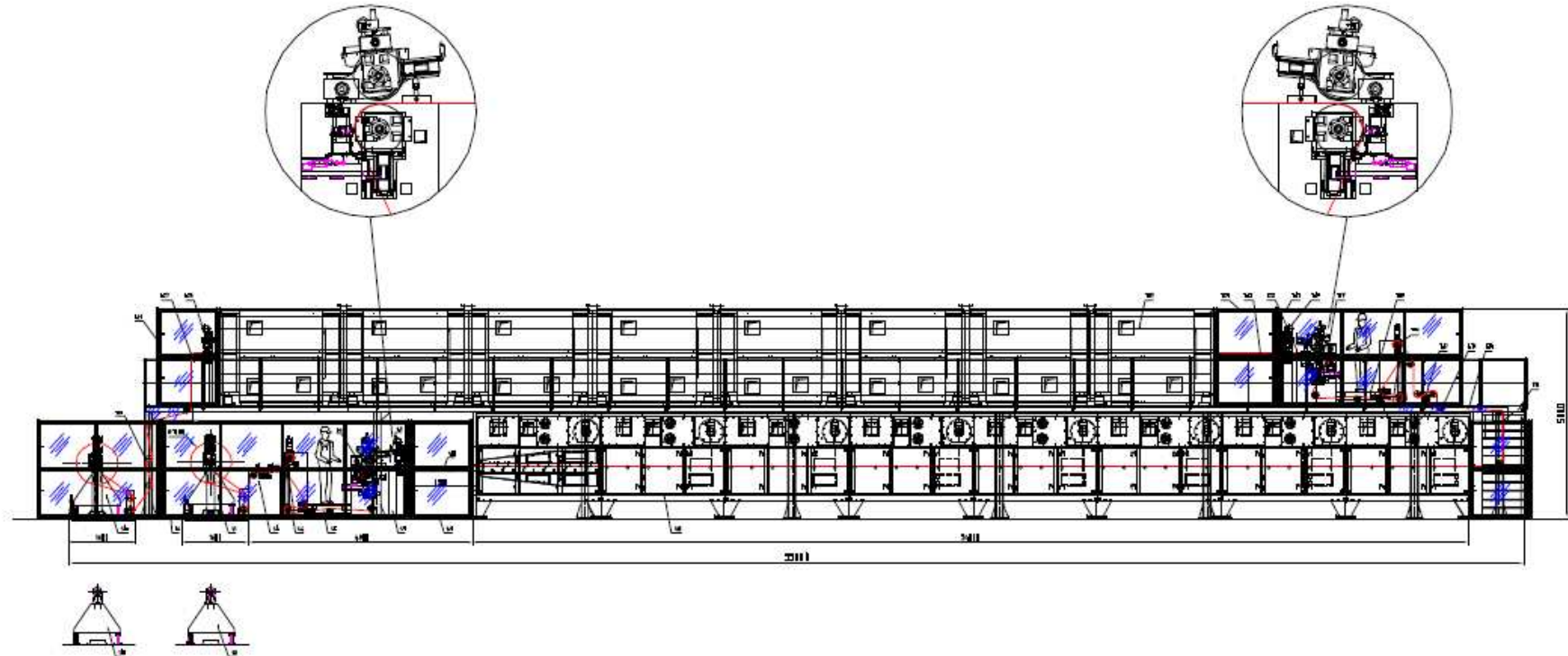


## Production line



The battery fab

## Coatema battery fab concept



# 10.

## 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](mailto:sales@coatema.de)

## Download brochures & presentations



# ***Coatema***

## Thank you

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