

# Technology development and manufacturing for fuel cells and electrolyzers

***Coatema***

06/02/2024

MEMBER OF ATH

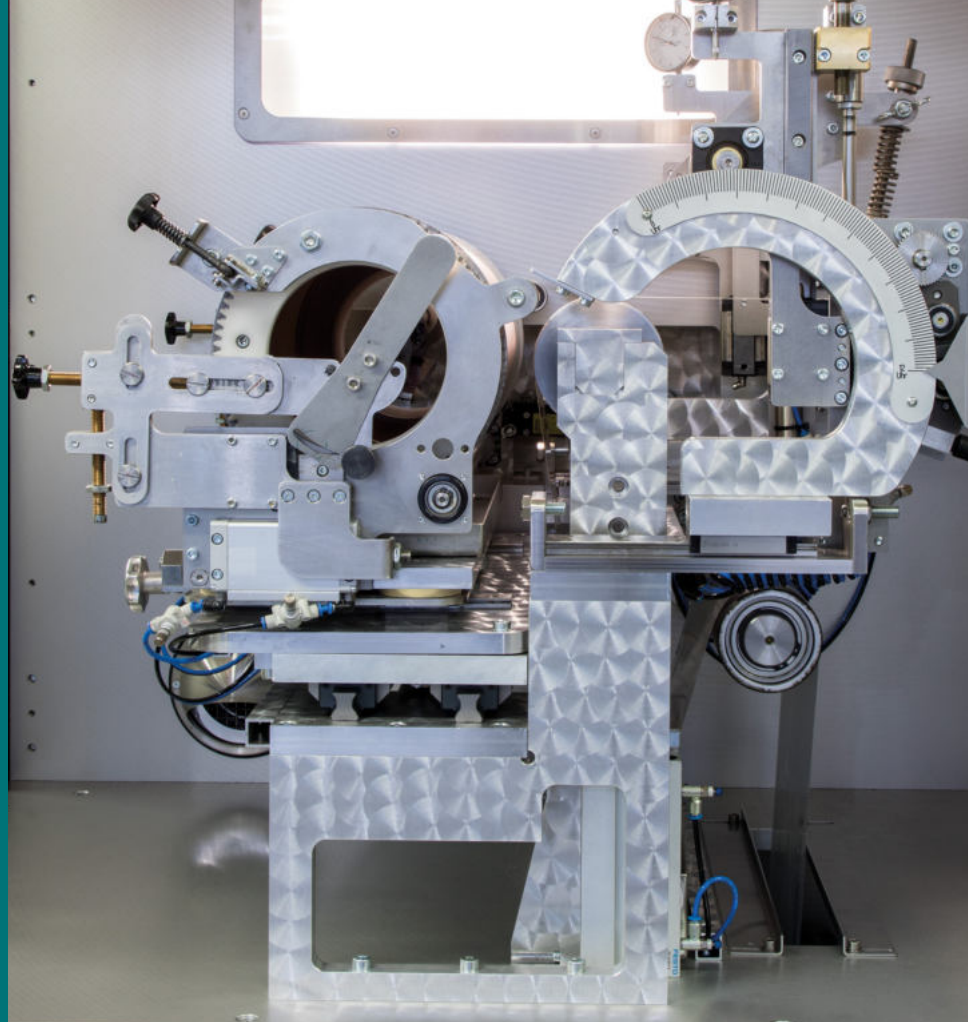
# Agenda

1. Introduction
2. Today's equipment
3. Coating systems
4. Slot die for fuel cells
5. Digital application system
6. Drying technologies
7. Simulation
8. Summary

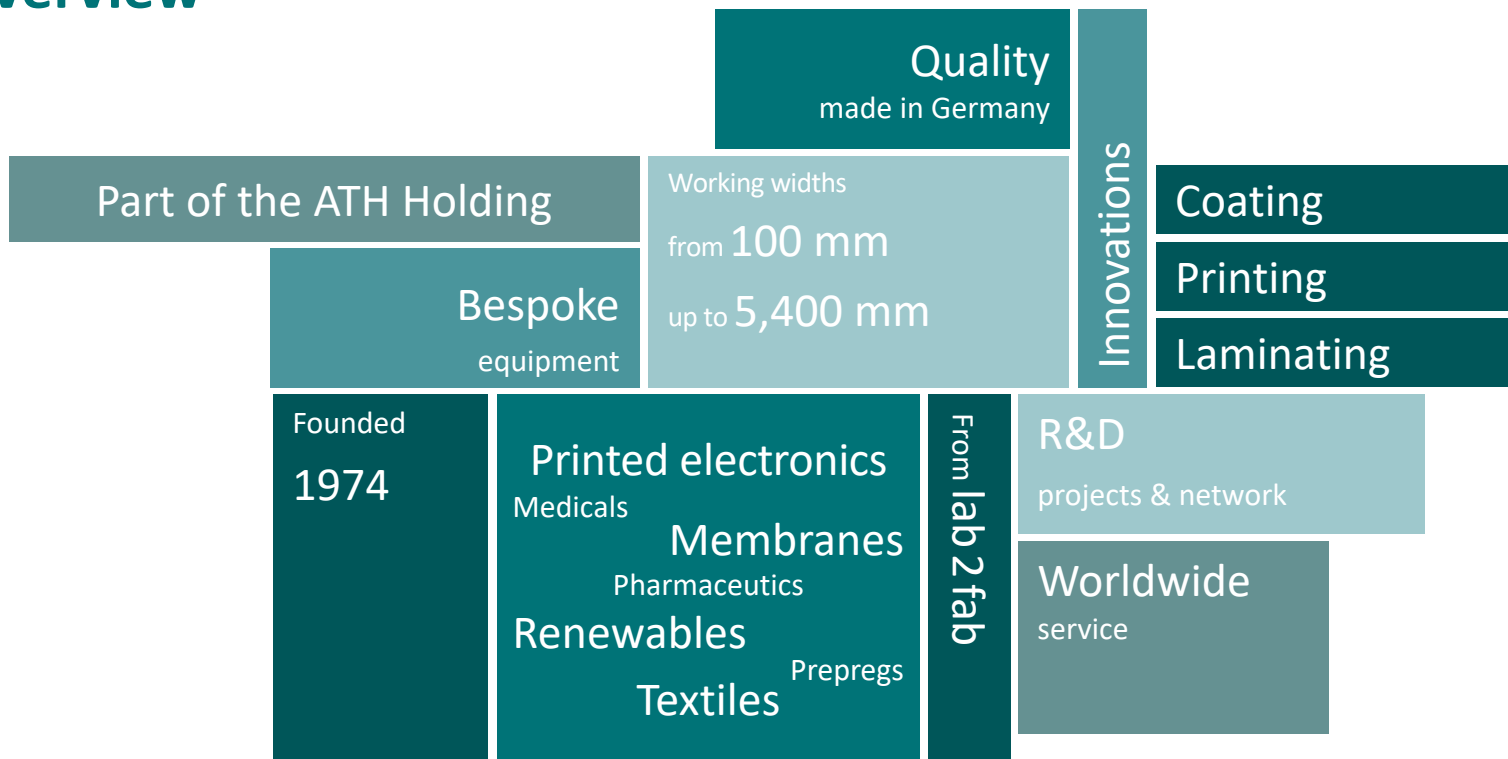


# 1.

## Introduction



## Overview



## Group of companies

**ATH** ALTONAER  
TECHNOLOGIE  
HOLDING



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

**DRY/TEC**

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



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

## Our markets – Coatema focus areas

Green Hydrogen

Fuel cells

Batteries

Solar



Sustainability

Digital fabrication

Printed  
electronics

The next thing



## Coatema equipment platform strategy for lab2fab



Lab

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



Pilot Production

- ✓ Proven electrolyzer and fuel cell coating and laminating equipment
- ✓ Highest-quality pilot product lines enable stable pilot production and reduce cost
- ✓ Scaling laboratory equipment to enable pilot production



Production

- ✓ Full-scale production line for electrolyzers
- ✓ Elevating our in-depth roll-to-roll equipment to fully scale production and further reduce adoption cost

## 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



## R&D customers



## R&D projects overview 2022 – 2024

Printed  
electronics &  
process control



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

Process &  
equipment for  
printed  
electronics



R2R production line for OPV solar with integrated backend



Development of near-field electro hydrodynamic nanowire printing

Battery  
production



Implementation of laser drying processes for lithium-ion battery production



R2R process optimization for solid state batteries

Fabric  
functionalization



Plasmonically enhanced photocatalysis for wastewater treatment

### RetroWin

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

Sustainable  
production  
technology



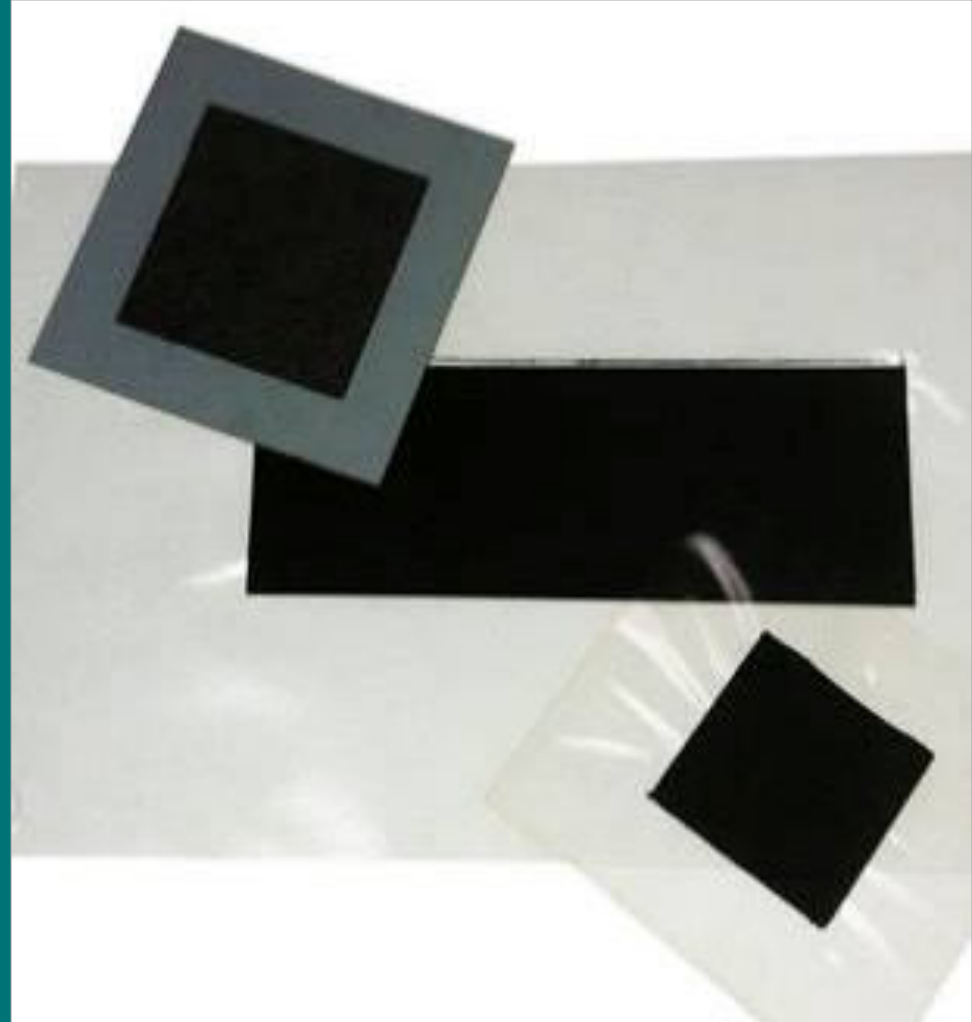
The WaterProof project aims at developing an electrochemical process that converts CO<sub>2</sub> emission



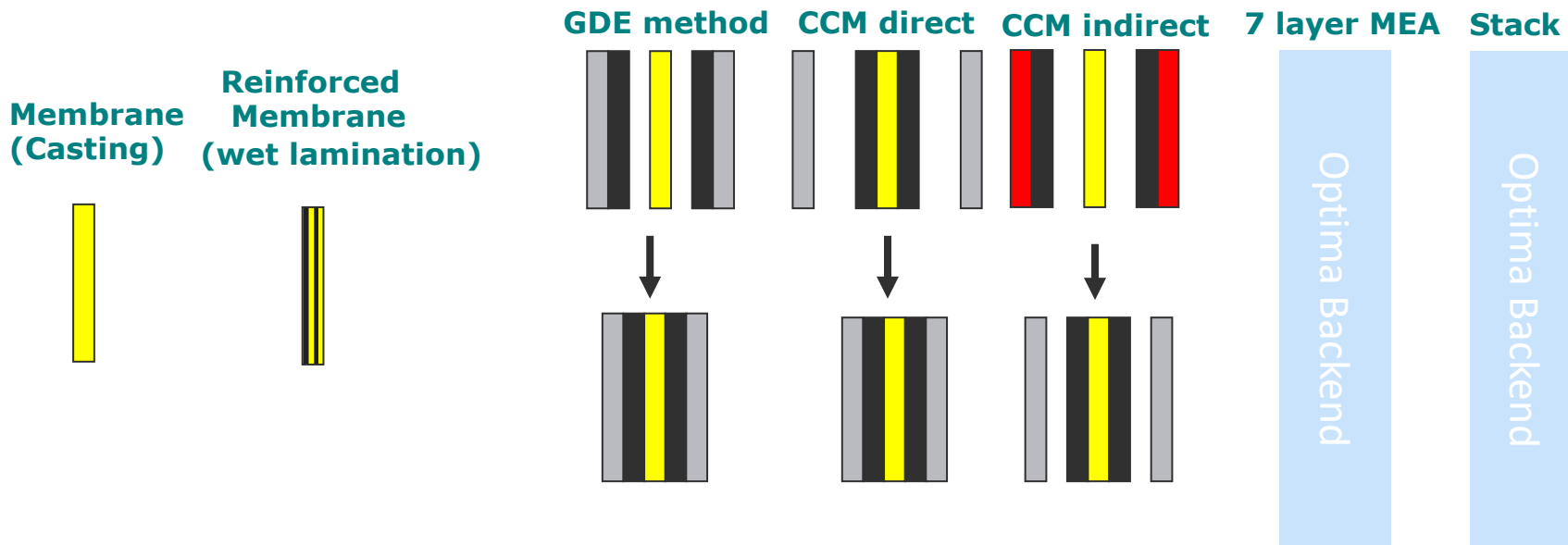
Creating an open-innovation testbed for sustainable packaging

# 2.

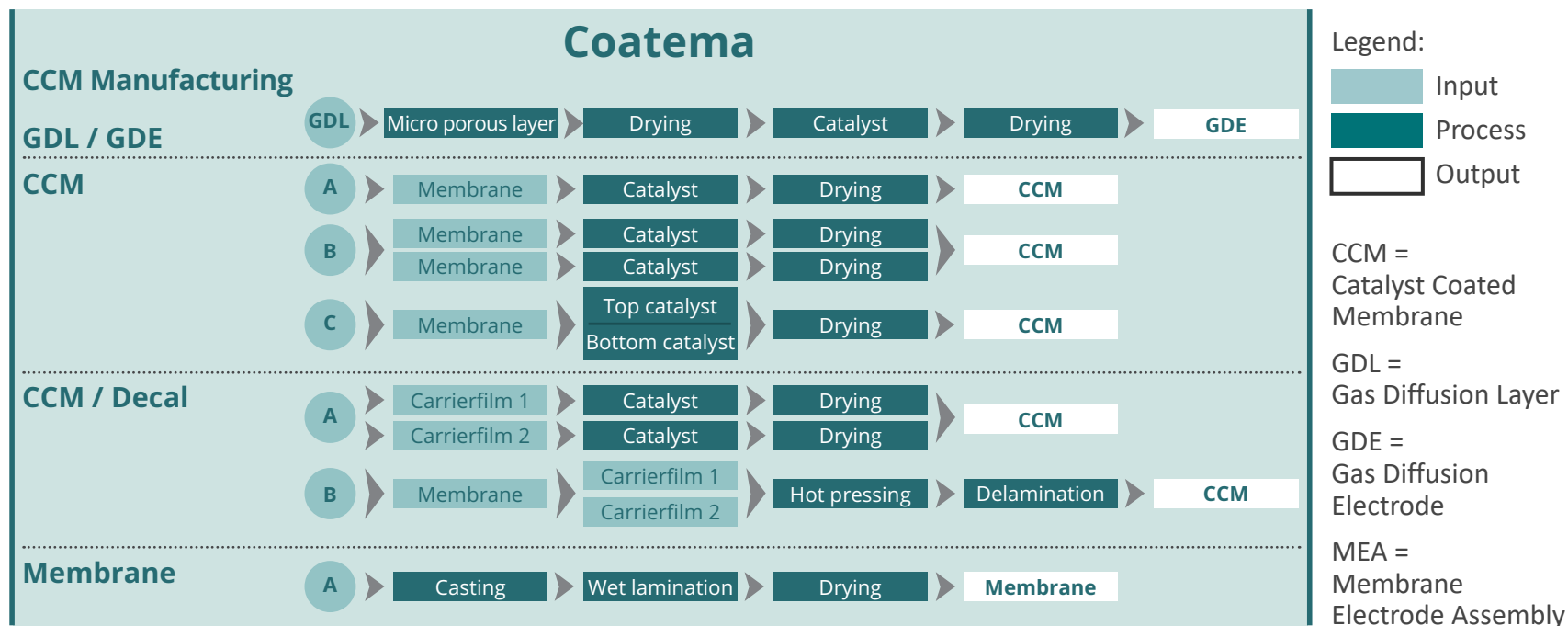
**Today's equipment for  
today's  
fuel cells/electrolyzers**



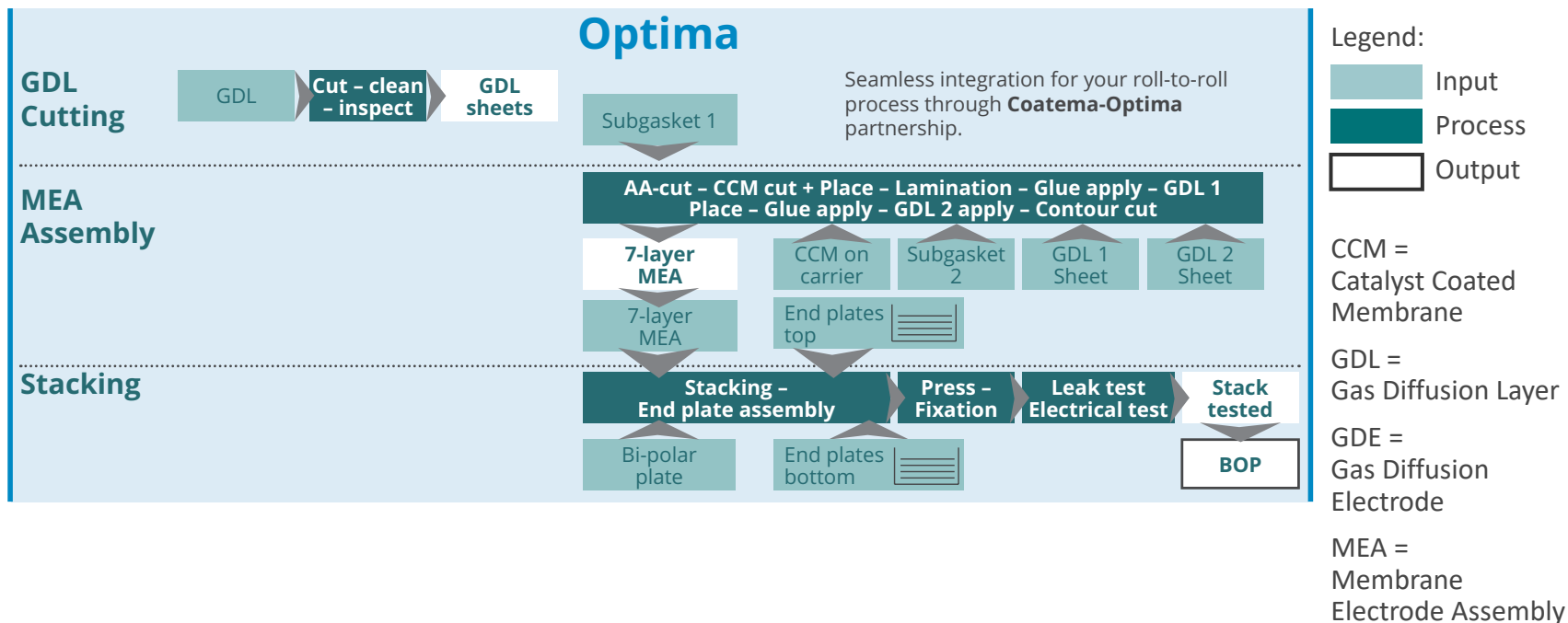
## Integrated production processes:



## Reference equipment for electrolyzer Coatema



## Reference equipment for electrolyzer Optima





Today's equipment

## S2S



Test Solution



Easycoater



Easycoater Evolution

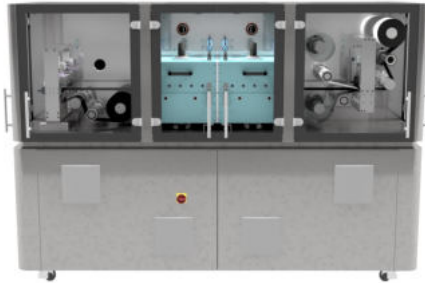
Ink testing

First sample product

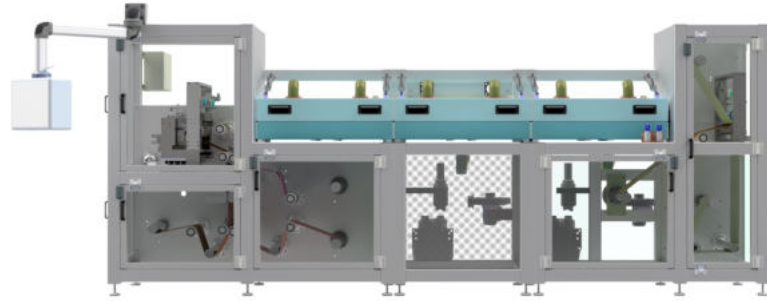
First pilot as S2S

Today's equipment

## Roll-to-Roll (R2R) lab systems



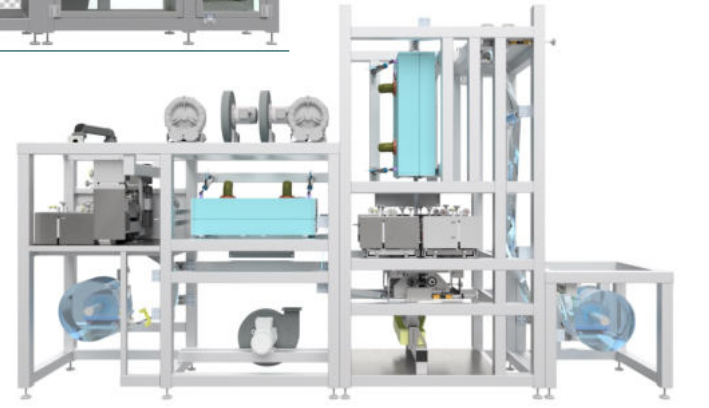
Test Solution R2R



Basecoater R2R



Smartcoater R2R



Verticoater R2R

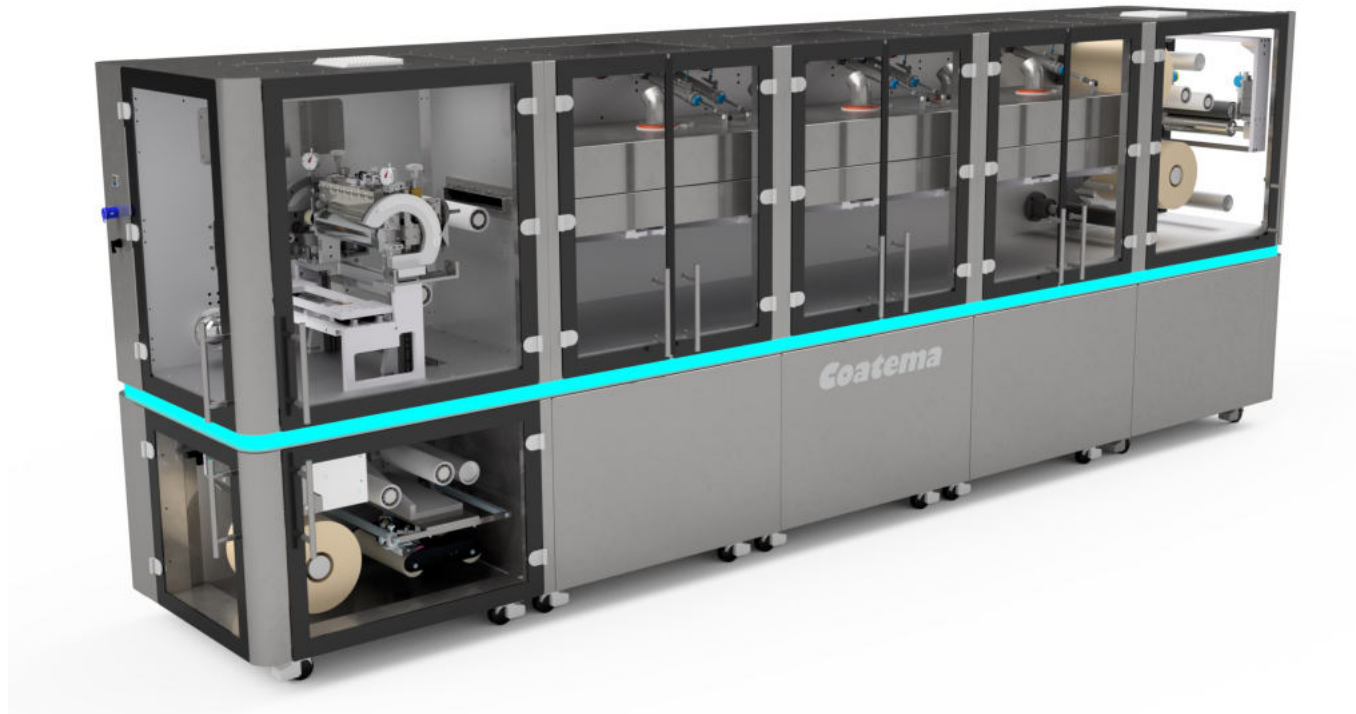
Today's equipment for batteries

## The Smartcoater



Today's equipment for batteries

## The Smartcoater

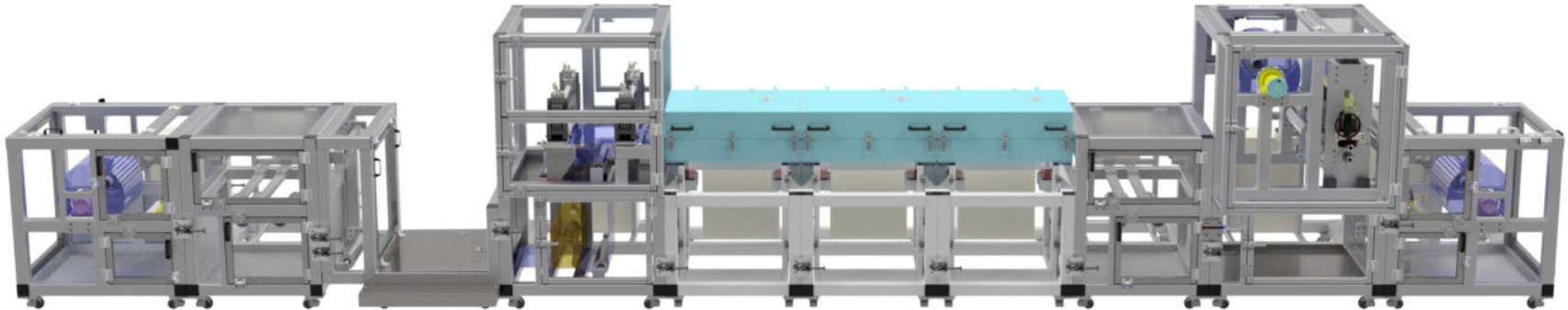


Today's equipment

## Roll-to-Roll (R2R) pilot



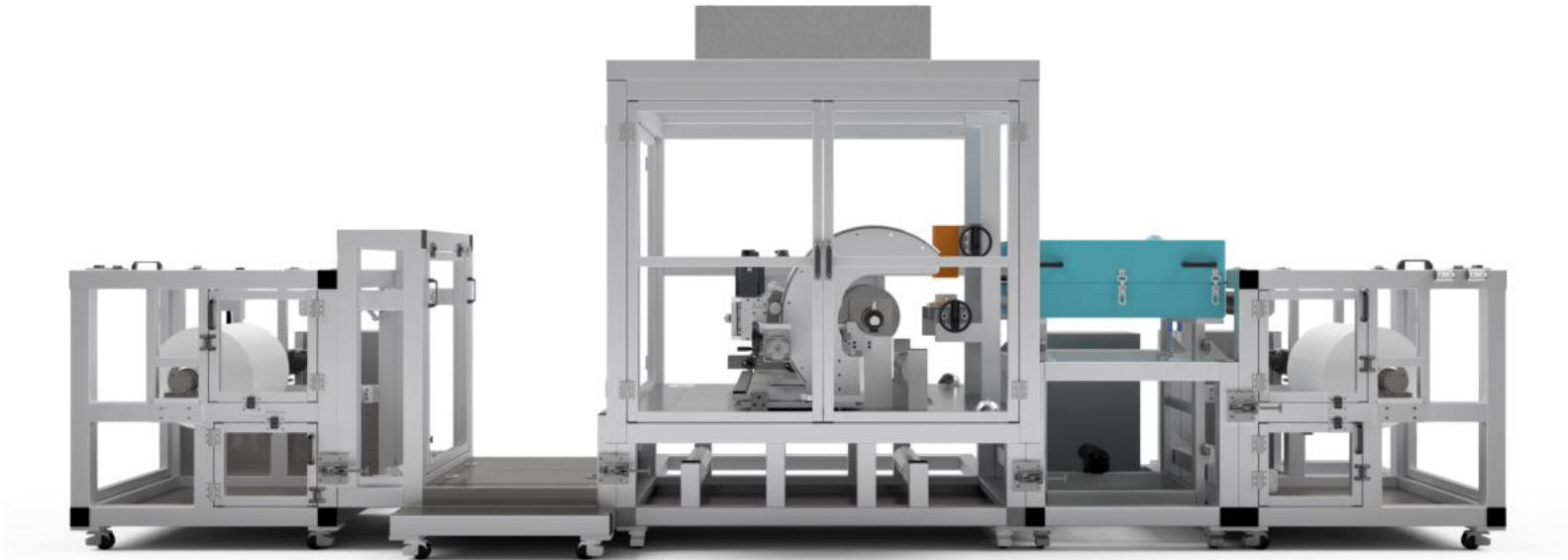
Basecoater Pilot R2R



Click&Coat™ R2R

Today's equipment

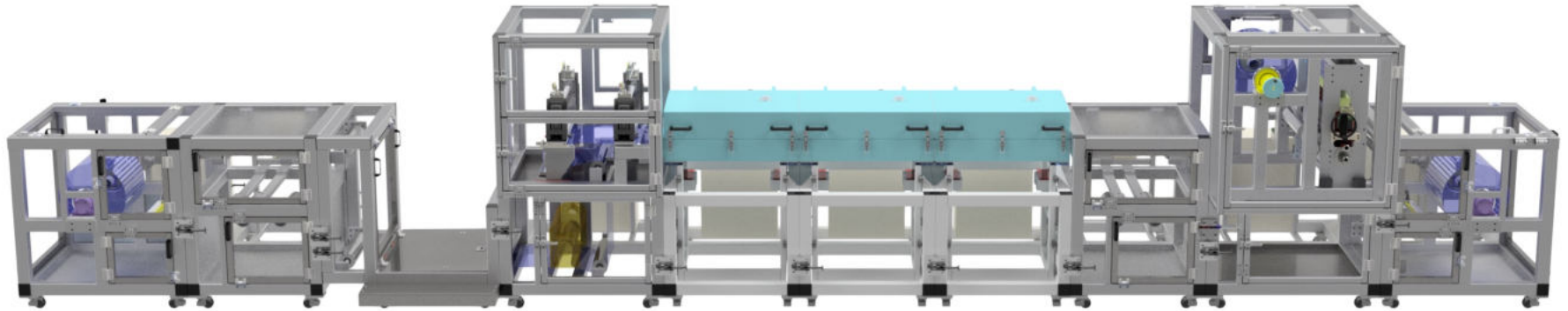
## The Click&Coat™





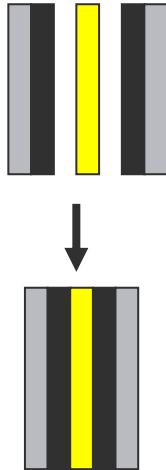
Today's equipment

## The Click&Coat™

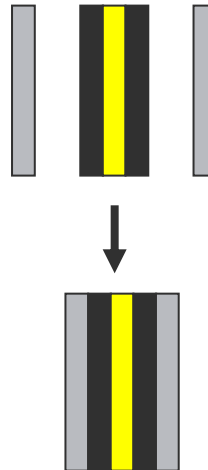


## GDE and CCM coating lines

**GDE method**



**CCM direct**



Today's equipment

## The Click&Coat™



Today's equipment

## The Click&Coat™



Today's equipment

## Specific equipment in Click&Coat™ layout

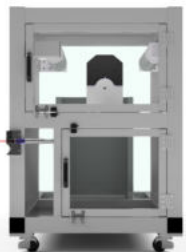




## Click&Coat™ your own ideas



Winder



Corona



Podestral



Coating



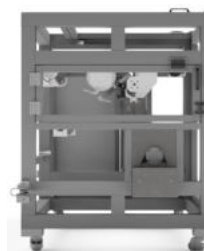
Printing



Dryer



Laminator



Rewinder



Chemical treatment bath



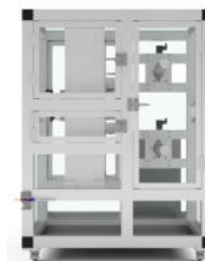
Inert Coating and  
laminating



Registration  
control



Turning  
device



Lamination

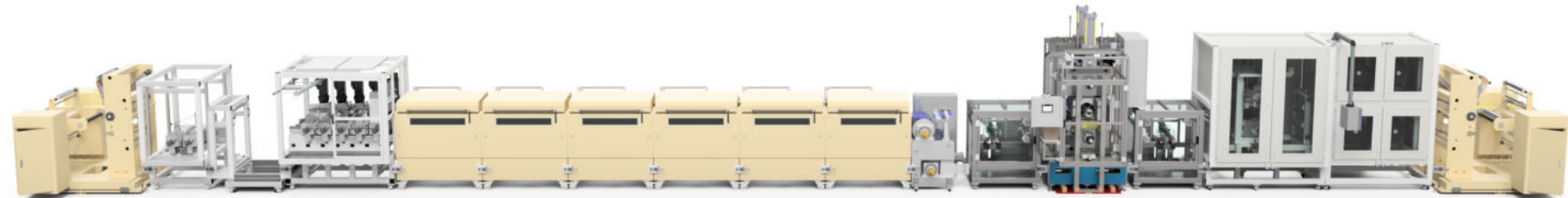


Cutting  
device



Today's equipment

## The Click&Coat™ in production scale in the R&D centre



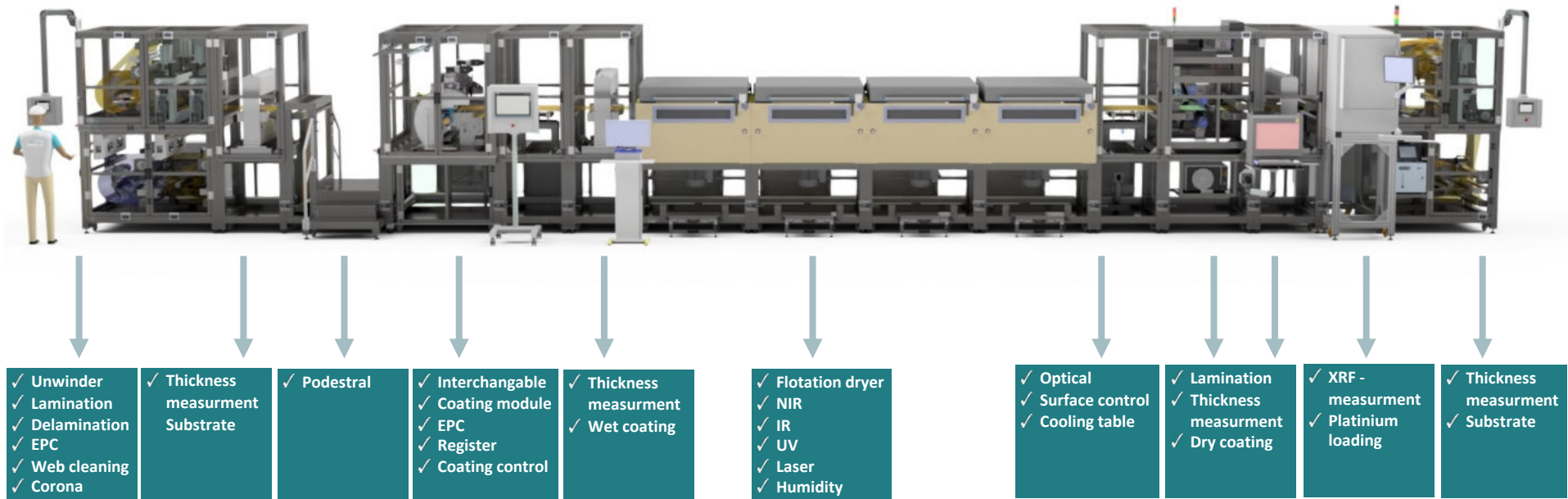
Today's equipment

## The Click&Coat™ in production scale



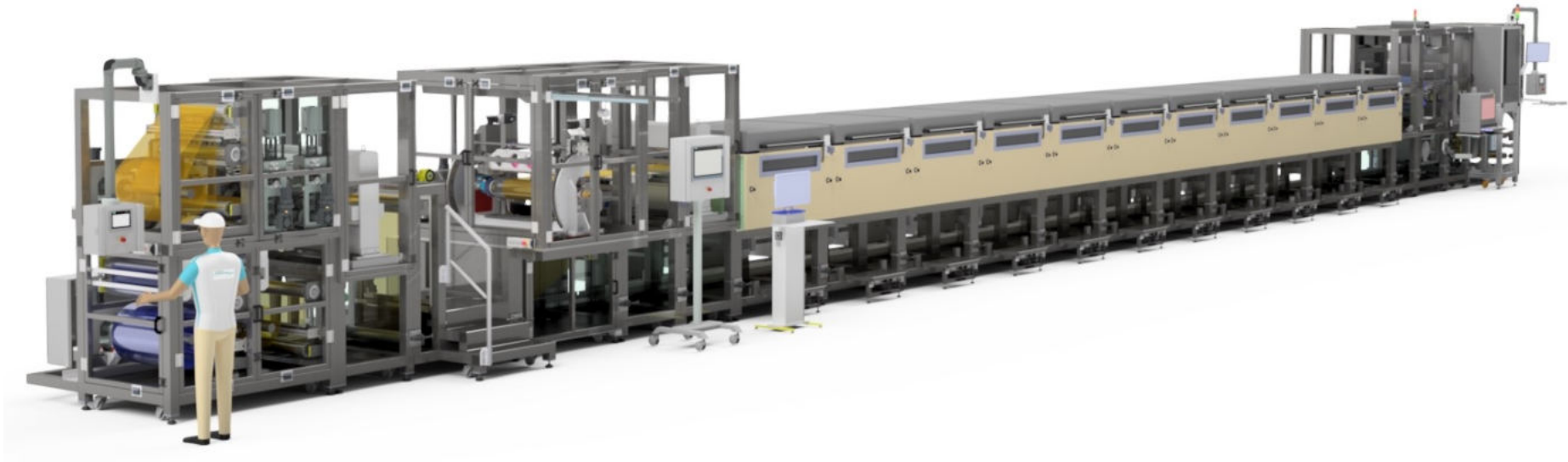
Today's equipment

## The Click&Coat™ in production scale



Today's equipment

## The Click&Coat™ in production scale



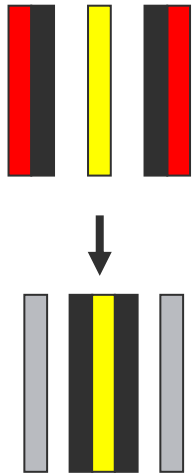
Today's equipment

## The Click&Coat™ in production scale



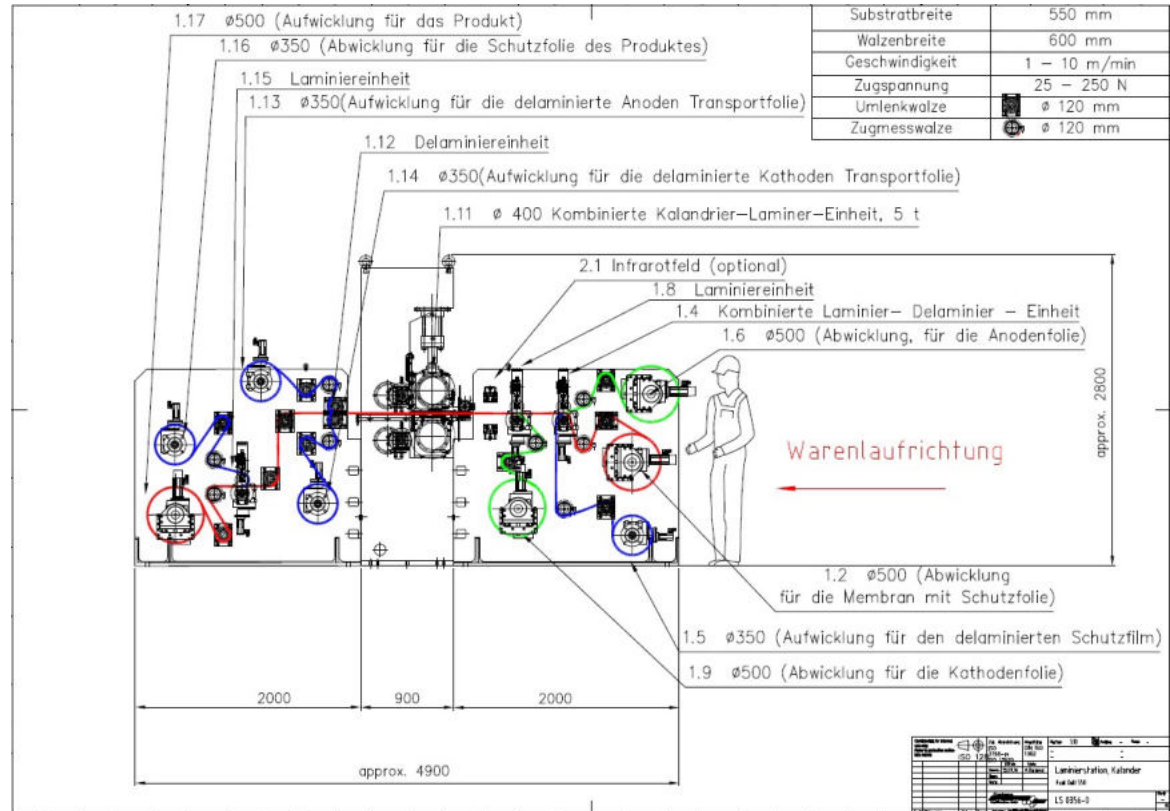
## Indirect CCM (Decal) Method

CCM indirect



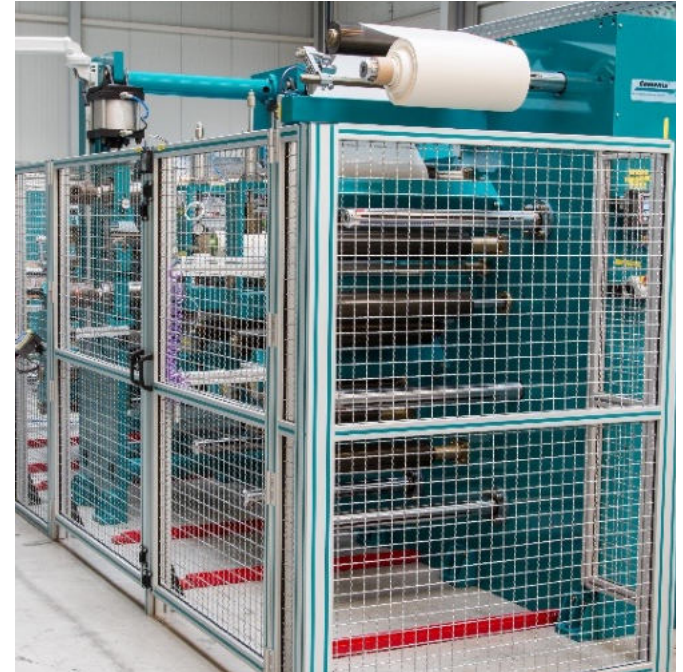
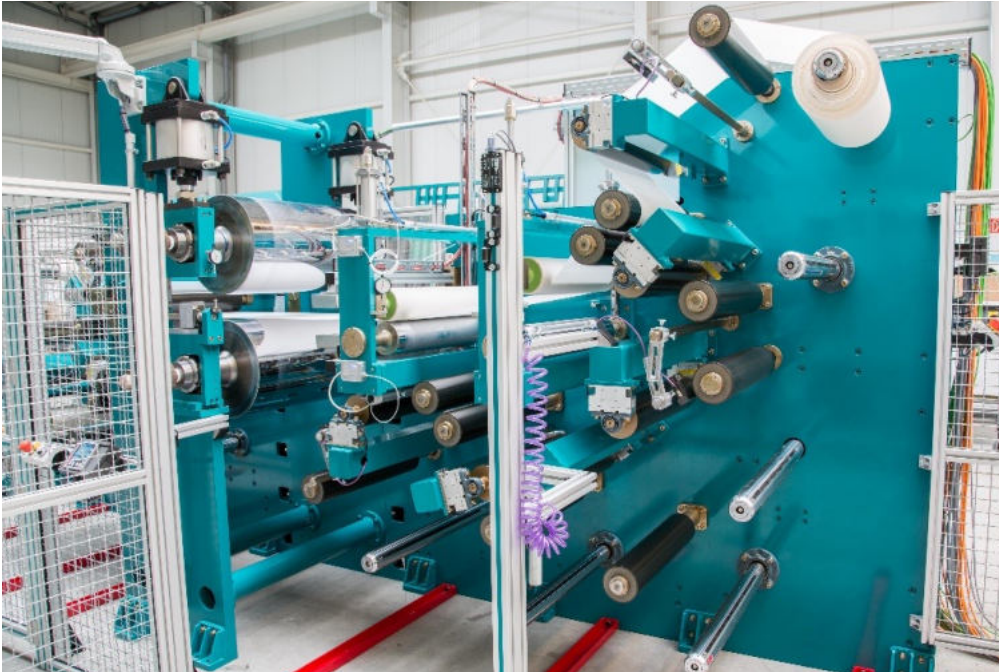


## Decal 3<sup>rd</sup> Generation



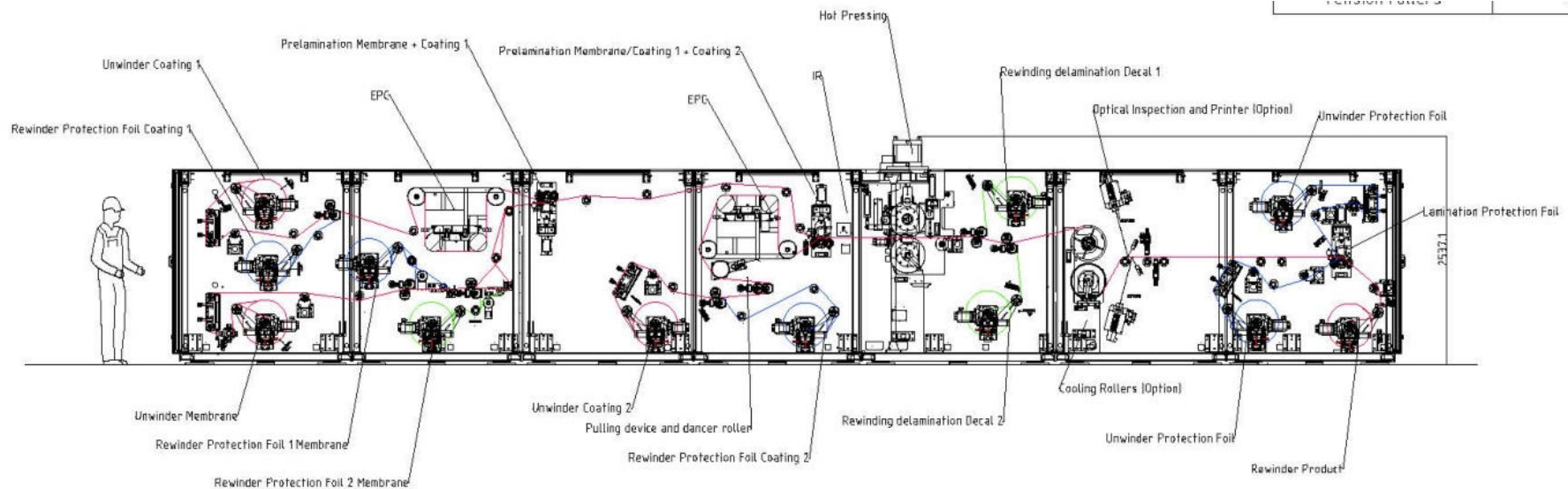
Today's equipment for fuel cells

## Hot pressing



Today's equipment for fuel cells

## Decal 3<sup>rd</sup> Generation



## Membrane casting and reinforced membrane (wet lamination)

**Membrane  
(Casting)**



**Reinforced  
Membrane  
(wet lamination)**



Today's equipment for fuel cells

## Membrane casting





# Membrane casting



## Production line for fuel cells – 1000 mm working width





# 3.

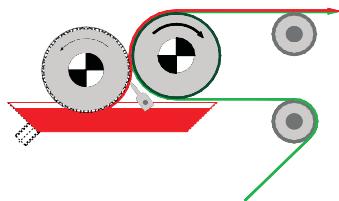
## Coating systems



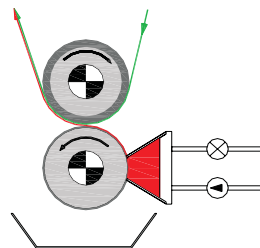
## Coating parameters

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>

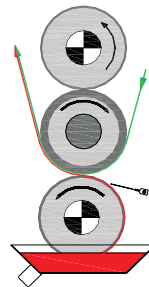
## Printing systems



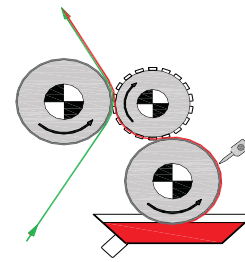
Engraved roller system



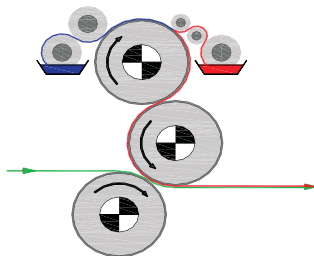
Gravure roller system



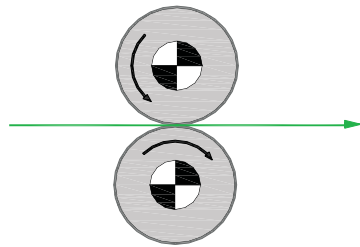
Gravure indirect system



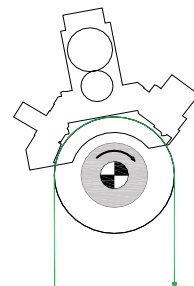
Flexography system



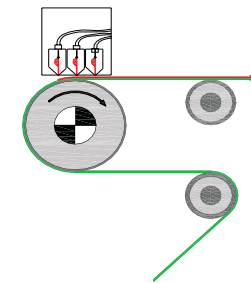
Offset lithography system



Hot embossing system

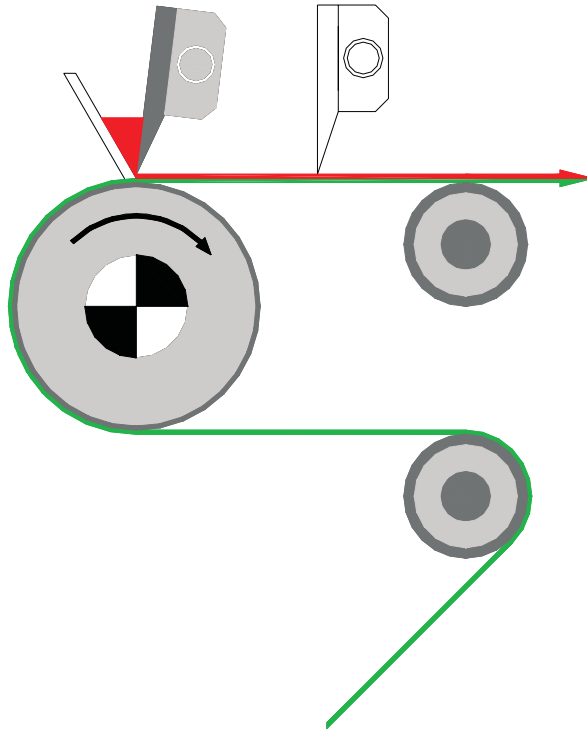


Nanoimprint system



Inkjet system

## Knife coating



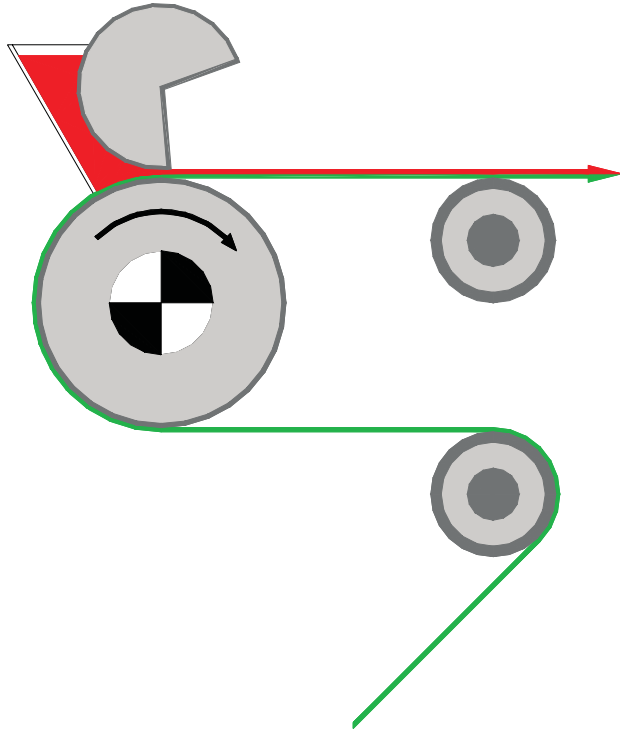
### Variation of the coating weight

- ✓ 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



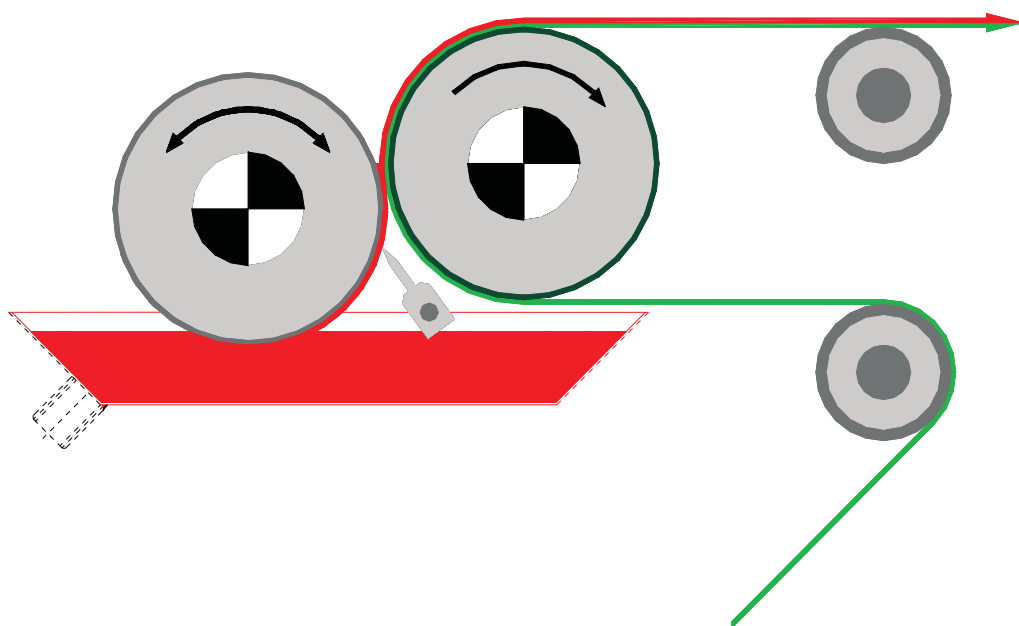
### Variation of the coating weight

- ✓ 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



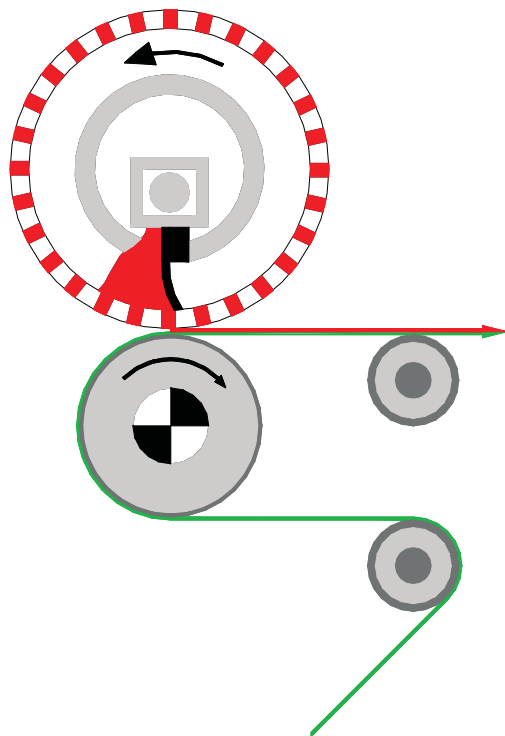
**Variation of the coating weight**

✓ 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

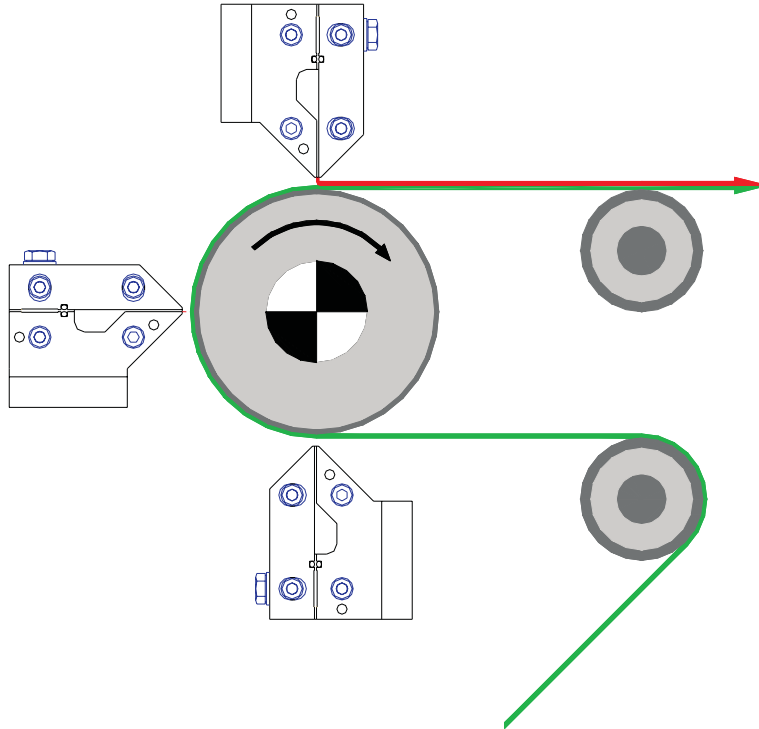
10 000 – 80 000 mPas

✓ Paste

10 000 – 25 000 mPas



## Slot die coating



**Variation of the coating weight**

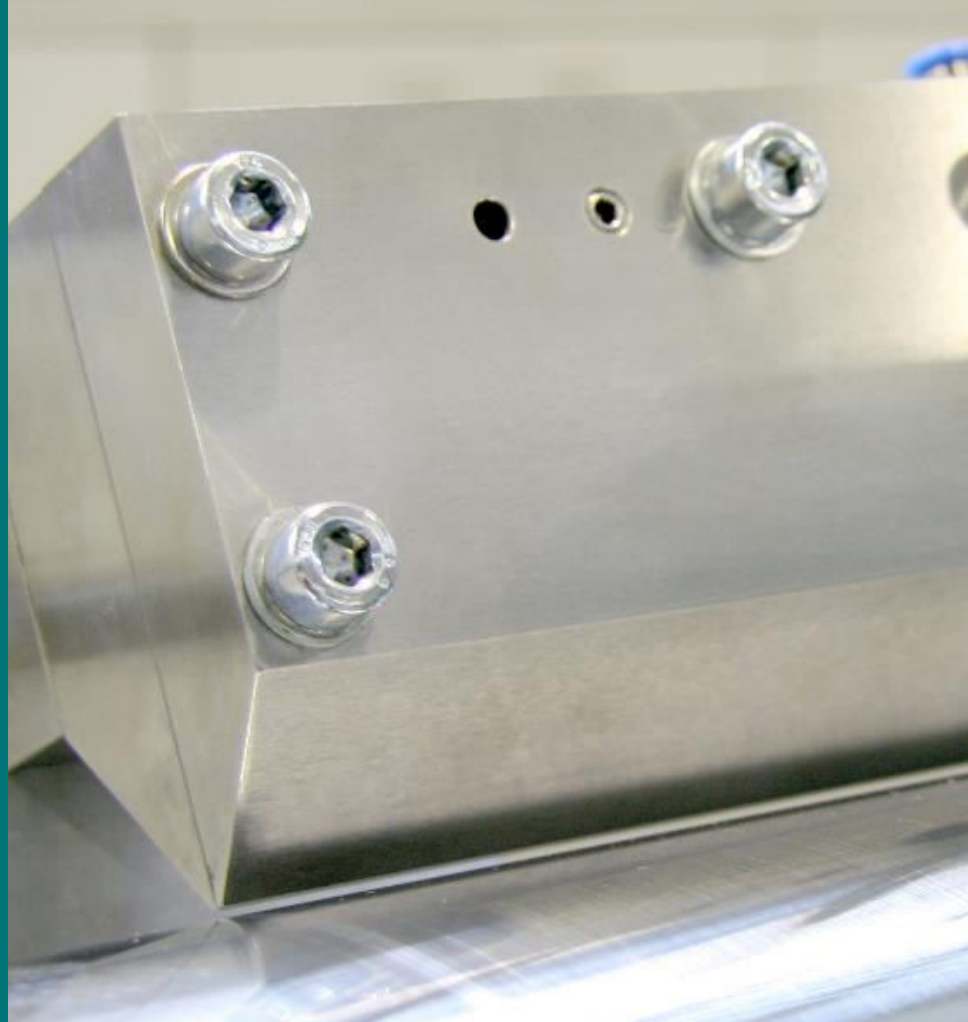
✓ 1 – 200 g/m<sup>2</sup>

**Range of viscosity**

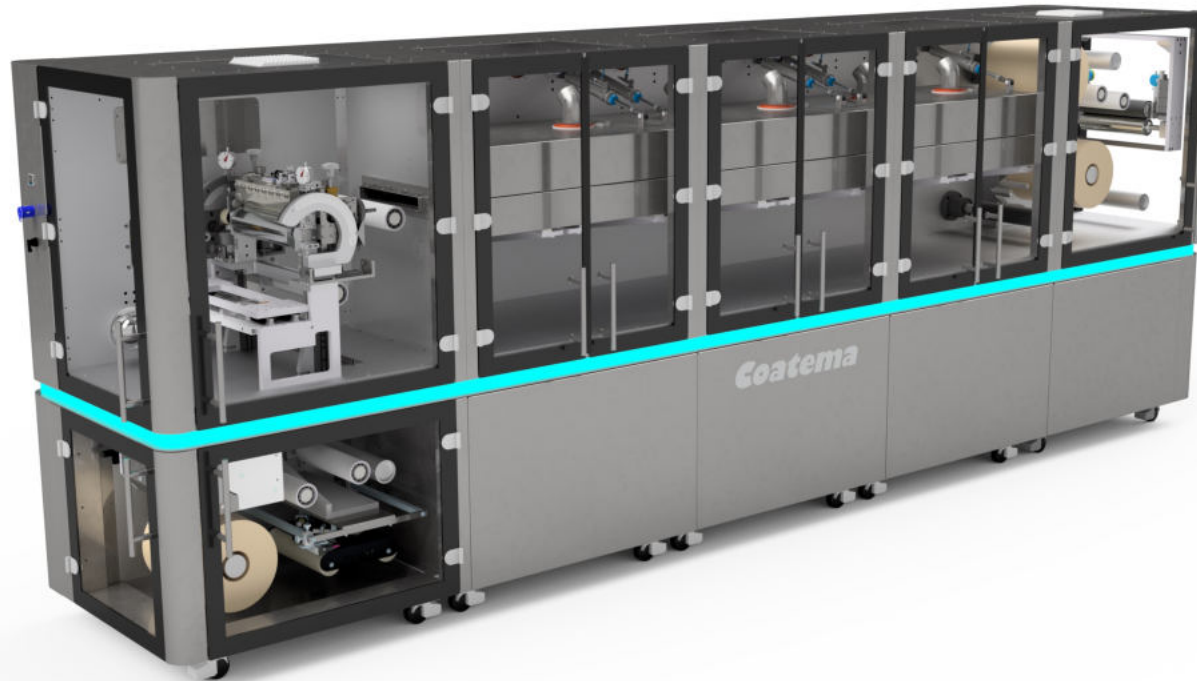
✓ 1 – 30 000 mPas

# 4.

## Slot die coating for fuel cells



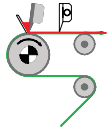
## Basic principle



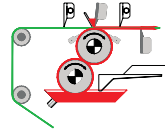
## Coating parameters

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>✓ 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>

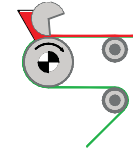
## Coating systems



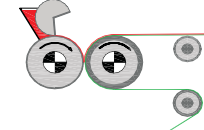
Knife system



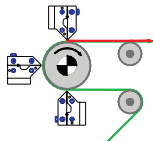
Double side coating system



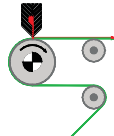
Commabar system



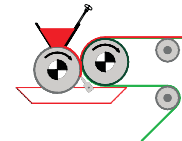
Reverse commabar system



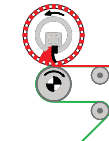
Slot die system



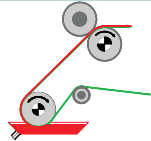
Curtain coating system



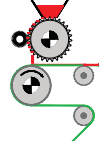
Case knife system



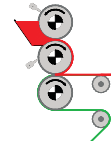
Rotary screen system



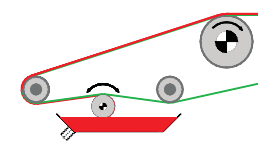
Dipping system (Foulard)



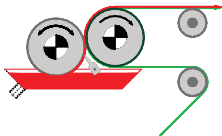
Powder scattering system



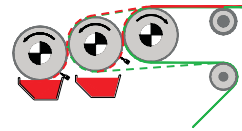
Reverse roll coating system



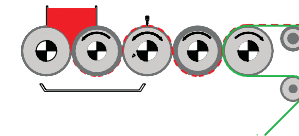
Micro roller coating system



2-roller coating system

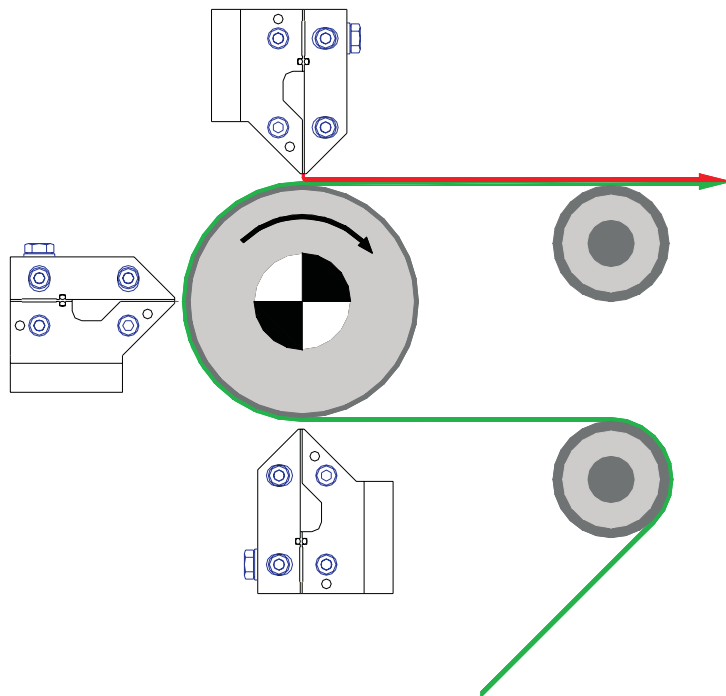


3-roller combi coating system



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  $\mu\text{m}$

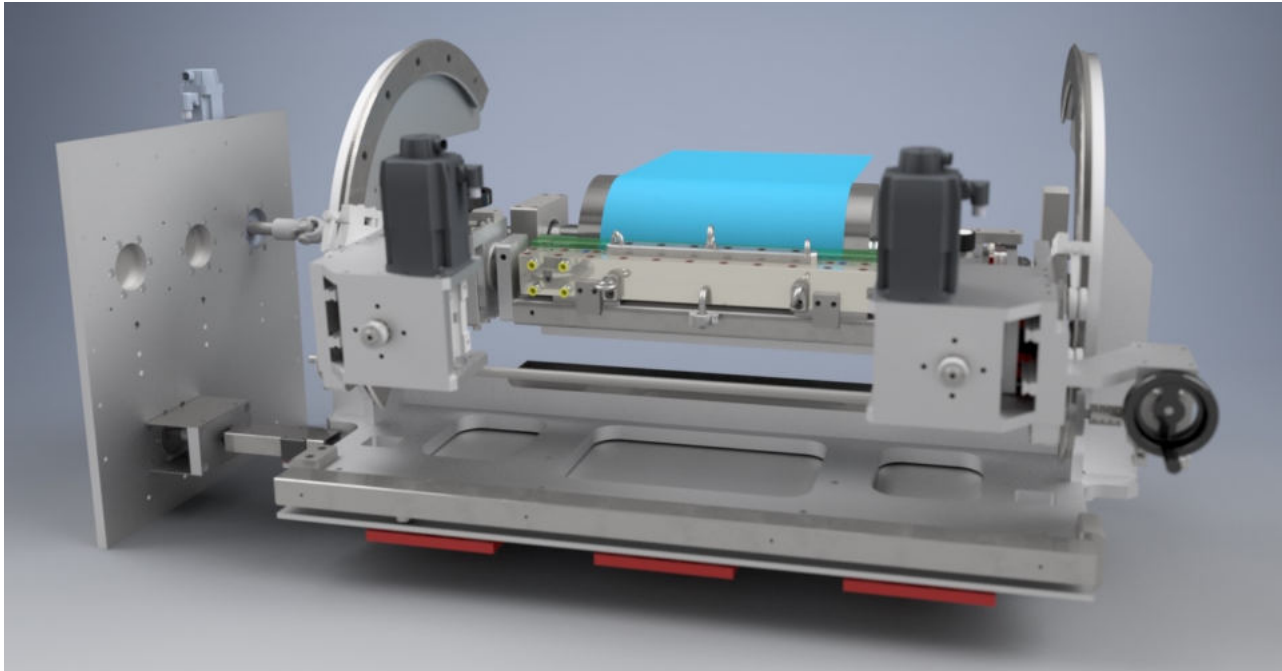
### Coating accuracy

✓ <1% (2 – 5%)

### Coating width

✓ up to approx. 3 m

## Basic principle

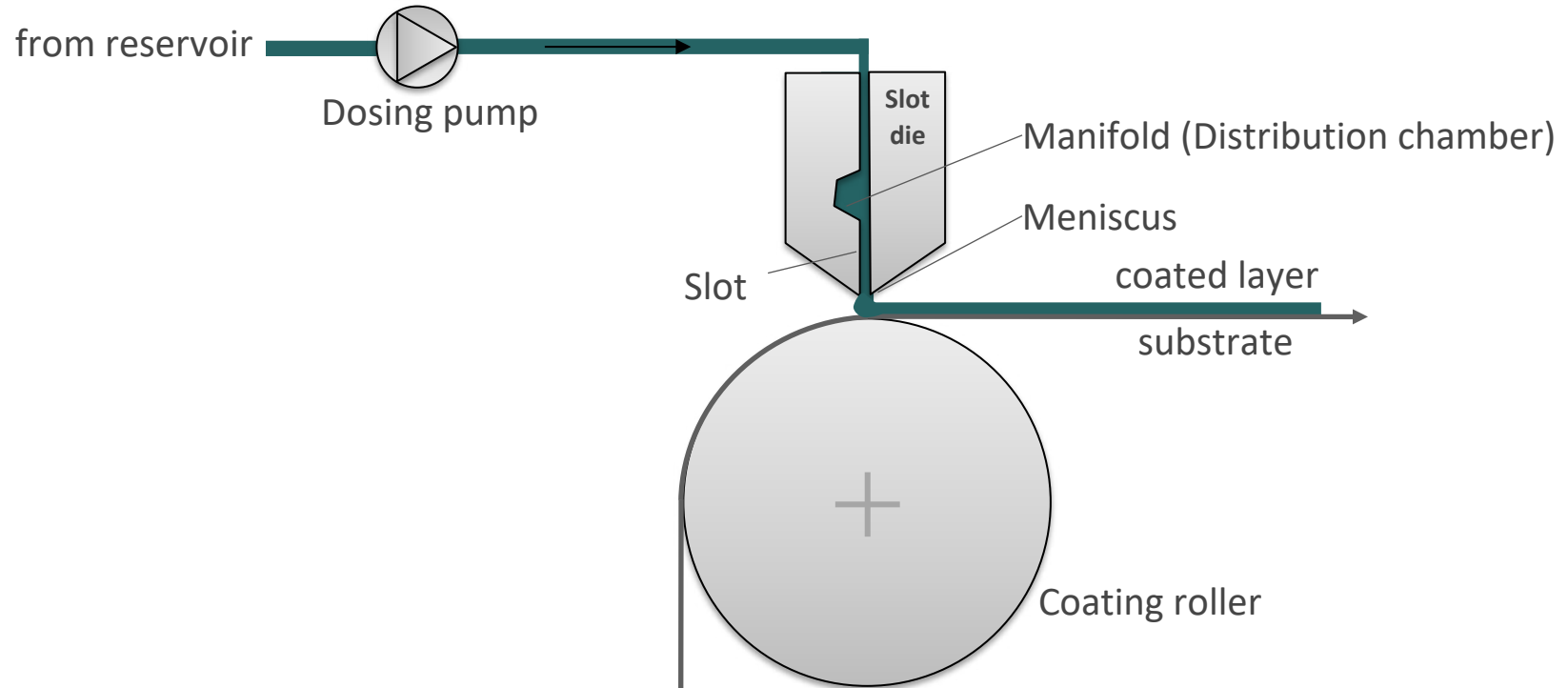




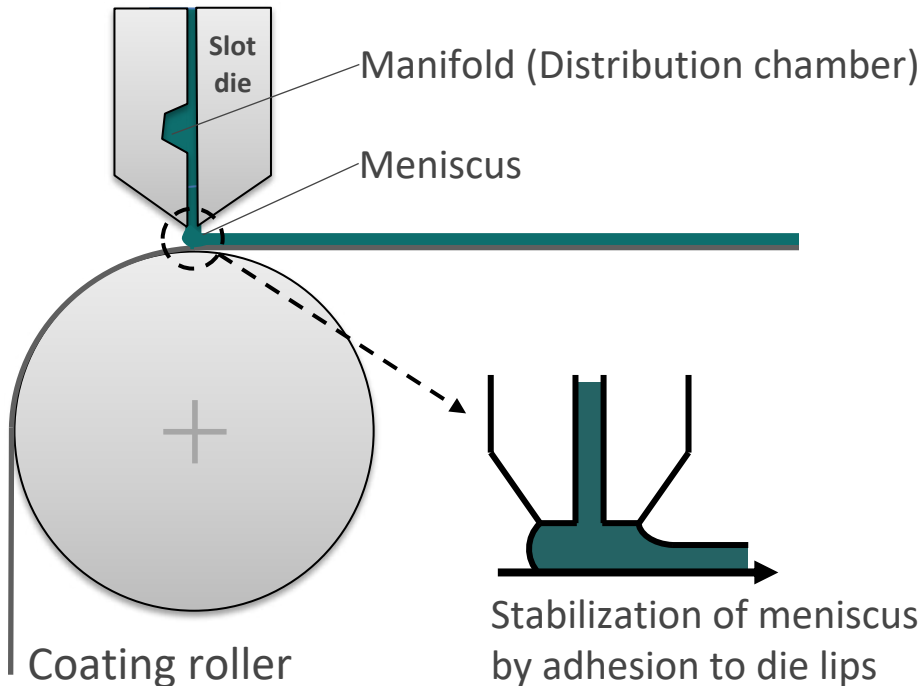
## Basic principle



## 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

## 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.

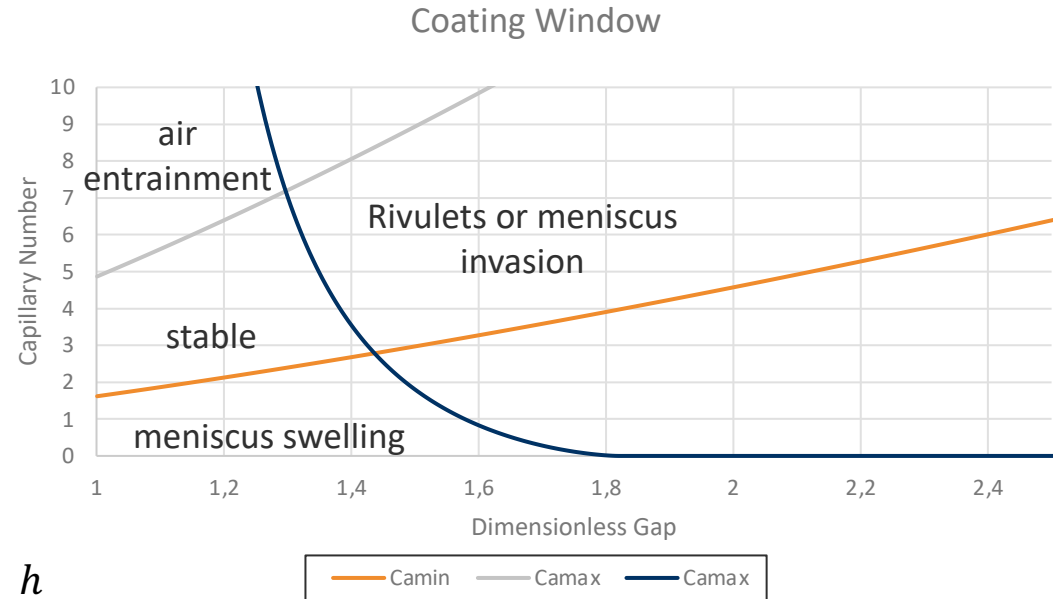
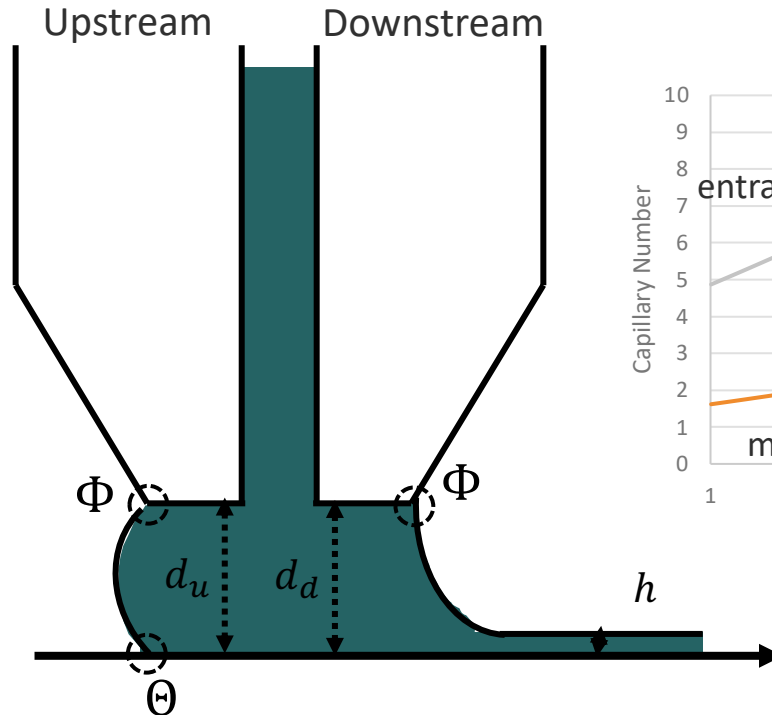
Can be done by appropriate computer programs.

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

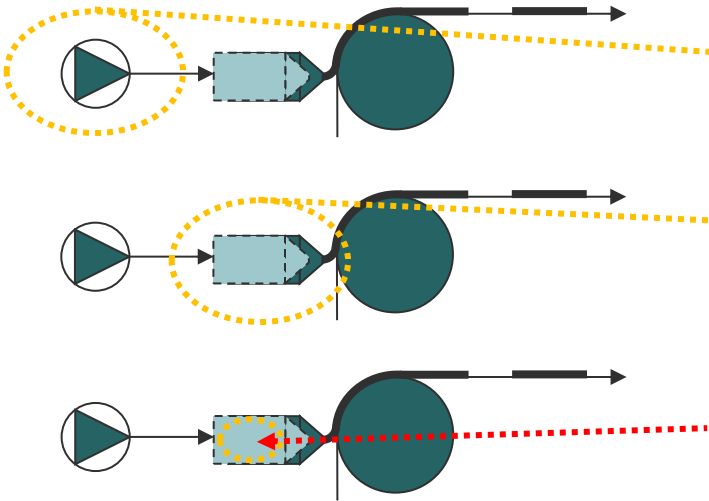
Navier-Stokes-equations (equations of motion for incompressible fluids,  $\rho = \text{const}$ )

$\Delta, \nabla$  = differential operators

## Calculation of the meniscus stability



## Standard techniques for intermittent coating



### **Pump:**

stop – reverse – restart

### **Slot die body:**

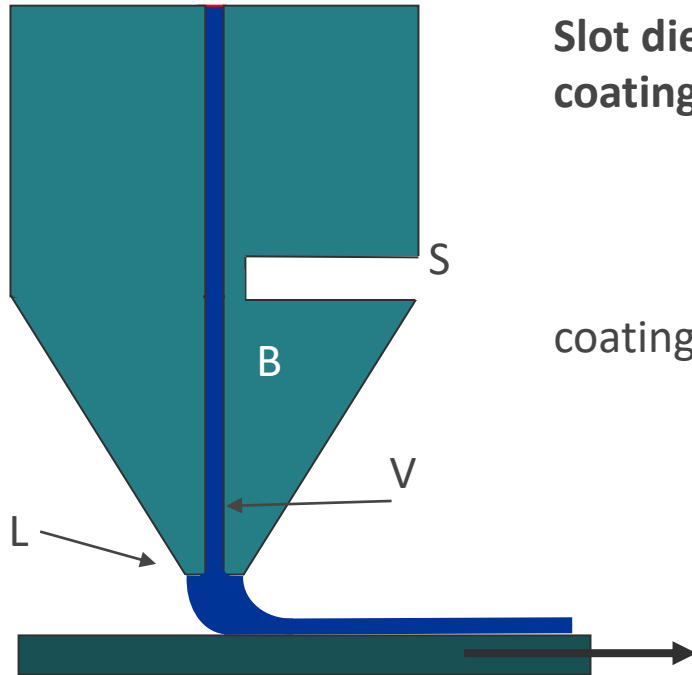
move back – move forth to minimum gap –  
move back to working gap (wedge procedure)

### **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 – the switching slot die lip



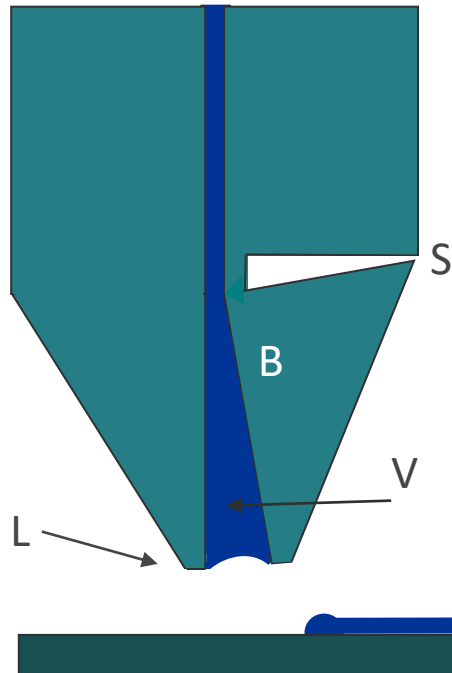
Slot die with movable lips:  
coating mode

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

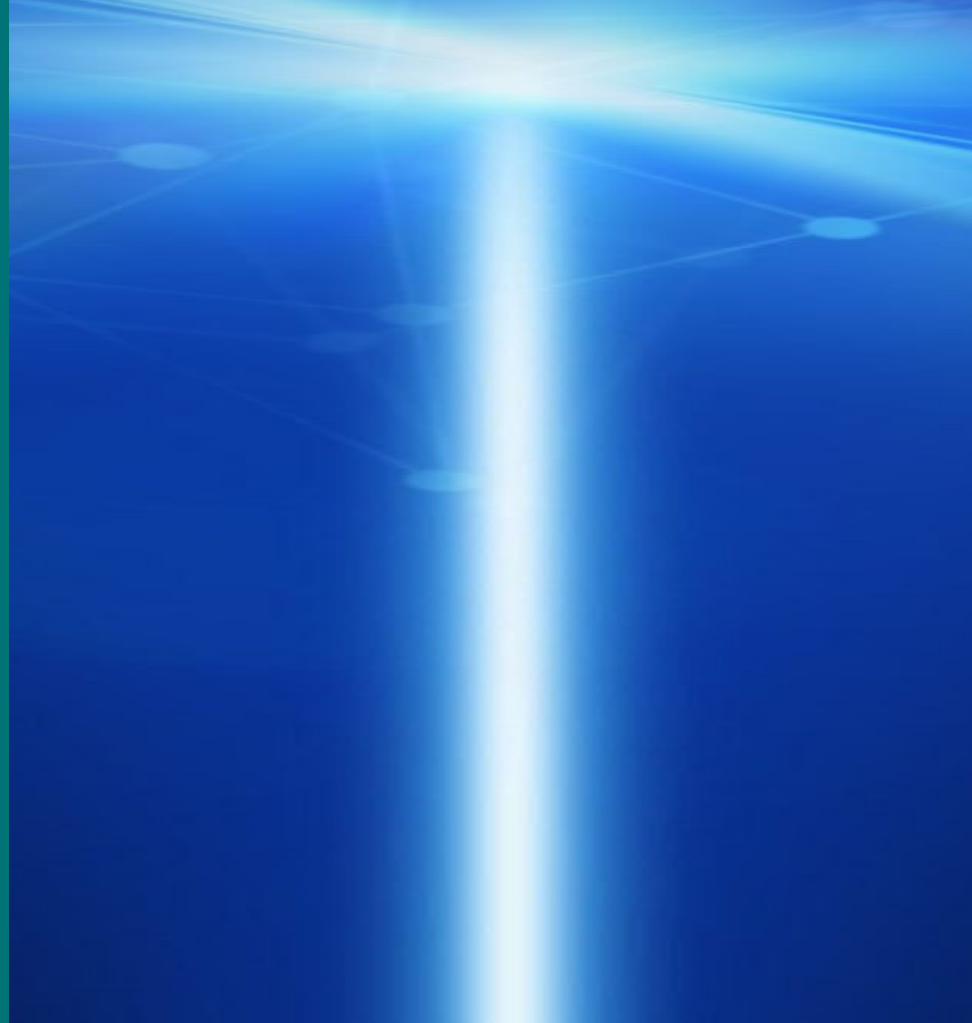
L lip  
V slot volume  
B bendable lip  
S bending slot

## Technical implementation with bendable lips in action



# 5.

## Digital application system



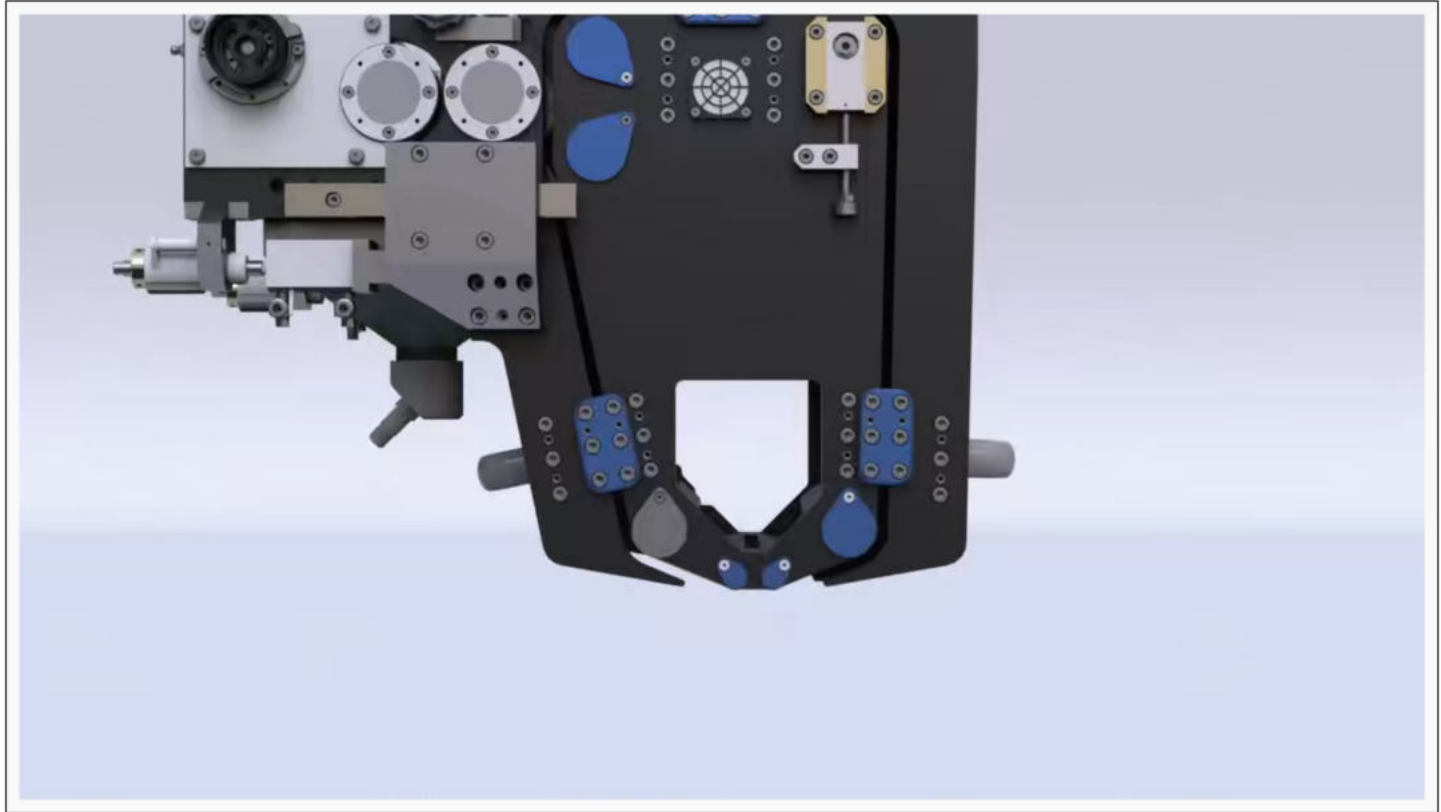


# HELIOSONIC PRINTING THE UNPRINTABLE

**HELIOSONIC PRINTING TECHNOLOGY**  
CREATES NEW POTENTIAL  
FOR INDUSTRIAL DIGITAL PRINTING  
AND SIGNIFICANTLY IMPROVES  
THE USE OF RESOURCES.

# Technology

## Droplet Generation



# Technology

## Inking & Printing



# Value Proposition

## Digitally deposited coatings

### General

- Fully digital printing process without printing form
- Non-contact printing
- Multiple “wet-on-wet” printing
- Printing on sensitive substrates
- Tunable layer thickness 10-100µm
- Upper particle size limit ~ 100µm

### Robustness

- Very robust and reliable process
  - No nozzle, slot or mesh clogging
  - Viscosity range of coatings/ inks from 10mPas to 1000mPas

### Process Development Support

- Specific additives to make any ink HELIOSONIC compatible
- Broad know how based on optimized inks for complex designs
- Print parameter setting service

### Functional Inserts

- Sensors
  - Feature width 100µm+
  - Temperature
  - pH
  - Pressure and more
- Adhesives
- Sealants

### Precision

- Addressable 600dpi precision material deposition allows for:
  - Option for structured coatings with defined porosity/ channels
  - Sharp outlines
  - Non continuous coating (stop/ start) without reducing speed

### Multi-material

- Combination of materials on dpi level; i.e.: -
  - Active/ inactive (inactive elements can be fillers or structural elements)
  - Conductive/ insulating

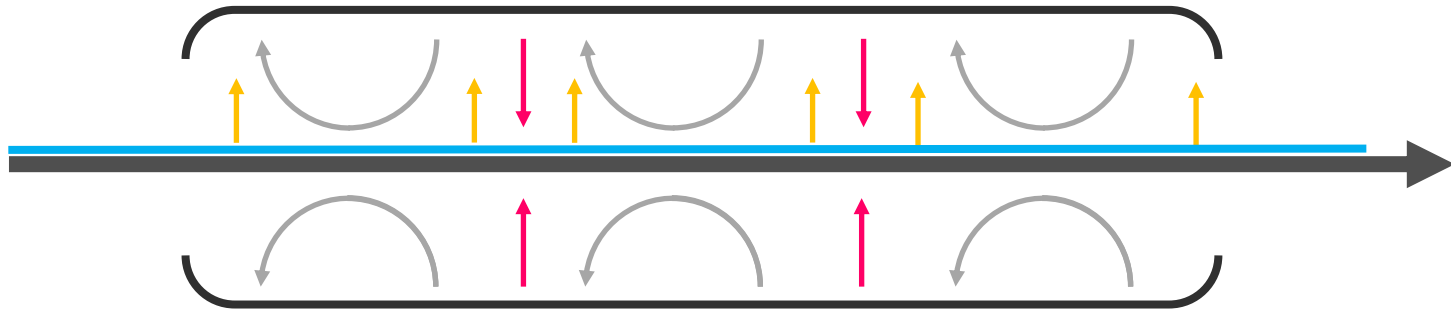
# 6.

## Drying technologies





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



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

Substrate

Coating

Heat transfer

Evaporating solvent

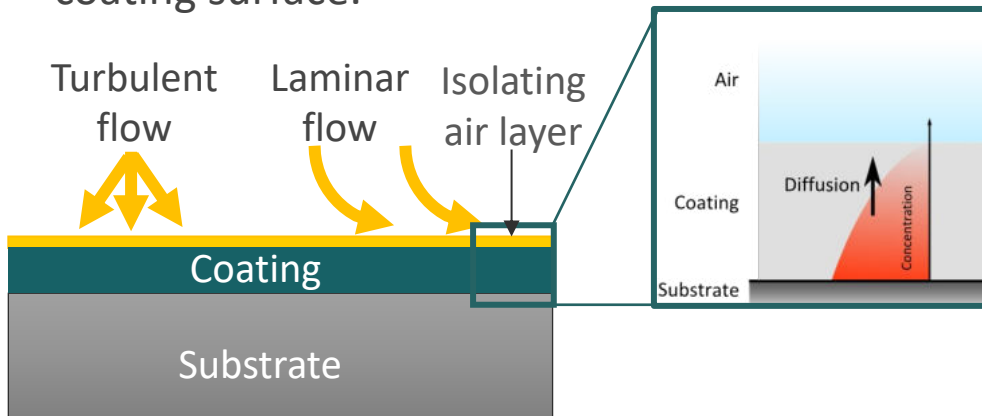
Solvent vapor transfer

**Mass Transfer**

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

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

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

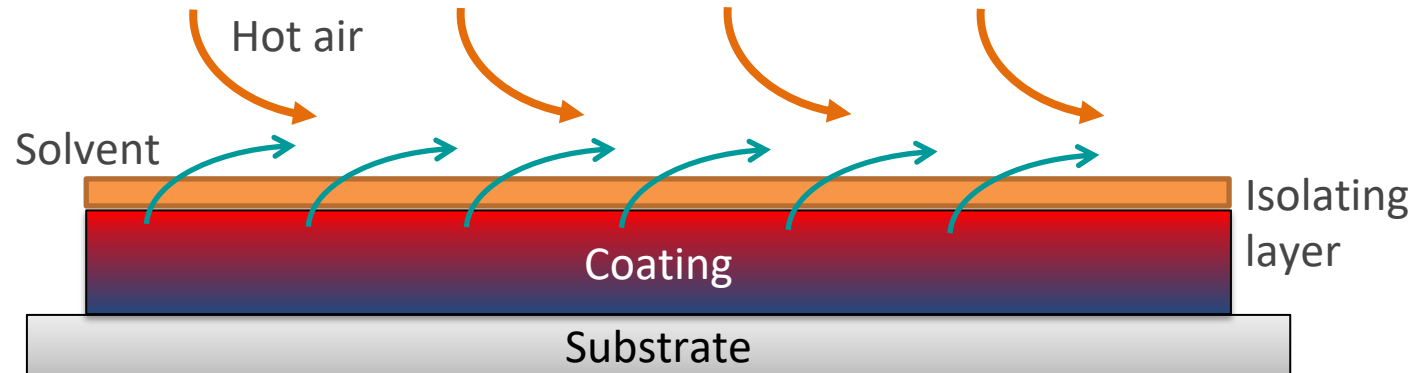


**Usually there is a trade-off:**

effective fast heat/mass transfer  
or  
gentle mild slow drying

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

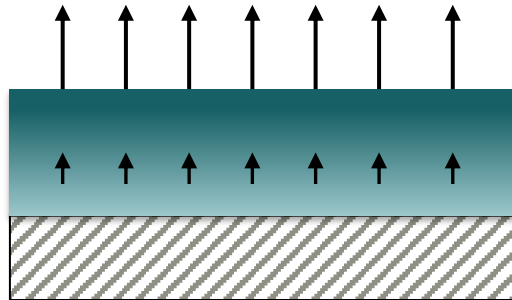
- ✓ Heating and vapor transport combined
- ✓ Bulk heating by thermal conductivity from surface
- ✓ Isolating layer to be overcome by air flow
- ✓ High air flow deteriorates surface
- ✓ Temperature easy to limit
- ✓ Slow



## Basics mass + heat transfer

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

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



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

## Industrial drying systems

Coatema slot  
nozle and  
circulation  
dryer on small  
scale



## Industrial drying systems

Coatema slot  
nozle and  
circulation  
dryer on small  
scale

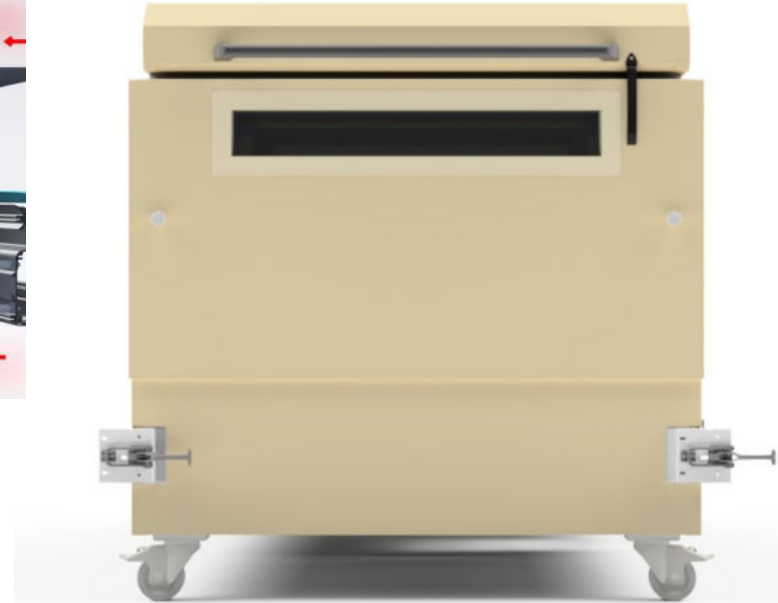
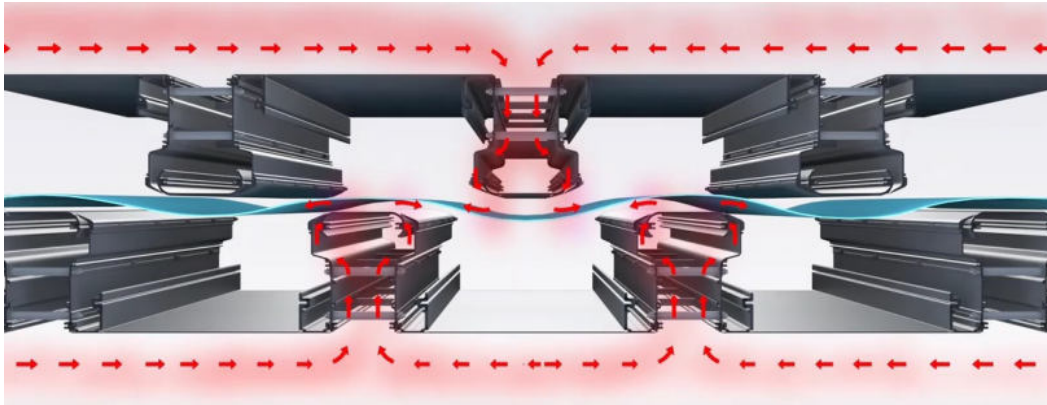


## Industrial drying systems

Coatema slot  
nozle and  
circulation  
dryer on small  
scale



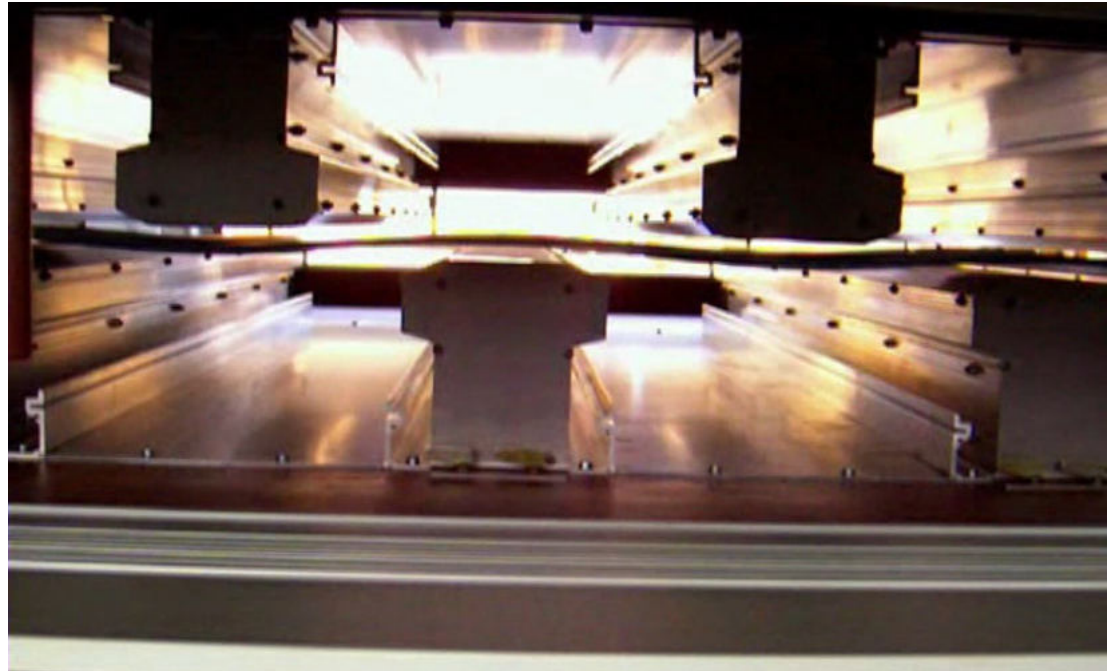
## Drytec Click&Coat™ dryer principle





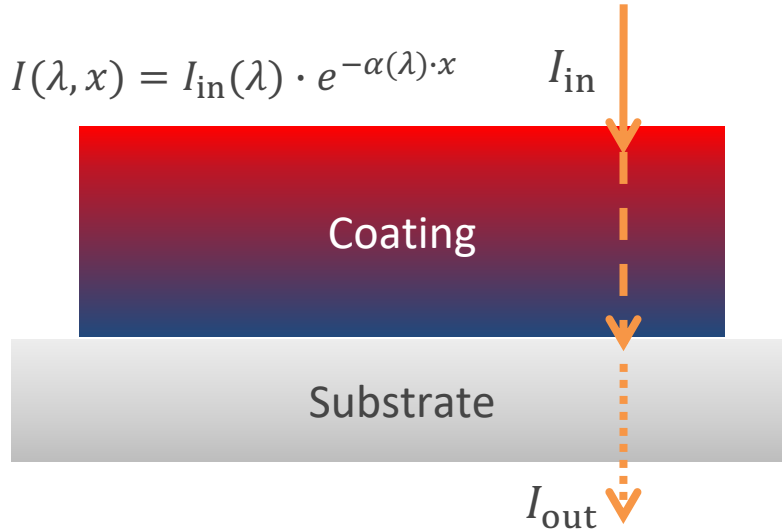
## Drying topics – drying technologies: HighDry HD500

Web behaviour in a  
flowtation dryer

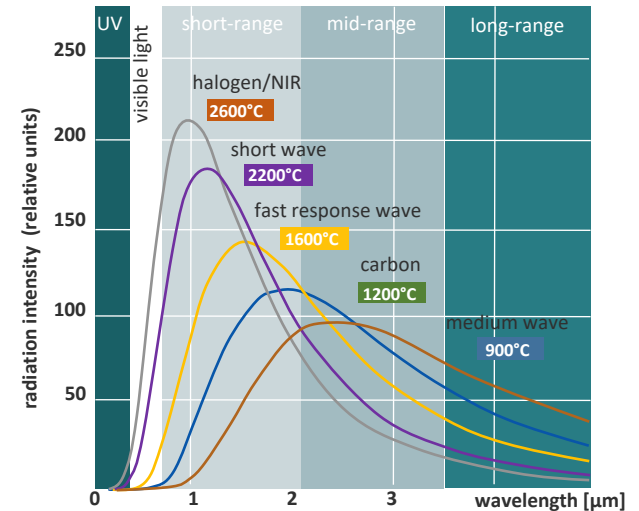
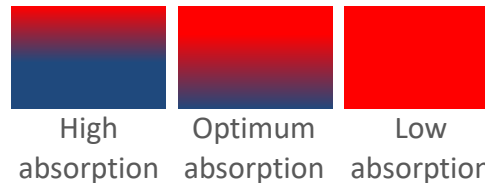


Press Button to  
show the video

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

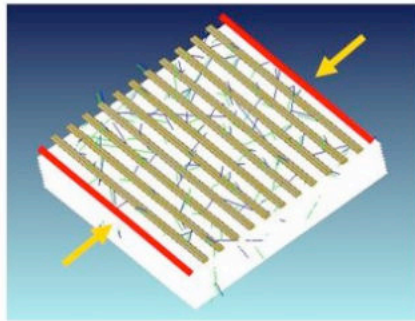


$I_{in}(\lambda)$  Intensity in  
 $I_{out}$  Intensity out  
 $\alpha(\lambda)$  Absorption coefficient  
 $d$  Layer thickness



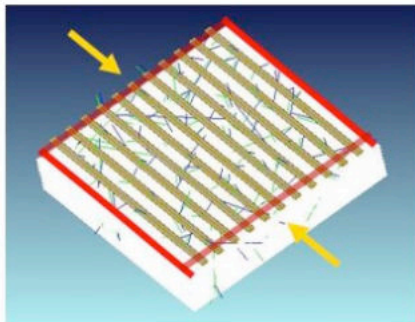
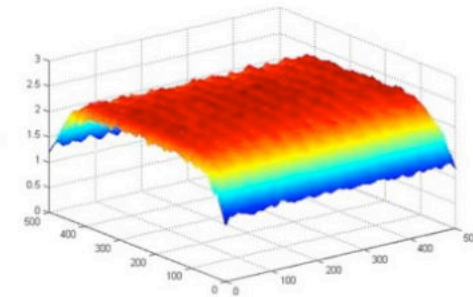
Relative intensity of radiators at different wavelengths

## IR / NIR Drying – Infrared drying



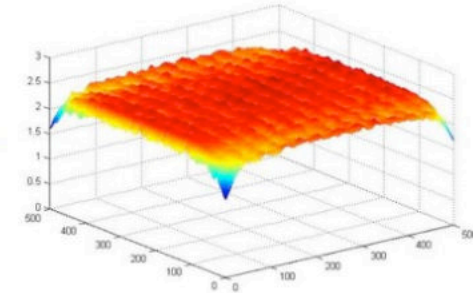
Continuous process

13 emitters, 2 types, 3 zones



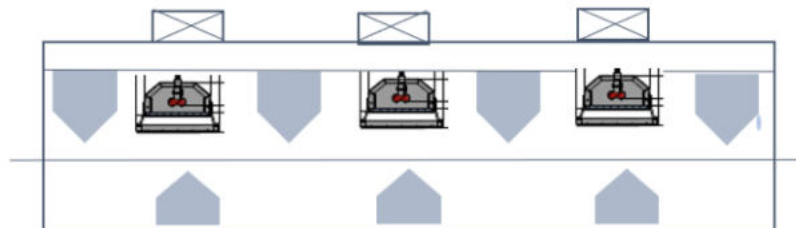
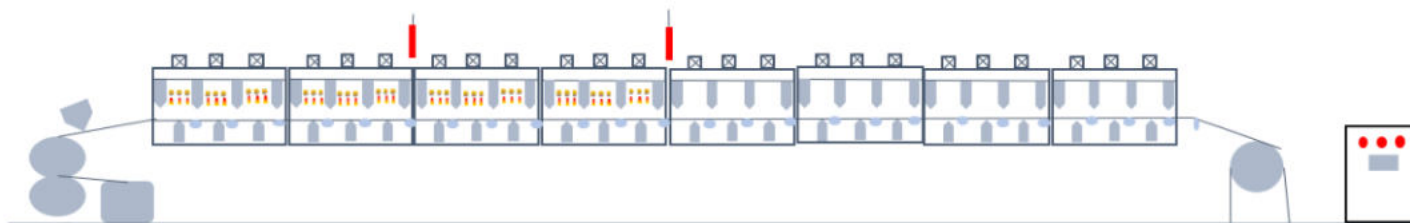
Batch process

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

# 7.

## Simulation



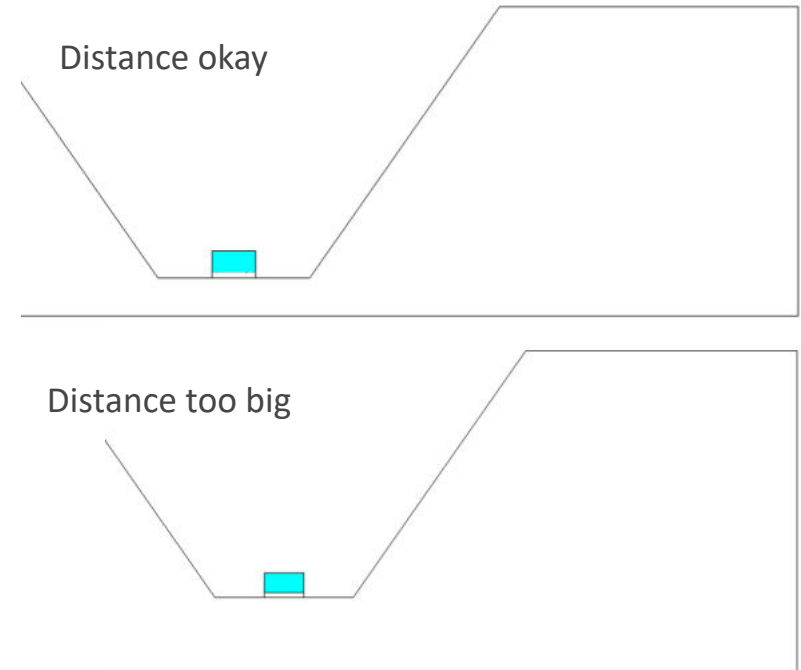
## Slot die chamber – Simulation parameters

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

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

## 3D Homogeneity – Slot die chamber – Simulation of anode coating

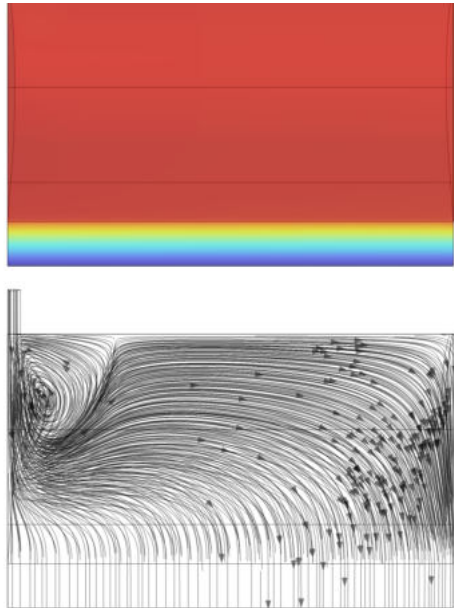
- ✓ Example for anode electrode coating
- ✓ Fluid data taken from real world (shear-thinning power law fluid)
- ✓ Process parameters for 90m/min 400µm coating and 300 mm width
- ✓ No „fancy” slot-die „just” Coatema standard



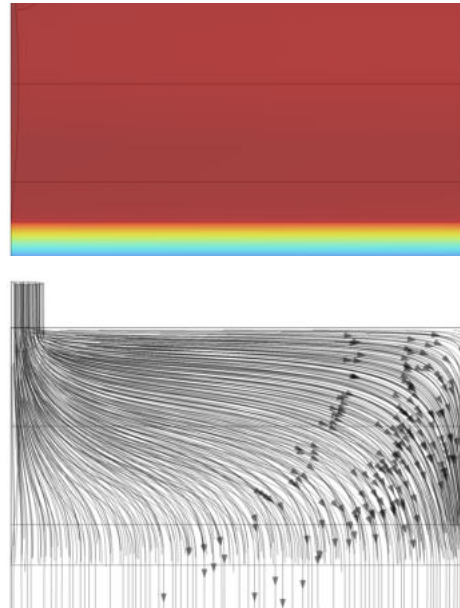


## 3D Homogeneity – Slot die chamber – Streamlines and pressure distribution

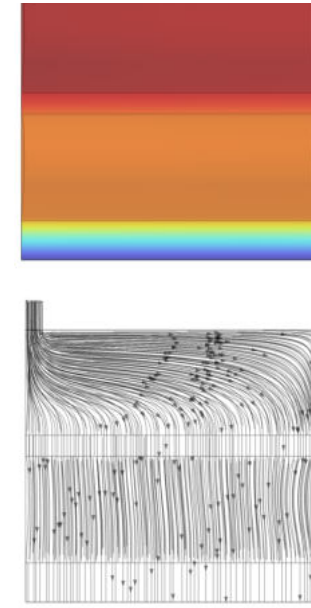
Single Chamber with too small inlet (4 mm)



Single Chamber with correct chamber layout (10 mm inlet)

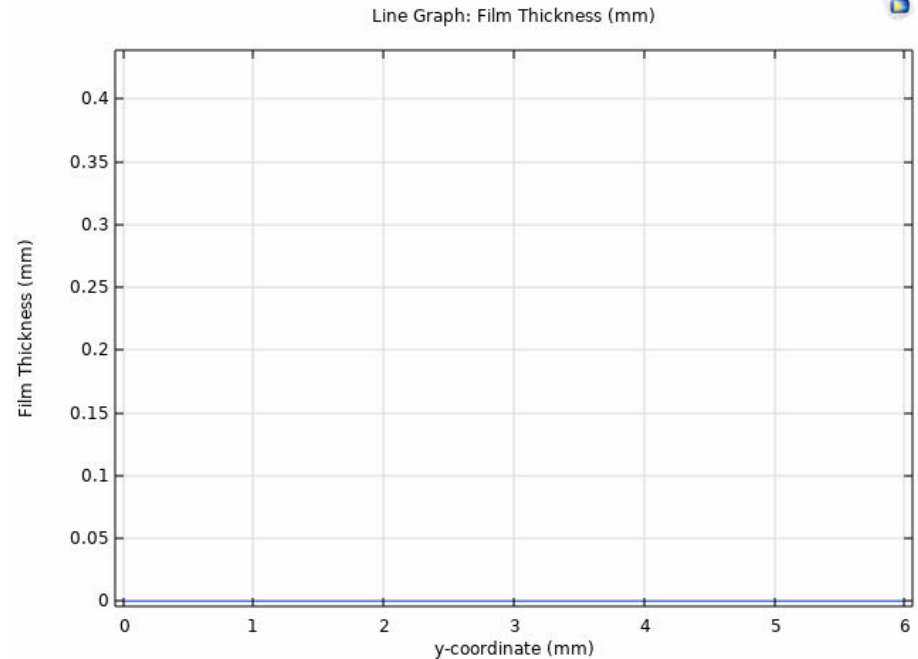
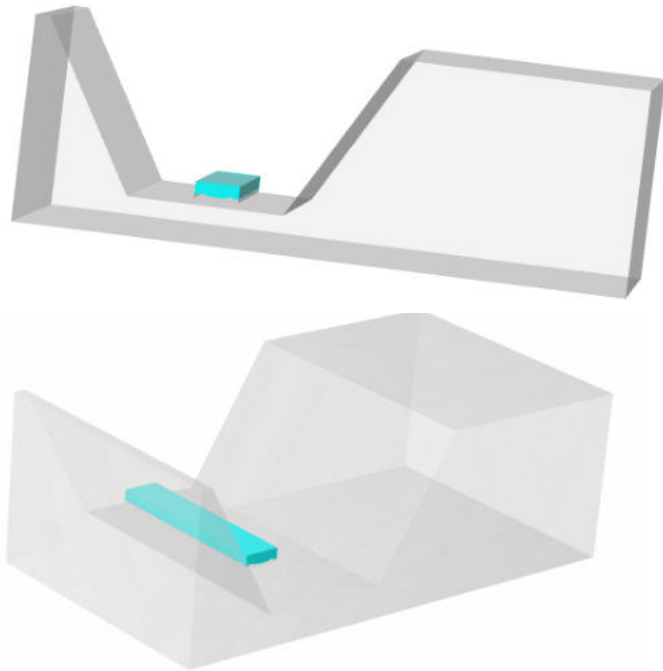


Dual chamber slot die (8 mm inlet same dead volume)





## 3D Homogeneity – Slot die chamber – Meniscus makes or breaks Homogeneity



# 8.

## Summary



# Outlook

- ✓ Latest 2030 – 2050 the whole automotive car fleet has to be zero emission
- ✓ Impact markets will be automotive, light / heavy trucks, trains and decentralized power supply
- ✓ New green deal of the European Commission
- ✓ Markets will be PEMFC / HTPEMFC / SOFC / AFC / PEM Electrolyzer
- ✓ Coatema has over 22 years experience in the market of fuel cell equipment
- ✓ Electrolyzer to produce green hydrogen out of renewables will be the boom market in the next years to come and Coatema wants to be a part of it

## 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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