Technology development and manufacturing for fuel cells and electrolyzers

Coatema

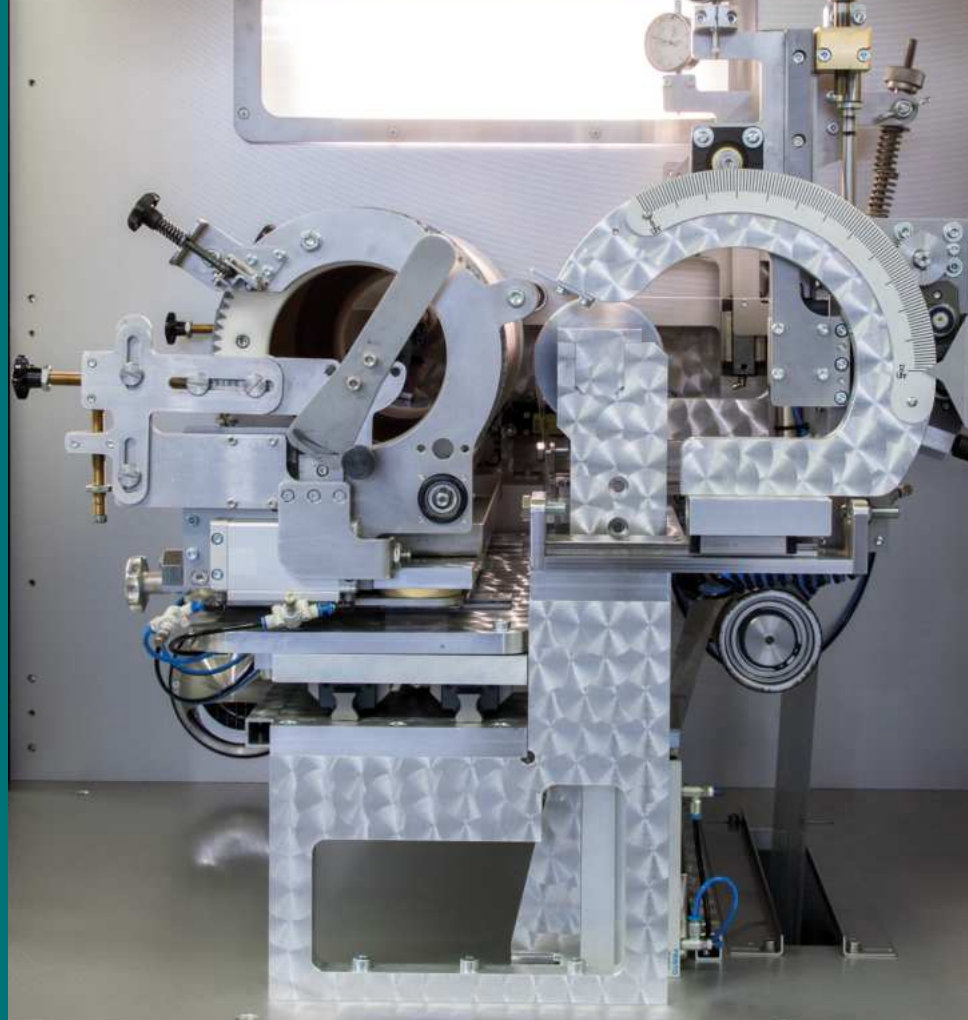11/12/2024

MEMBER OF ATH

Agenda

1. Introduction

2. Today's equipment

3. Coating systems

4. Slot die for fuel cells

5. Digital application system
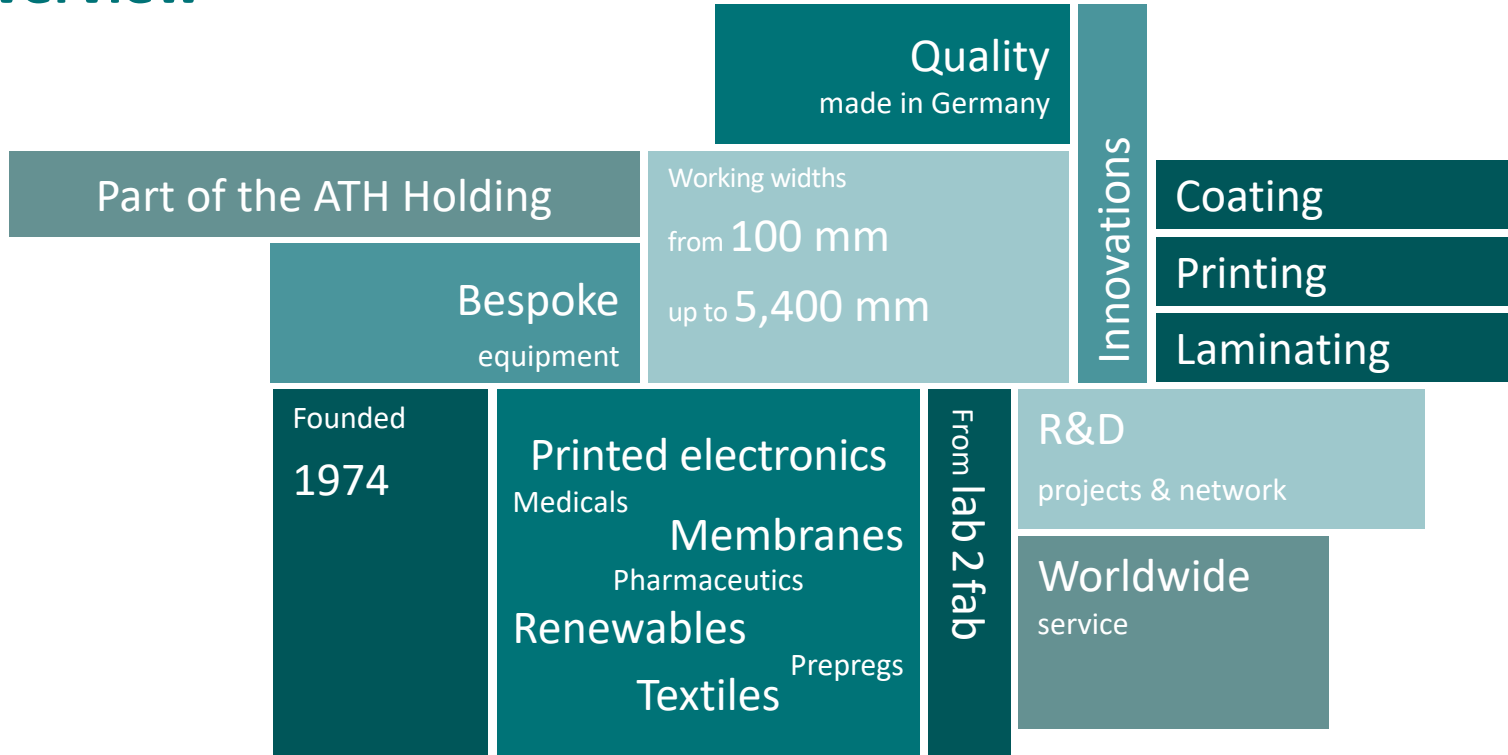
6. Drying technologies

7. Simulation

8. Summary

1.

Introduction

Overview

Quality
made in Germany

Part of the ATH Holding

Working widths

from 100 mm

up to 5,400 mm

Innovations

Coating

Printing

Laminating

Bespoke

equipment

Founded

1974

Printed electronics

Medicals

Membranes

Pharmaceutics

Renewables

Prepregs

Textiles

From lab 2 fab

R&D

projects & network

Worldwide

service

Group of companies

ATH — ALTONAER TECHNOLOGIE HOLDING

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

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

Coatema Coating Machinery GmbH
- ✓ 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

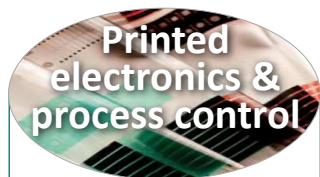**Development of custom-made design for equipment**
- ✓ Prototyping
- ✓ Proof of concept

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

REAL NANO

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

FLEX2ENERGY
AUTOMATED MANUFACTURING PRODUCTION LINE FOR IPVS
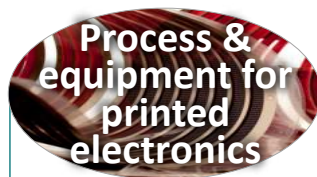
R2R production line for OPV solar with integrated backend

- - - - - - - - - - - -

ENP

Development of near-field electro hydrodynamic nanowire printing

Battery production

IDEEL

Implementation of laser drying processes for lithium-ion battery production

- - - - - - - - - - - -

SOLiD

R2R process optimization for solid state batteries

Fabric functionalization

PEPLAT

Plasmonically enhanced photocatalysis for wastewater treatment

- - - - - - - - - - - -

RetroWin

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

Sustainable production technology

WATER PROOF

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

- - - - - - - - - - - -

FLEX FUNCTION 2 SUSTAIN

Creating an open-innovation testbed for sustainable packaging

2.

Today's equipment for todays
fuel cells/electrolyzers
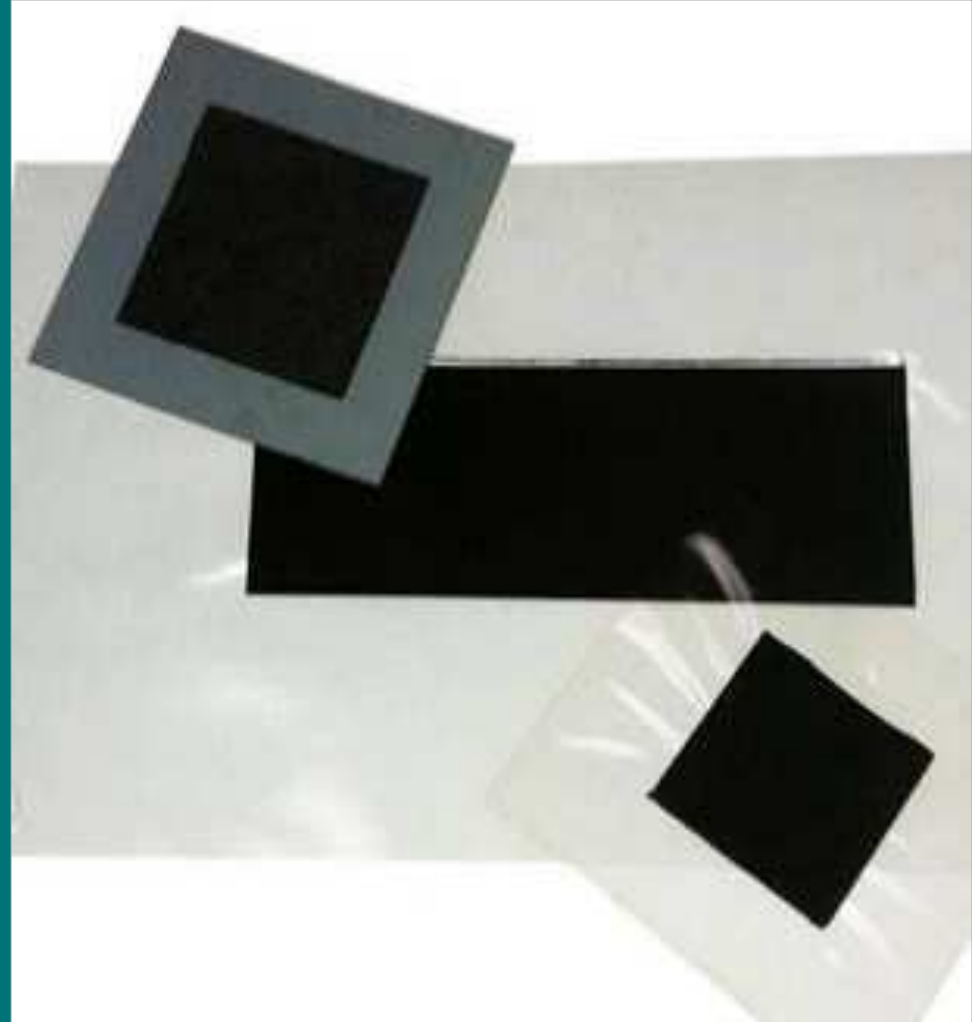
Reference equipment for electrolyzer Coatema

Coatema

CCM Manufacturing

GDL / GDE

GDL → Micro porous layer → Drying → Catalyst → Drying → **GDE**

CCM

A → Membrane → Catalyst → Drying → **CCM**

B → Membrane → Catalyst → Drying → **CCM**
   Membrane → Catalyst → Drying

C → Membrane → Top catalyst / Bottom catalyst → Drying → **CCM**

CCM / Decal

A → Carrierfilm 1 → Catalyst → Drying → **CCM**
   Carrierfilm 2 → Catalyst → Drying

B → Membrane → Carrierfilm 1 / Carrierfilm 2 → Hot pressing → Delamination → **CCM**

Membrane

A → Casting → Wet lamination → Drying → **Membrane**

Legend:
- Input
- Process
- Output

CCM =
Catalyst Coated Membrane

GDL =
Gas Diffusion Layer

GDE =
Gas Diffusion Electrode

MEA =
Membrane Electrode Assembly

S2S

Test Solution

Easycoater

Easycoater Evolution

Ink testing	First sample product	First pilot as S2S

Roll-to-Roll (R2R) lab systems
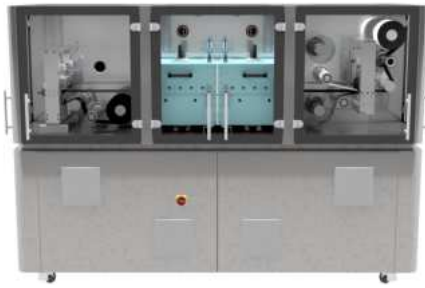
Test Solution R2R
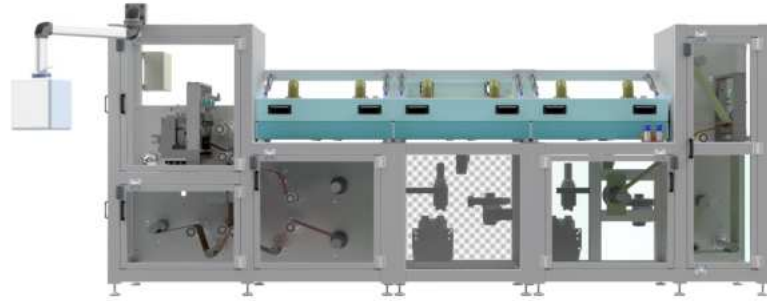
Basecoater R2R

Smartcoater R2R
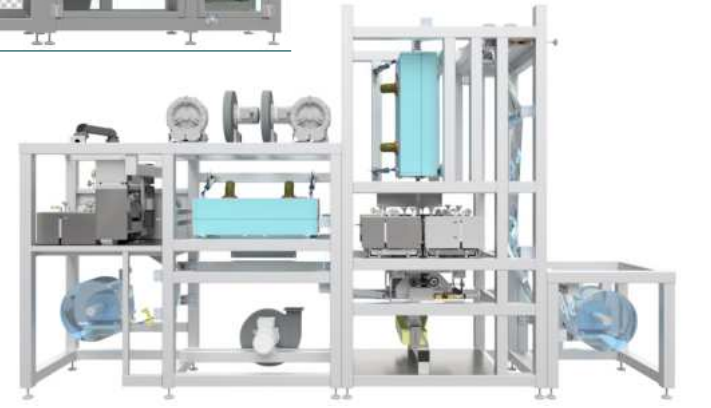
Verticoater R2R

The Smartcoater

The Smartcoater

Roll-to-Roll (R2R) pilot

Basecoater Pilot R2R
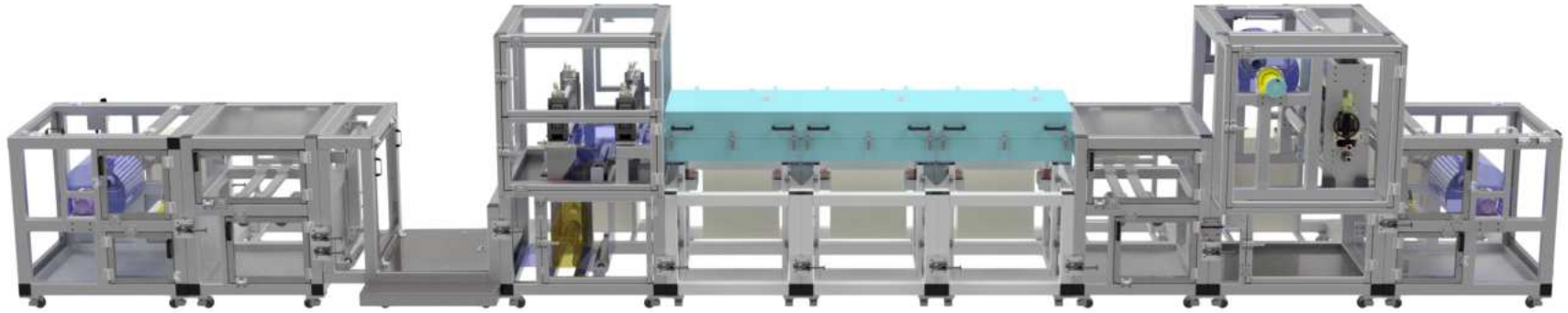
Click&Coat™ R2R

The Click&Coat^{TM}
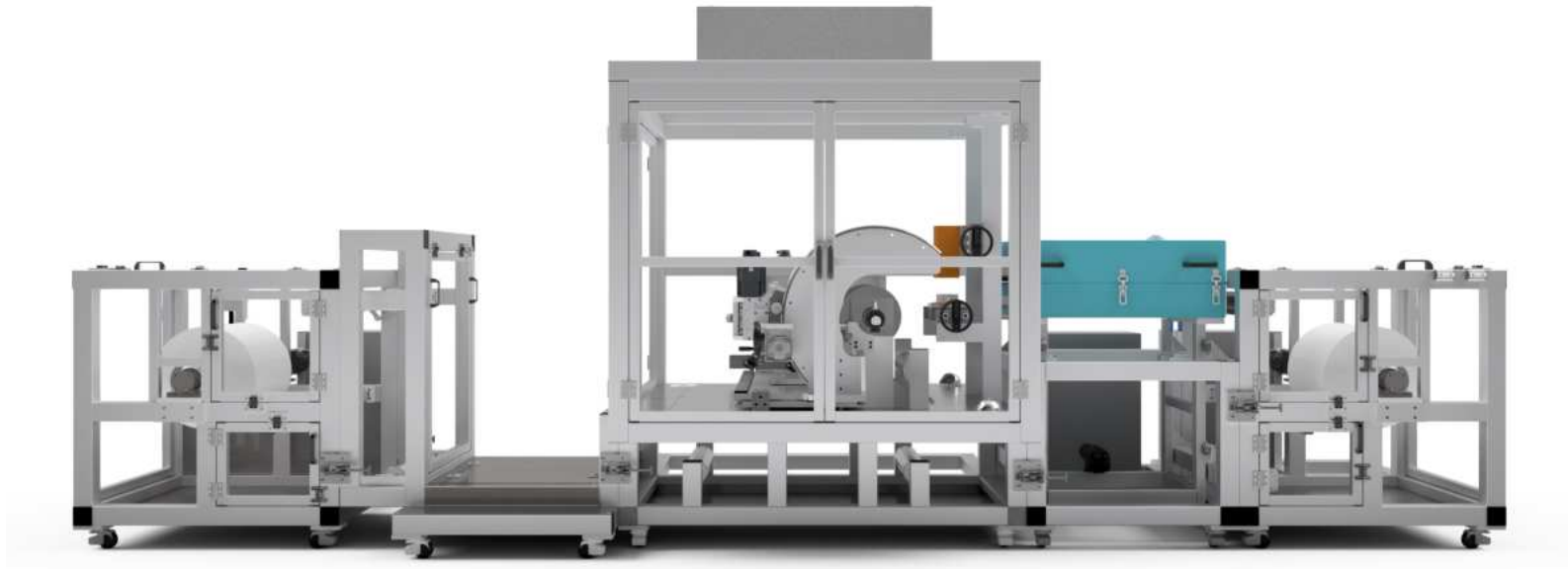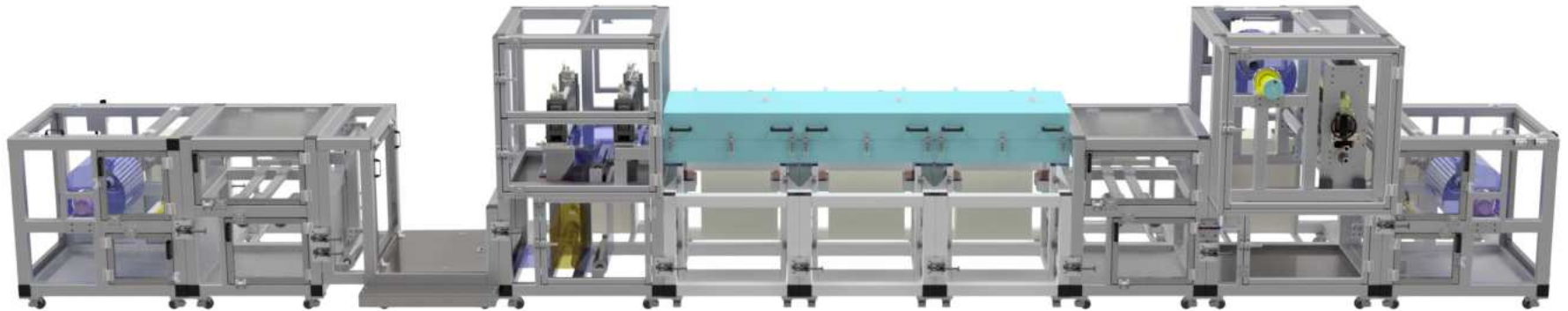
The Click&Coat™

GDE and CCM coating lines

GDE method
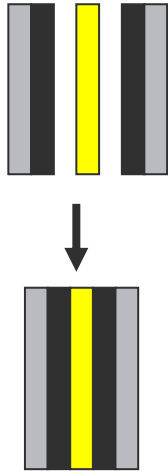
CCM direct
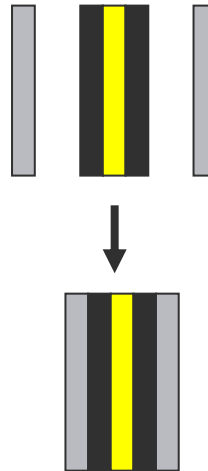
The Click&Coat™

The Click&Coat™

Specific equipment in Click&Coat™ layout

Click&Coat™ your own ideas
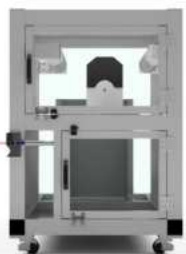
Winder   Corona   Podestral   Coating   Printing   Dryer   Laminator   Rewinder

Chemical treatment bath   Inert Coating and laminating   Registration control   Turning device   Lamination   Cutting
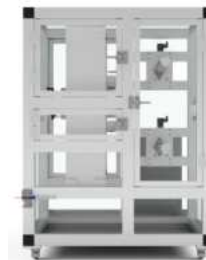
The Click&Coat^{TM} in production scale in the R&D centre
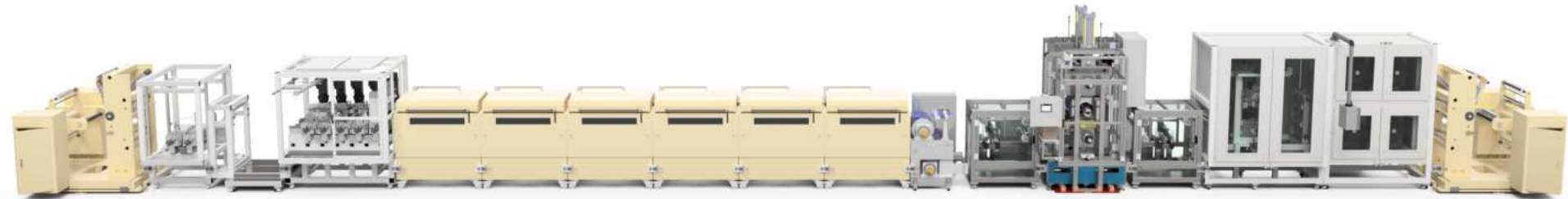
The Click&Coat™ in production scale

The Click&Coat™ in production scale

| ✓ Unwinder
✓ Lamination
✓ Delamination
✓ EPC
✓ Web cleaning
✓ Corona | ✓ Thickness measurment
Substrate | ✓ Podestral | ✓ Interchangable
✓ Coating module
✓ EPC
✓ Register
✓ Coating control | ✓ Thickness measurment
✓ Wet coating | ✓ Flotation dryer
✓ NIR
✓ IR
✓ UV
✓ Laser
✓ Humidity | ✓ Optical
✓ Surface control
✓ Cooling table | ✓ Lamination
✓ Thickness measurment
✓ Dry coating | ✓ XRF -measurment
✓ Platinium loading | ✓ Thickness measurment
✓ Substrate |
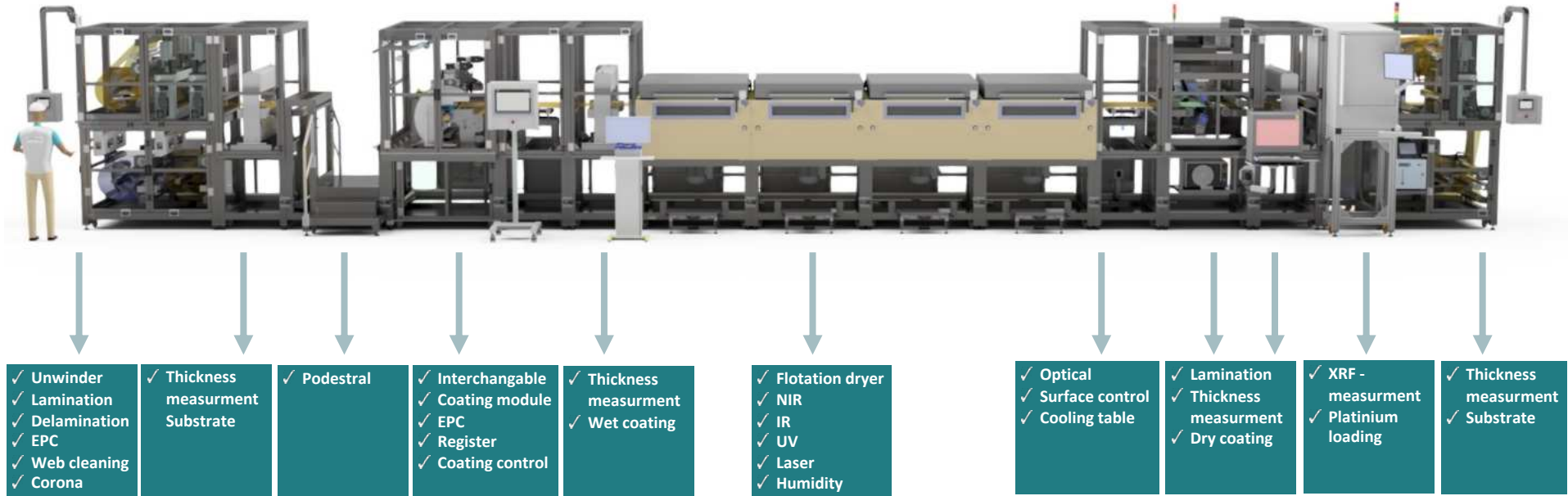
The Click&Coat™ in production scale

The Click&Coat™ in production scale

Indirect CCM (Decal) Method

CCM indirect
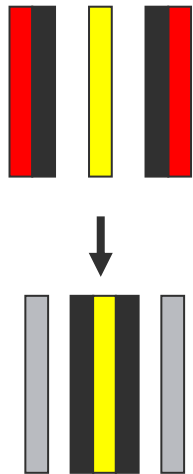
Decal 3rd Generation

Hot pressing

Decal 3rd Generation
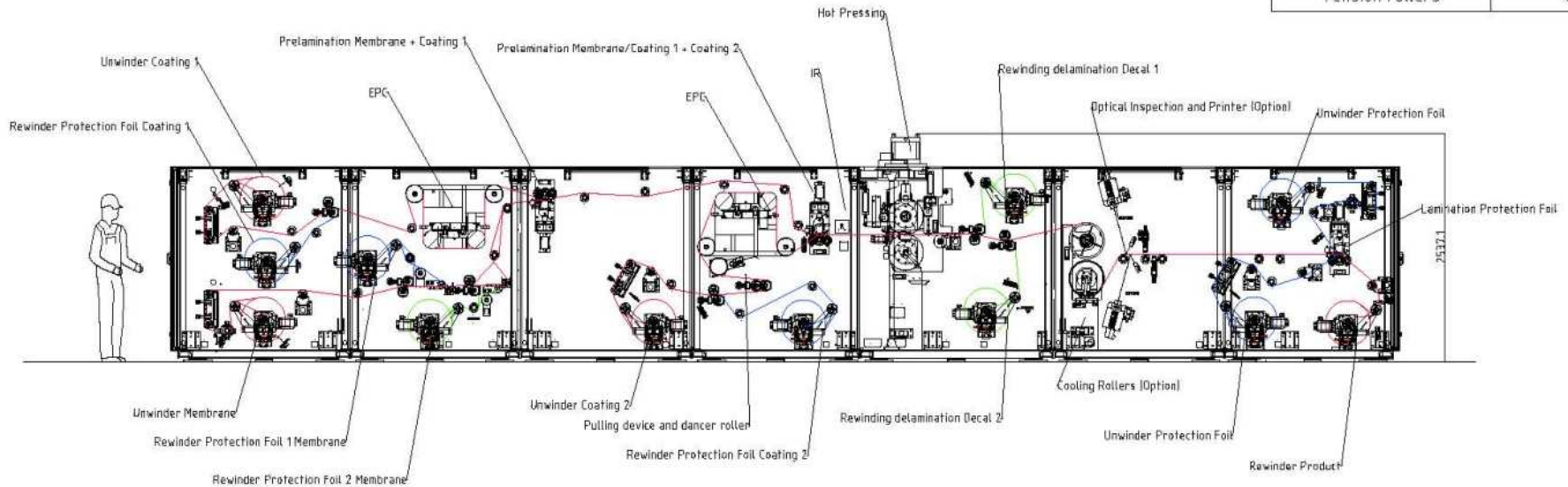
Membrane casting and reinforced membrane (wet lamination)

Membrane (Casting)

Reinforced Membrane (wet lamination)

Membrane casting

Membrane casting
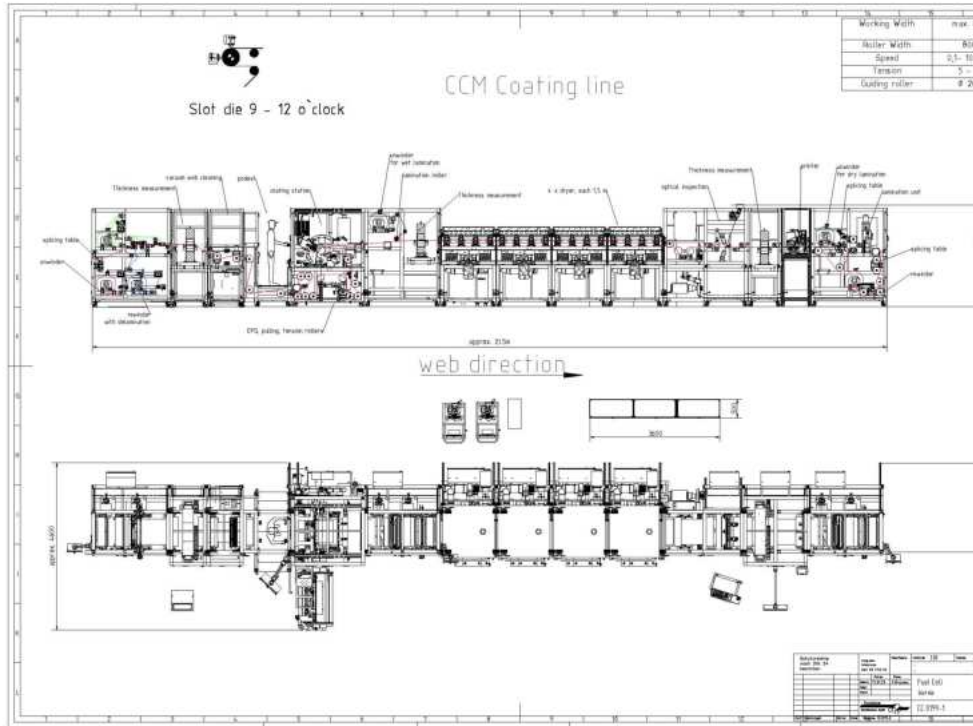
Production line for fuel cells – 1000 mm working width

3.

Coating systems

Coating parameters

Coating chemistry	Coating processes	Process control	Drying
✓ Rheology	✓ Coating systems	✓ Process layout	✓ Convection drying
✓ Viscosity	✓ Single or multilayer coatings	✓ Tension control system	✓ Contact drying
✓ Viscoelasticity	✓ Direct coatings	✓ Material guiding system	✓ Infrared drying
✓ Type of solvents	✓ Transfer (indirect) coatings	✓ Inline parameter control	✓ Sintering
✓ Solid content	✓ Substrate speed	✓ Quality control	✓ NIR
✓ Van der Waals force	✓ Layer thickness		✓ High frequency
✓ Sheer ratio	✓ Coating accuracy		✓ UV crosslinking systems
✓ Adhesion/Cohesion			

Substrate	Pretreatment	Environment	Finishing
✓ Surface tension	✓ Corona	✓ Humidity	✓ Calendaring
✓ Dimension stability	✓ Plasma	✓ Temperature	✓ Embossing
✓ Surface structure	✓ Cleaning	✓ Inert conditions	✓ Slitting
✓ Contact angle			

Printing systems

Engraved roller system
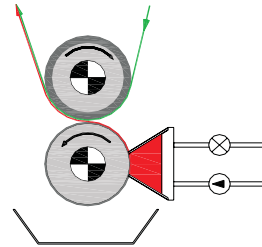
Gravure roller system
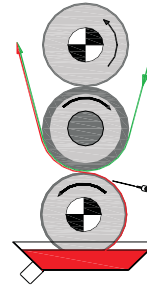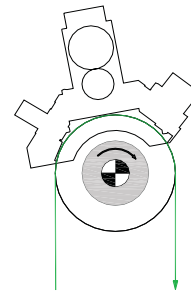

Gravure indirect system
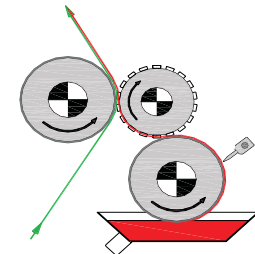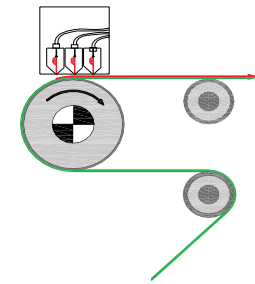

Flexography system
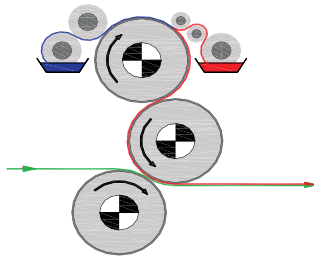
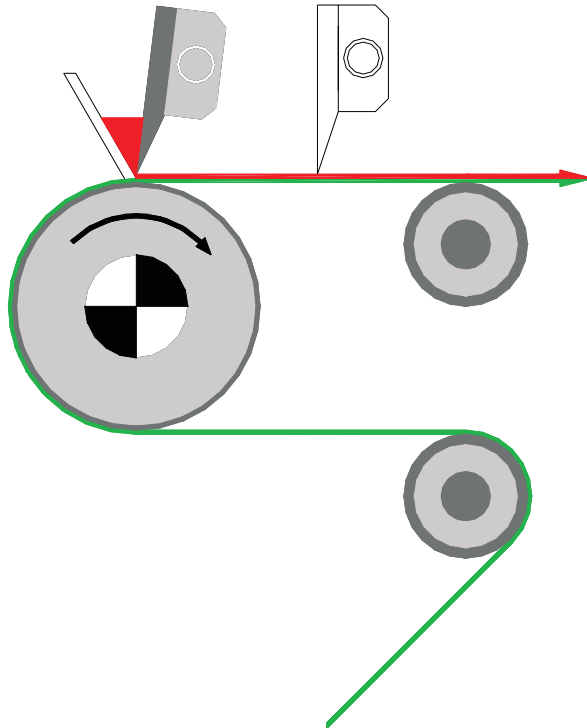Offset lithography system
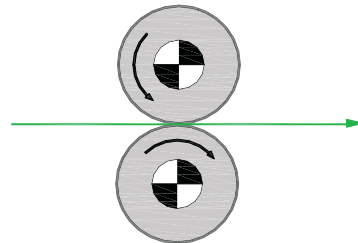
Hot embossing system

Nanoimprint system
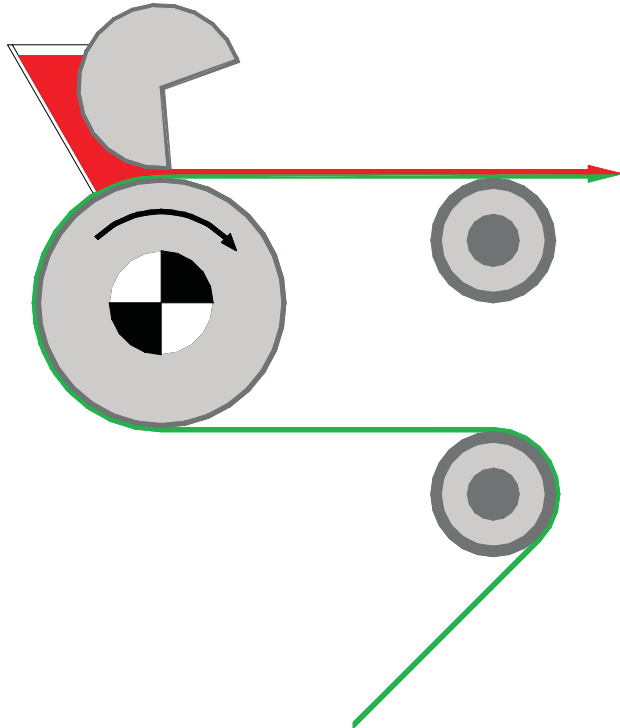

Inkjet system

Knife coating

Variation of the coating weight

✓ Roller knife
   10 – 1.250 g/m^2

✓ Air knife 5 – 6 to 60 g/m^2

Range of viscosity

✓ Paste (1000)
   100 – 50 000 mPas

✓ Foam
   10 000 – 25 000 mPas
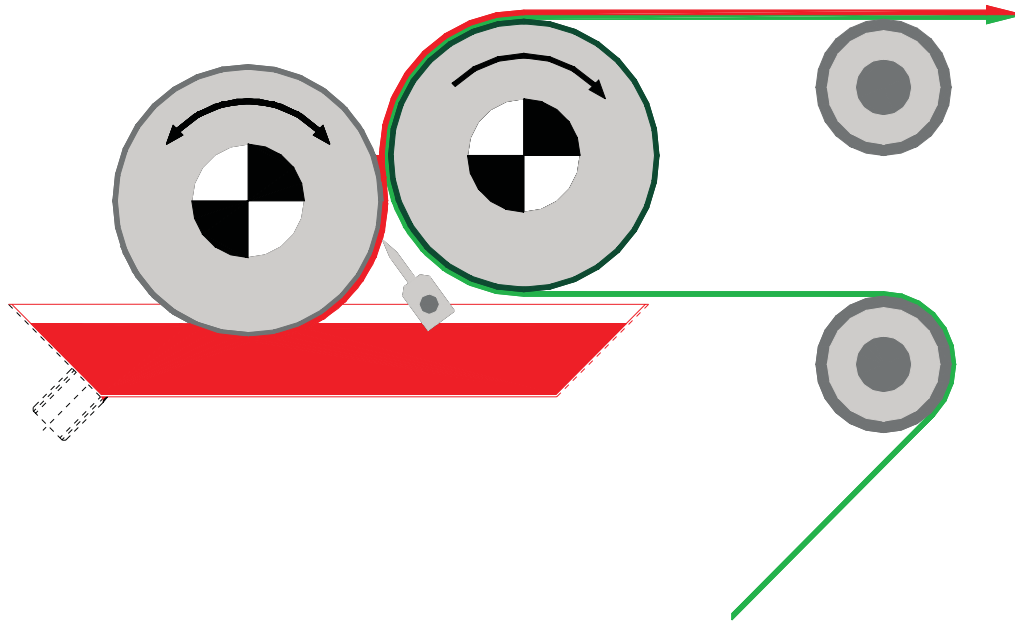
✓ Air knife
   5 – 10 000 mPas

Commabar coating

Variation of the coating weight

✓ Air knife
   5 – 6 to 1.250 g/m²

Range of viscosity

✓ Paste
   5 – 6 to 60 g/m²

✓ Foam
   10 000 – 25 000 mPas

Gravur coating

Variation of the coating weight

✓ 2 – 200 g/m²

Range of viscosity

✓ 1 – 15 000 mPas

Rotary screen coating
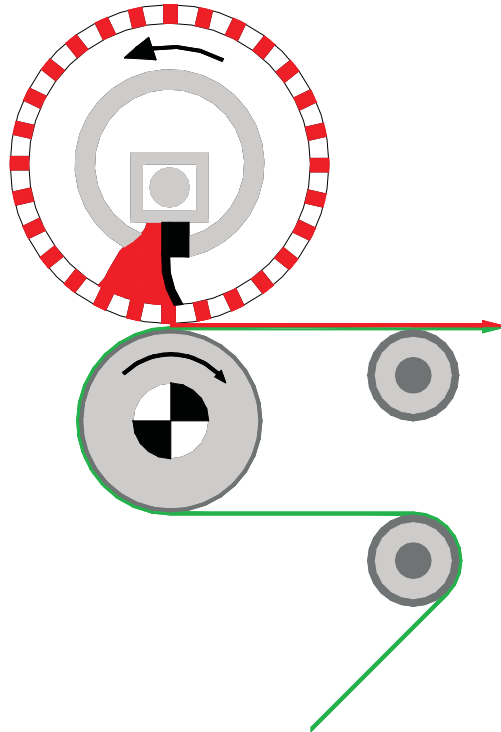
Variation of the coating weight

✓ 10 – 300 g/m2

Range of viscosity

✓ Paste

10 000 – 80 000 mPas

✓ Paste

10 000 – 25 000 mPas

Slot die coating
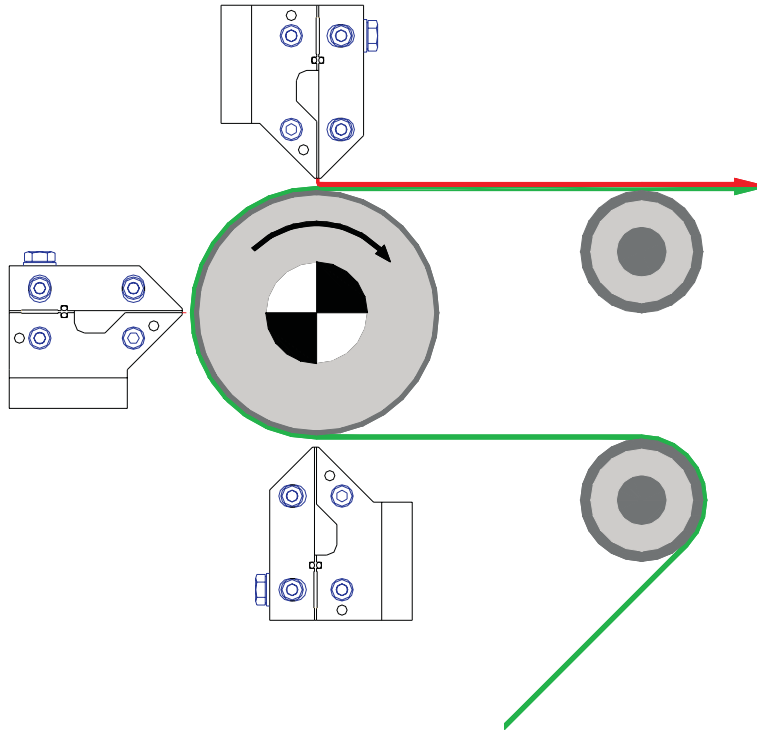
Variation of the coating weight

✓ 1 – 200 g/m²

Range of viscosity

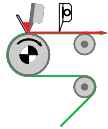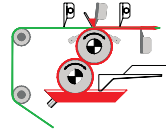✓ 1 – 30 000 mPas

4.

Slot die coating for fuel cells
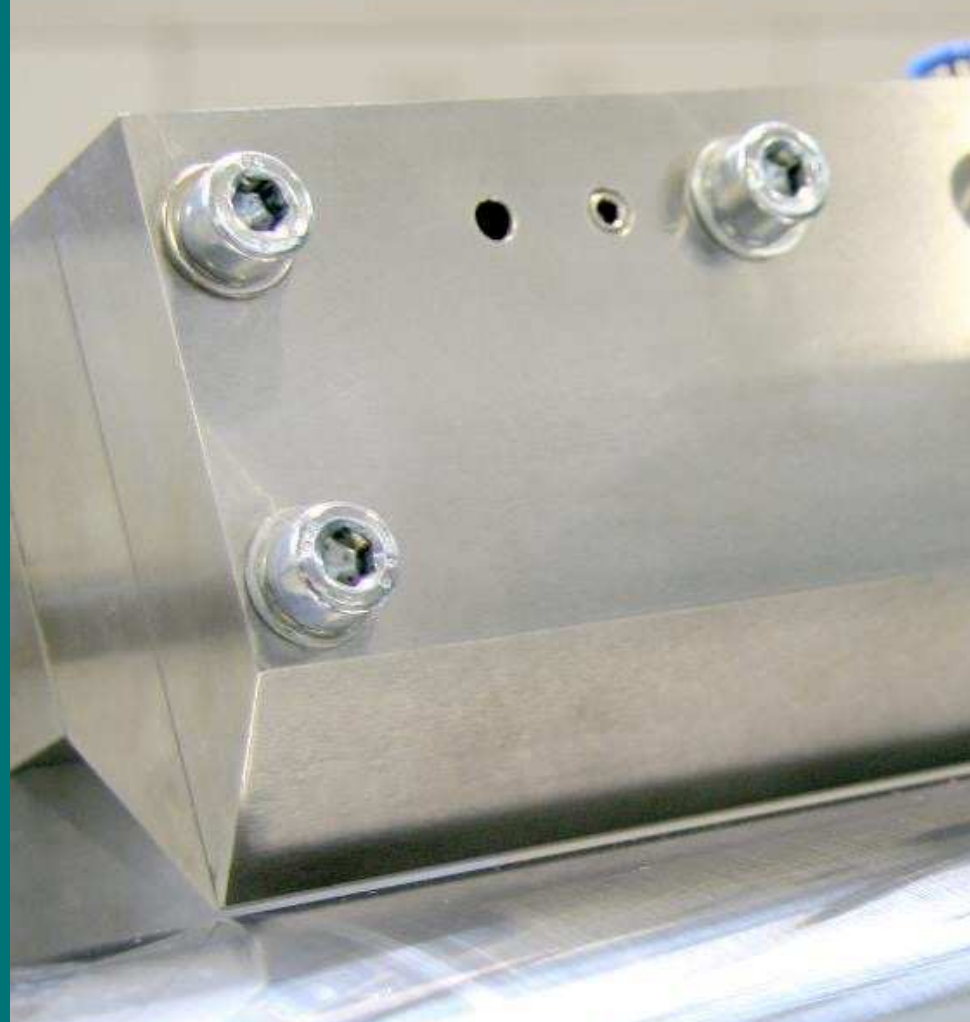
Basic principle

Coating parameters

Ink properties	Coating processes	Process control	Drying
✓ Rheology	✓ Coating systems	✓ Process layout	✓ Convection drying
✓ Viscosity	✓ Single or multilayer coatings	✓ Tension control system	✓ Contact drying
✓ Viscoelasticity	✓ Direct coatings	✓ Material guiding system	✓ Infrared drying
✓ Type of solvents	✓ Transfer (indirect) coatings	✓ Inline parameter control	✓ Sintering
✓ Solid content	✓ Substrate speed	✓ Quality control	✓ NIR
✓ Van der Waals force	✓ Layer thickness		✓ High frequency
✓ Sheer ratio	✓ Coating accuracy		✓ UV crosslinking systems
✓ Adhesion/Cohesion			

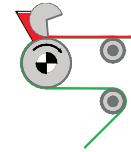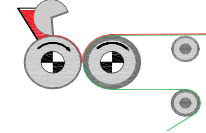| Substrate	Pretreatment	Environment	Finishing
✓ Surface tension	✓ Corona	✓ Humidity	✓ Calendaring
✓ Dimension stability	✓ Plasma	✓ Temperature	✓ Embossing
✓ Surface structure	✓ Cleaning	✓ Inert conditions	✓ Slitting
✓ Contact angle			

Coating systems

Knife system
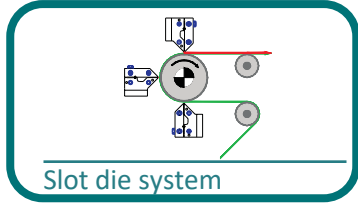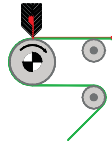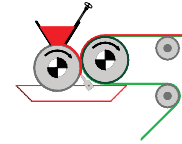
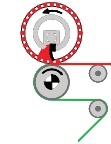Double side coating system
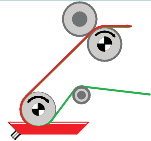
Commabar system

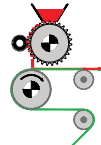Reverse commabar system

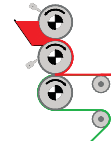Slot die system

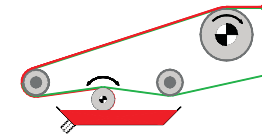Curtain coating system

Case knife system
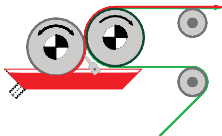
Rotary screen system

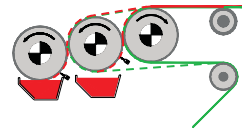Dipping system (Foulard)

Powder scattering system

Reverse roll coating system

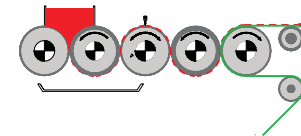Micro roller coating system

2-roller coating system

3-roller combi coating system

5-roller coating system

Basics of slot die coating – range of parameters
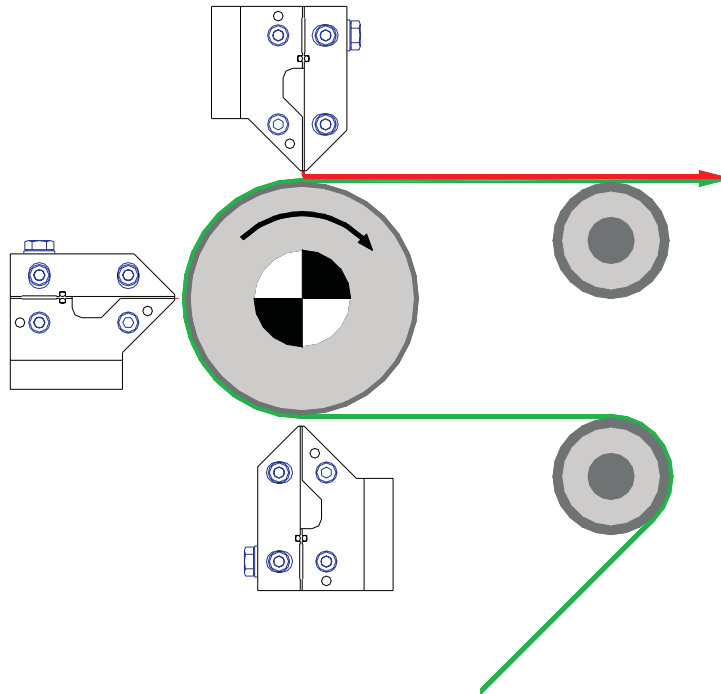
Coating speed

✔ 0.1 – >1000 m/min

Ink viscosity

✔ 1 – 300 000 mPas

Layer thickness (dry)

✔ 0.1 – >200 µm

Coating accuracy

✔ <1%   (2 – 5%)

Coating width

✔ up to approx. 3 m

Basic principle

Basic principle

Basic principle

from reservoir

Dosing pump

Slot die

Manifold (Distribution chamber)

Meniscus

Slot

coated layer

substrate

Coating roller

Bead mode

Slot die

Manifold (Distribution chamber)

Meniscus

Coating roller
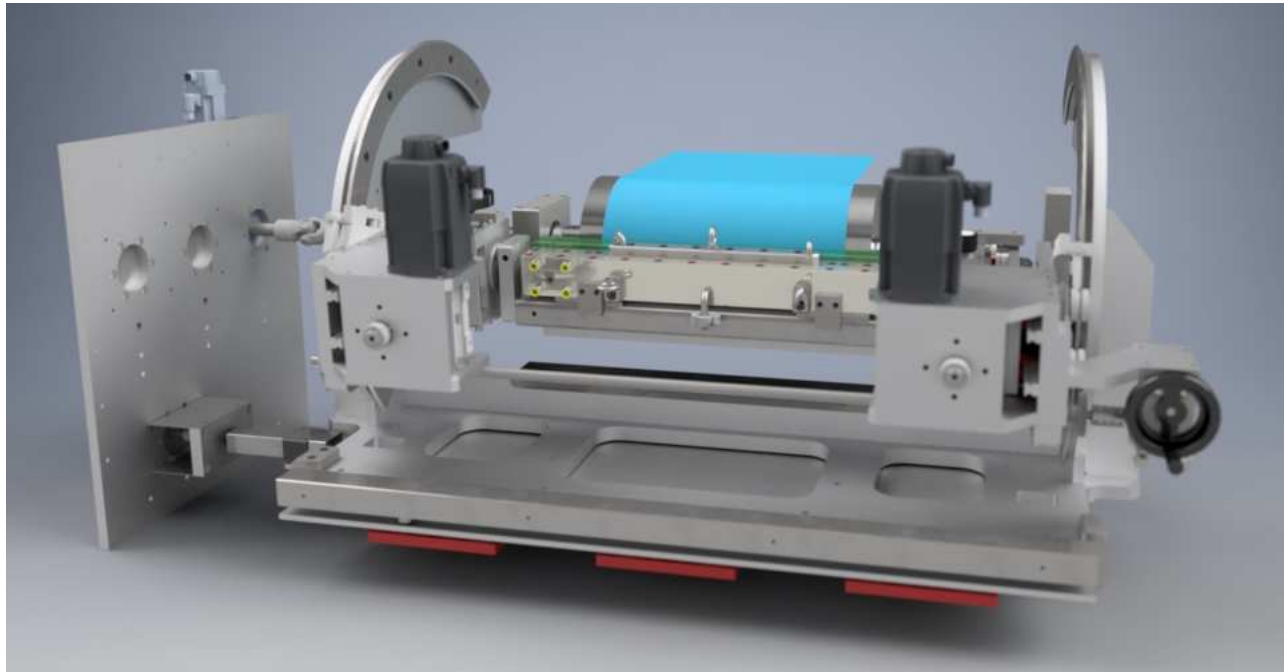
Stabilization of meniscus by adhesion to die lips
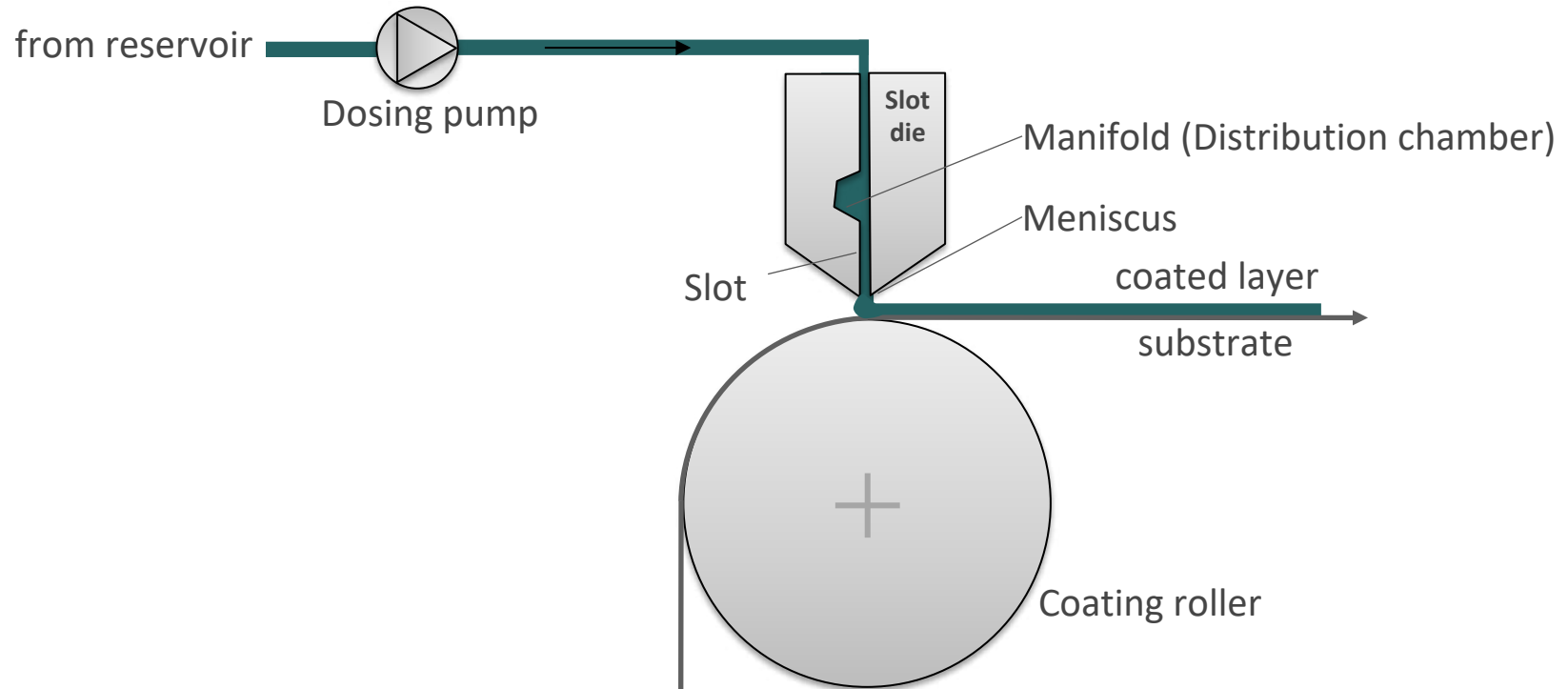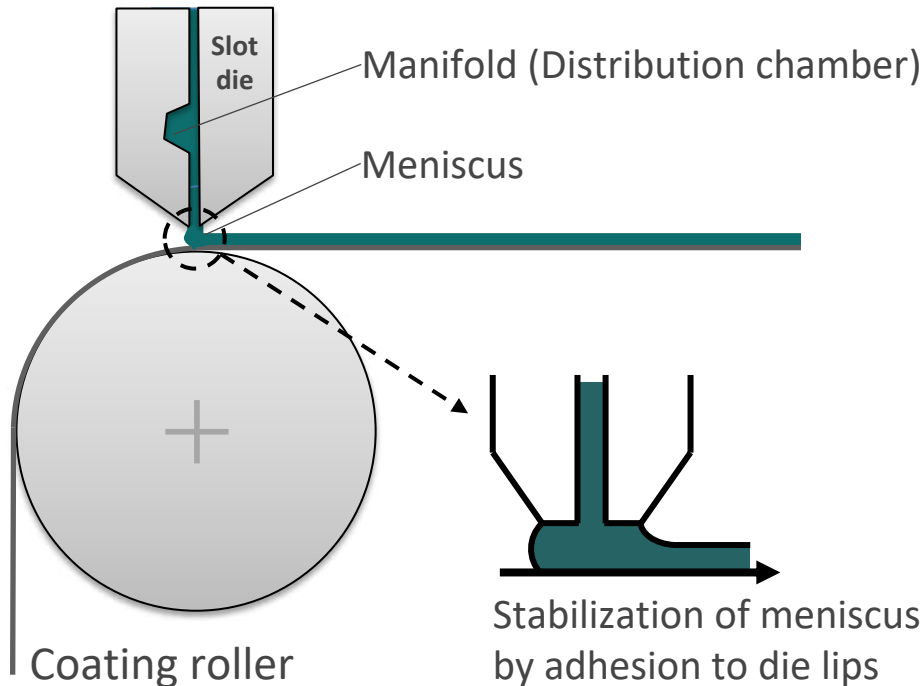
✓ Meniscus is formed between die lips and substrate

✓ Adhesive stabilization of meniscus by die lips

✓ Very low minimum flow rate possible

✓ For a stable process the range of rheological parameters is limited

✓ Preferrably for low coating speed

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.
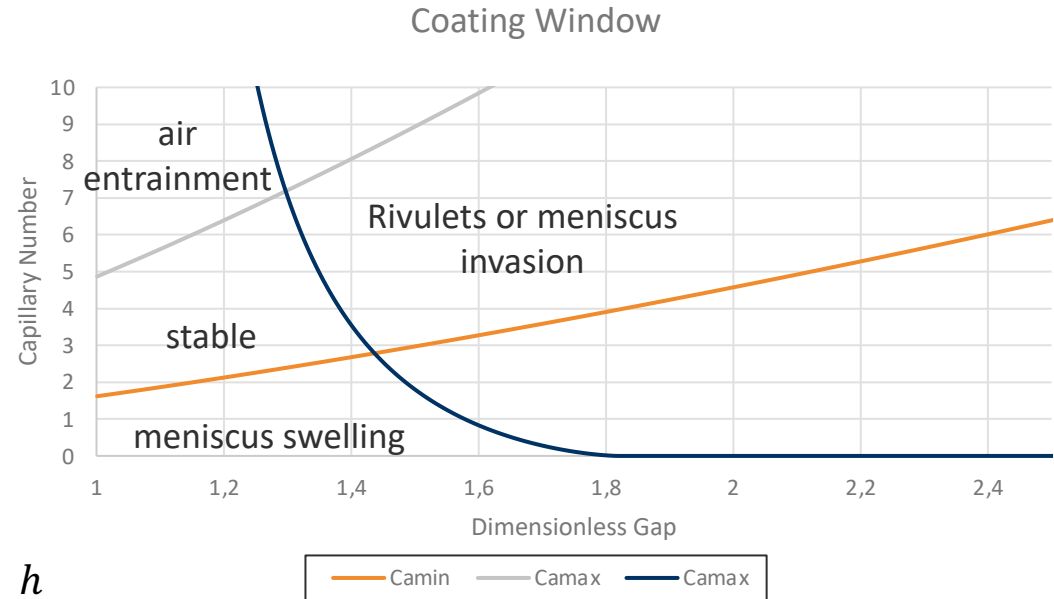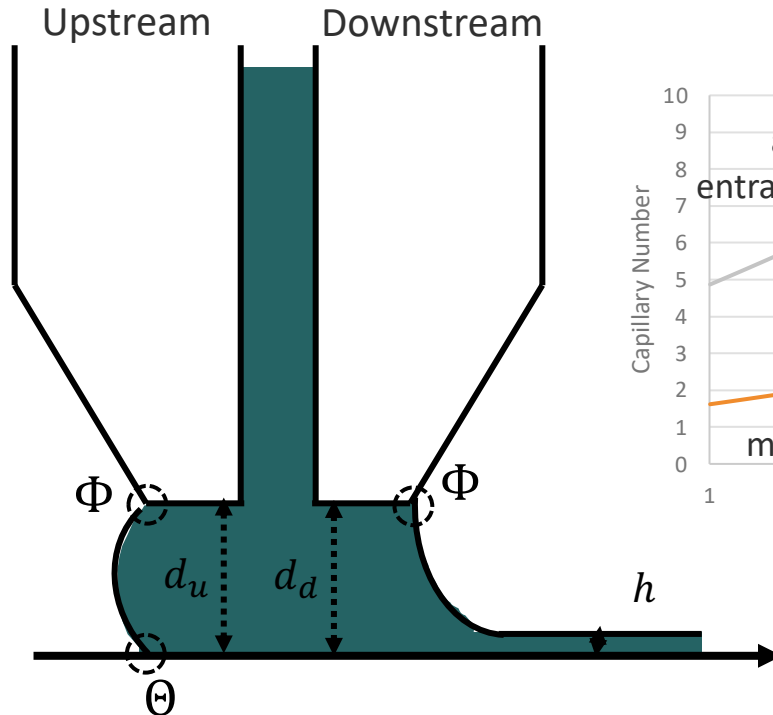
Can be done by appropriate computer programs.

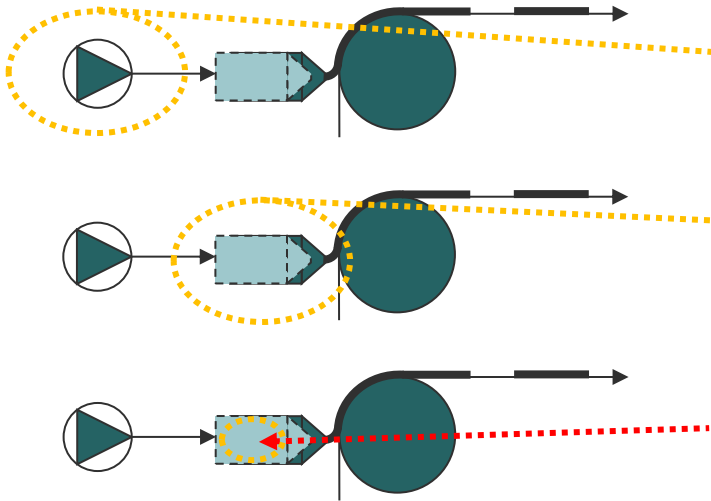$$\frac{\partial v}{\partial t} + (v \nabla) \, \text{v} = \frac{(-\nabla p + \eta \Delta v + f)}{\rho}$$

Navier-Stokes-equations (equations of motion for incompressible fluids, ρ = const)
Δ,∇= 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 defintion is not more precise than around 1 mm. All techniques may be combined with a vacuum pump upstream to stabilize the meniscus and suck away residual liquid.

Structured coating – the switching slot die lip
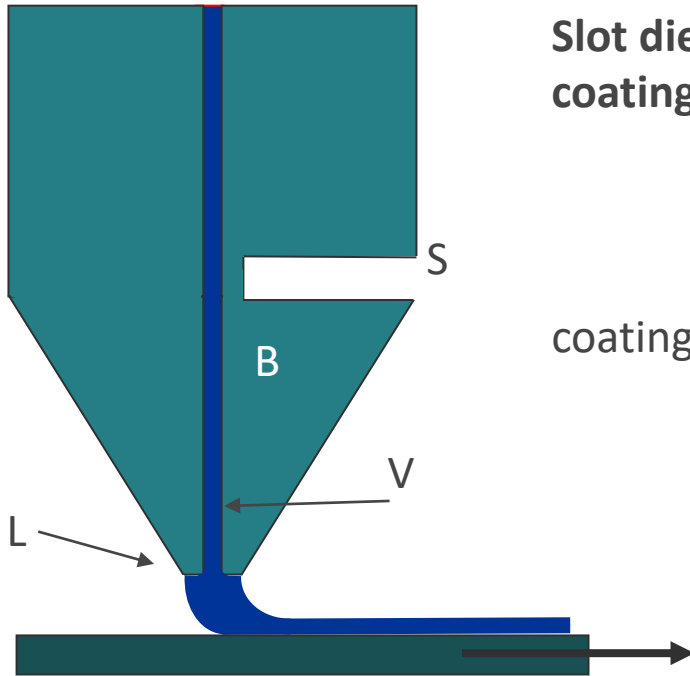
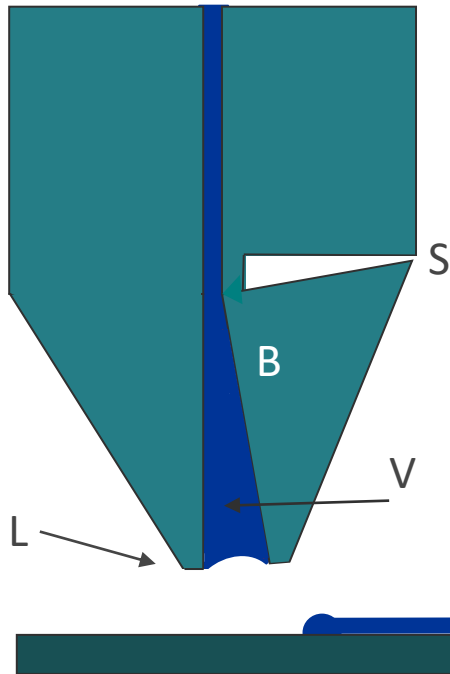**Slot die with movable lips: coating mode**

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
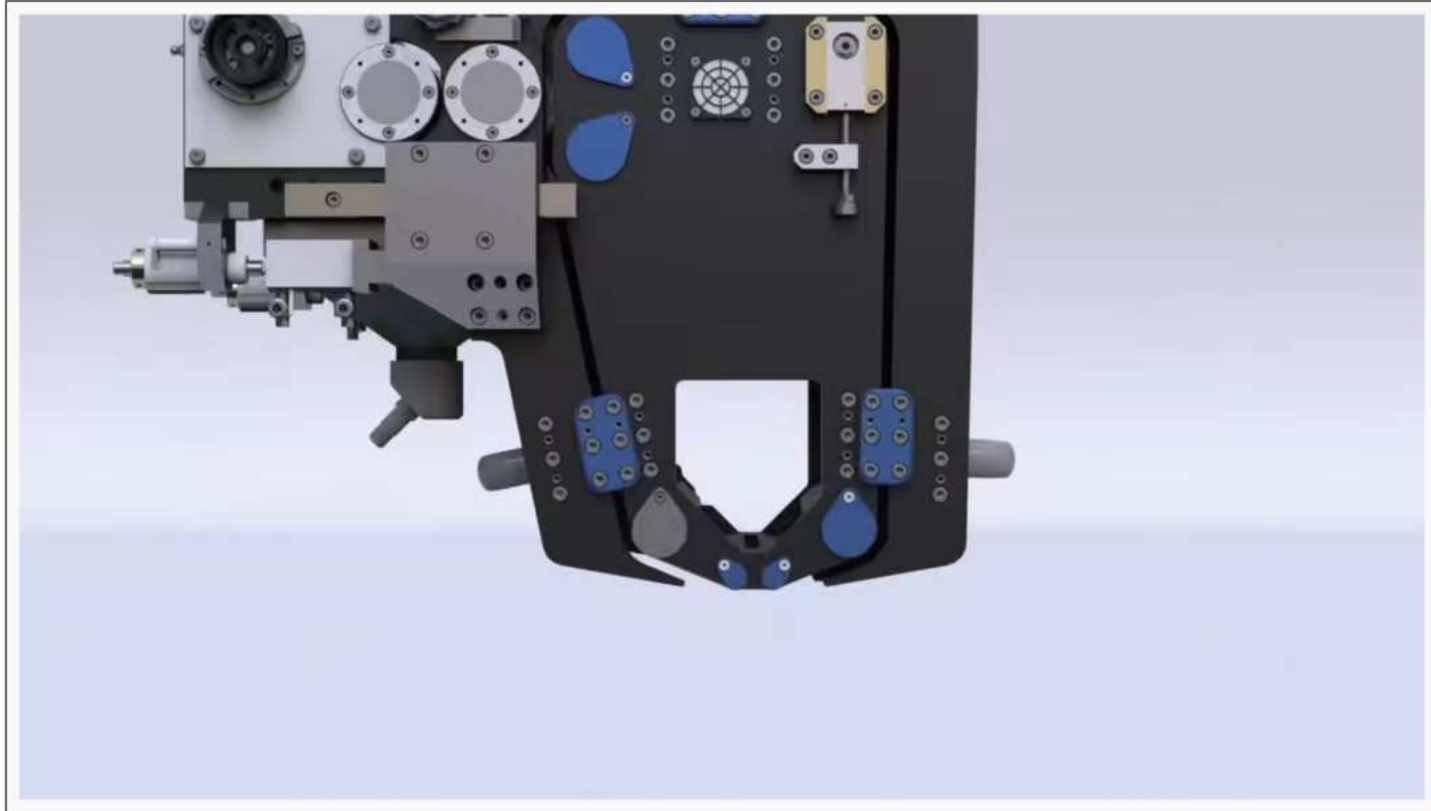
5.

Digital application system

HELIO**SONIC**
PRINTING THE UNPRINTABLE

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

HELIOSONIC - Printing the Unprintable

ALTANA

HELIOSONIC - Printing the Unprintable

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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

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

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

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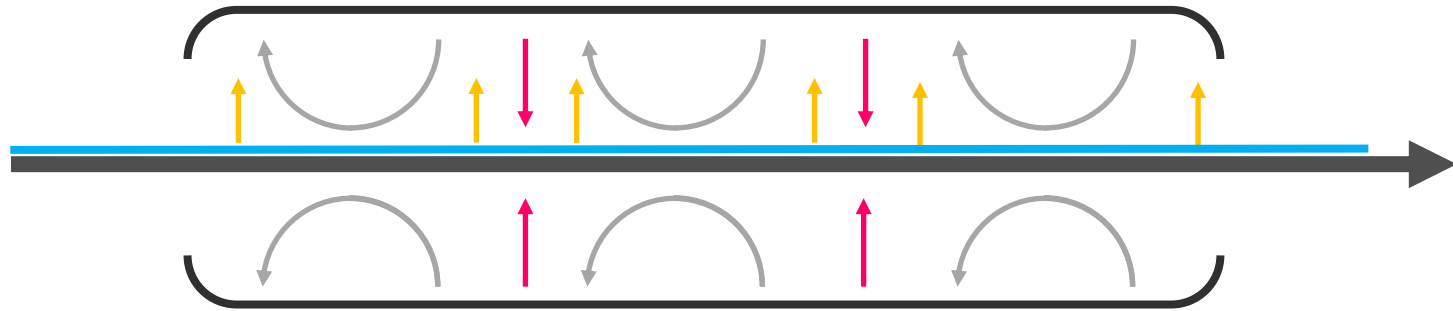
Multi-material
- Combination of materials on dpi level; i.e.: -
  - Active/ inactive (inactive elements can be fillers or structural elements)
  - Conductive/ insulating

HELIOSONIC - Printing the Unprintable

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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.
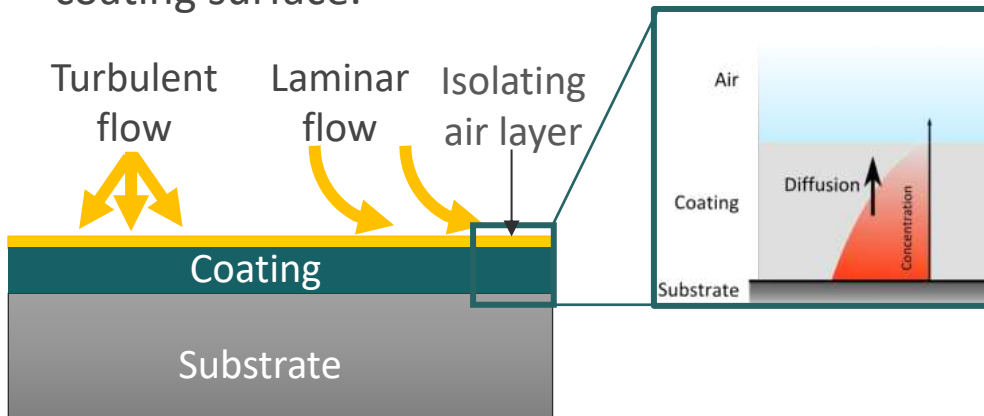
Usually there is a trade-off:

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
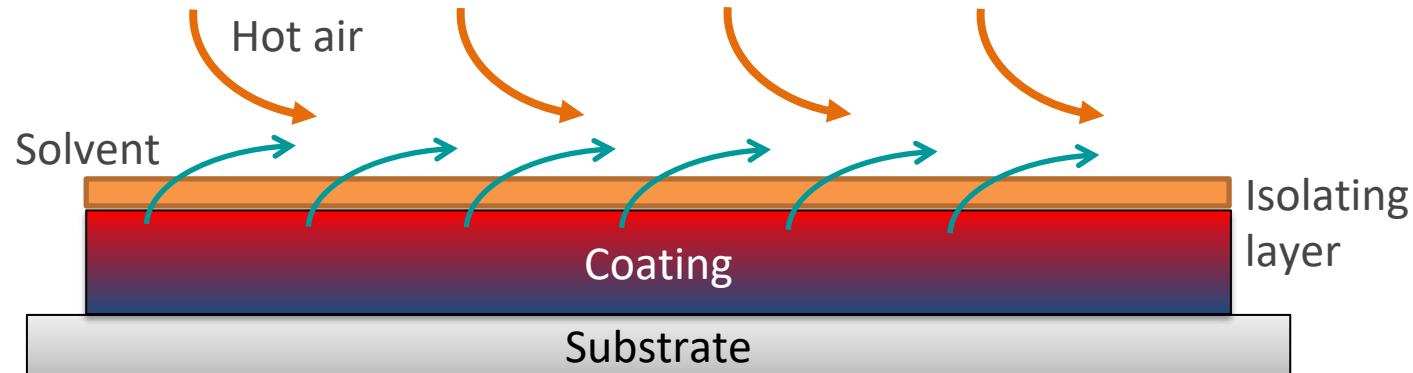
Basics mass + heat transfer

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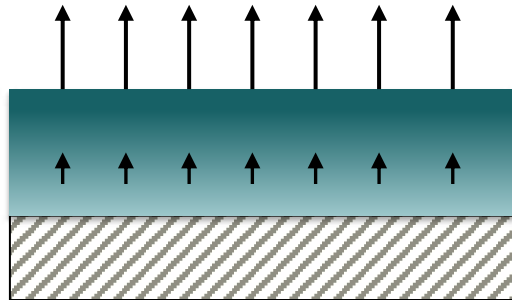
So the initial evaporation must be reduced by low temperature and/or by partially saturated atmosphere. Despite reduced evaporation the total drying time then may be shorter than at full initial evaporation.

Industrial drying systems

Coatema slot
nozel and
circulation
dryer on small
scale

Industrial drying systems

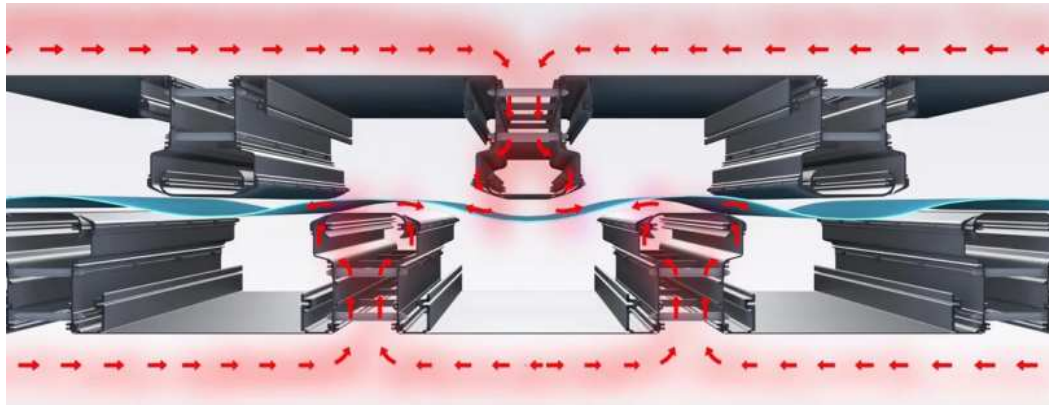Coatema slot nozel and circulation dryer on small scale

Industrial drying systems

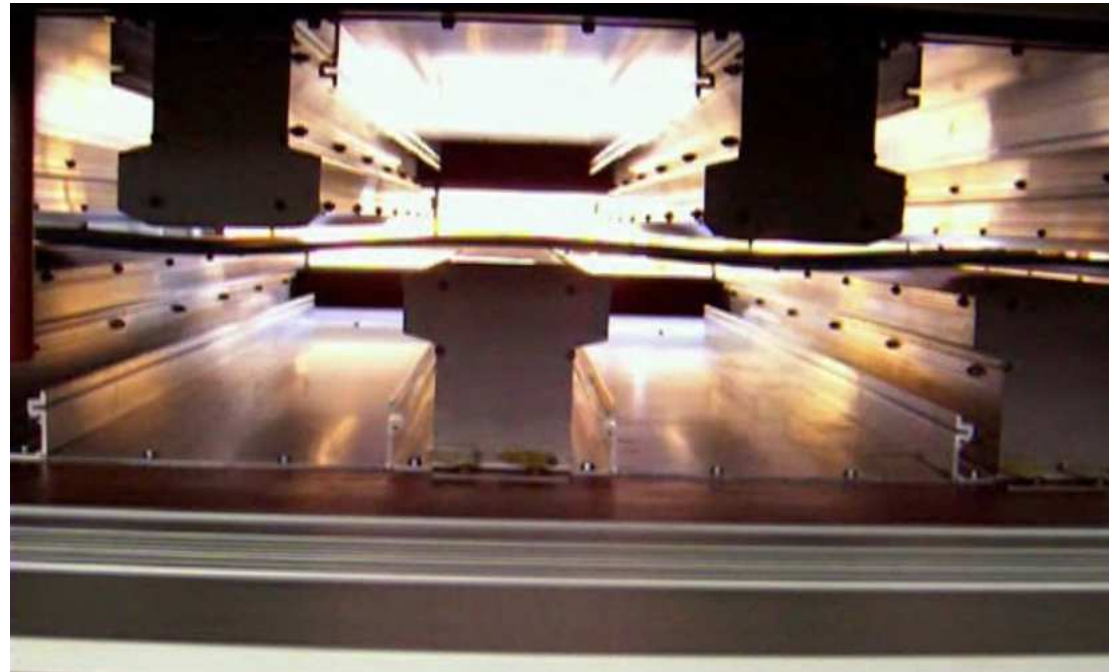Coatema slot
nozel and
circulation
dryer on small
scale

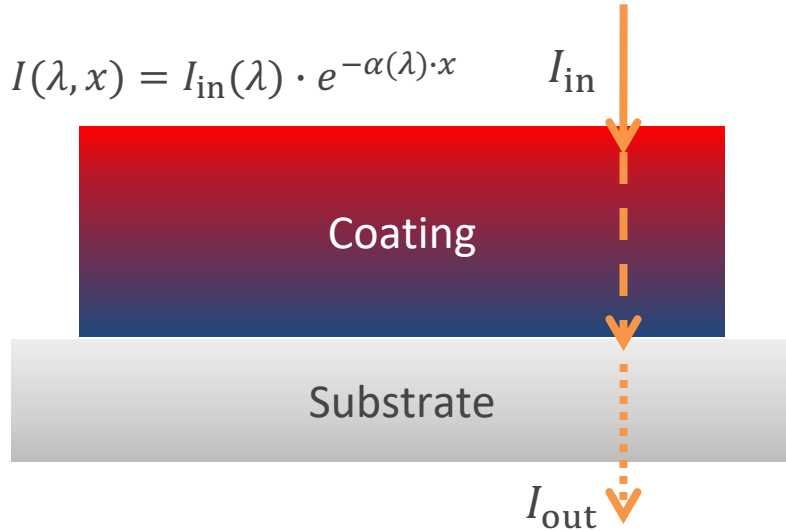# Drytec Click&Coat™ dryer prinziple

Drying topics – drying technologies: HighDry HD500
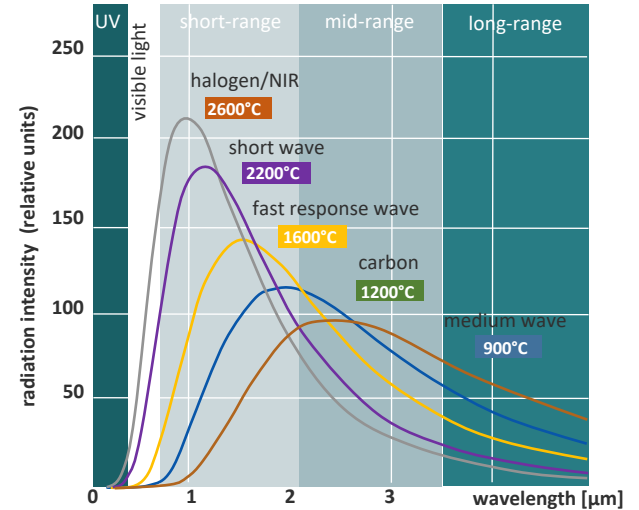
Web behaviour in a
flowtation dryer

Press Button to
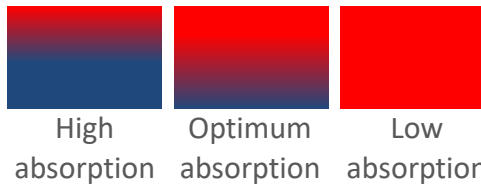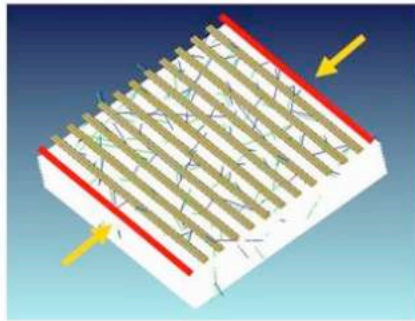show the video

Basics mass + heat transfer: (N)IR technology

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

I_{in}

Coating

Substrate

I_{out}

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

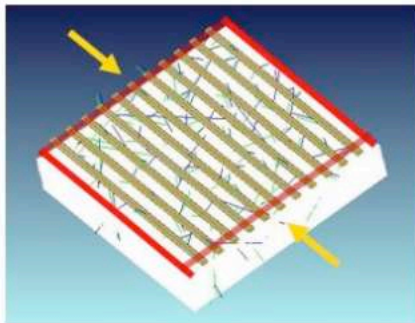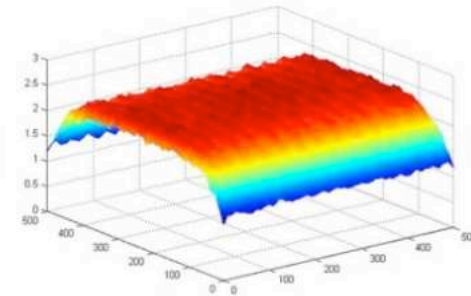High absorption   Optimum absorption   Low absorption

Relative intensity of radiators at different wavelengths

IR / NIR Drying – Infrared drying

Continuous process

13 emitters, 2 types, 3 zones

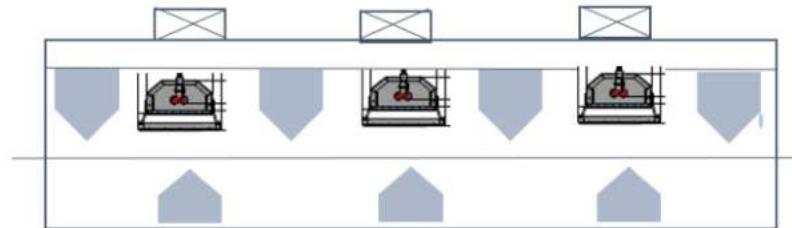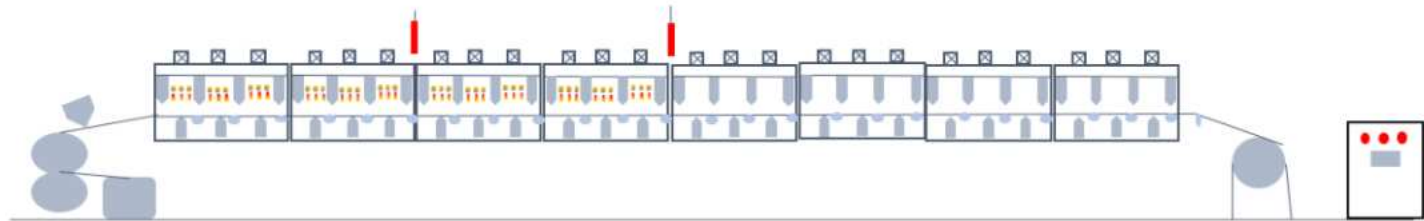Batch process

15 emitters, 3 types, 5 zones

Source: Heraeus Noblelight
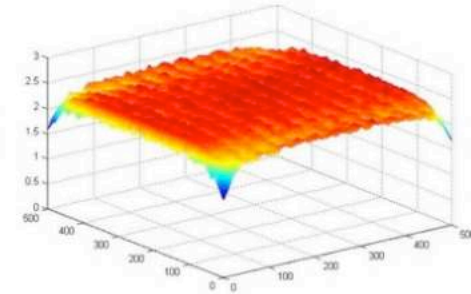
IR / NIR Drying – Infrared drying

Layout

Hotair oven: 50m (10 zone)

IR at first 25m (5 zone) for boost

Heating distance : 100mm

Qty of IR : 60 *3.1Kw = 186Kw

Source: Heraeus Noblelight

7.

Simulation

Slot die chamber – Simulation parameters

✓ Example for anode coating

✓ Copper substrate

✓ Pseudo-Carreau Fluid match power law (μinf=1mPas time-constant =1 sec)

✓ Typical Coatema Slot die

✓ Process parameters for 90m/min 400μm 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
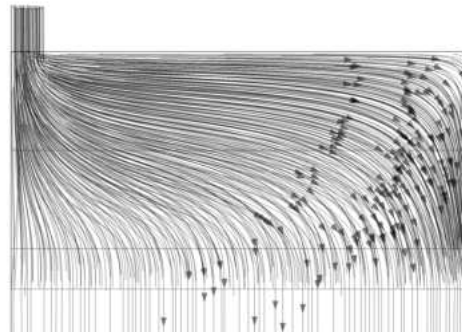
✓ No „fancy" slot-die „just" Coatema standard

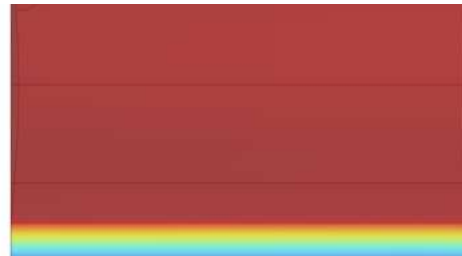Distance okay

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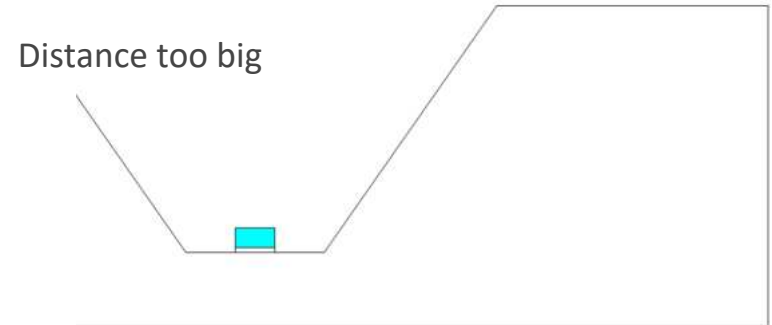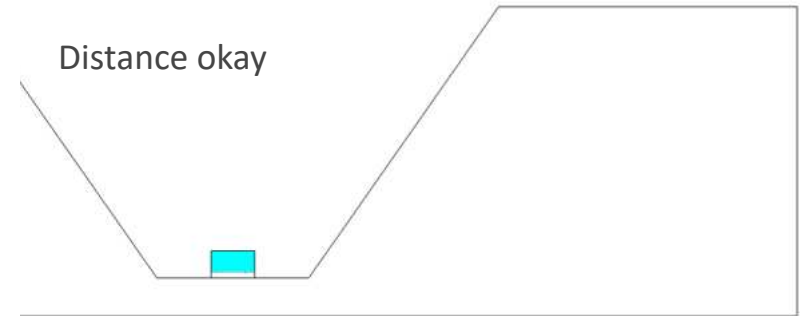
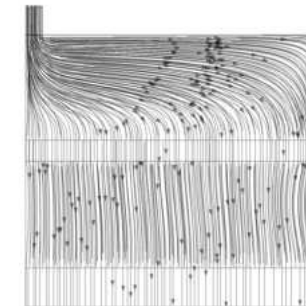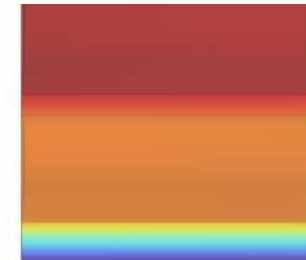# 3D Homogeneity – Slot die chamber – Streamlines and pressure distribution

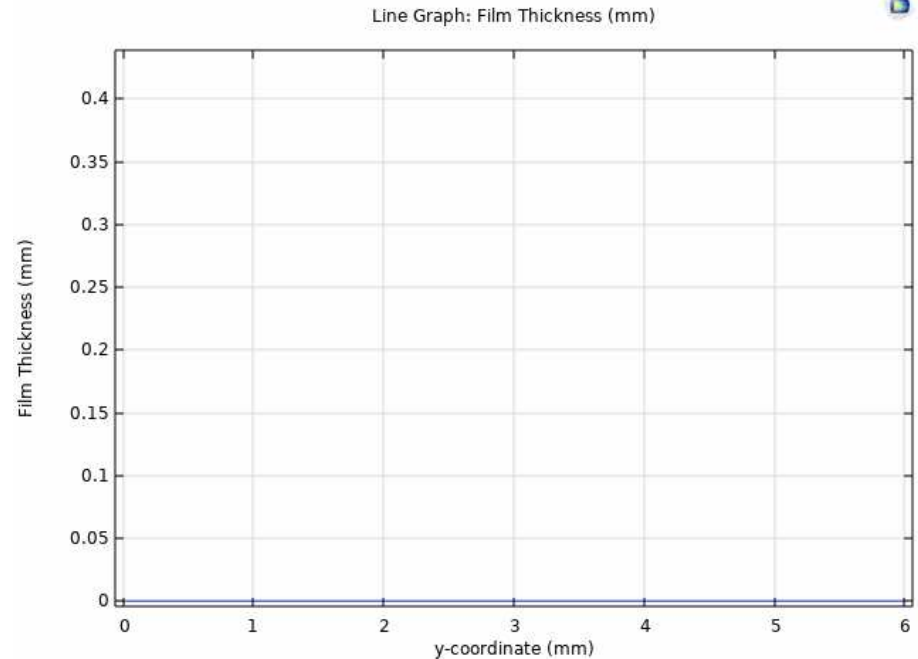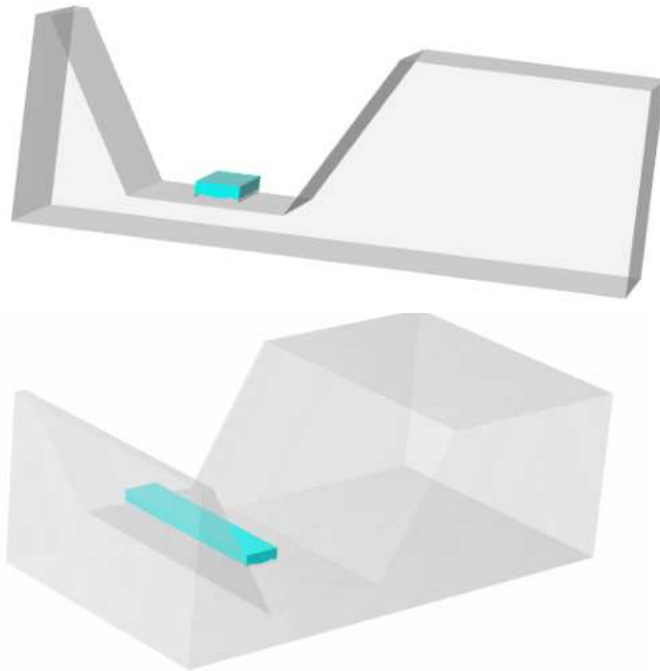Single Chamber with too small inlet (4 mm)
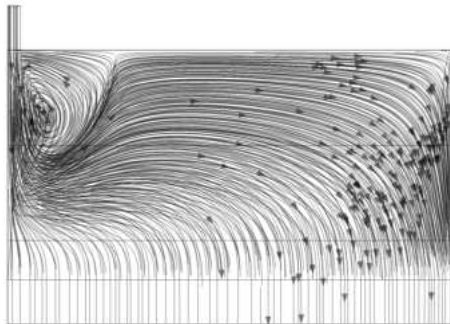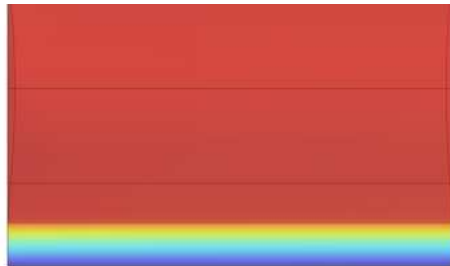
Single Chamber with correct chamber layout (10 mm inlet)

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 Comission

✓ 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.

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