Technology development and manufacturing for 3rd Gen solar cells

Coatema

28/05/25

MEMBER OF ATH

Agenda

1. Introduction
2. 3rd Gen solar technology
3. Flex2Energy project
4. Process control
5. Slot die coating for 3rd Gen PV
6. Drying technologies for 3rd Gen PV
7. Today`s equipment for 3rd Gen PV
8. Summary

1.

Introduction

Overview

Quality
made in Germany

Part of the ATH Holding

S2S equipment

R2R equipment

Innovations

Coating

Printing

Laminating

Bespoke
equipment

Founded
1974

Printed electronics
Fuel cells
Membranes
Pharmaceutics
Solar
Batteries
Prepregs
Green Hydrogen

From lab 2 fab

R&D
projects & network

Worldwide
service

Group of companies

ALTONAER
TECHNOLOGIE
HOLDING

KROENERT

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

DRYTEC

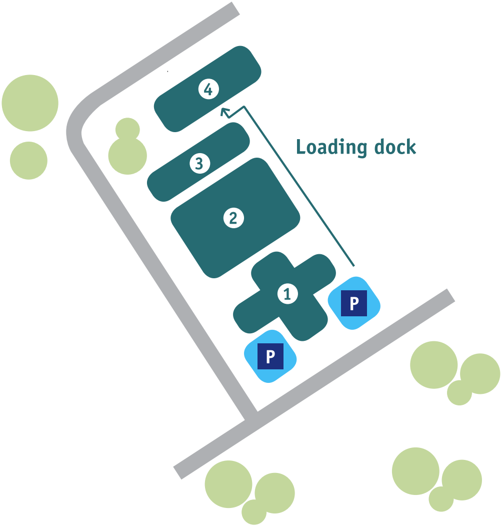
- ✓ Founded 1995
- ✓ Approx. 50 employees
- ✓ Located in Norderstedt

Coatema® Coating Machinery GmbH

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

Represented worldwide

Headquarter in Dormagen

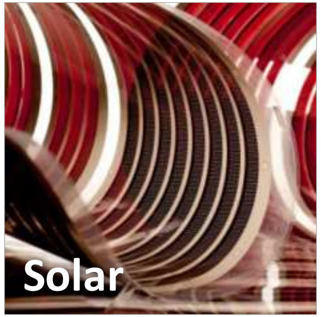


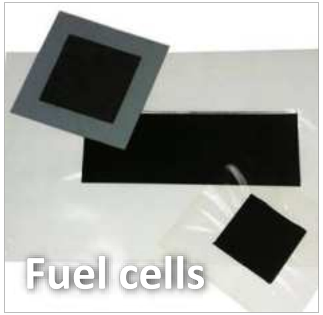
1. Head office
2. R&D centre
3. Assembly
4. Loading dock

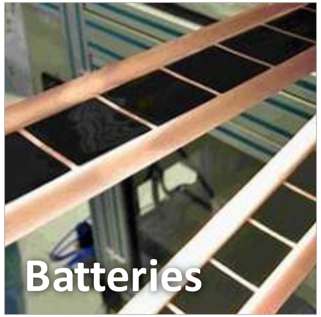
P Visitor parking

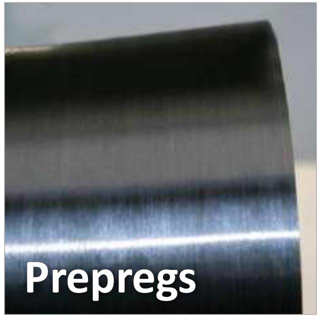
Coatema®
Coating Machinery GmbH

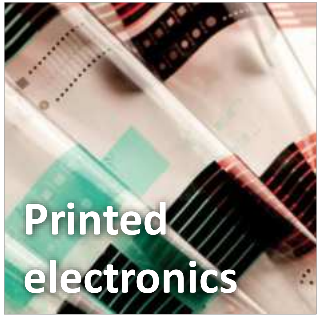
Our markets











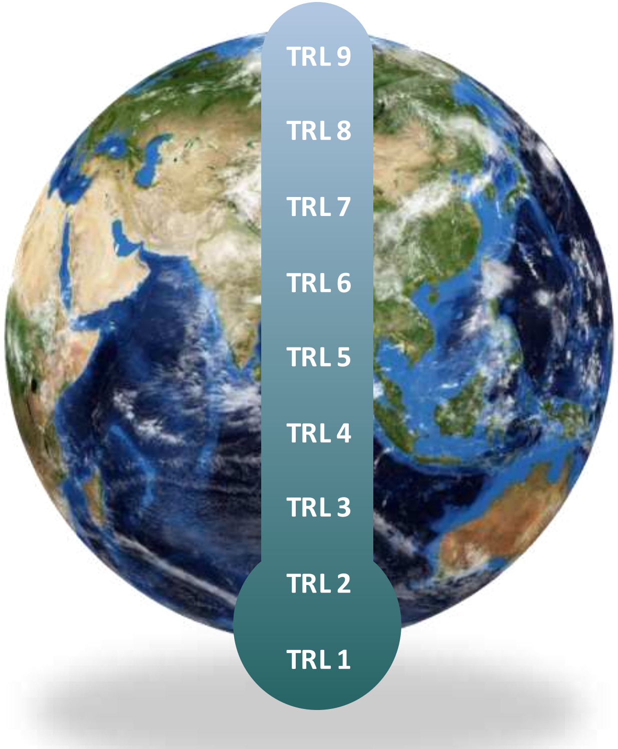
Actual system proven in operational environment

TRL 9
TRL 8
TRL 7
TRL 6
TRL 5
TRL 4
TRL 3
TRL 2
TRL 1

Basic principles observed

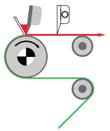
Our markets – Coatema focus areas

- Green Hydrogen
- Fuel cells
- Batteries
- Solar

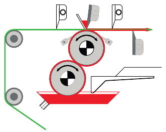


- Sustainability
- Digital fabrication
- Printed electronics
- The next thing

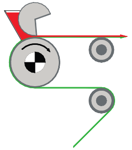
Coating systems



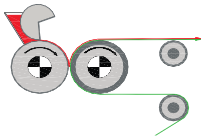
Knife system



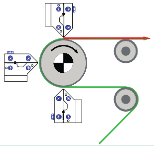
Double side coating system



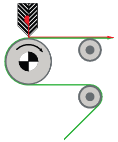
Commabar system



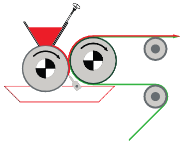
Reverse commabar system



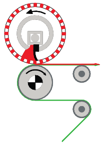
Slot die system



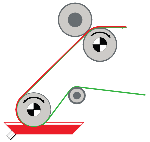
Curtain coating system



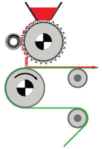
Case knife system



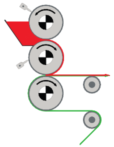
Rotary screen system



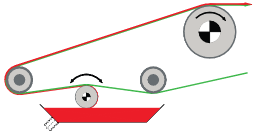
Dipping system (Foulard)



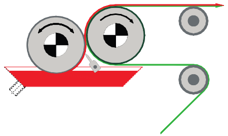
Powder scattering system



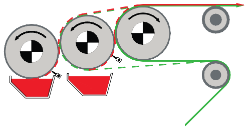
Reverse roll coating system



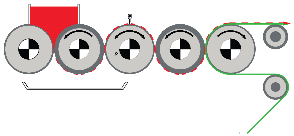
Micro roller coating system



2-roller coating system

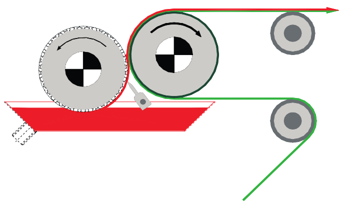


3-roller combi coating system

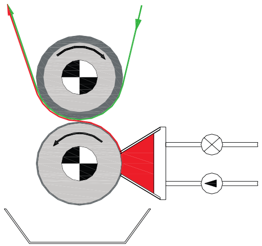


5-roller coating system

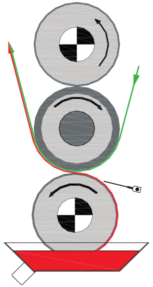
Printing systems



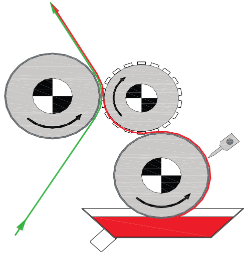
Engraved roller system



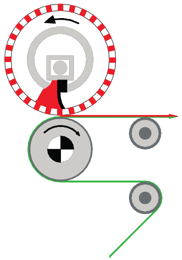
Gravure roller system



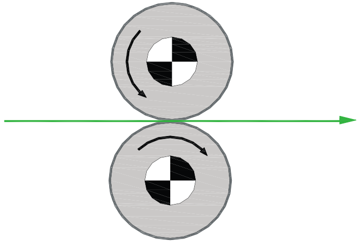
Gravure indirect system



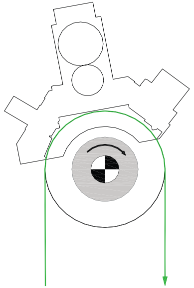
Flexography system



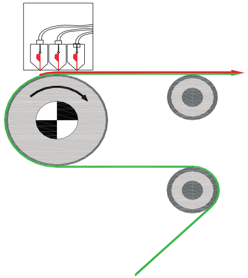
Rotary screen system



Hot embossing system



Nanoimprint system



Inkjet system

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Coating Machinery GmbH

R&D customers

Technische Universität Dresden
KIT Karlsruhe Institute of Technology
Agency for Science, Technology and Research SINGAPORE
The University of Arizona
UNSW Sydney
Queen Mary University of London
Aristotle University of Thessaloniki
TTRI Taiwan Textile Reasarch Institute
ITA Institut für Textiltechnik und Lehrstuhl für Textilmaschinenbau
RWTH Aachen University
NREL Transforming ENERGY
Ruhr Universität Bochum RUB
Technical University of Liberec www.tul.cz
hochschule hof University of Applied Sciences
Deutsches Textilforschungszentrum Nord-West German Textile Research Centre North-West
cea
CSIRO
Fachhochschule Kiel Hochschule für Angewandte Wissenschaften
CeNTI Centre for Nanotechnology and Smart Materials
FILK Forschungsinstitut Leder und Kunststoffbahnen
The Ohio State University
Hochschule Niederrhein University of Applied Sciences
Georgia Institute of Technology
University of Cambridge
Neue Materialien Fürth
Joanneum Research
Heriot Watt University
SW
DITF Deutsche Institute für Textil+Faserforschung
Jülich Forschungszentrum
National University of Mongolia
VTT
TNO innovation for life
eurecat Centre Tecnològic de Catalunya
Fraunhofer IMM
Fraunhofer LBF
KITECH Korea Institute of Industrial Technology
Holst Centre
Hochschule Reutlingen Reutlingen University
tecnalia
Fraunhofer IAP
Fraunhofer IAF
Fraunhofer ILT
Fraunhofer IFAM
Fraunhofer ISC
Fraunhofer FEP
Fraunhofer IVV
Fraunhofer ISE
Fraunhofer ICT
Fraunhofer PYCO
Fraunhofer IPT
Fraunhofer IWM

Our work in associations – global networking

Board Member:
OE-A

Advisory Board:
Fraunhofer ITA

Coatema customers

GUMOTEX
EVONIK INDUSTRIES
covestro
SAMSUNG
DAIMLER
era

SEKISUI alveo
ASTORPLAST
BIERBAUM UNTERNEHMENSGRUPPE seit 1895
Continental CONTITECH
analyticon

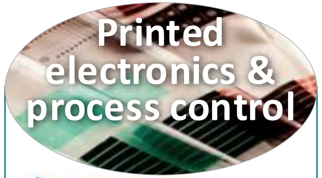
TDK
BASF We create chemistry
FREUDENBERG INNOVATING TOGETHER
HÜBNER
EVEREST
DELTA

SolarIntegrated
Scheuten
M EN SHU
LTS TRANSDERMAL. MARKETLEADER.
SCHERING making medicine work
SARTORIUS

HARTMANN
Hydro
habasit
stahl
3P InkJet Textiles
ionity

Coatema® Coating Machinery GmbH

R&D projects overview 2022 – 2025

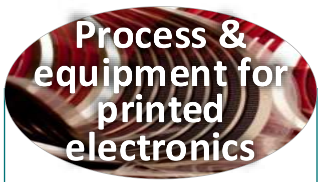


REAL NANO

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

NOUVEAU

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

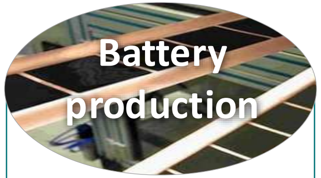


FLEX2ENERGY AUTOMATED MANUFACTURING PRODUCTION LINE FOR IPVS

R2R production line for OPV solar with integrated backend

FLEX-G 4.0

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



IDEEL

Implementation of laser drying processes for lithium-ion battery production

SOLiD

R2R process optimization for solid state batteries

PEP LAT

Plasmonically enhanced photocatalysis for wastewater treatment

ROLL 2 SOL

R2R nanostructuring of functional films

WATER PROOF

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

FLEX FUNCTION 2 SUSTAIN

Creating an open-innovation testbed for sustainable packaging

2.

3rd Gen solar technology

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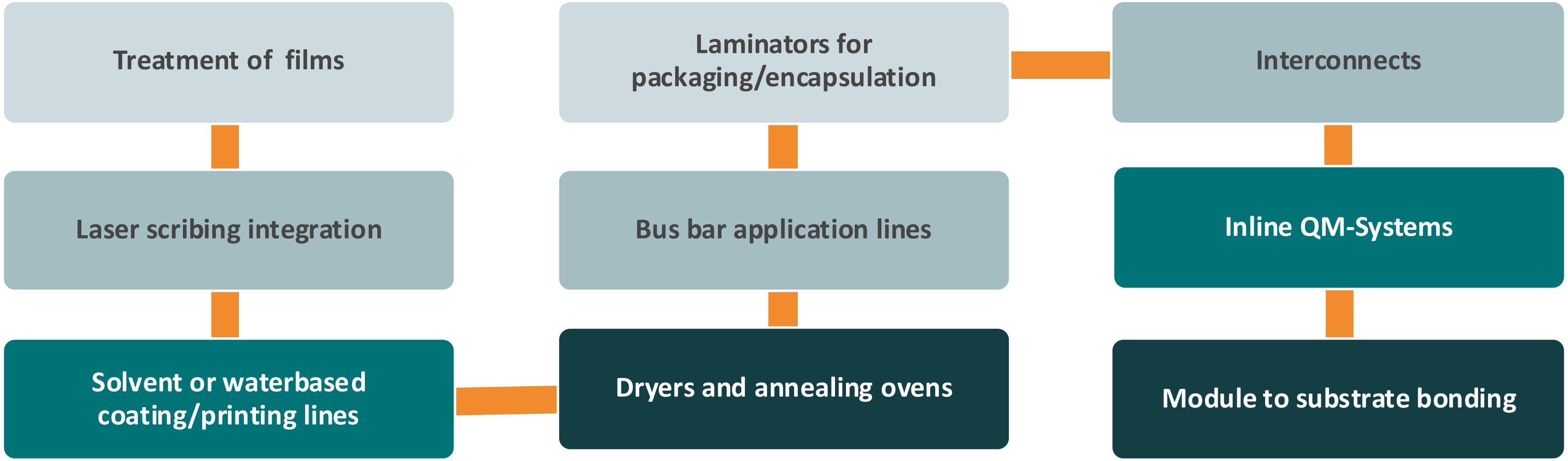
Overview of the different flexible solar cell types

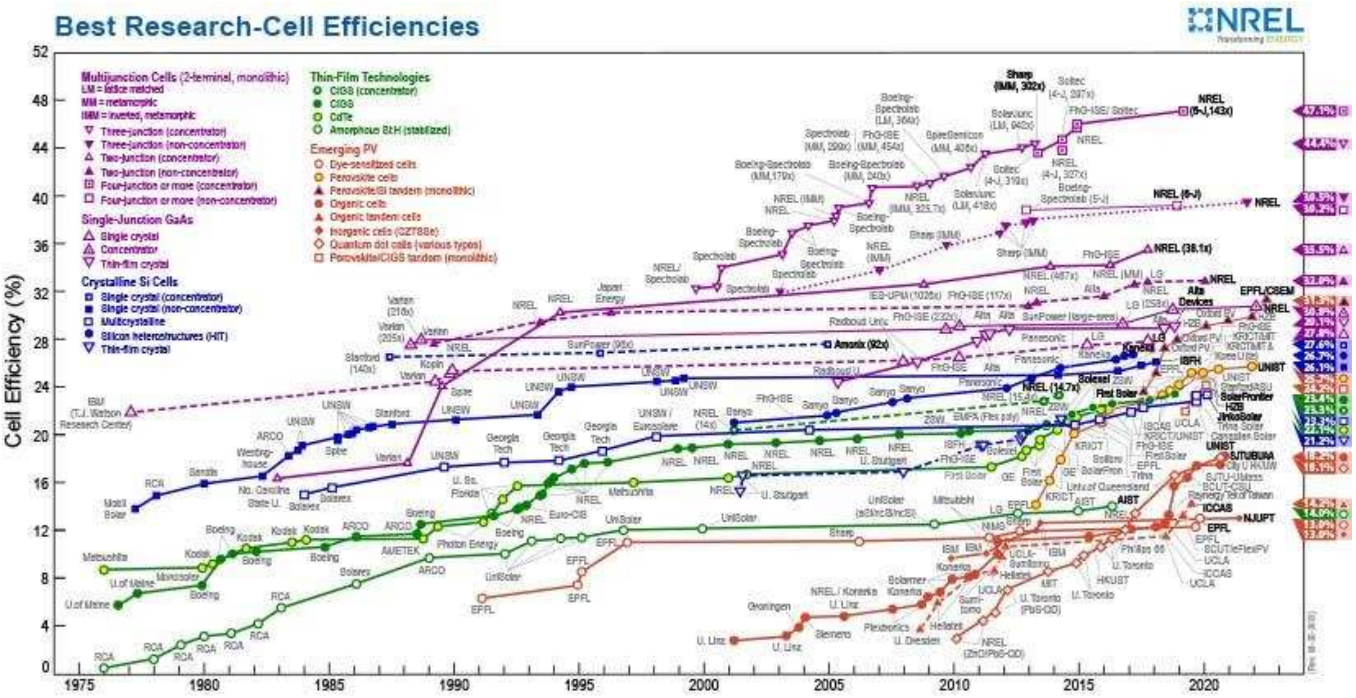
Technology	Advantage	Challenge
a-Si	Excellent for BIPV due to a prooven life time longer than 10 years	Light-induced degradation, Efficiency, Cost for production equipment
CIS/CIGS	Low cost, Efficiency, R2R processes	Availability of Indium
DSSC	low weight, R2R, good performance in diffuse light conditions,real flexible, low cost production methods	Device stability, life time, efficiency
OPV	Lightweight, flexible, low cost coating or printing methods	Efficiency, device stability, life time
Perovskite	Lightweight, high efficiency from the beginning	Lead layer and lifetime

RWTH Aachen Campus

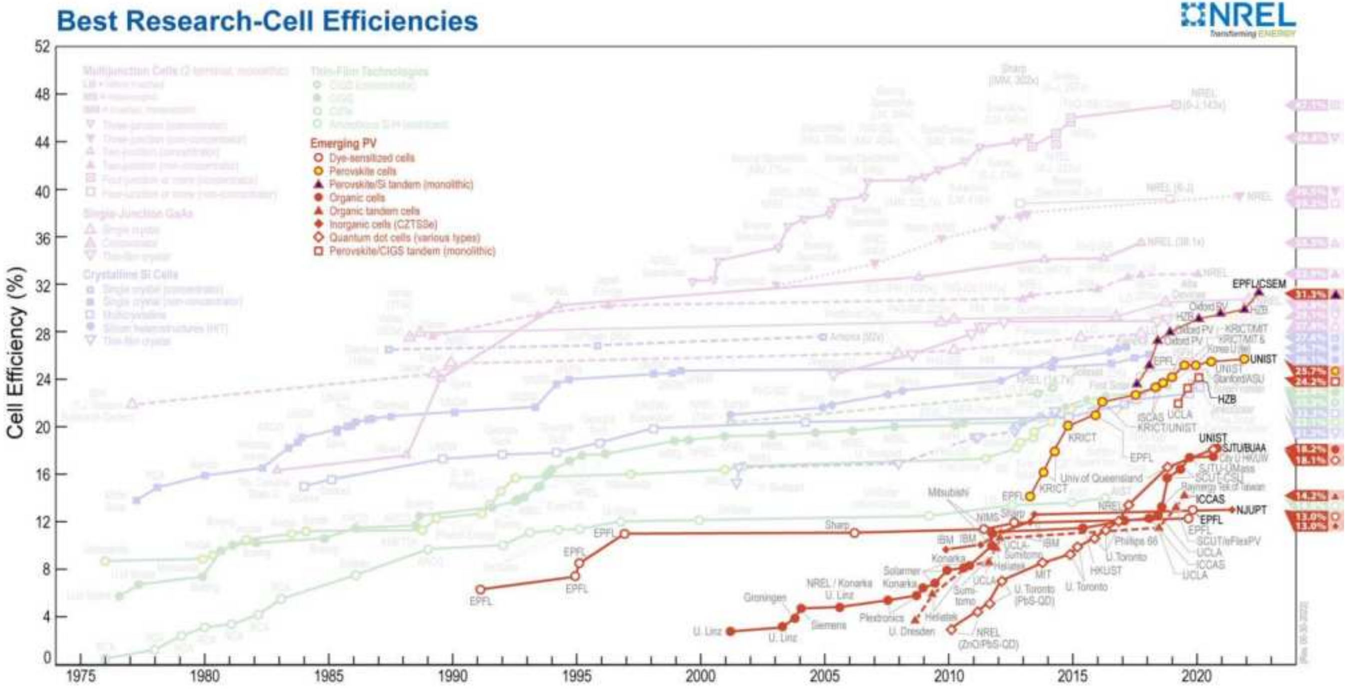
Production chain modules



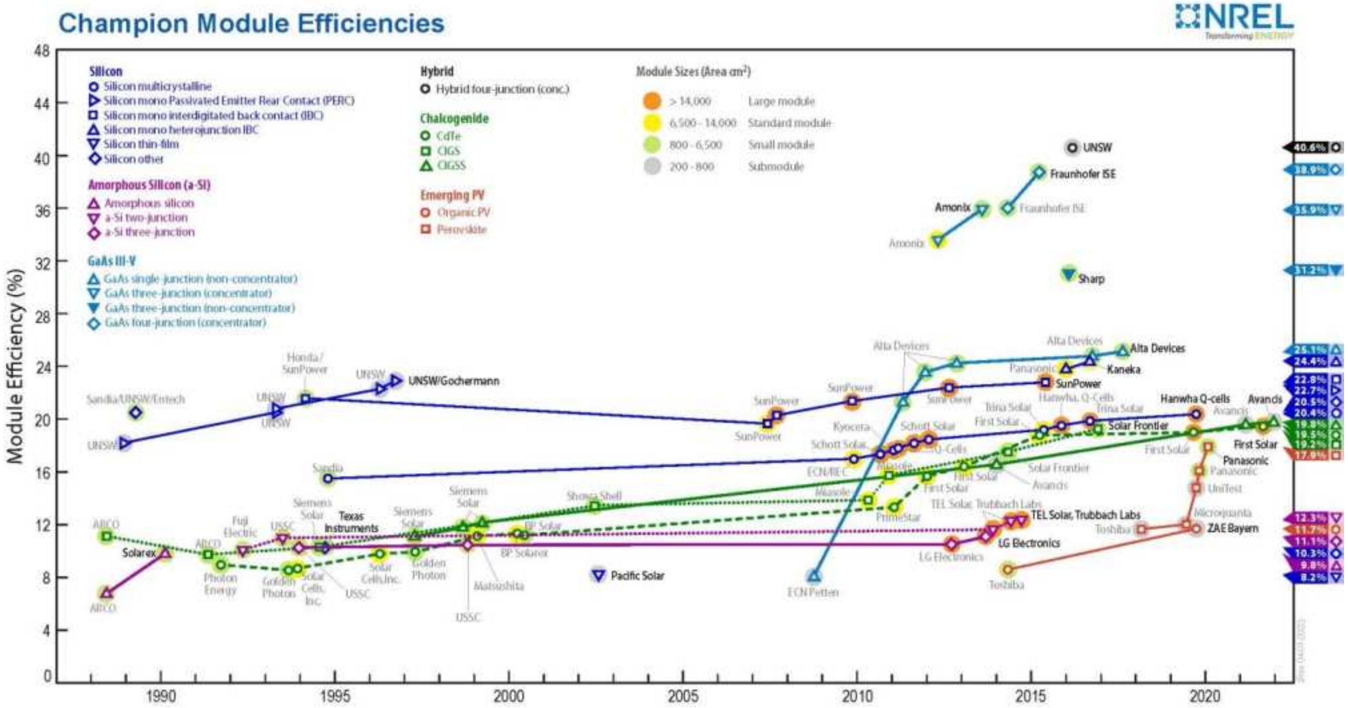
Cell efficiency



Cell efficiency for 3rd Gen solar



Module efficiency



OPV USP

- ✓ Flexible
- ✓ Low cost
- ✓ High volume R2R processes
- ✓ Thin
- ✓ Light weight
- ✓ Versatile applications
- ✓ Green mobile power
- ✓ Sexy

Encapsulation (Glass or barrier film)

Anode 50 nm – 10µm Solution-processed metals (such as Silver)

Hole transport layer 30 – 100 nm

Photoactive Layer 80 – 300 nm

Cathode

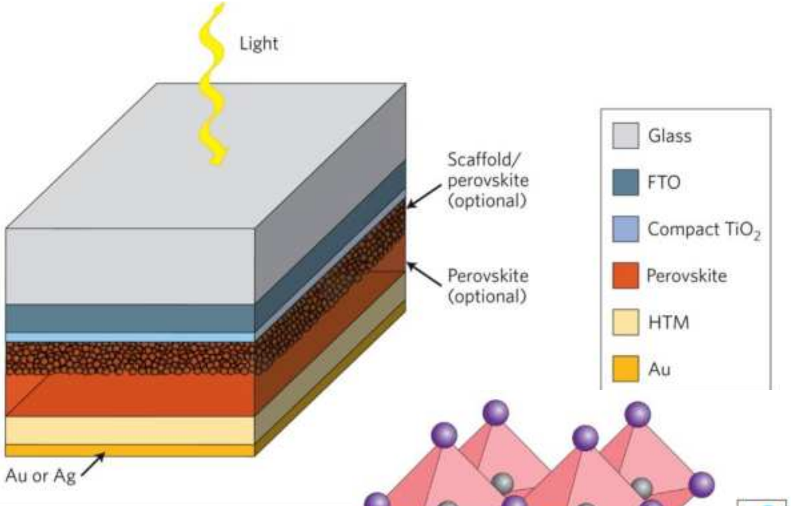
Transparent Electrode 50 nm – 1µm (Solution-processed ZnOx)

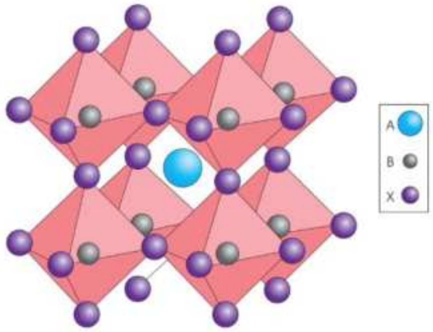
Substrate (Transparent ITO or metal oxides plastic film (i.e. PET, PEN)

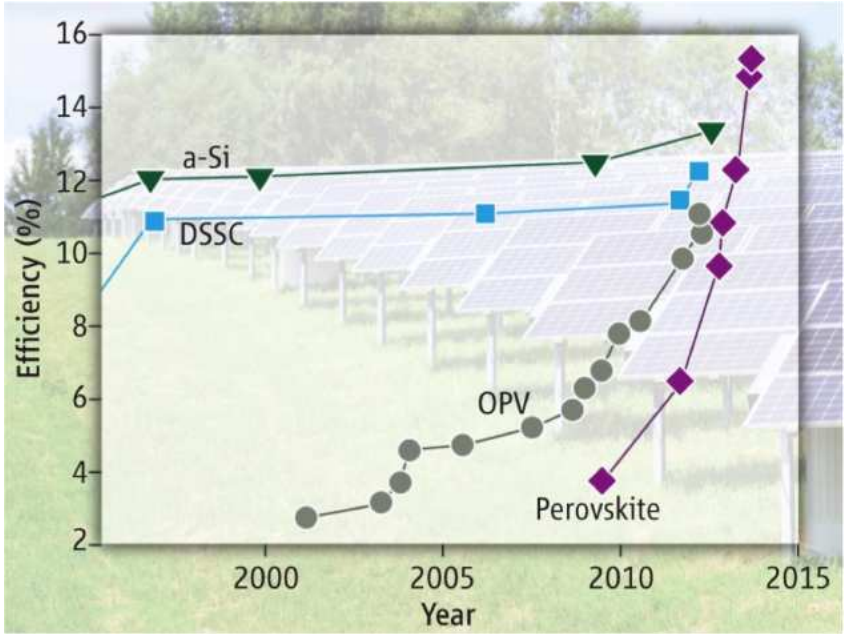
Conductive solution with
- ✓ Conductive polymer
- ✓ Matrix material
- ✓ Additives
- ✓ Co-solvents

Bulk heterojunction with
- ✓ Polymer p-type (P3HT)
- ✓ Fullerene n-type (C60 PCBM)
- ✓ Aromatic solvents

Perovskite, the 3rd wave of 3rd gen solar







Source: Image Credit: Martin Green et al / Nature Photonics

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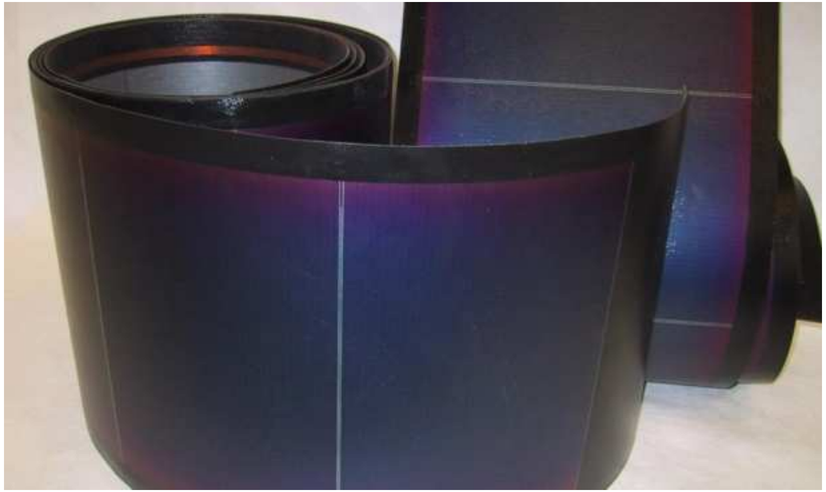
Coatema Core Technologies in solar technologies

Dye sensitized solar cell (DSSC)	Organic photovoltaics (OPV)	Perovskite	Slot die coating/ Printing processes
Process inline control	Drying/ Anealing	Encapsulation	Laser Integration

1999 – Vision on flexible roofing integrated PV

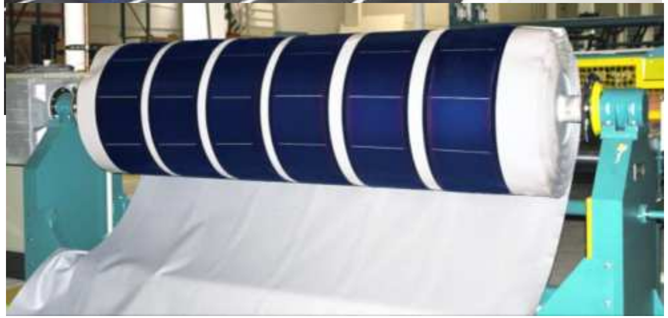


Solar integrated technologies strategic partnership with Uni-Solar, provides SIT with up to 30MW annually of flexible photovoltaic cells

Worlds largest flexible amorphous silicon photovoltaic cell production line. A three year, $100 million dollar commitment

1999 – flexible PV on roofing membrane

Production facility in Los Angeles



Vision on flexible roofing integrated PV on roofing membrane

Vision on flexible roofing integrated PV on roofing membrane

1999 – flexible PV on roofing membrane

Solar cell projects at Coatema

2005 – 2023

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Coating Machinery GmbH

Process upscaling – Developing 3rd Gen PV at Coatema

- 2008 – Facess
- 2010 – Smartonics
- 2015 – Clean4Yield
- 2019 – OLED Solar
- 2020 – Real Nano
- 2023 – Flex2Energy

✓ 3 BMWF Projects with Ruhr Uni Bochum and ILT: FlexLAS – Photonflex – Effilayers

✓ 1 REGAC project – LS09 Registration improvement on the MAXI Line at VTT

<u>OPV equipment outside of funded projects</u>

G24i, Solarpower, CSEM, VTT-LS09 MAXILINE, UNSW, CSRIO

CSEM, Eight Nineteen, Heliatek

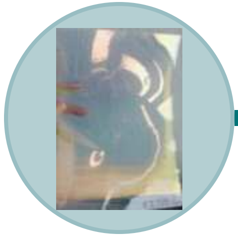
Developed and integrated technologies in 3rd Gen PV

- ✓ Inert pilotcoater design
- ✓ Slot die coating
- ✓ Screen printing, gravure and flexo printing
- ✓ Laser integration
- ✓ Inkjet integration
- ✓ Registration control
- ✓ Inline quality control
- ✓ Inline layer performance control
- ✓ Nanoimprint surface modification

Proces feasibility study – function & design study

50 mm; 1 – 5 m/min

Lab scale



A4

Process specification
→Machinery
→Fluid
→Coating
→ Drying
→ Curing

Defining optim. dilution
50 % → 70 %

Defining optim. layer thickness
3 µm ± 0,2 µm

Ajustment, testing initiators
→ UV LED 365 nm

Trials
→ Quality
→ Speed
→ Curing
→ Thickness

Defining Pilot-line set up for coating, lamination
CC08

Transfer to
CC08

Pilot scale

200 mm; 1 m/min

Process & Equipment specifications

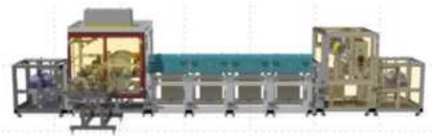
- ✓ Suitable R2R coating and lamination solutions at COA will be defined / evaluated

Process & Ink development

- ✓ Testing defined coating/ process parameter at R&D centre COA
- ✓ Ink & Process optimization
- ✓ Defining most suitable R2R process

Upscale to production in the Coateam R&D centre

Pilot scale



Further optimization
→ Ink formulation
→ UV LED 365 & 395 nm

Pumping method

Pre treatment

Production scale

Process transfer
→ 200 mm coating width
→ 1 m/min

Trials

Integration lamination
→Adhesive foil
→Protective layer

Production demonstrator
→

500 mm; 3 m/min

Process integration

- ✓ Integration into a single R2R process suitable for the production of the OPV modules → Further optimization ink formulation
- ✓ The boundaries of the R2R process regarding quality, speed and costs

Demonstration and evaluation

- ✓ Production final R2R window film & comparison to the initial S2S
- ✓ Was the transfer from lab-to-pilot scale successful?
- ✓ Process equipment / Plant for Flex2Energy
- ✓ Design of a suitable R2R pilot line (500 mm)

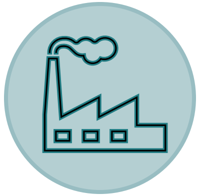
Proof of production process in Greece – Flex2Energy

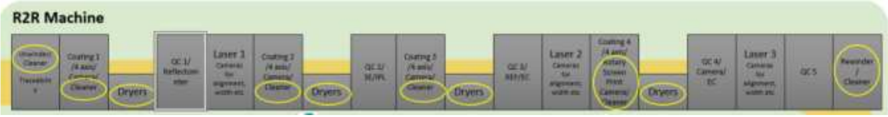
Production scale

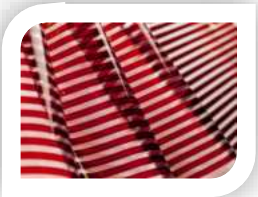
Front end

Backend

Production scale







500 mm; 10 m/min

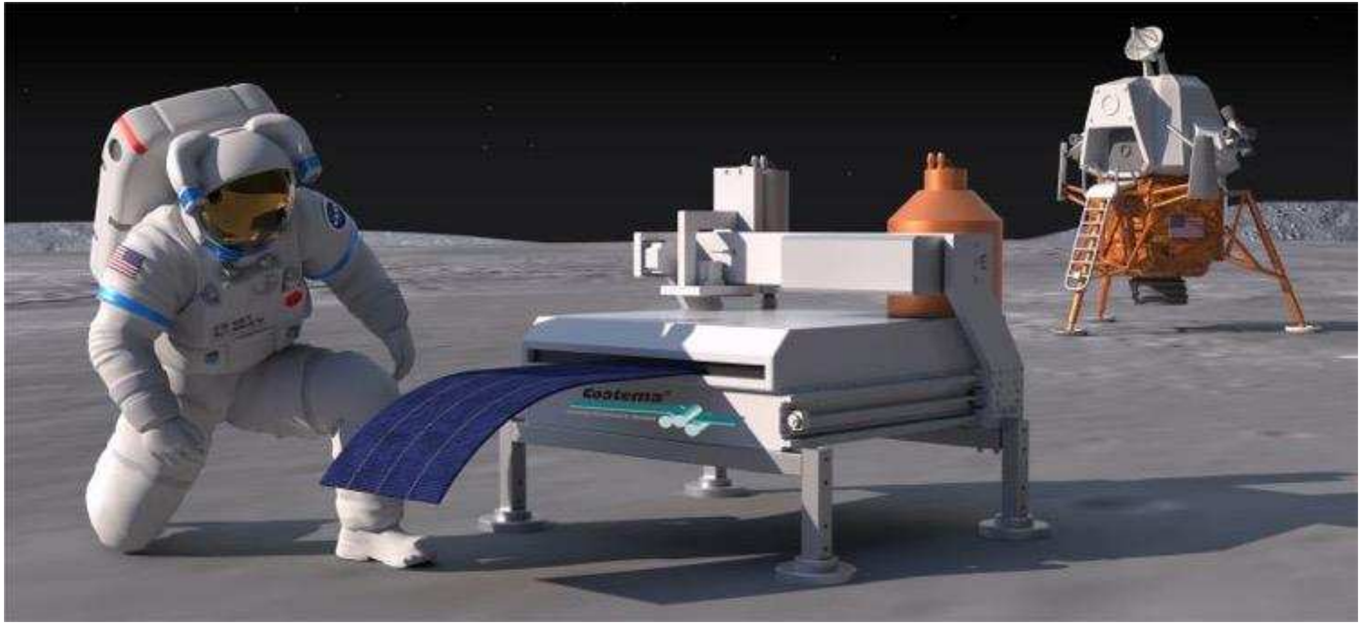
Process integration as industrial standard

- ✓ Integration into a single R2R process suitable for the production of the OPV modules
- ✓ Integration of backend

Demonstration and evaluation

- ✓ Production of 3rd Gen OPV
- ✓ Licensing the overall giga fab concept

The vision from NASA – perovskite on the moon

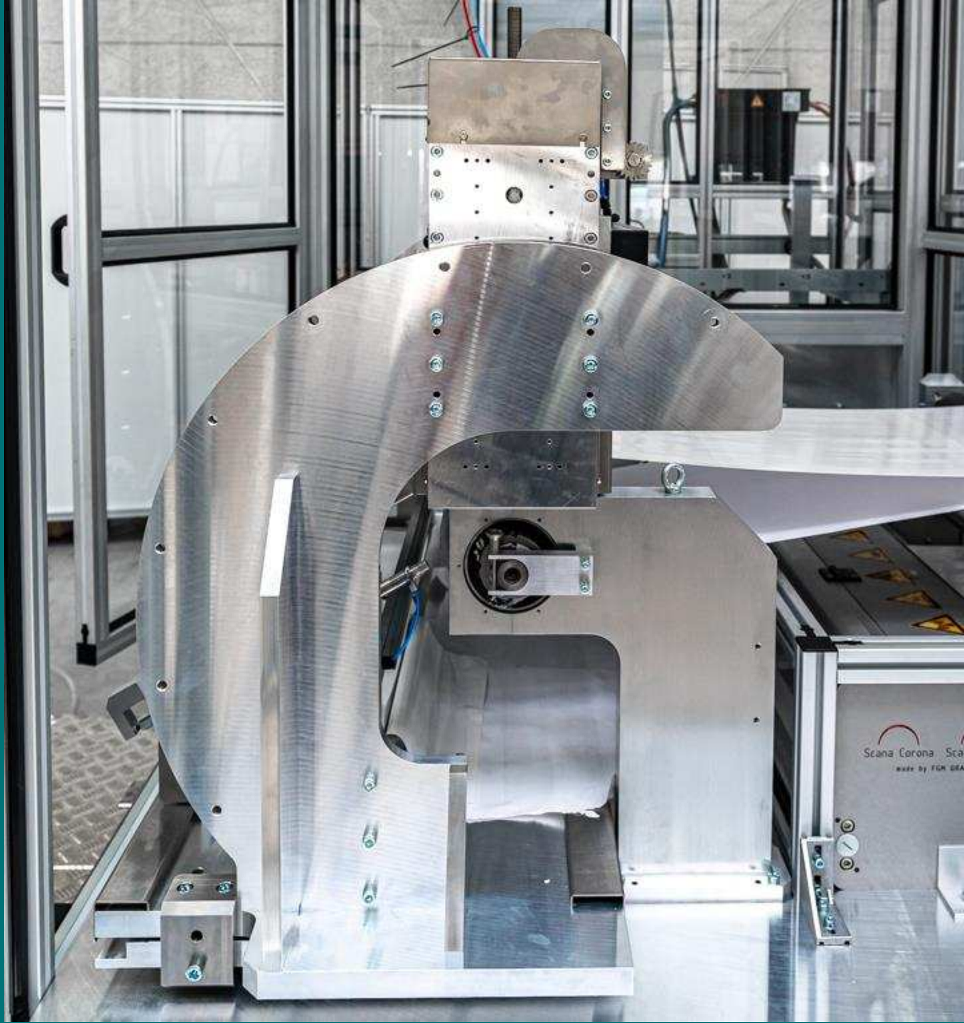


What would it take to manufacture Perovskite Solar Cells in space? | ACS Energy Letters

Source: Author: Lindsey Mc Millon-Brown

3.

Flex2Energy project



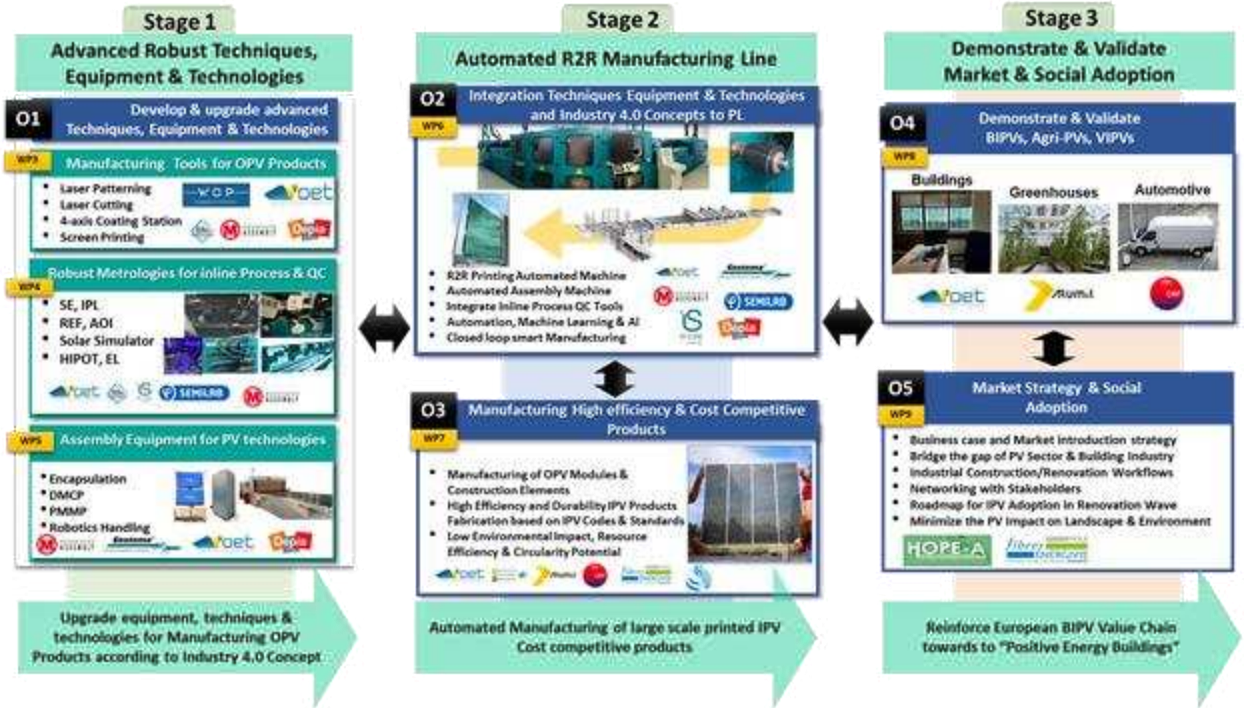
FLEX2ENERGY

AUTOMATED MANUFACTURING PRODUCTION LINE FOR IPVS

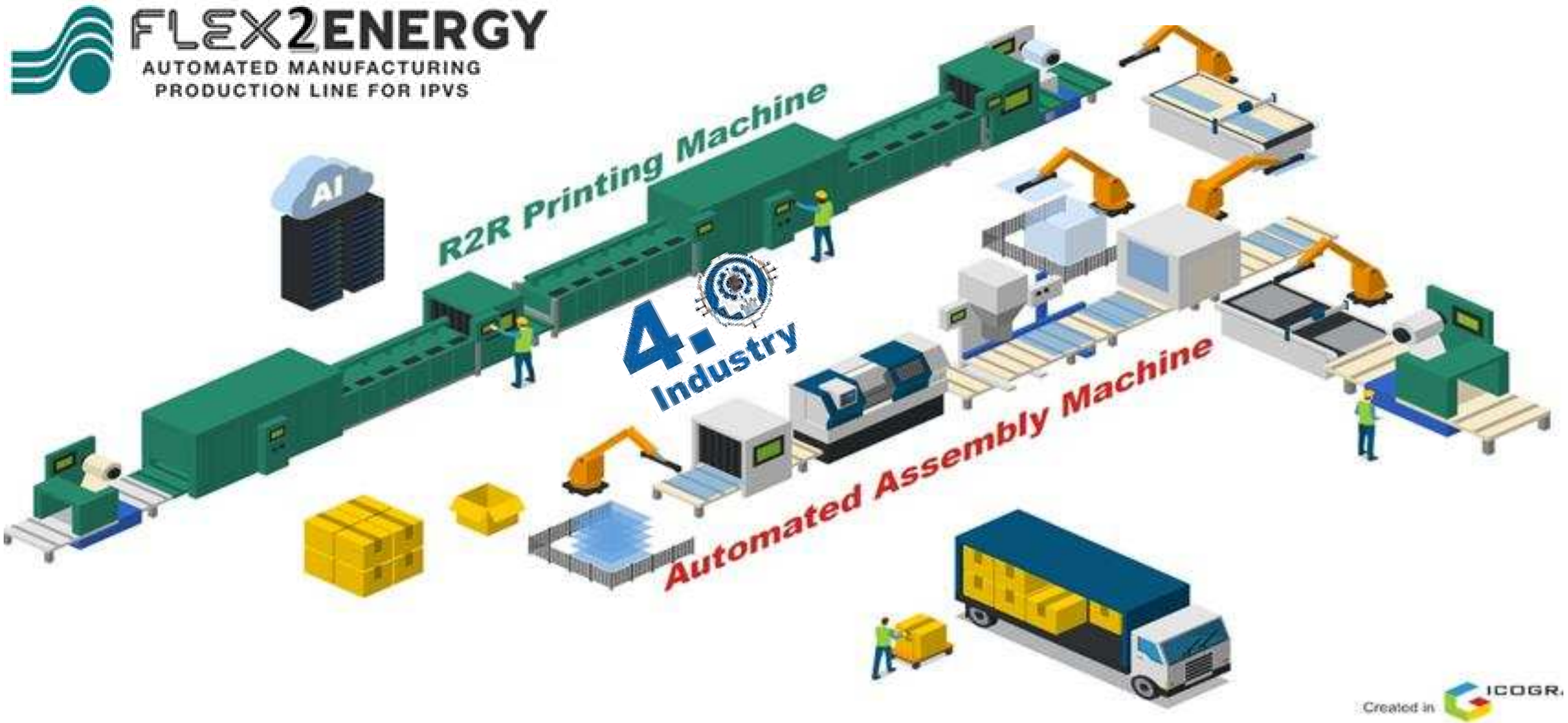
European Commission

Consortium partners

Flex2Energy Concept: The 3 Stages in relation with the Obs & WPs

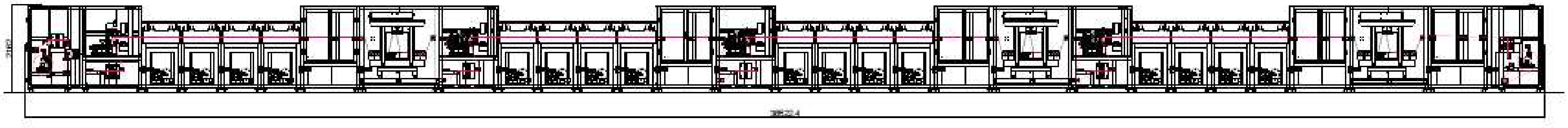


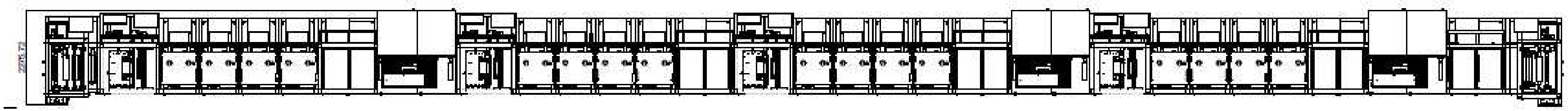
Flex2Energy project



Layout idea

R2R Machine





Flex2Energy (submission 04/2022; start beginning 2023)

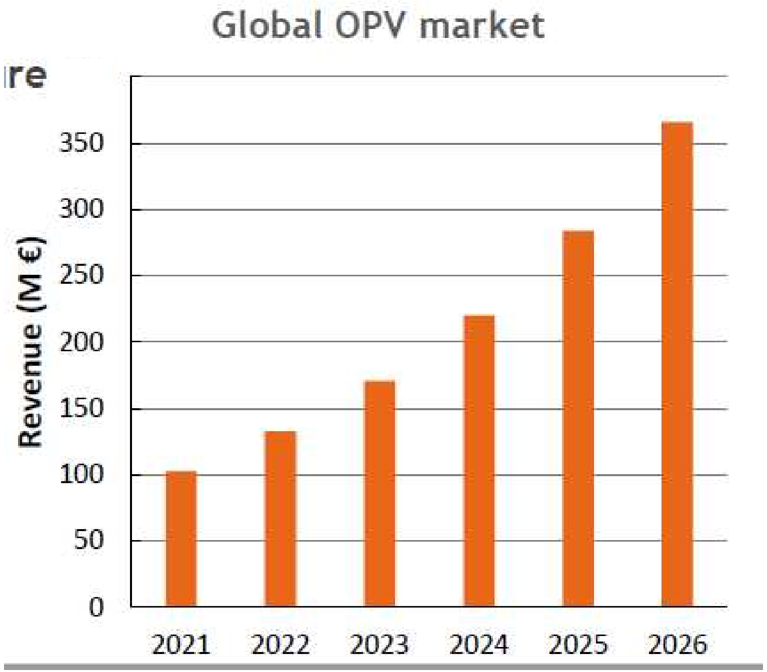
- ✓ **Call:** HORIZON-CL5 2022-D3-01-03:Advanced manufacturing of Integrated PV
- ✓ ***Project aim:*** boost Integrated Photovoltaics manufacturing and the reliability
  - ✓ New R2R pilot-to-production line with integrating smart, cognitive and adaptive in-line sensors and actuators for quality control with Artificial Intelligence (AI)-based analysis

✓ ***Partners***

Market opportunities and volume

Global OPV Market is estimated to reach up to 366 M$ by 2026 and there are few key-players that open the market today

- ✓ CSEM, sunew, Brasil
- ✓ Rayenergy, PRC
- ✓ Heliatek, Germany
- ✓ ARMOR, France



Innovation F2E – OPV products

- ✓ Highly efficient OPV products easily adaptable in buildings, automotive, agriculture and infrastructure
- ✓ Sophisticated architectures of novel nano-layers from organic semiconductors (electron donors and acceptors), transparent electrodes and inorganic electrodes
- ✓ Can be printed on transparent flexible polymer substrates
- ✓ OPV panels with increased uniformity, power output of **90 W/m²**, high **transparency >60 %** and improved **lifetime >20 years** and unique uniform and homogeneous design

3rd Generation PVs

- ✓ High and tinable optical transparency
- ✓ Lightweight & flexible structure
- ✓ Large-scale production by R2R Printing Process that is less Energy Demanding, Cheaper and Eco-Friendly
- ✓ Free-form design and color uniformity
- ✓ Recycleability

The novel idea of Flex2Energy

- ✓ Revolutionize the renovation & construction wave of the EU's building industry (buildings, infrastructure, greenhouses and automotive) of all kinds of uses and locations
  - → Implementation of novel IPV products for energy positive building concept (Fig. 1)
- ✓ Spread novel IPV products through the setup of a strong Innovation Clusters Network (ICN) in green buildings agriculture and transportation to form and connect this Value Chain of 40 ICs across Europe (Construction, Architects, Designers, Engineers, Contractors, Suppliers, end users etc.)
- ✓ Demonstrate, evaluate, spread and ultimately replicate the developed innovations

Fig. 1. F2E automated Manufacturing line for OPVs and IPV products to open the way for energy positive buildings & to minimize landscape

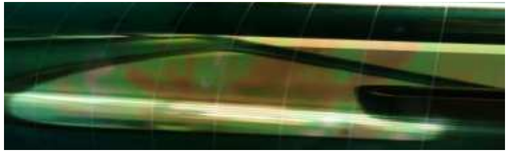
Ambition

- ✓ The European industry needs to regain its position as a global leader in the manufacturing of high-tech materials, components, and products, such as Photovoltaics (PVs)
- ✓ The global Building Integrated Photovoltaics (BIPV) market was valued at **12,8 B€ in 2020**
- ✓ and is projected to reach **79,4 B€ by 2030**, growing at a CAGR of 20.1% from 2021 – 2030 [1].
- ✓ **Europe** as **a global leader in manufacturing** Organic Electronics (OE) materials, components, and products, mainly Organic Photovoltaics (OPVs) for energy.

[1] E. P. Anil Chaudhary, "Global BIPV Market," 2021. [Online]. Available: https://www.alliedmarketresearch.com/building-integrated-photovoltaic-market

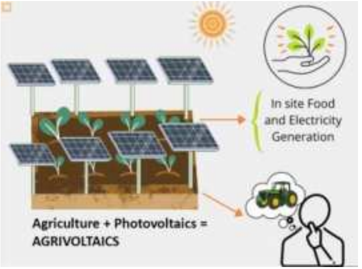
State of the art – OPVs

- ✓ IPVs = Potential to produce electricity on site, directly from the sun, without concern for energy supply or environmental harm
- ✓ The existing BIPV solutions have a significant number of drawbacks that limit the widespread deployment of energy generating building elements in existing and new construction concepts



1st Generation (OPV)	2nd Generation (PV)
✓ No optical transparency	✓ Optical transparency but limited up to 30 %
✓ High weights (~20 kg), heavy structure	✓ High weight increases CO_2 footprint
✓ Not Applicable in Greenhouse roofs due to limited Transparency	✓ High fabrication costs due to current production technology (Vacuum deposition)
✓ Efficiency is reduced abruptly in vertical-90° placement → can not cover the energy demands of building	✓ Constant change of the orientation while being in motion results in decreased performance

Application example – Agrivoltaic systems



Agrivoltaics

Environmental impact and carbon emissions Demand and challenges in Greenhouse sector

- ✓ **Energy consumption in a greenhouse could reach up to 50 % of the total production cost** (e.g. due to large heating/cooling costs in winter/summer
- ✓ Energy is consumed in **heating, cooling and ventilation systems, LED grow light, automations, sensing, distance monitoring, irrigation systems and control systems**
- ✓ **Thermal heating demand represents ~ 80 % of the energy consumption**, while electricity the 15 %
- ✓ **Indicative average energy consumption for a greenhouse in Spain ranges 30 to 70 kWh/m²**
- ✓ **RES** for facilitating rational and sustainable farming **are necessary**
- ✓ Demand for integration of **new and smart technologies**
- ✓ **Growing need for energy autonomy**

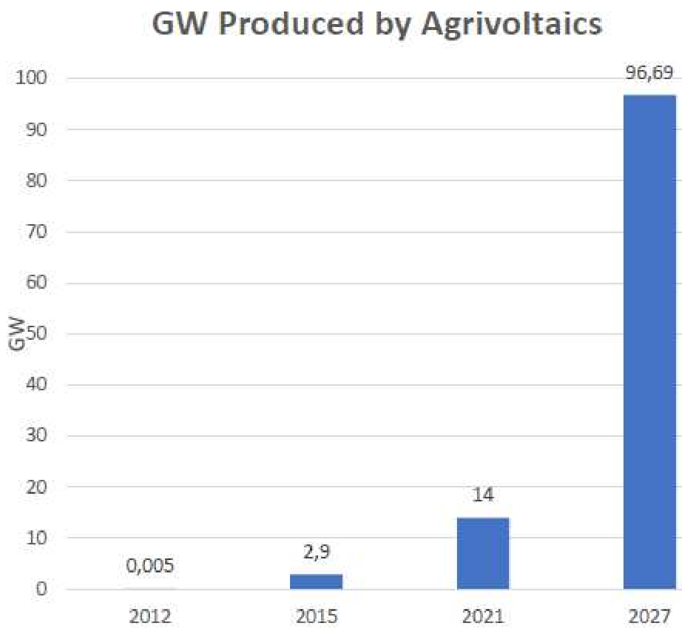
Argivoltaics
Sustainable Green Development

- The Co-location of PVs and Crops in the same area could minimize land impact
- Clean Energy Production- Increase of Crop Production
- Shading and Cooling Effect
- Land and Water use efficiency
- Increase income

NANOTEXNOLOGY 2022 Special Workshop: Agrivoltaics 07/07/2022

Expected market grow for Agrivoltaics

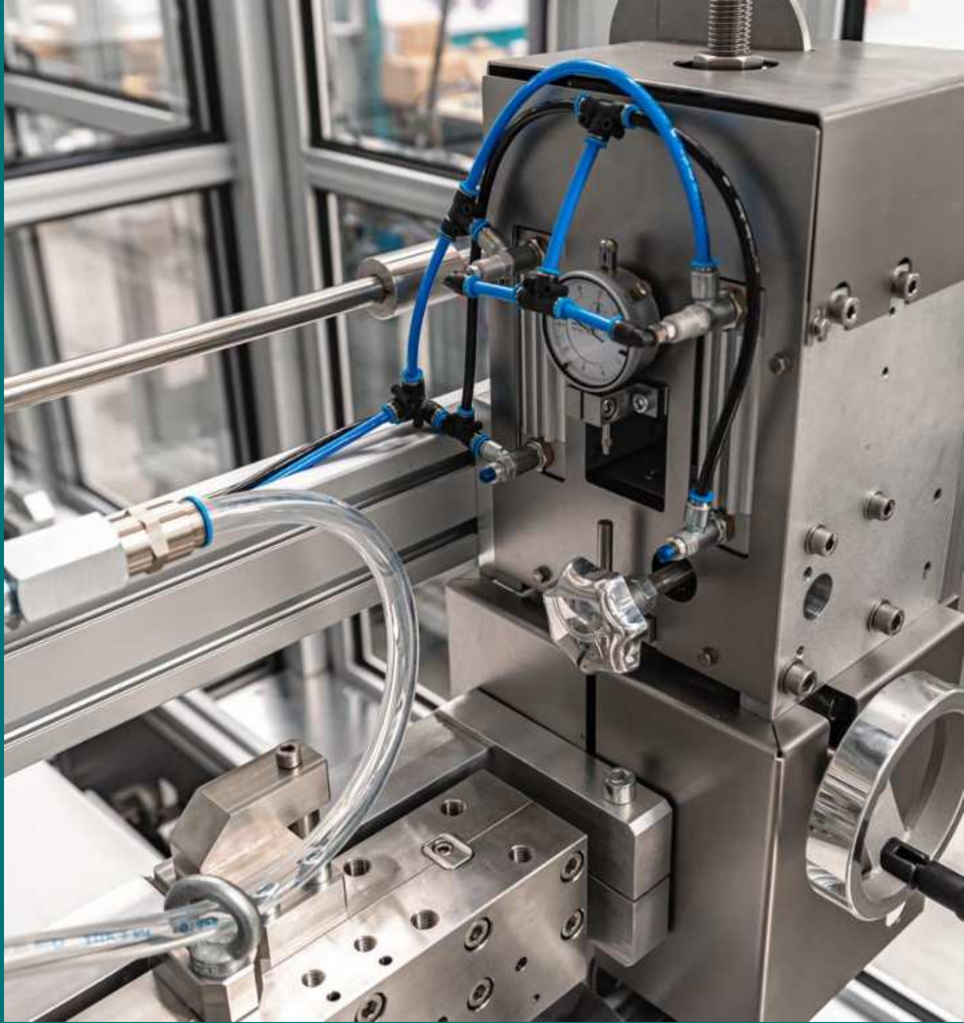
- ✓ Global installed Agri-PV capacity has increased exponentially from 5 MW in 2012 to 14 GW in 2021 (Expected reach of 97 GW in 2027)
- ✓ The global agrivoltaic market will grow at a CAGR of ~38 % (2022 – 27)
- ✓ Due to rapid climate changes create huge challenges for energy & agriculture worldwide
- ✓ The shift focus toward adopting agrivoltaics to enable the effective use of sunlight for crop growth



Source: MarkNtel 2021

4.

Process control

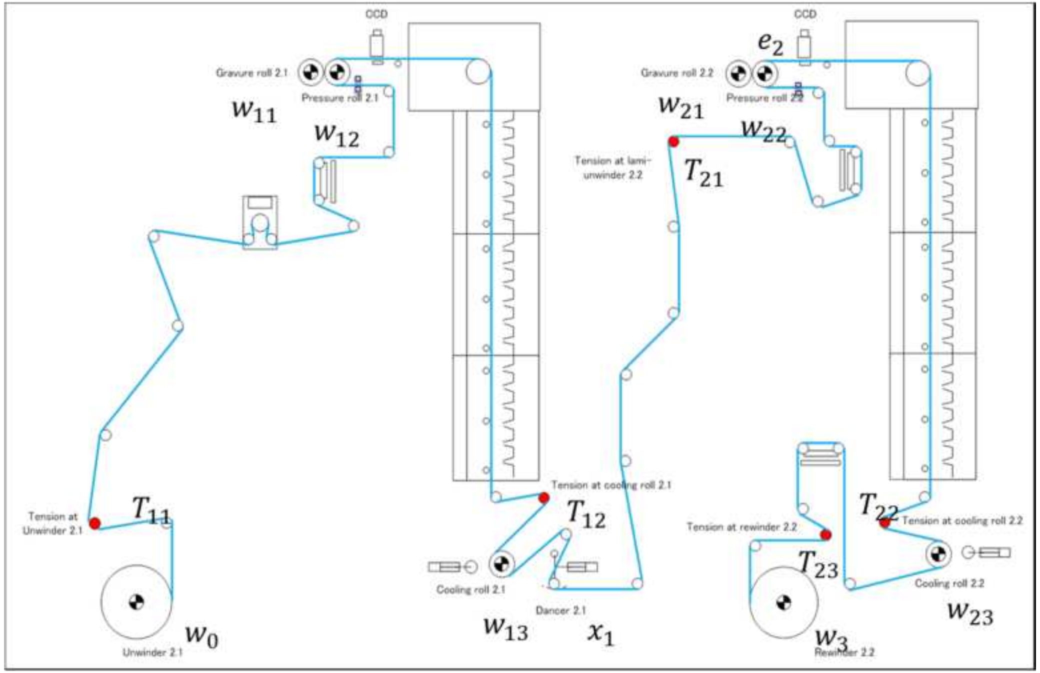


Technologies & processes – process parameters

Process parameters are:

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

Inline process control



Processes

Surface treatment	Printing	Coating	Digital fabrication Inkjet printing Laser patterning
Nano-imprint	Lamination	Encapsulation	Pick & place

Inline process integration

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

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

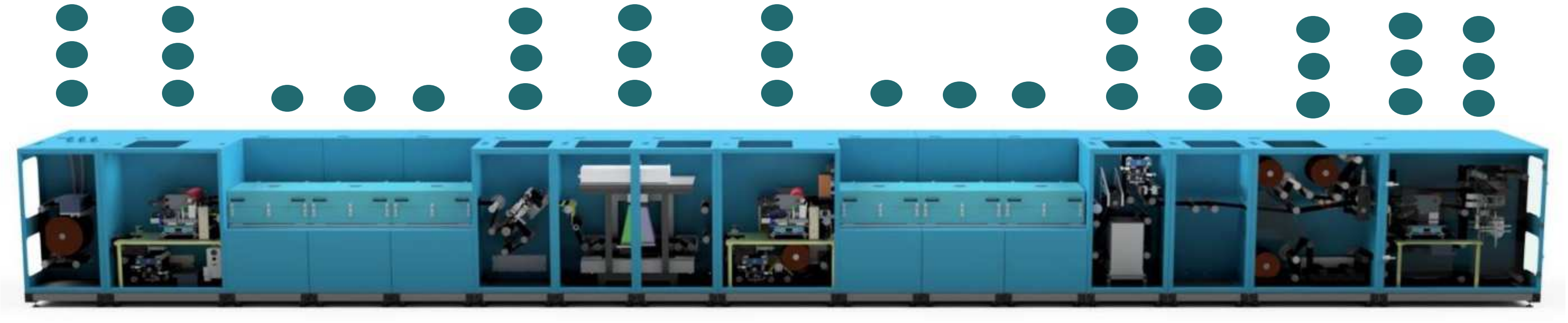
Quality control
- ✓ Particle contamination analysis
- ✓ Defect detection
- ✓ Thickness control
- ✓ Function control of the device or layer
- ✓ Big data (Cloud)
- ✓ IoT
- ✓ AI / ML

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

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

Inline process integration and measuring points

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

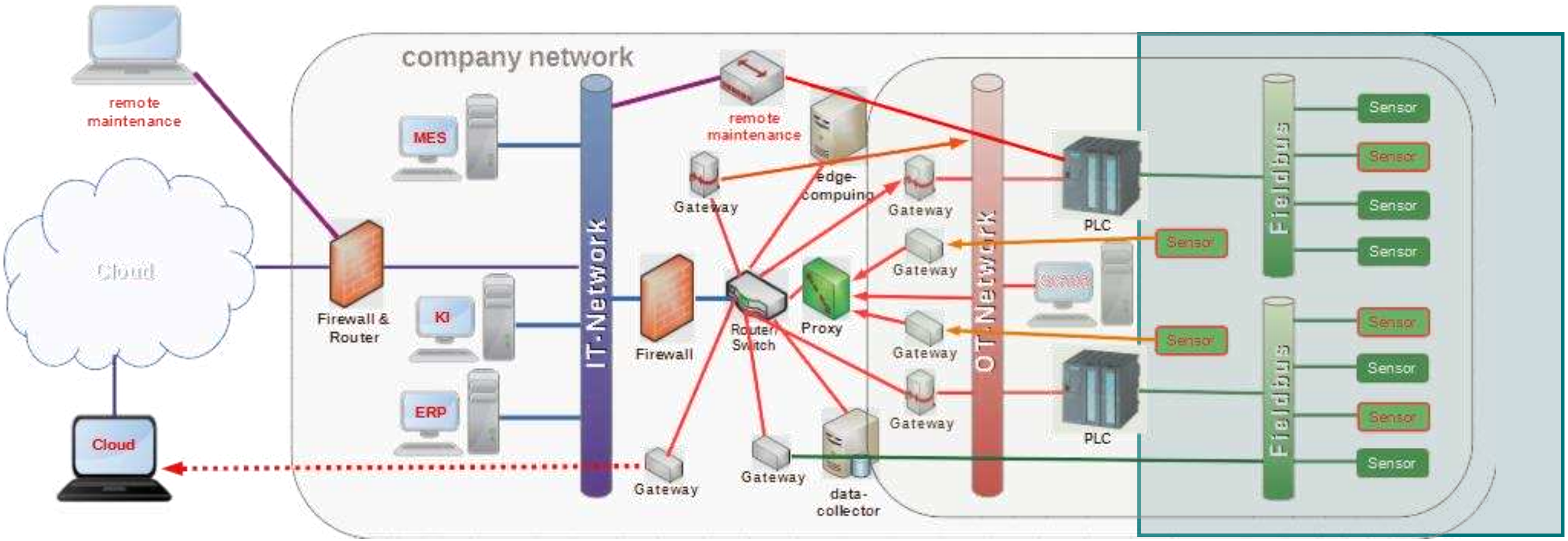


Unwinder | OET 4 Axis system | 3m dryers | ps laser | OET 4 Axis system | Ink jet | 3m dryers | IPL | In-line optical metrology (SE, Raman) | LBIC | Rewinder

- Number of measuring points
- Amount of measurements per time

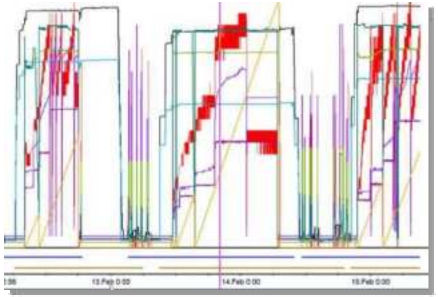
oet
ORGANIC ELECTRONIC TECHNOLOGIES

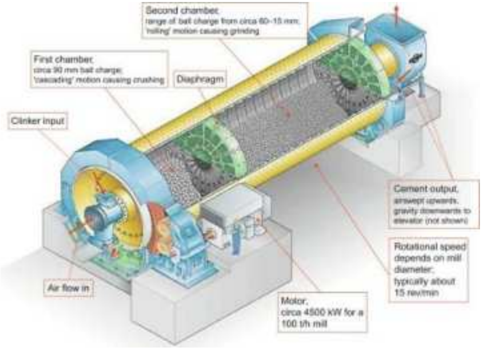
Complexity introduced through connectivity



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

AI / Industry 4.0 / IOT & processes – Solution based approach





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

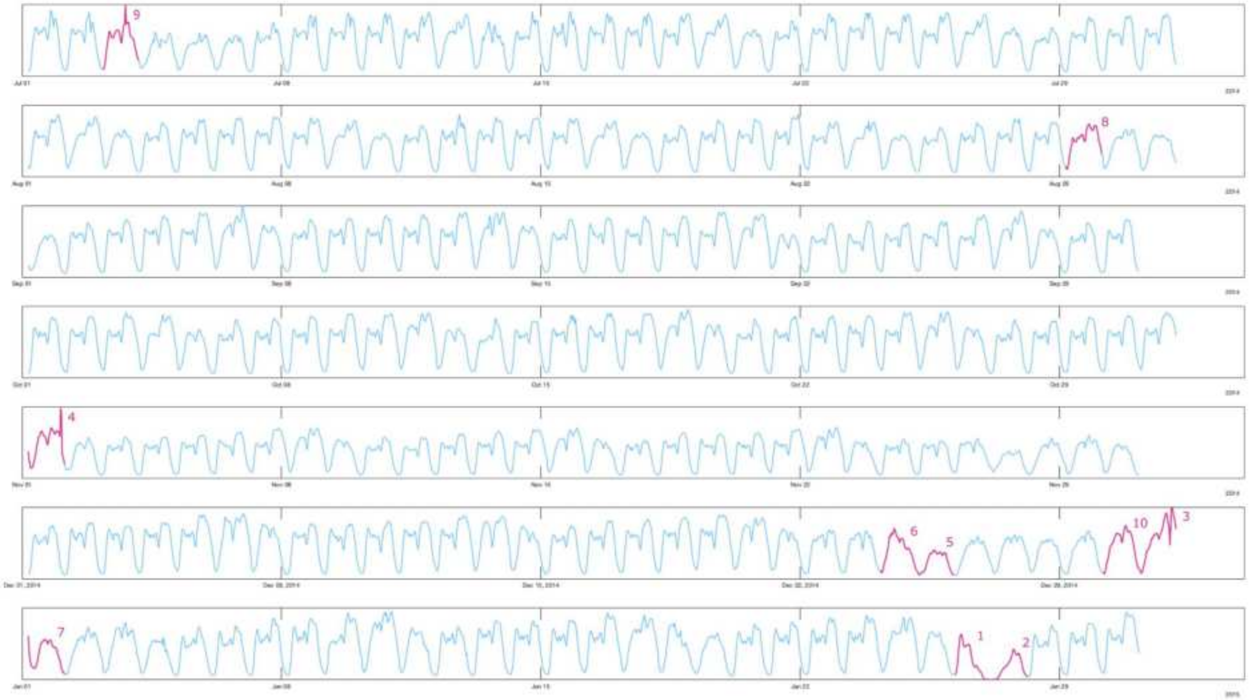
Detection
Analysis of specific system states (e.g. characteristic freequencies)

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

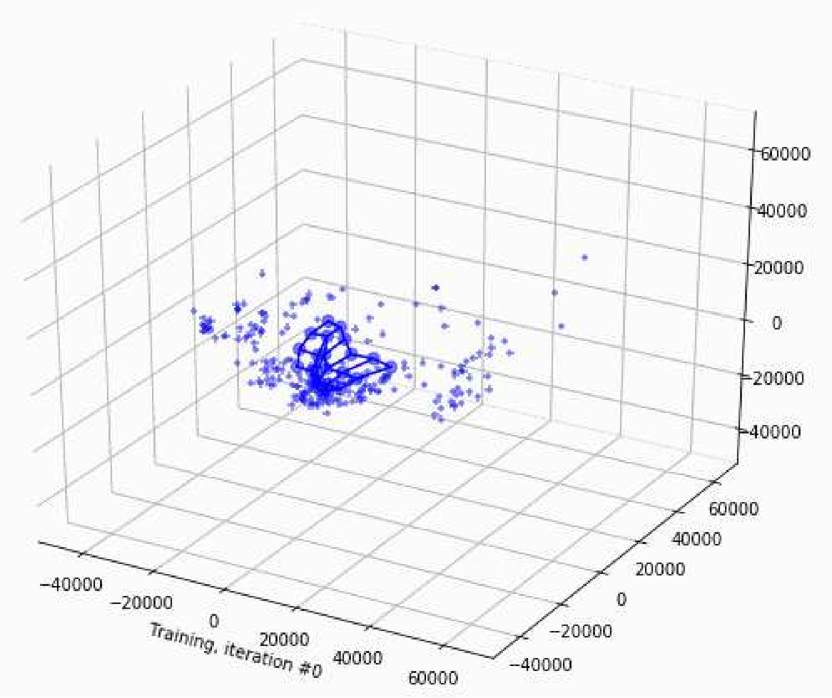
Prediction
Spare parts and maintenance (next service, service tasks, …)

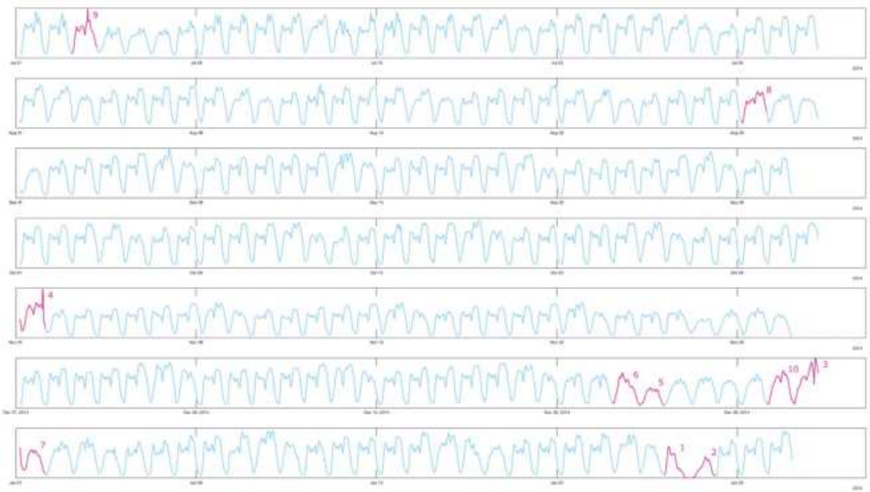
Control
Maintaining productivity (e.g. increasing viscosity)

Automatic anomaly detection for time series



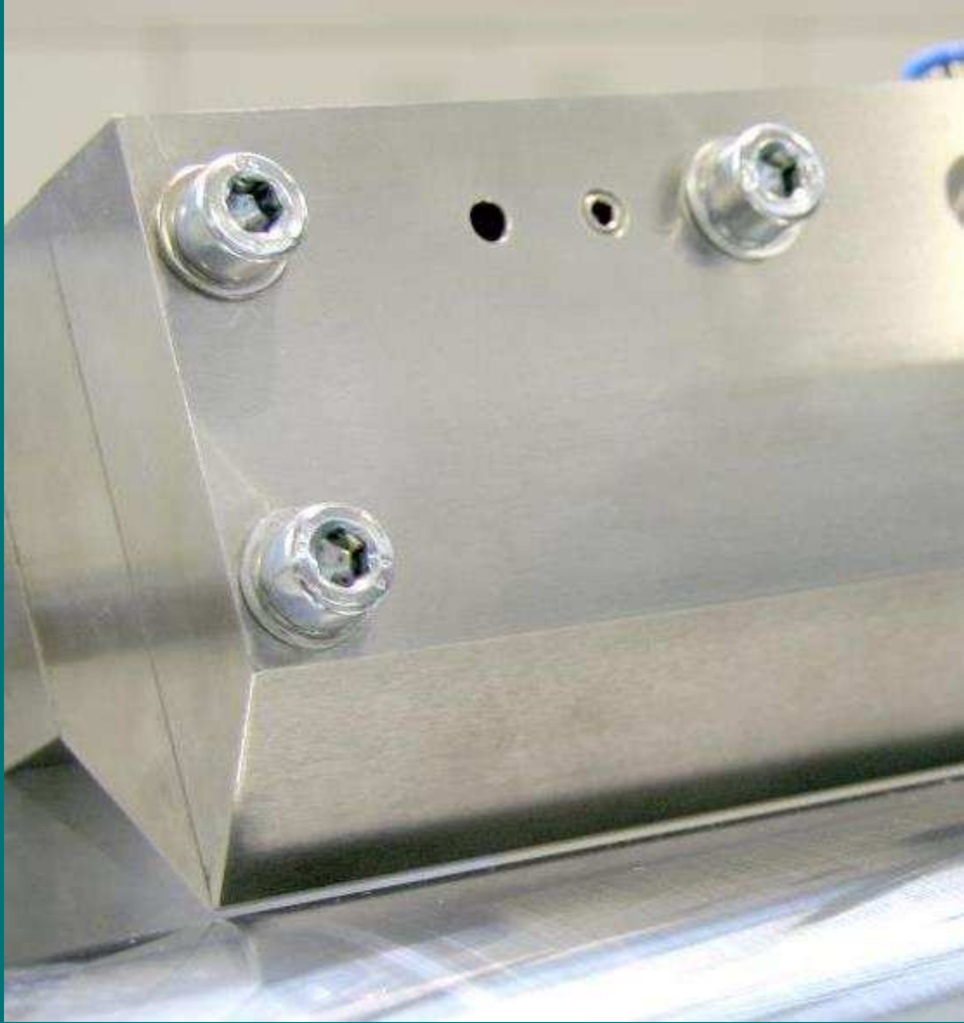
… what the algorithm is doing





5.

Slot die coating for 3rd Gen PV



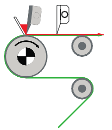
Coating parameters

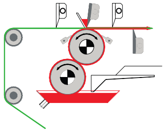
Ink properties	Coating processes	Process control	Drying
✓ Rheology ✓ Viscosity ✓ Viscoelasticity ✓ Type of solvents ✓ Solid content ✓ Van der Waals force ✓ Sheer ratio ✓ Adhesion/Cohesion	✓ Coating systems ✓ Single or multilayer coatings ✓ Direct coatings ✓ Transfer (indirect) coatings ✓ Substrate speed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

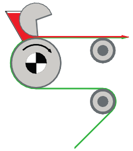
Substrate	Pretreatment	Environment	Finishing
✓ Surface tension ✓ Dimension stability ✓ Surface structure ✓ Contact angle	✓ Corona ✓ Plasma ✓ Cleaning	✓ Humidity ✓ Temperature ✓ Inert conditions	✓ Calendaring ✓ Embossing ✓ Slitting

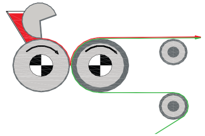
Coatema®
Coating Machinery GmbH

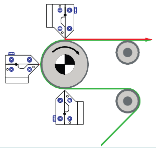
Coating systems

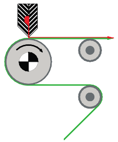

Knife system

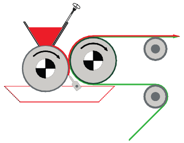

Double side coating system

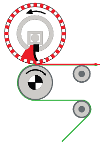

Commabar system

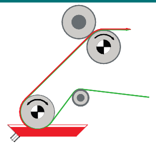

Reverse commabar system

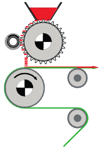

Slot die system

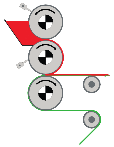

Curtain coating system

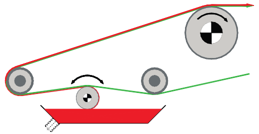

Case knife system

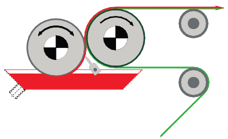

Rotary screen system

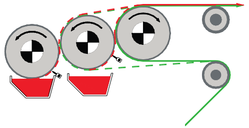

Dipping system (Foulard)

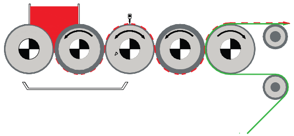

Powder scattering system


Reverse roll coating system

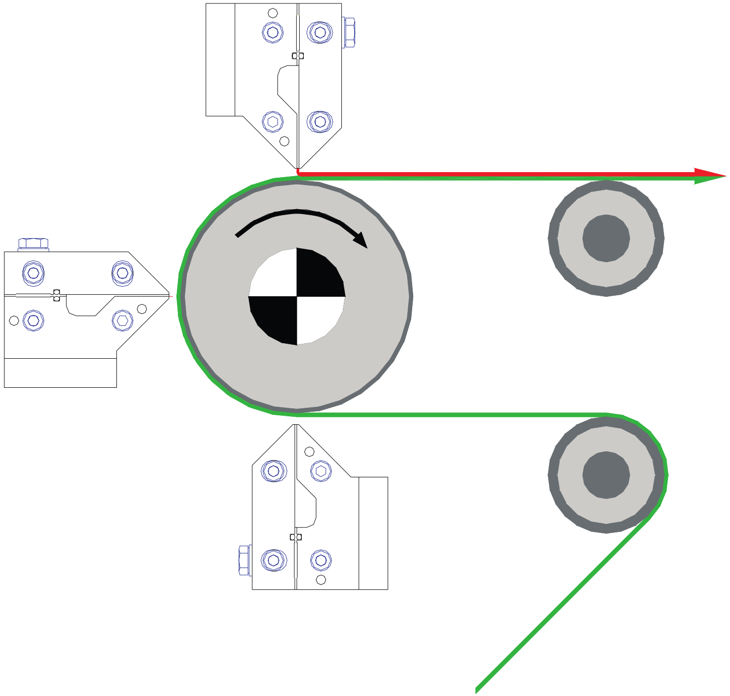

Micro roller coating system


2-roller coating system


3-roller combi coating system


5-roller coating system

Basics of slot die coating – range of parameters



Coating speed
- ✓ 0.1 – >1000 m/min

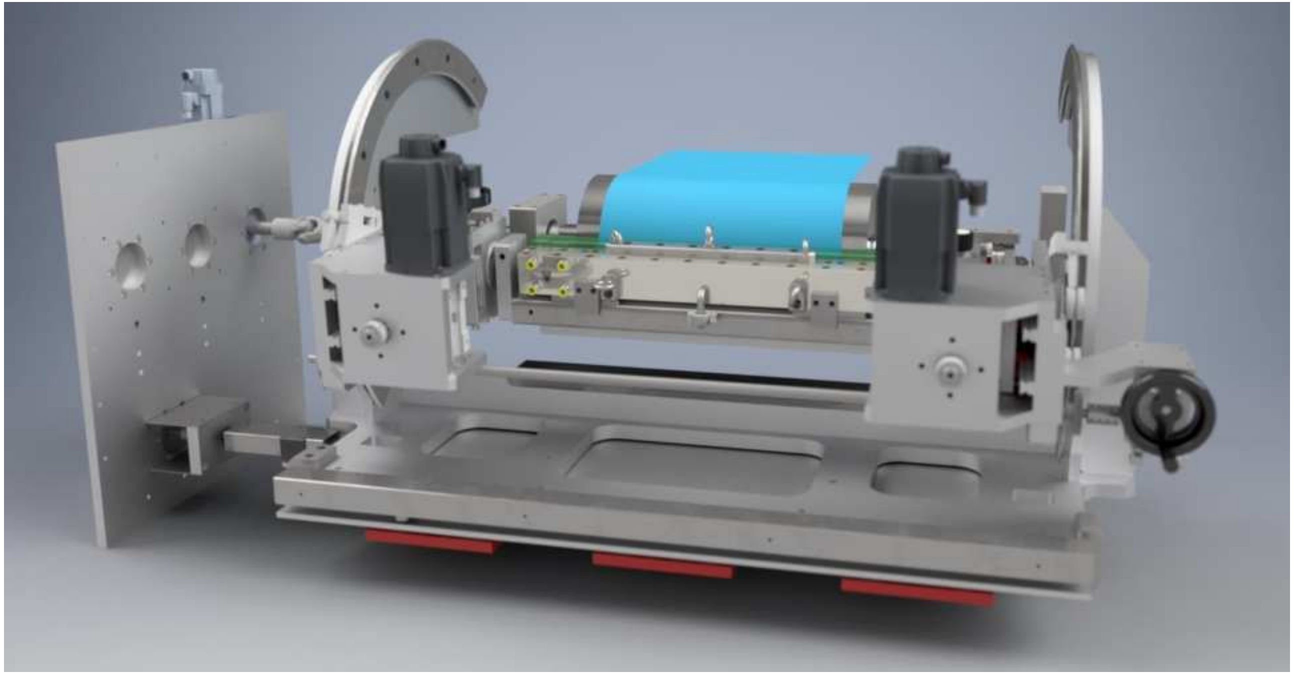
Ink viscosity
- ✓ 1 – 300 000 mPas

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

Coating accuracy
- ✓ <1% (2 – 5%)

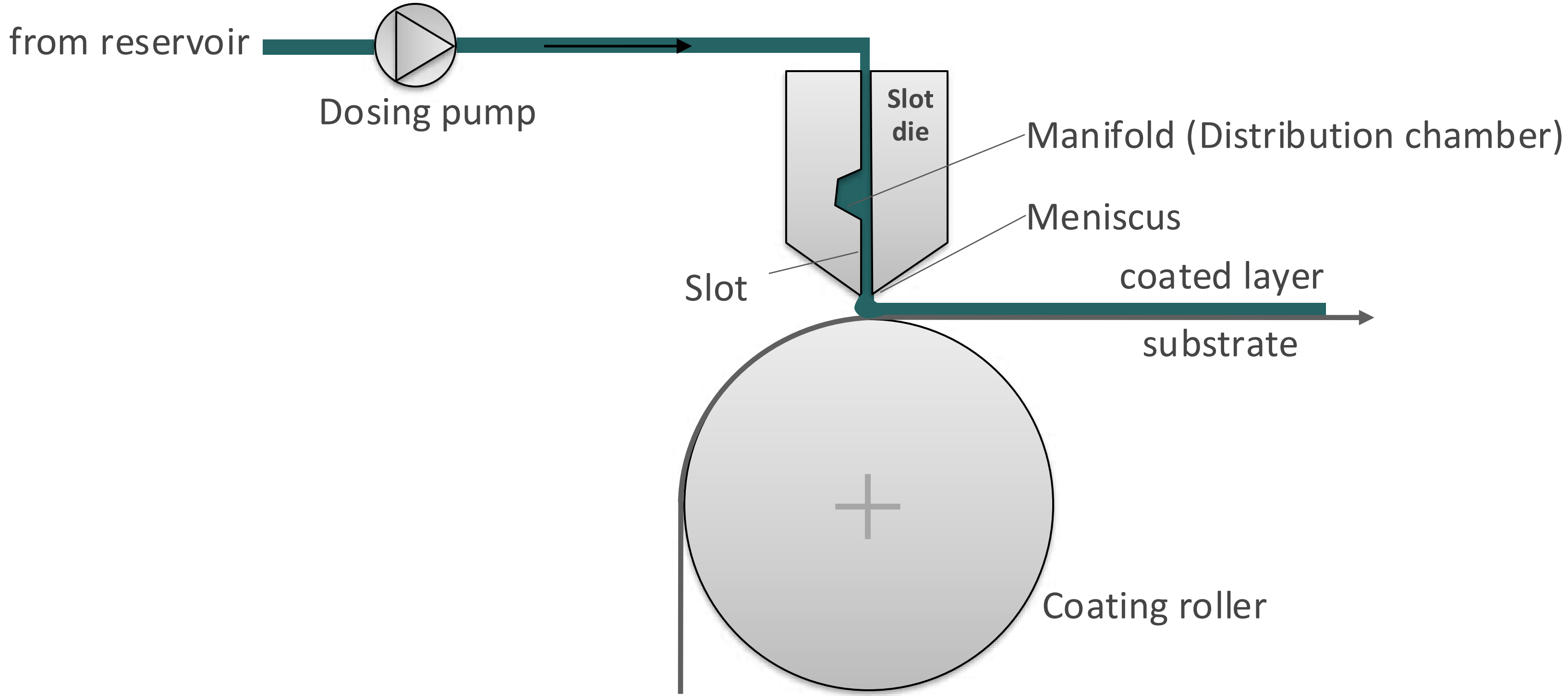
Coating width
- ✓ up to approx. 3 m

Basic principle

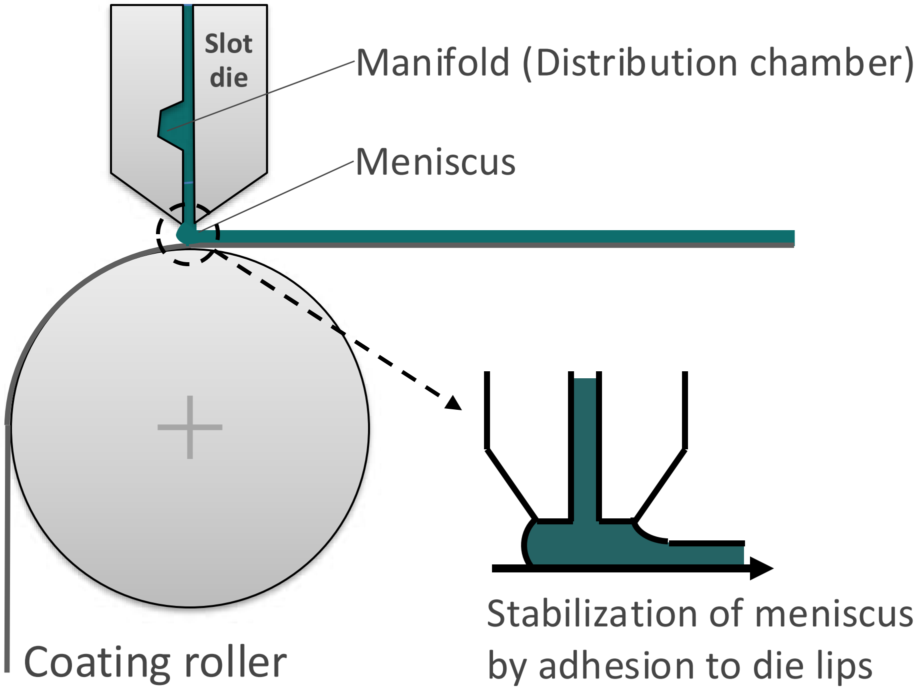


Basic principle

Basic principle



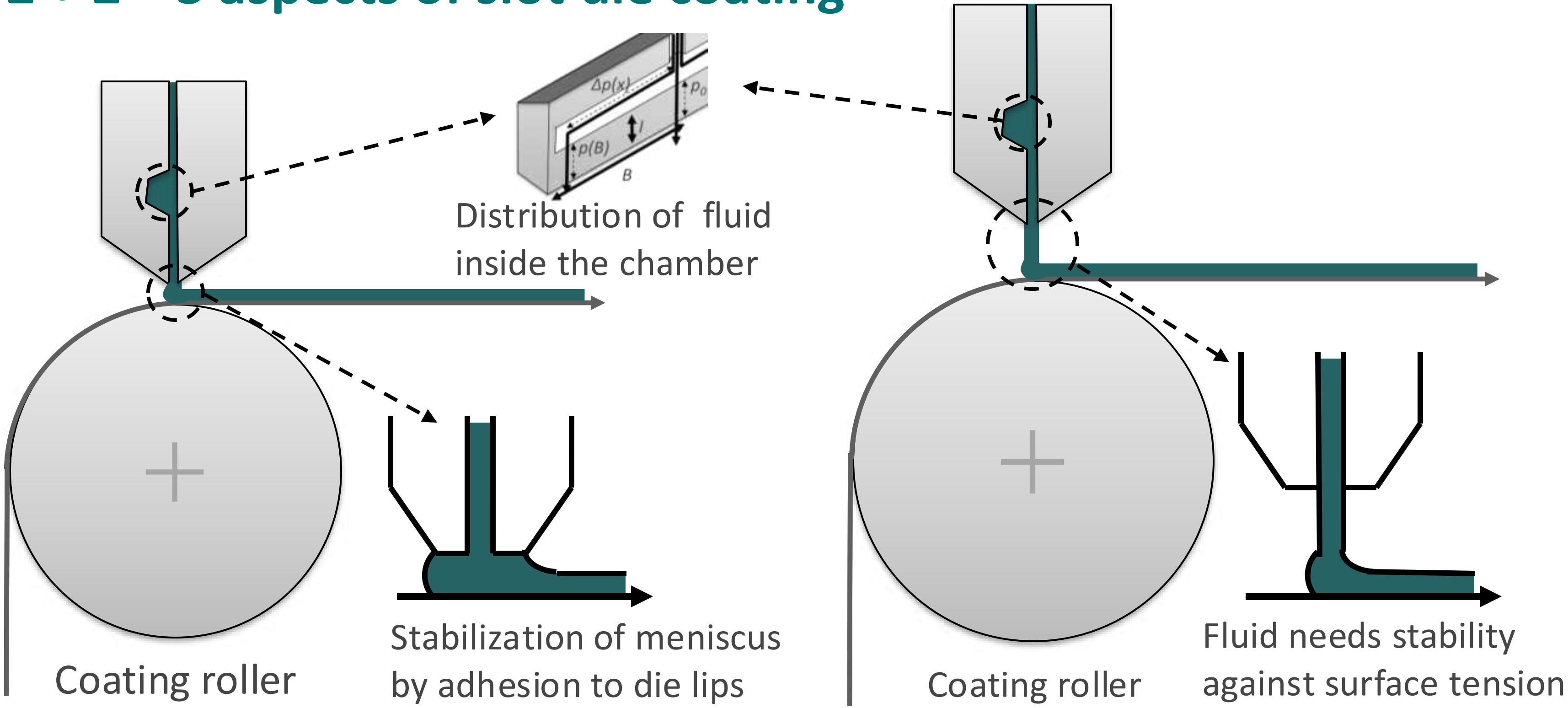
Bead mode



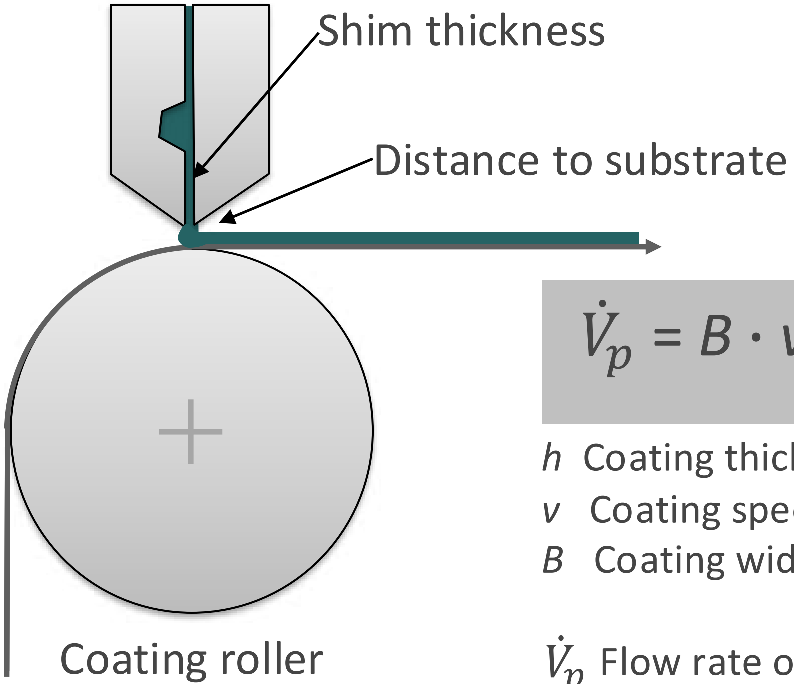
Stabilization of meniscus by adhesion to die lips

- ✓ 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

2 + 2 = 3 aspects of slot die coating



Theoretical background



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

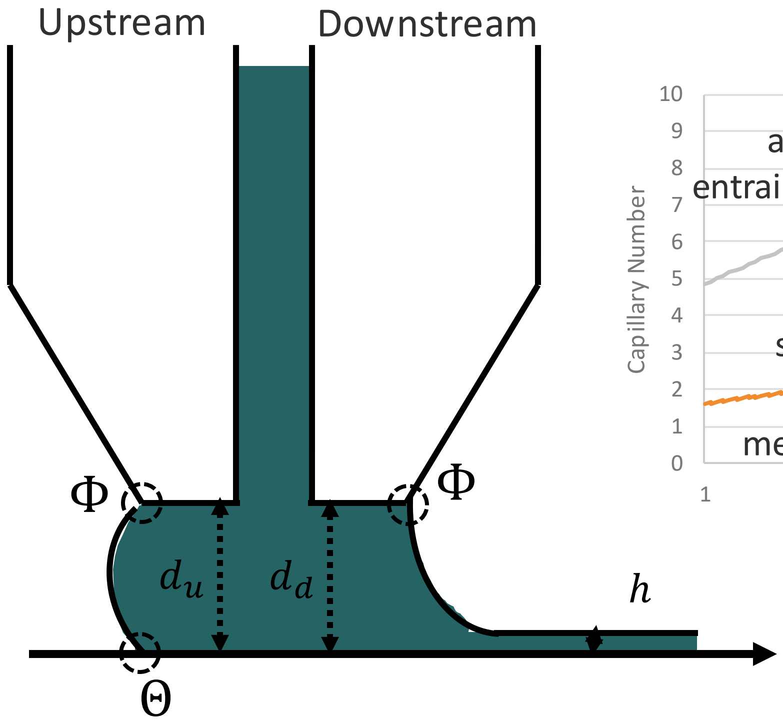
h Coating thickness wet
v Coating speed
B Coating width

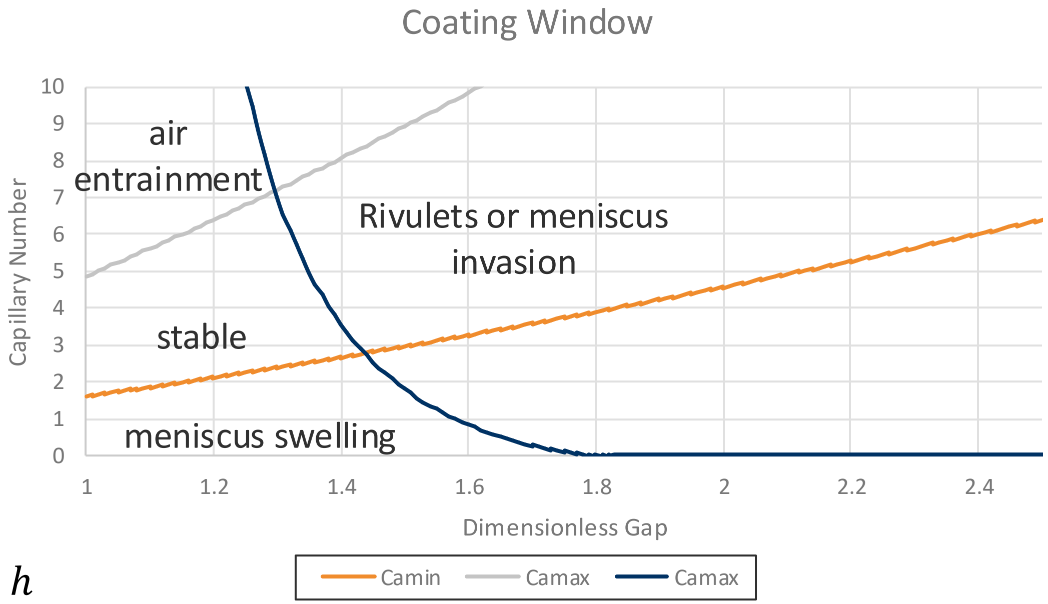
$\dot{V}_p$ Flow rate of the pump

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

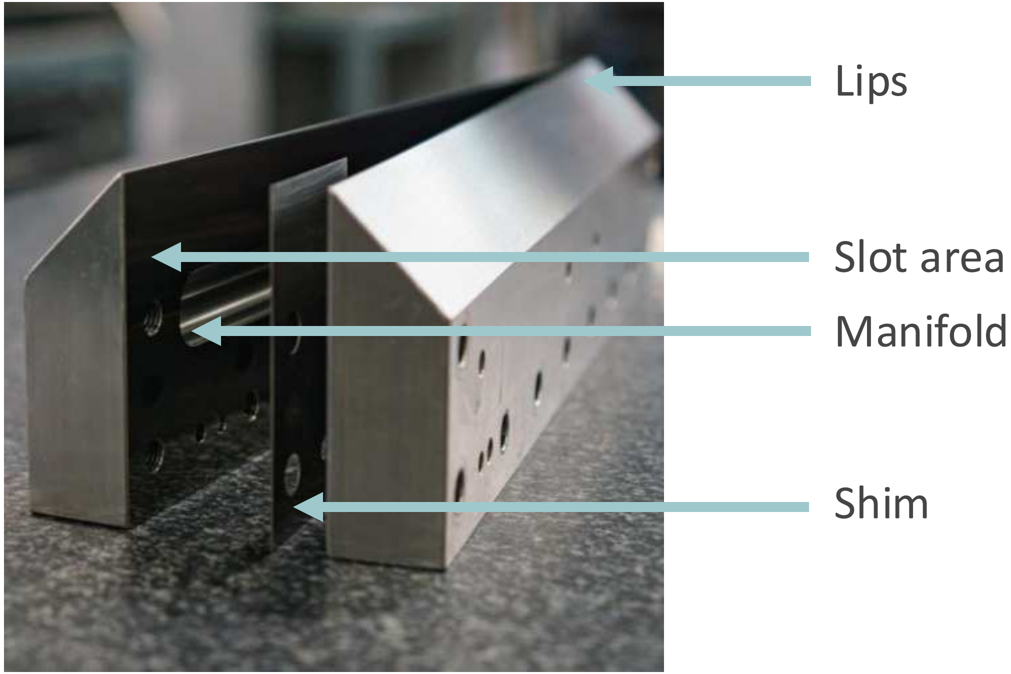
Shim thickness and distance to substrate only help to stabilize the meniscus.

Calculation of the meniscus stability





Coatema standard layout – one design among many available

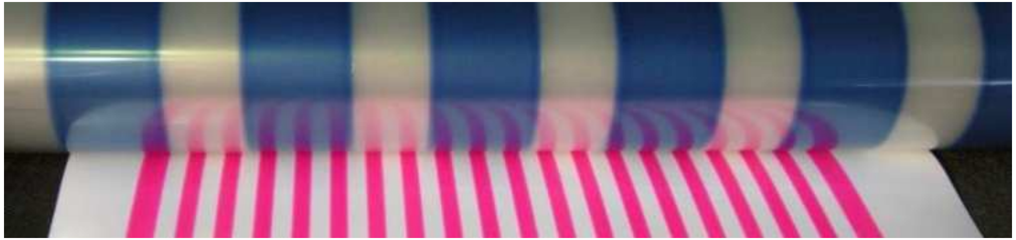


Structured coating – levels of complexity

Web direction

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

Level 2 – downweb stripes

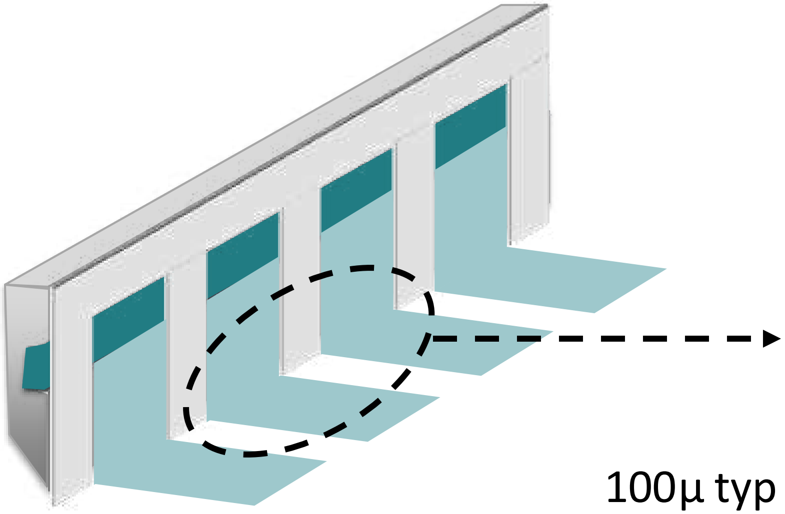


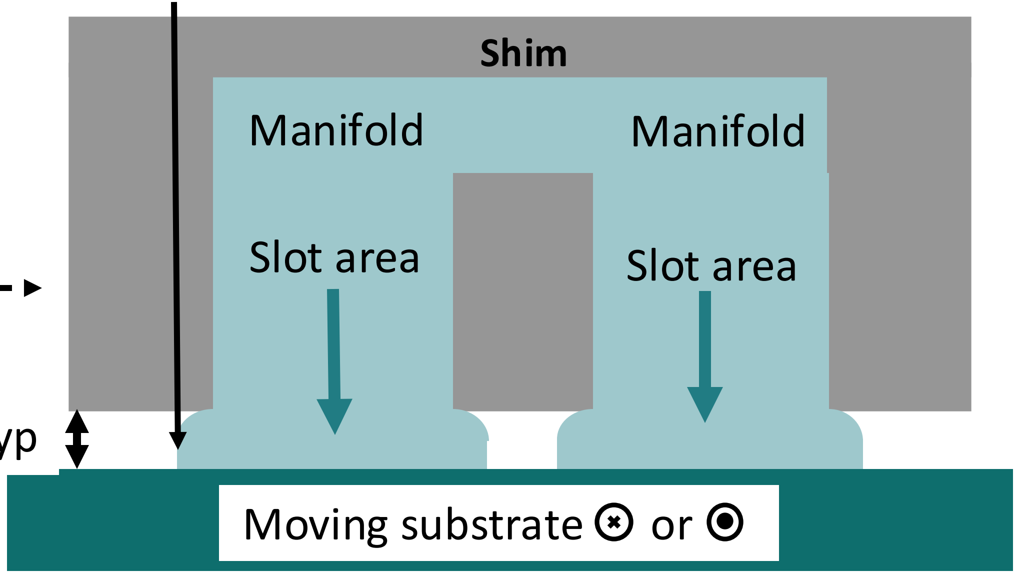
Downweb stripes of different width …

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

Level 2 – downweb stripes

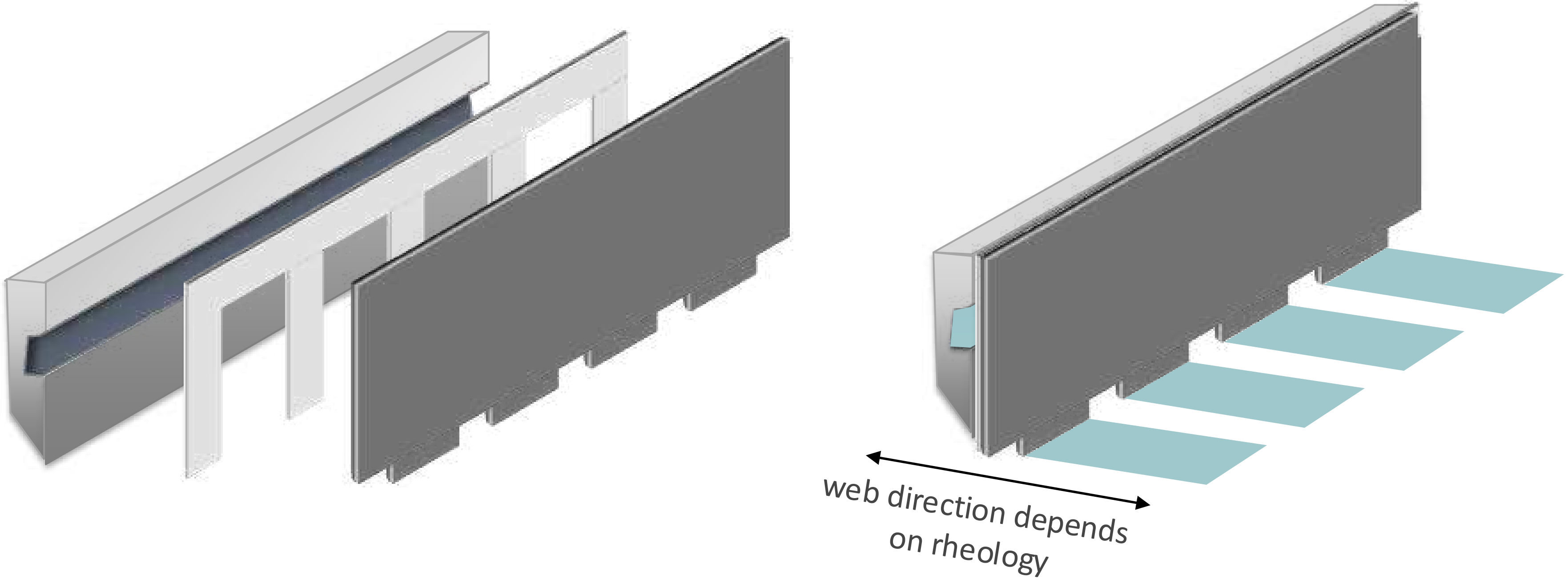
Problem:
Stripe widening by capillary forces at the edges of the shim teeth



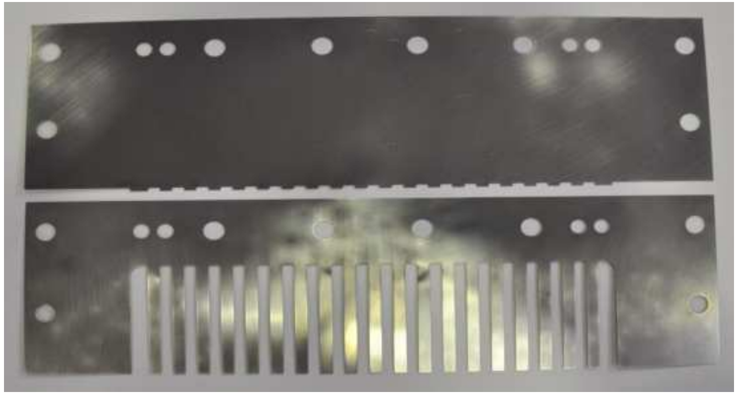


Level 2 – downweb stripes

Manifold + Shim + Meniscus guide = well defined stripes



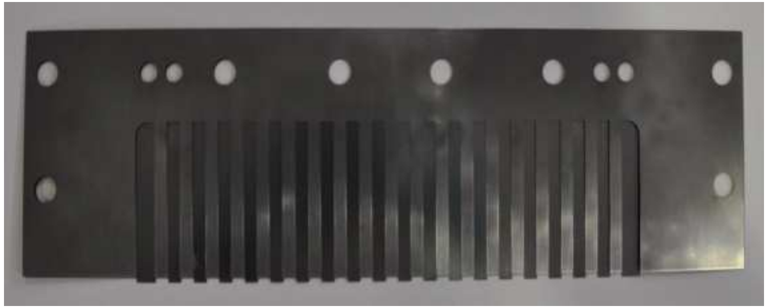
Level 2 – downweb stripes

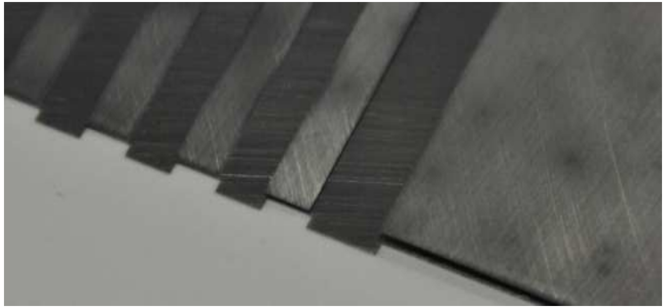


Meniscus guide

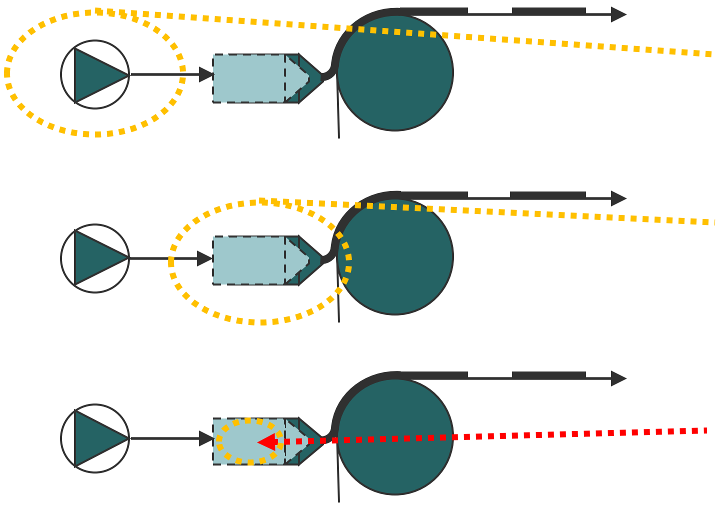
Shim

Meniscus guide + shim





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.

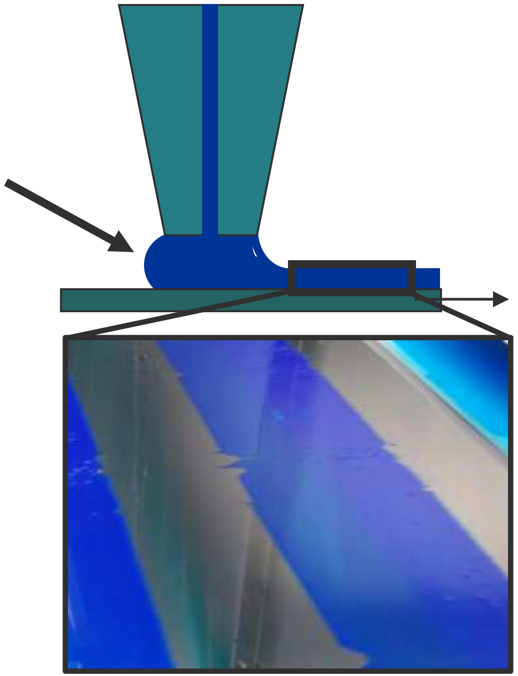
All 3 techniques (single or in combination) work quite well, if the viscosity is rather high and the required edge defintion is not more precise than around 1 mm. All techniques may be combined with a vacuum pump upstream to stabilize the meniscus and suck away residual liquid.

Coatema® Coating Machinery GmbH

Structured coating – reason for bad edges at low viscosity

- ✓ Mensicus has to be interrupted
- ✓ Low viscous liquids do not break along a straight line
- ✓ Meniscus has to be sucked back and restored
- ✓ Speed is of essence

→ For low viscosity, all of the three methods are too slow and too indirect



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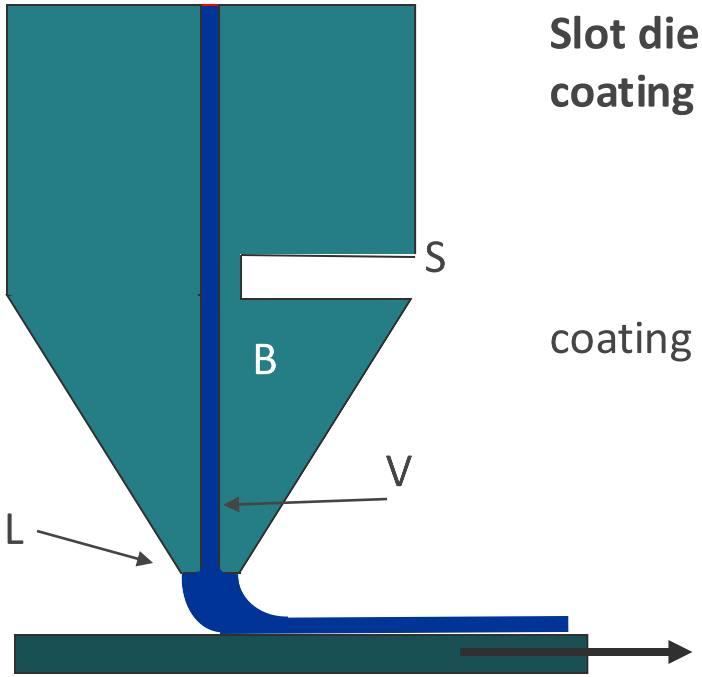
Structured coating – the switching slot die lip

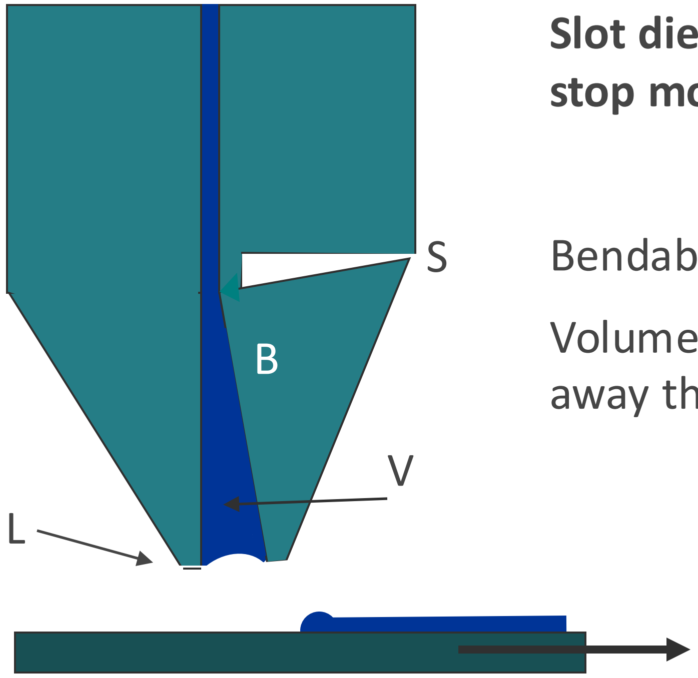


Slot die with movable lips:
coating mode

coating works as usual

L lip
V slot volume
B bendable lip
S bending slot

Structured coating – the switching slot die lip



Slot die with movable lips:
stop mode

Bendable lip B flips open

Volume V increases and sucks away the meniscus

L lip
V slot volume
B bendable lip
S bending slot

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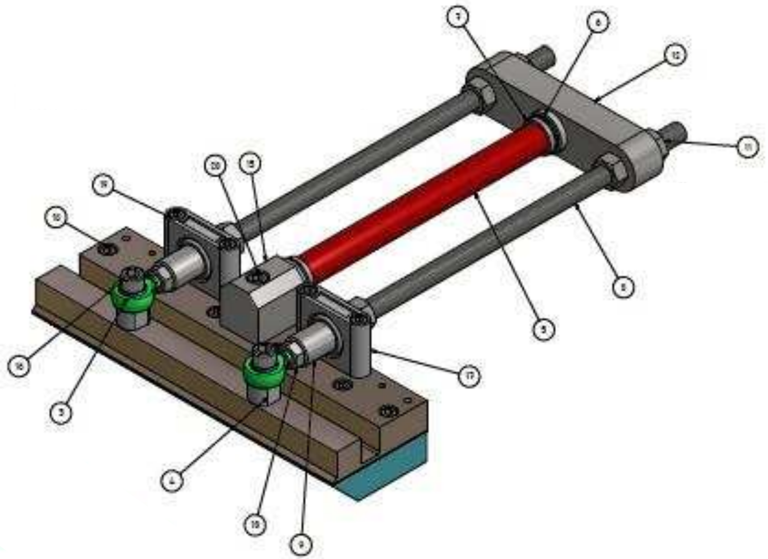
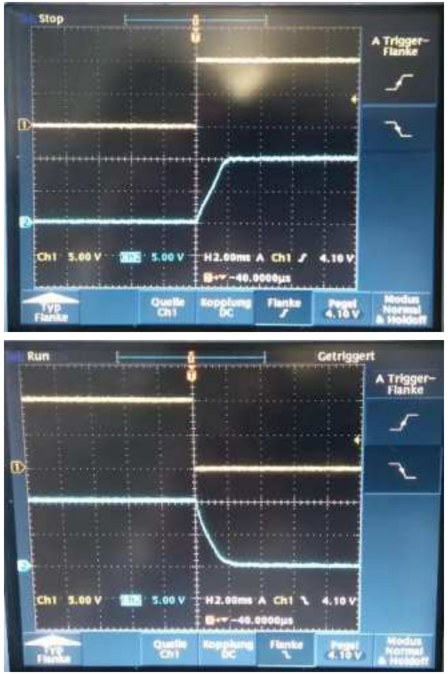
Structured coating – technical implementation with Piezo-Drive



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

Control Voltage

Piezo Response



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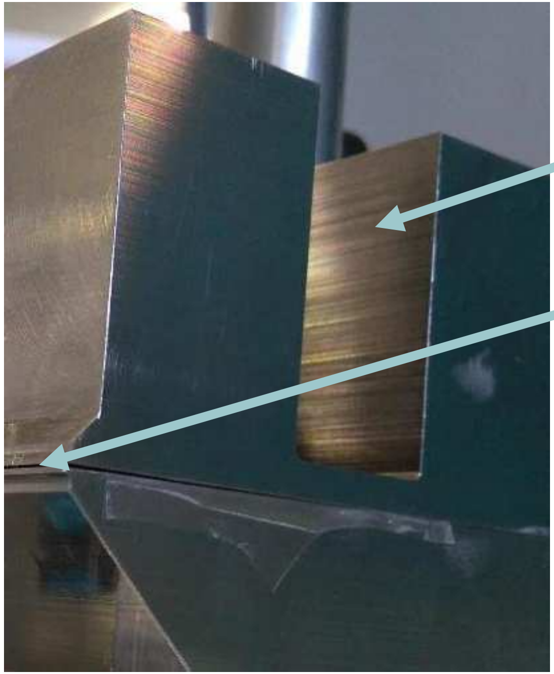
Structured coating – technical implementation with bendable lips

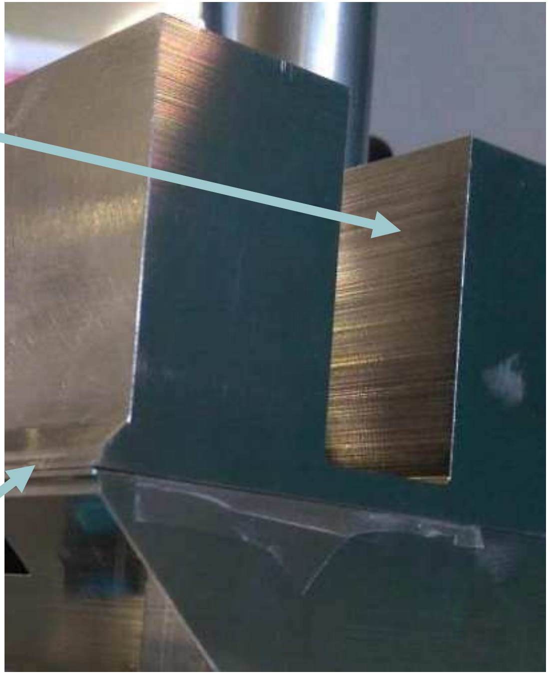


Bending slot

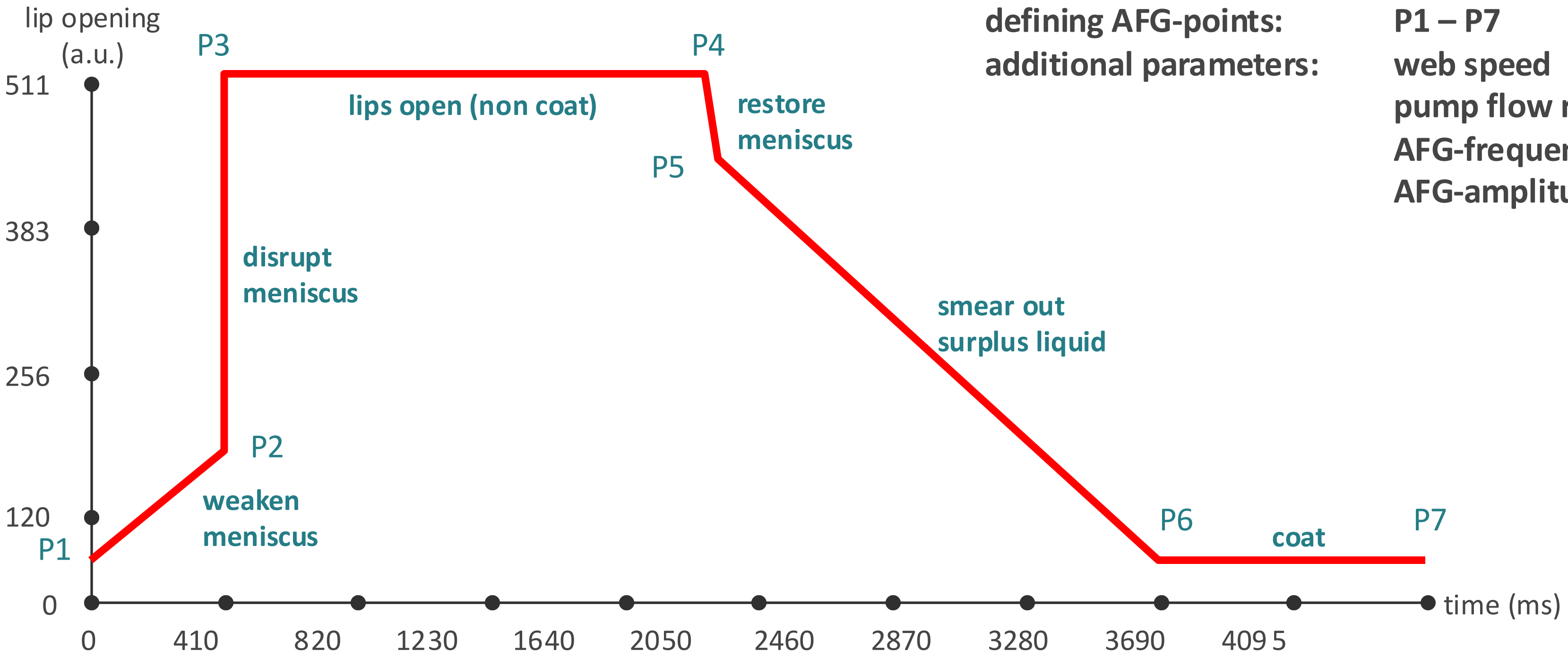
Lips open

Difference
is 300 µm only

Lips closed



Structured coating – stages of lip motion



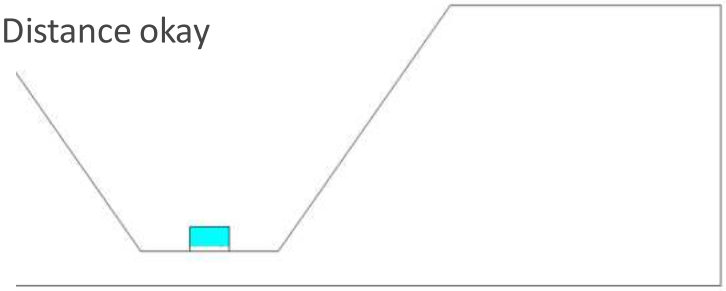
defining AFG-points: **P1 – P7**

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

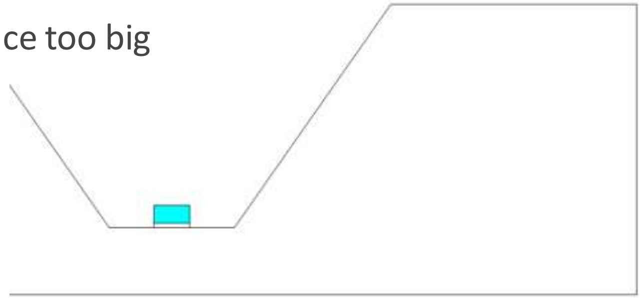
Slot die chamber – Simulation of anode Coating

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

Distance okay

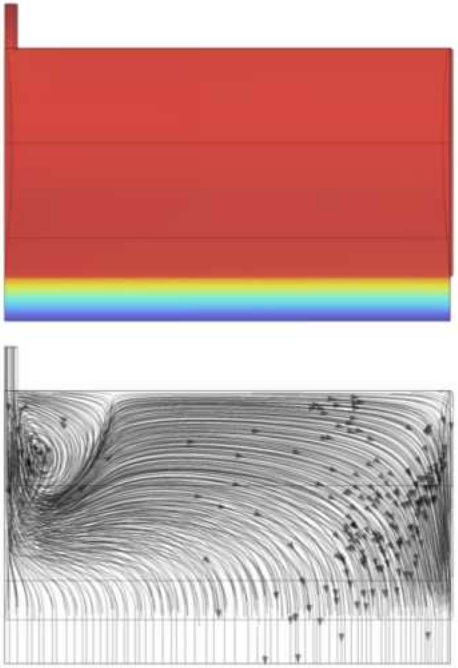


Distance too big

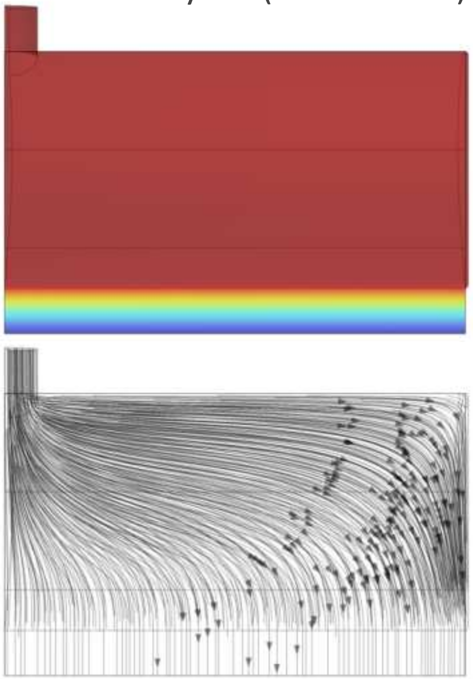


Slot die chamber – Streamlines and pressure distribution

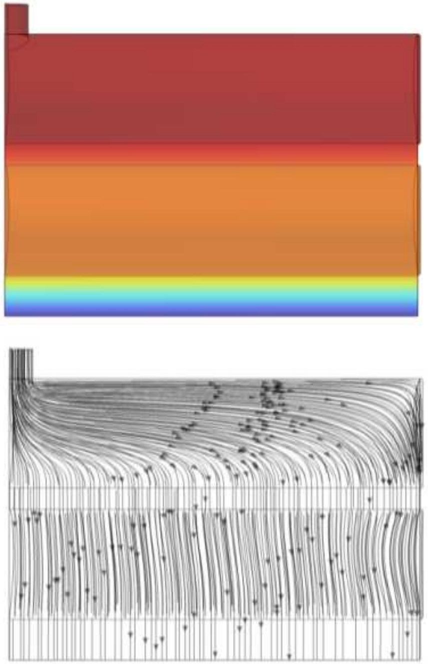
Single Chamber with too small inlet (4 mm)



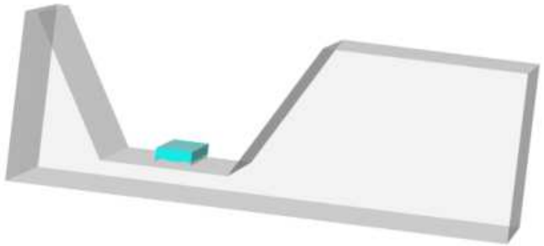
Single Chamber with correct chamber layout (10 mm inlet)

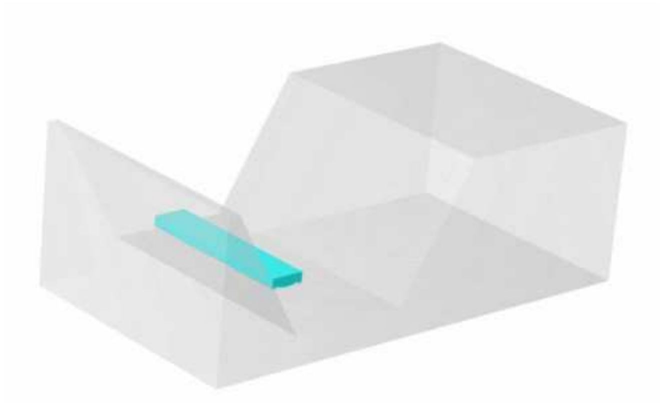


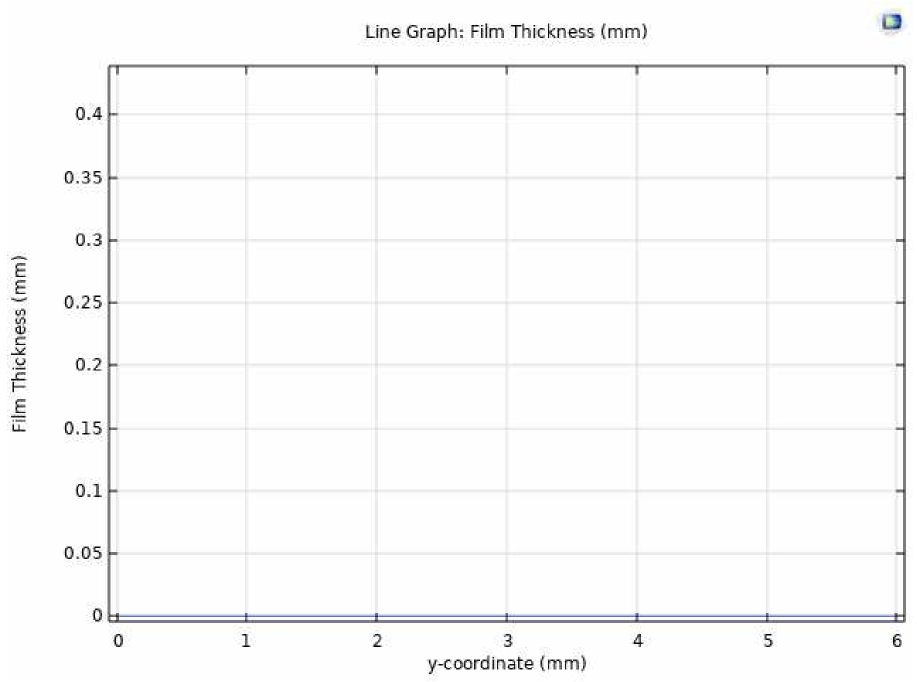
Dual chamber slot die (8 mm inlet same dead volume)



Slot die chamber – Meniscus makes or breaks homogeneity







6.

Drying technologies for 3rd Gen PV

Introduction thermal drying – Coating parameters

Coating chemistry
- Rheology
- Viscosity
- Viscoelasticity
- Type of solvents
- Solid content
- Van der Waals force
- Sheer ratio
- Adhesion/Cohesion

Coating processes
- Coating systems
- Single or multilayer coatings
- Direct coatings
- Transfer (indirect) coatings
- Substrate speed
- Layer thickness
- Coating accuracy

Process control
- Process layout
- Tension control system
- Material guiding system
- Inline parameter control
- Quality control

Drying
- Convection drying
- Contact drying
- Infrared drying
- Sintering
- NIR
- High frequency
- UV crosslinking systems

Substrate
- Surface tension
- Dimension stability
- Surface structure
- Contact angle

Pretreatment
- Corona
- Plasma
- Cleaning

Environment
- Humidity
- Temperature
- Inert conditions

Finishing
- Calendaring
- Embossing
- Slitting

Dryer specs needed for the layout

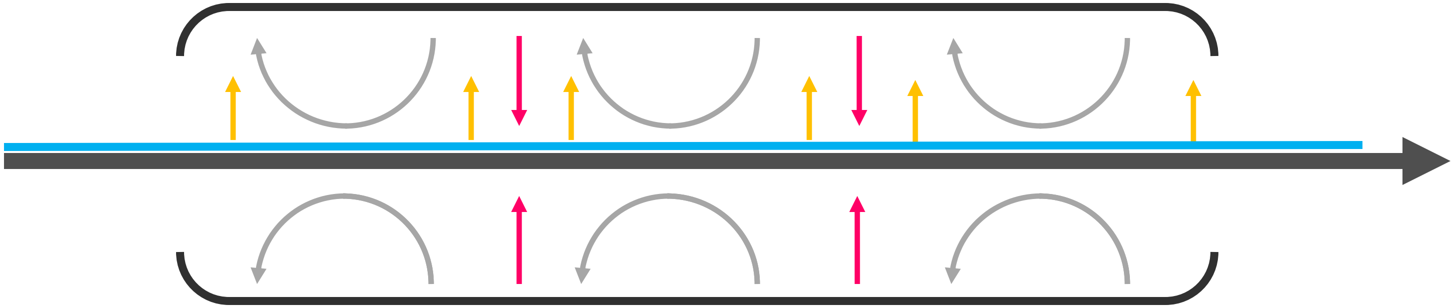
Information about the substrate

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

Drying technologies for 3rd Gen PV

Soucre: Drytec

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



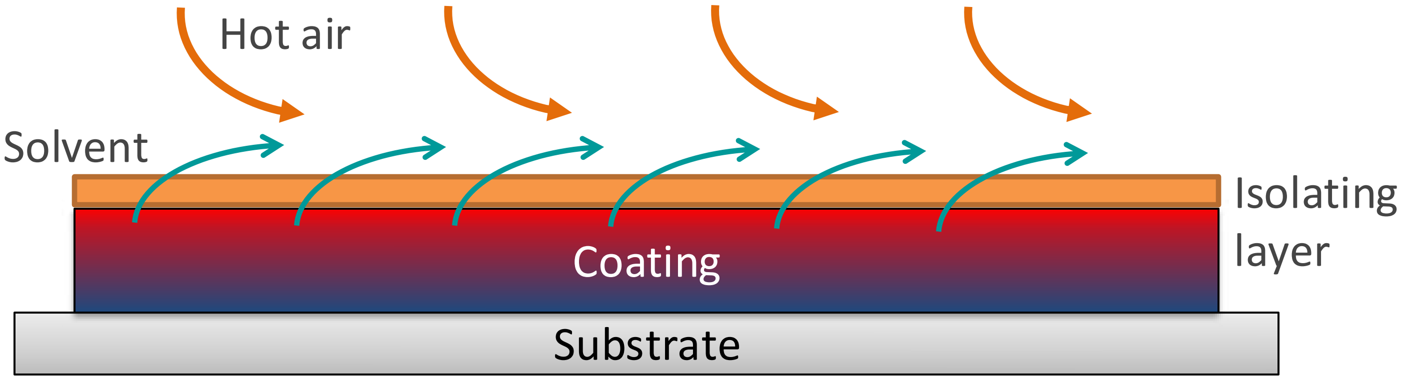
- ✓ Heat Conduction/ Heat Diffusion
- ✓ Heat Convection/ **Mass Transfer**
- ✓ Radiation

Substrate
Coating
Heat transfer
Evaporating solvent
Solvent vapor transfer

Mass Transfer

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

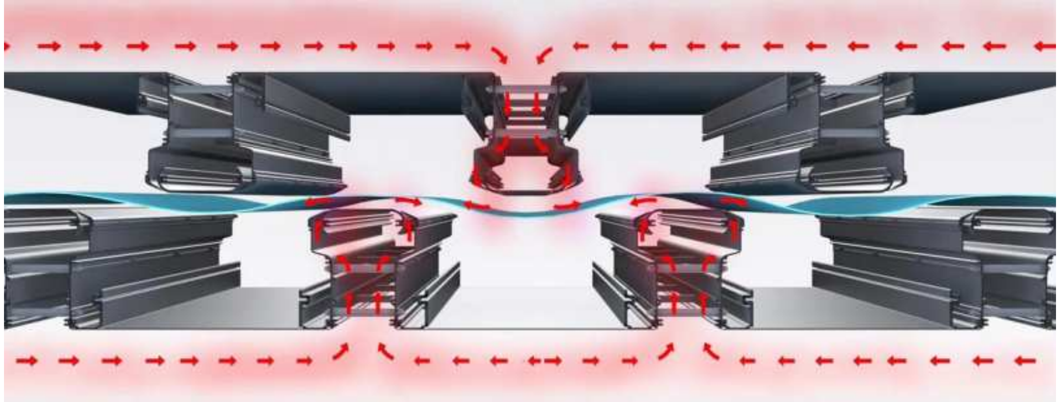
- ✓ Heating and vapor transport combined
- ✓ Bulk heating by thermal conductivity from surface
- ✓ Isolating layer to be overcome by air flow
- ✓ High air flow deteriorates surface
- ✓ Temperature easy to limit
- ✓ Slow



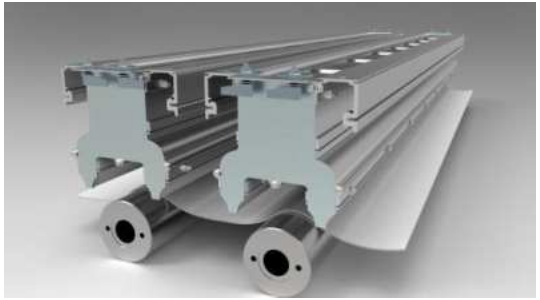
Industrial drying systems

Coatema slot nozel and circulation dryer on small scale

Drytec Click&Coat™ dryer prinziple



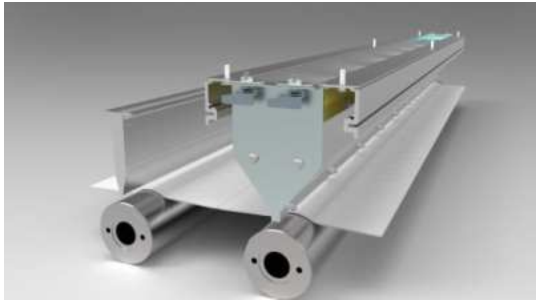
Industrial drying systems: Nozzle shapes 1



Impingement nozzles with two jets

Flotation nozzles with adjustable air direction

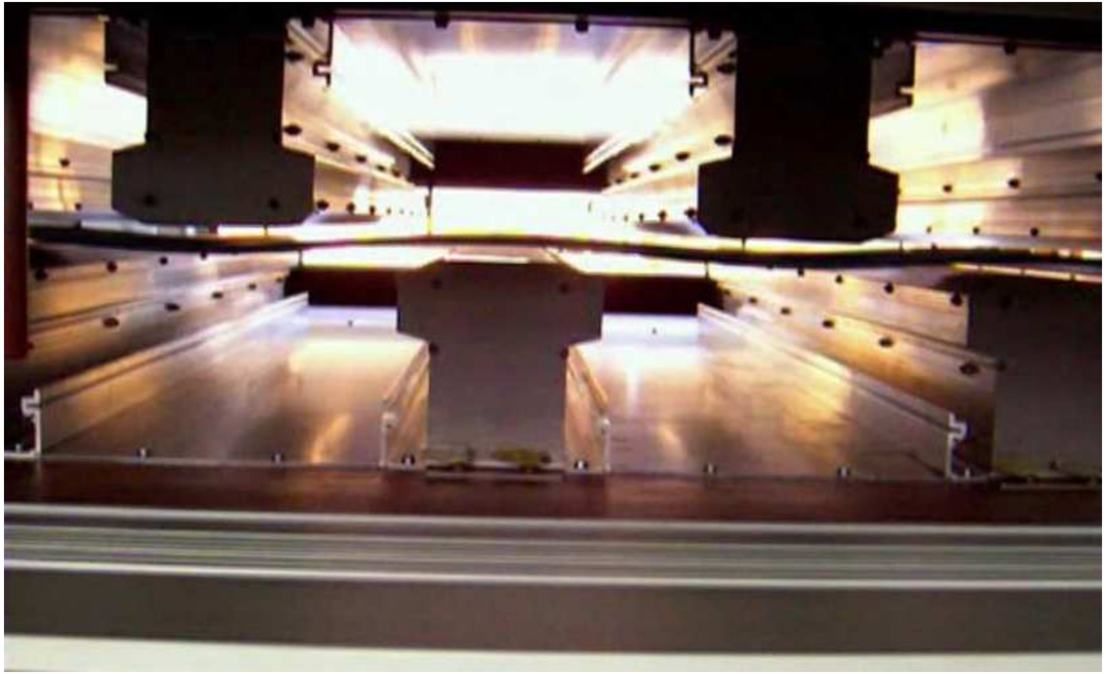
Flotation nozzles



Impingement nozzles with one jet

Flotation nozzles with Contec 3 roller nozzle

Drying topics – drying technologies: HighDry HD500



Web behaviour in a flowtation dryer

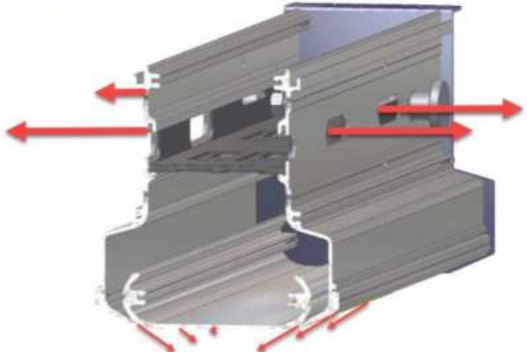
Click on the picture to show the video

Drying topics – drying technologies: HighDry HD500

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

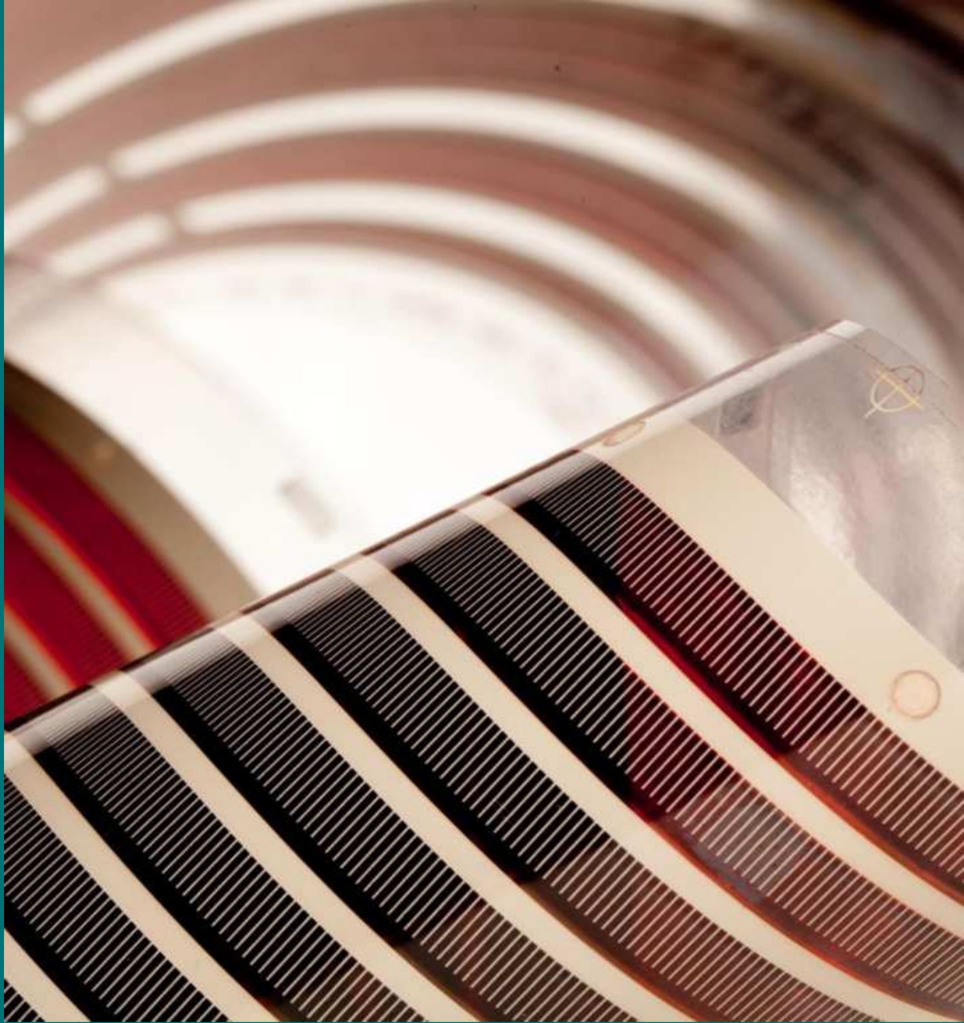
This function is often used, for example, in processes with low-viscosity coatings.

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



7.

Today‘s equipment for 3rd Gen PV



S2S

Test Solution

Easycoater

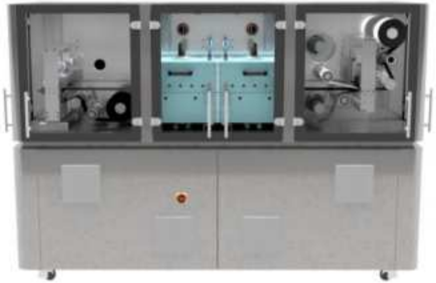
Easycoater Evolution

Ink testing

First sample product

First pilot as S2S

R2R lab systems



Test Solution R2R

Basecoater R2R

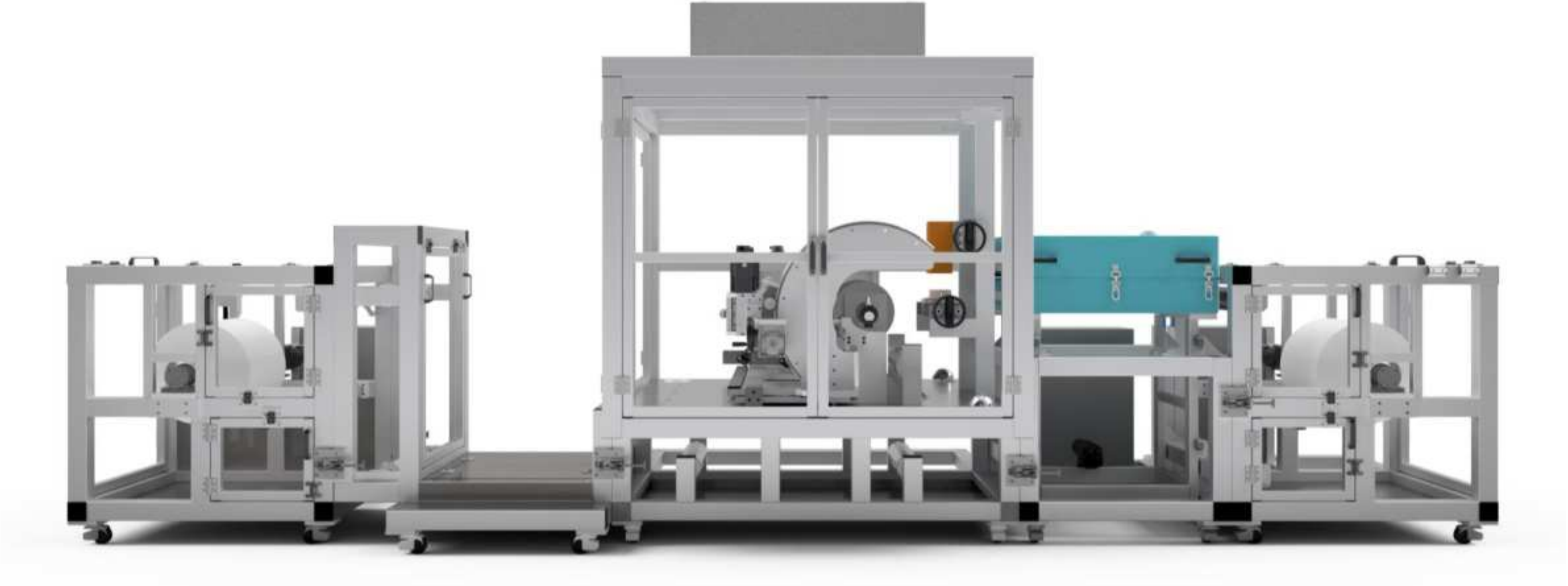
Smartcoater R2R

R2R pilot

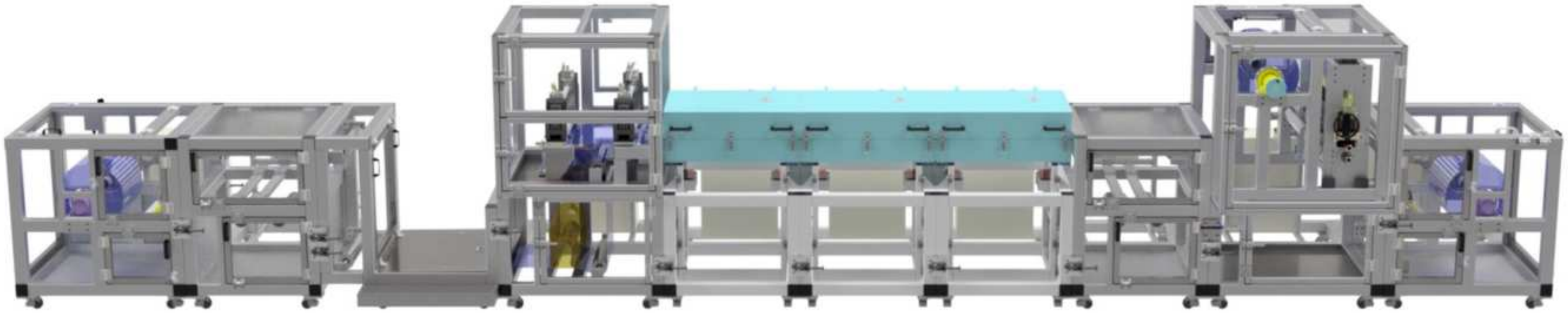
Basecoater Pilot R2R

The Basecoater

The Click&Coat™



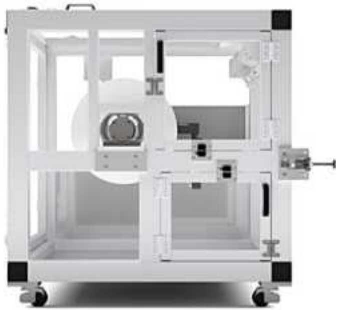
The Click&Coat™

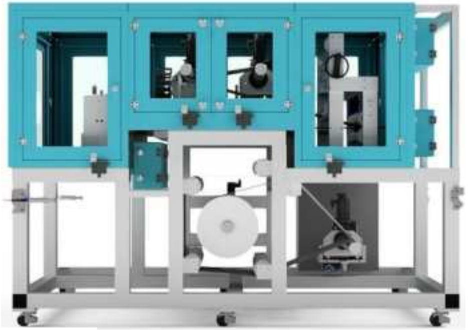


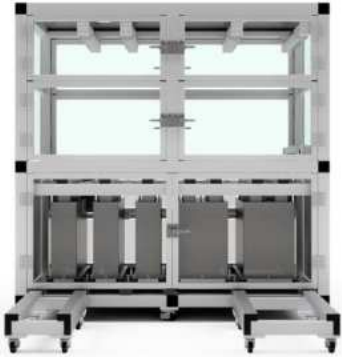
The Click&Coat™

Today‘s equipment for 3rd Gen PV

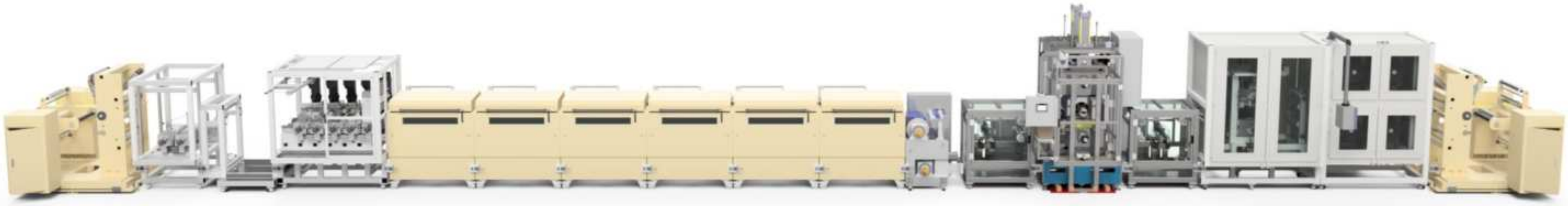
The Click&CoatTM single modules







The Click&CoatTM in production scale in the R&D centre



The Click&Coat™ in production scale

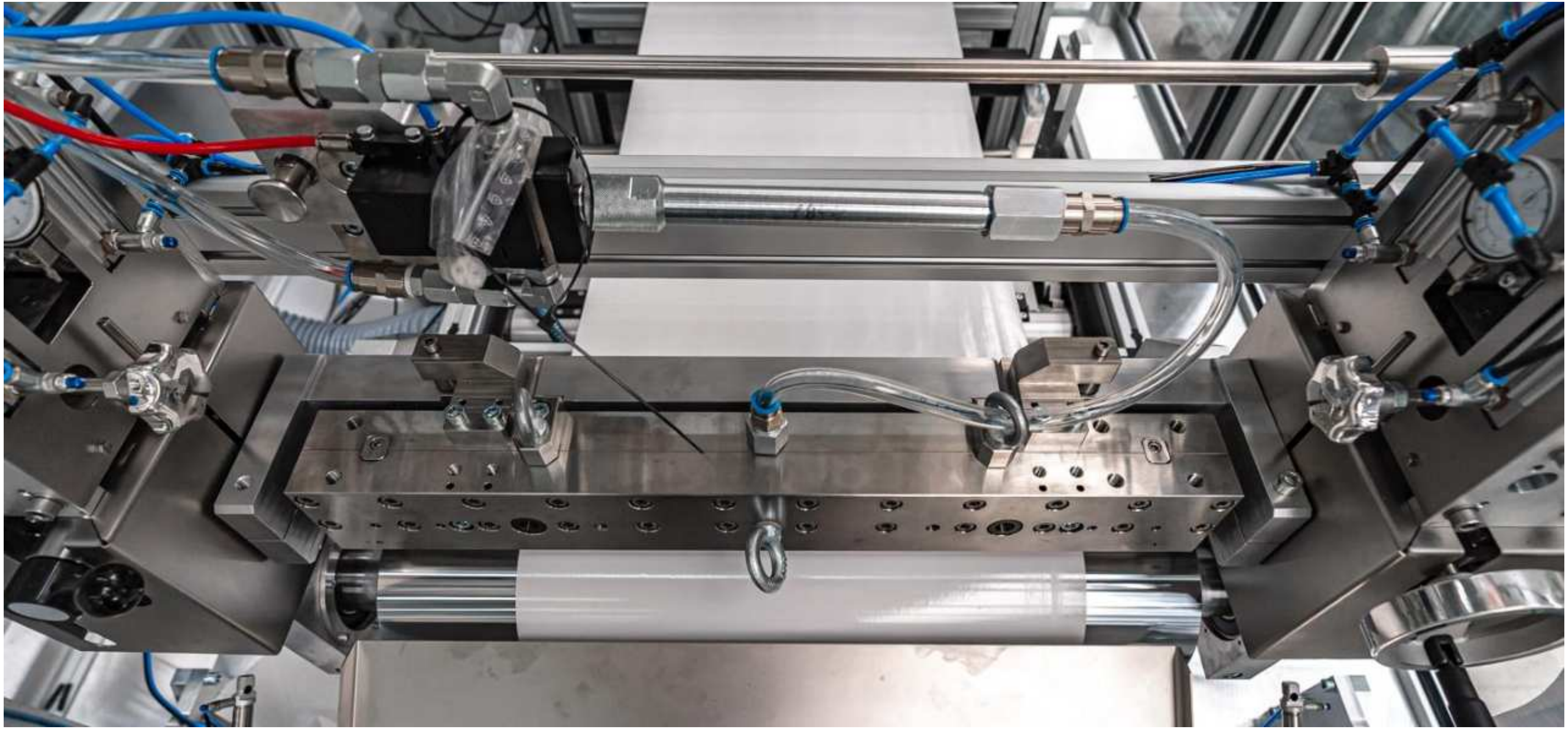
The Click&Coat™ in production scale

The Click&CoatTM in production scale

Today‘s equipment for 3rd Gen PV

Today‘s equipment for 3rd Gen PV

Today‘s equipment for 3rd Gen PV

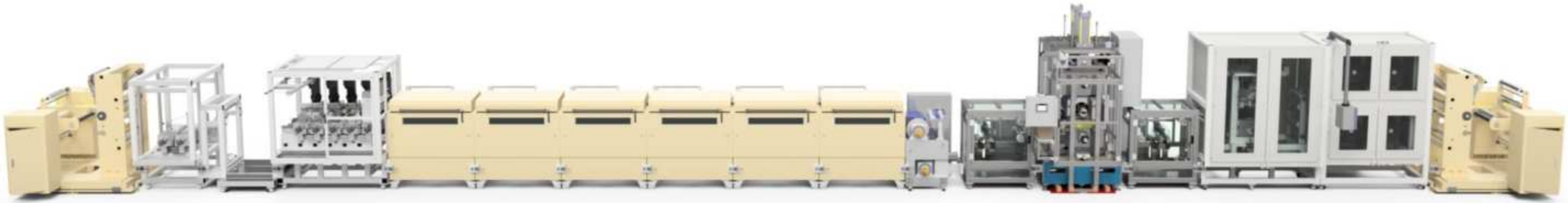


Today‘s equipment for 3rd Gen PV

Coatema®
Coating Machinery GmbH

Today's equipment for 3rd Gen PV

The Click&Coat™ in production scale



The Click&Coat™ in production scale

8.

Summary

Outlook

Needed for success:

- ✓ Reproducible results in every step of scale?
- ✓ Reality check if the approach is really scalable?
- ✓ Is the approach an approach for the real life production environment or is it rocket science?
- ✓ Are economies of scale reachable and when?
- ✓ Is durability really needed?
- ✓ Standardization of device manufacturing is the key for the industry

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

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Thank you

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