



Technology development and manufacturing for 3rd Gen solar cells

Coatema

07/08/2024

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

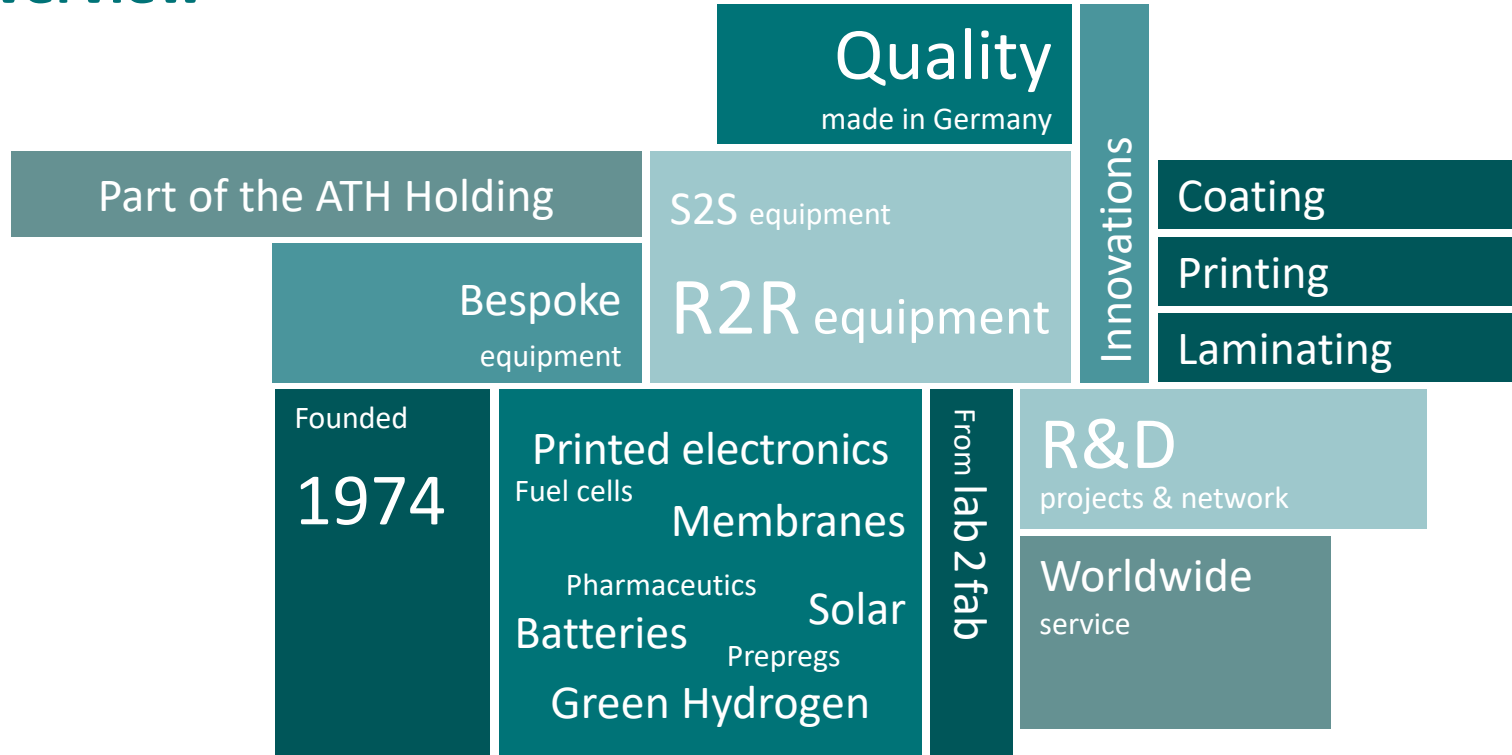


1.

Introduction



Overview



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



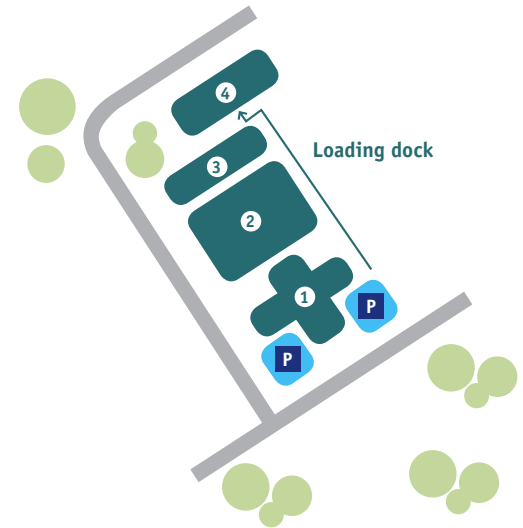
Coatema[®]
Coating Machinery GmbH

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

Represented worldwide

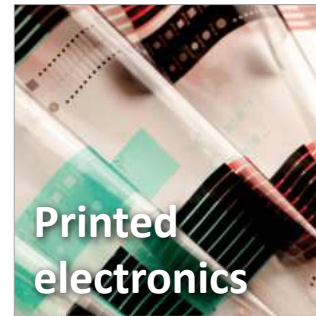
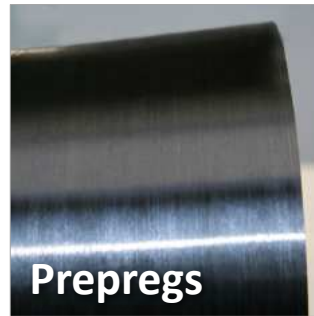
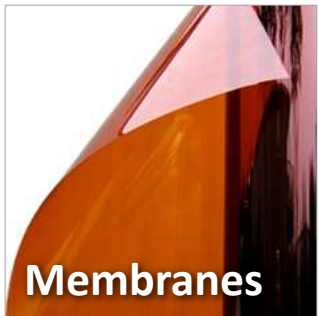
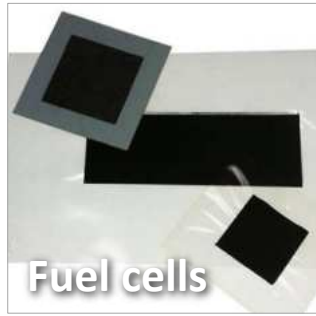
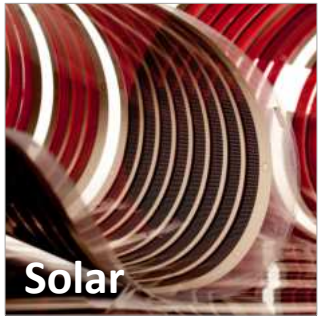


Headquarter in Dormagen

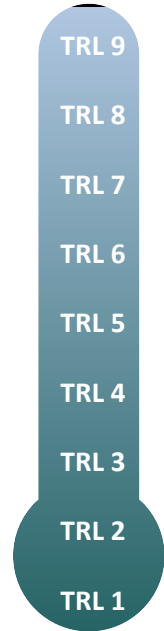


- ① Head office
- ② R&D centre
- ③ Assembly
- ④ Loading dock
- P Visitor parking

Our markets



Actual system proven in operational environment



Basic principles observed

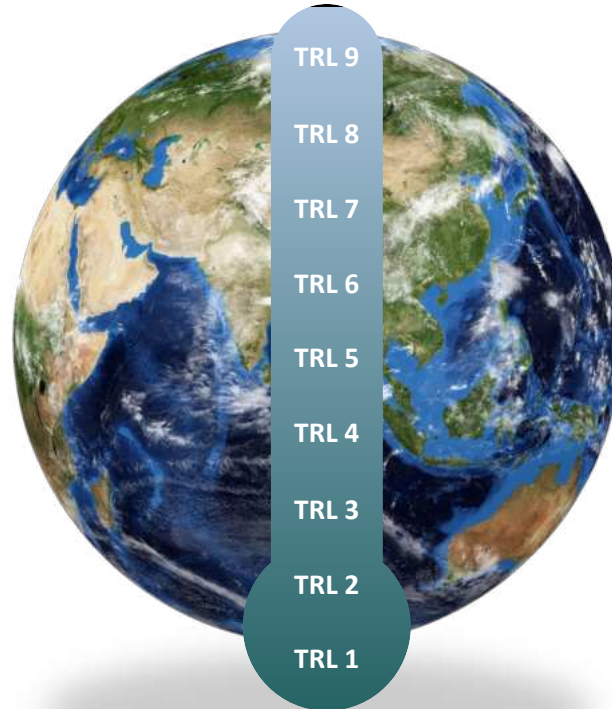
Our markets – Coatema focus areas

Green Hydrogen

Fuel cells

Batteries

Solar



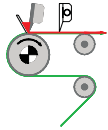
Sustainability

Digital fabrication

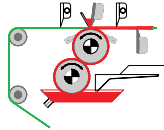
Printed
electronics

The next thing

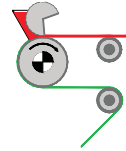
Coating systems



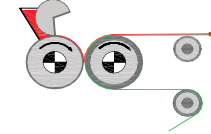
Knife system



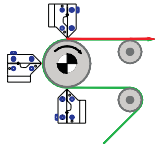
Double side coating system



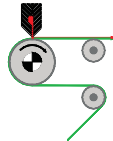
Commabar system



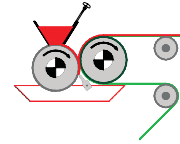
Reverse commabar system



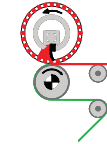
Slot die system



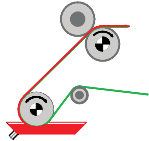
Curtain coating system



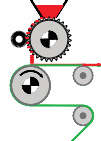
Case knife system



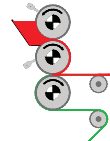
Rotary screen system



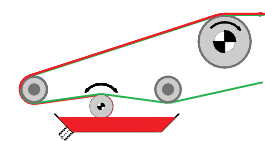
Dipping system (Foulard)



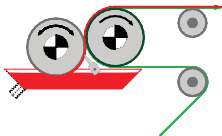
Powder scattering system



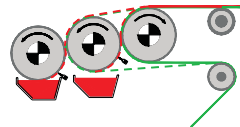
Reverse roll coating system



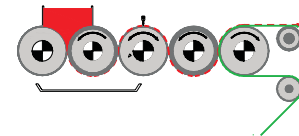
Micro roller coating system



2-roller coating system

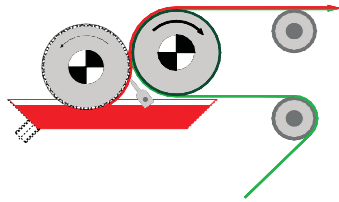


3-roller combi coating system

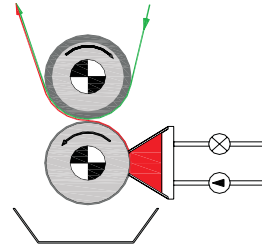


5-roller coating system

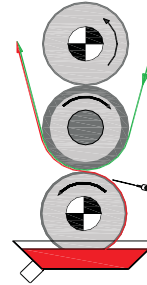
Printing systems



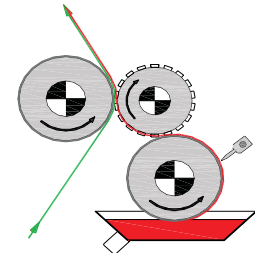
Engraved roller system



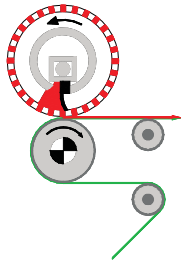
Gravure roller system



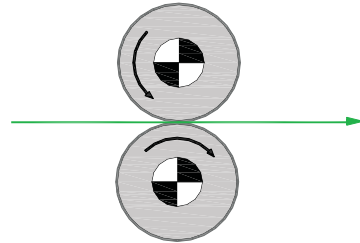
Gravure indirect system



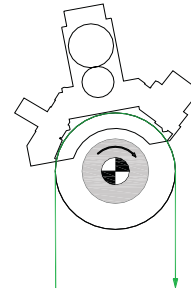
Flexography system



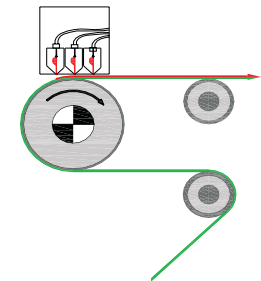
Rotary screen system



Hot embossing system



Nanoimprint system



Inkjet system

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 Research 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 Centre for Nanotechnology and Smart Materials
Fachhochschule Kiel Hochschule für Angewandte Wissenschaften
CENTI Centre for Nanotechnology and Smart Materials
FILK Forschungsinstitut Leder und Kunststoffbahnen
Hochschule Niederrhein University of Applied Sciences
Georgia Institute of Technology
UNIVERSITY OF CAMBRIDGE
Neue Materialien Fürth
JOANNEUM RESEARCH
HERIOT WATT UNIVERSITY
ZSW
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 (Open membership since 2002)
Hochschule Reutlingen Reutlingen University
Fraunhofer IAP
Fraunhofer IAF
Fraunhofer ILT
Fraunhofer IFAM
Fraunhofer ISC
Fraunhofer IFP
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

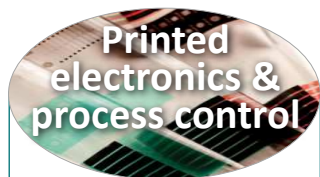
Coatema customers



R&D customers

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Fraunhofer IAP
Fraunhofer IAF
Fraunhofer ILT
Fraunhofer IFAM
Fraunhofer ISC
Fraunhofer IFP
Fraunhofer IVV
Fraunhofer ISE
Fraunhofer ICT
Fraunhofer PYCO
Fraunhofer IPT
Fraunhofer IWM

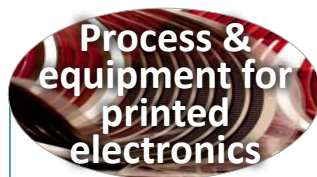
R&D projects overview 2022 – 2024



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

NOUVEAU PROJECT

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



R2R production line for OPV solar with integrated backend



Development of near-field electro hydrodynamic nanowire printing



Implementation of laser drying processes for lithium-ion battery production



R2R process optimization for solid state batteries



Plasmonically enhanced photocatalysis for wastewater treatment

RetroWin

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



The WaterProof project aims at developing an electrochemical process that converts CO₂ emission



Creating an open-innovation testbed for sustainable packaging

2.

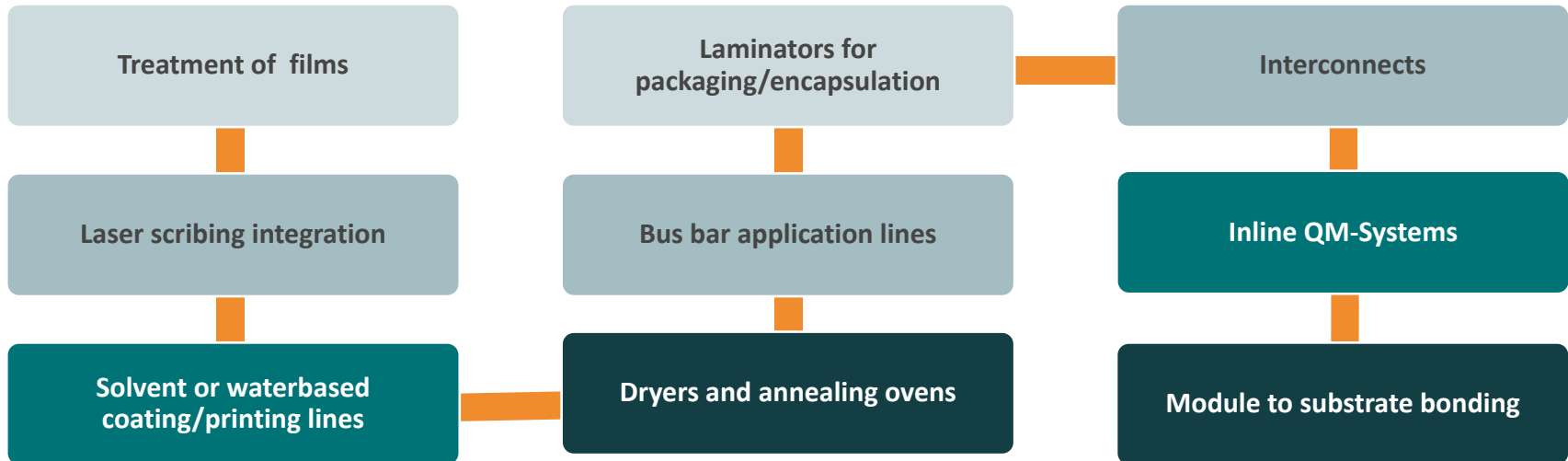
3rd Gen solar technology



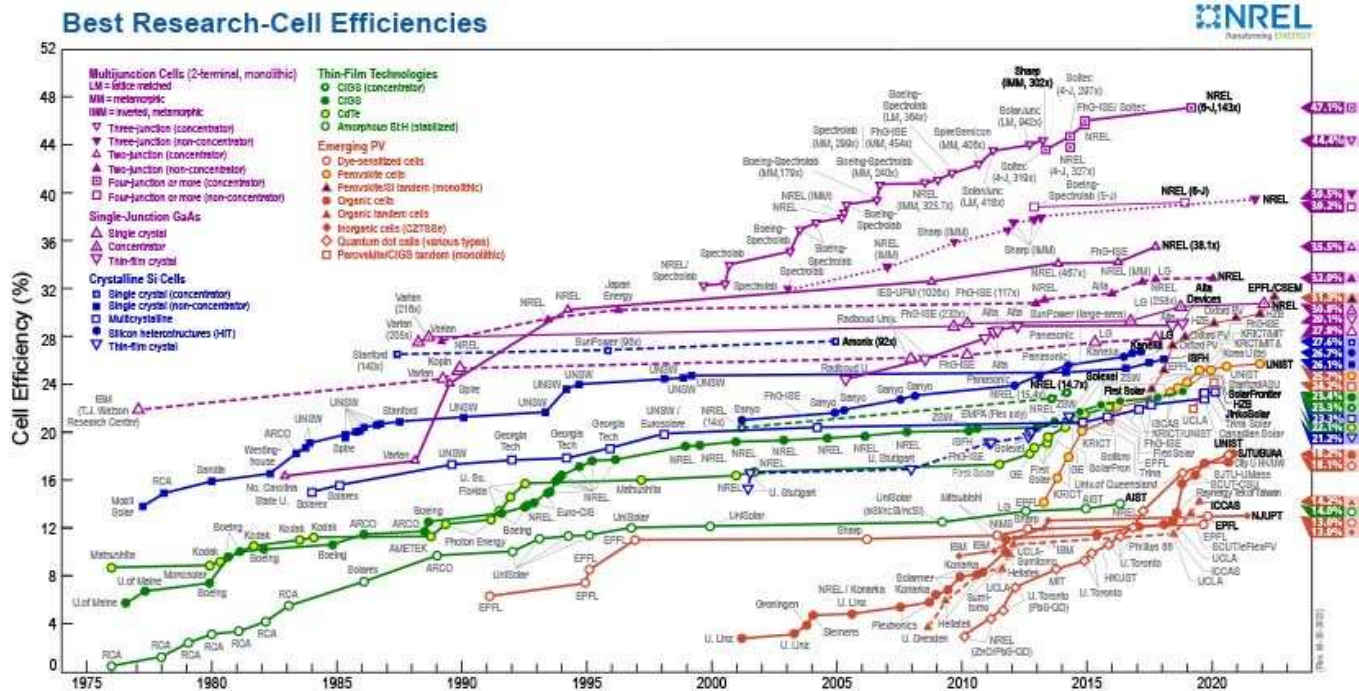
Overview of the different flexible solar cell types

Technology	Advantage	Challenge
a-Si	Excellent for BIPV due to a proven 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

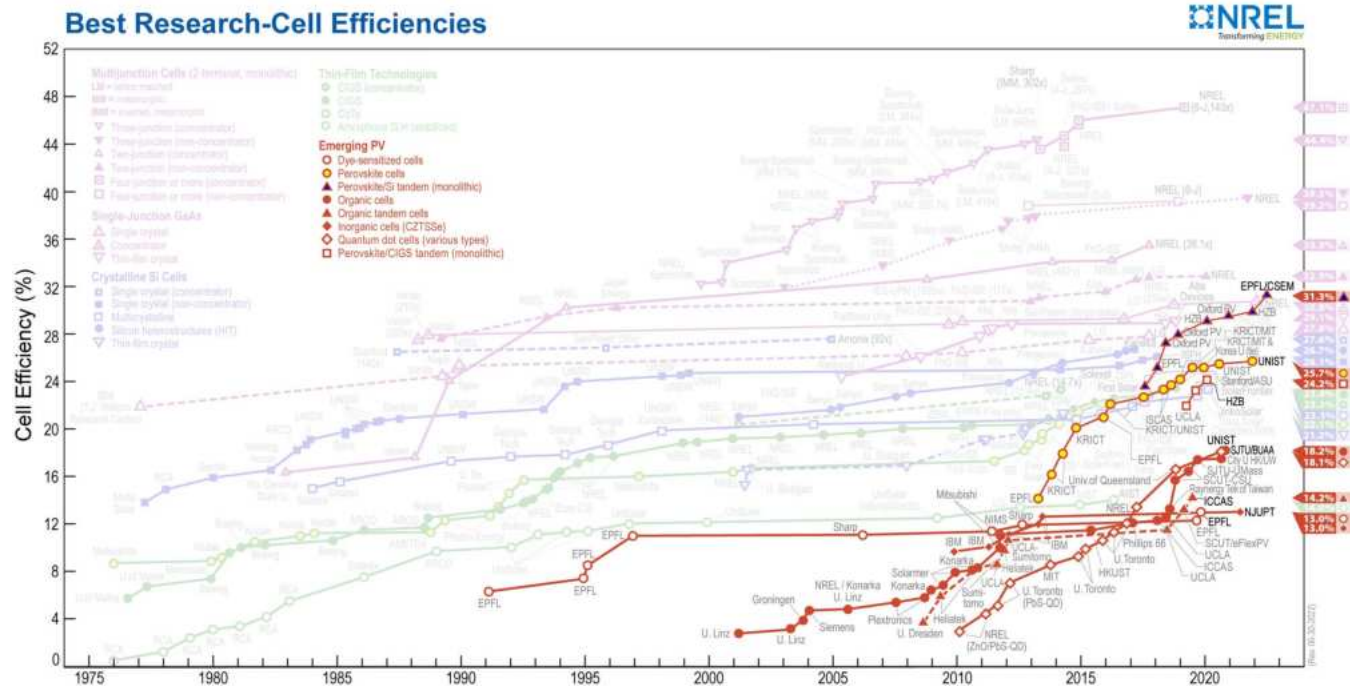
Production chain modules



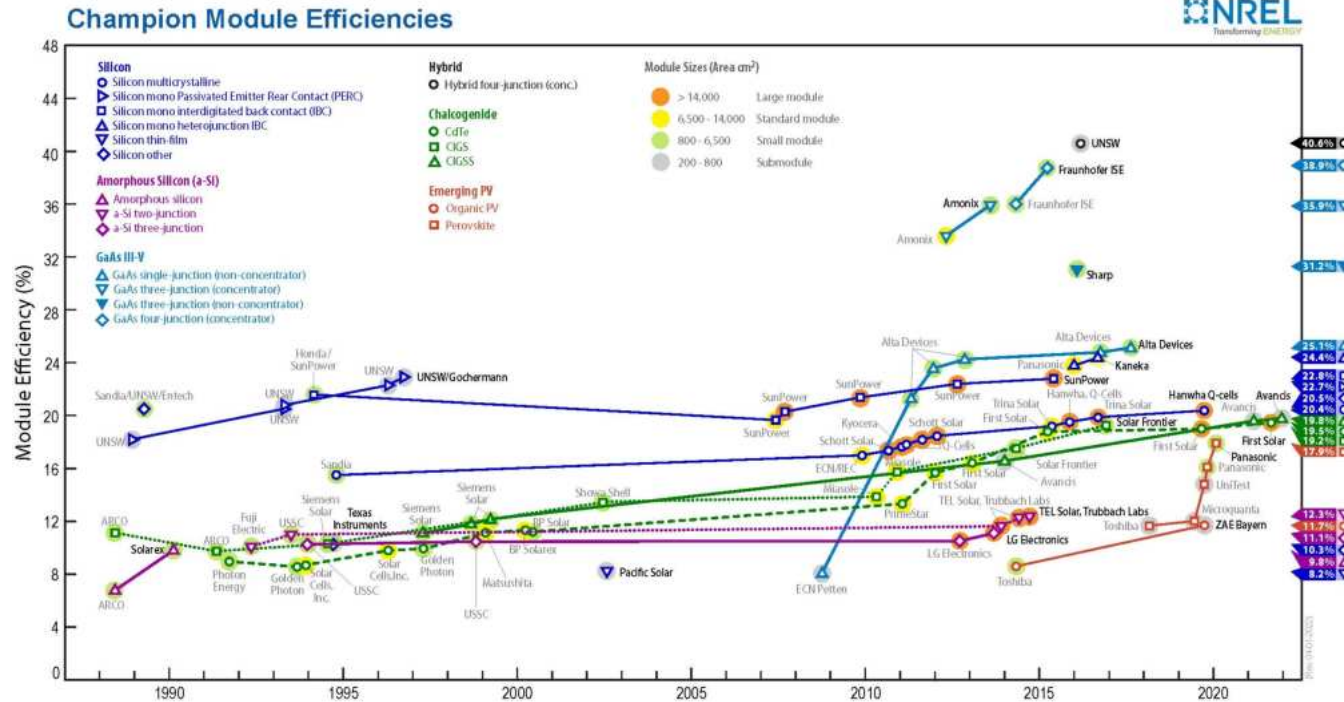
Cell efficiency



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))



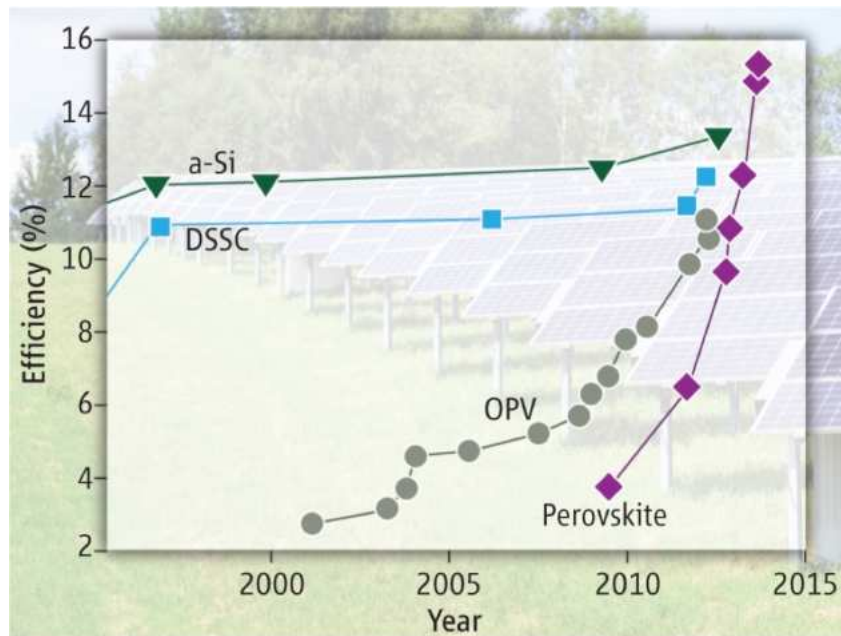
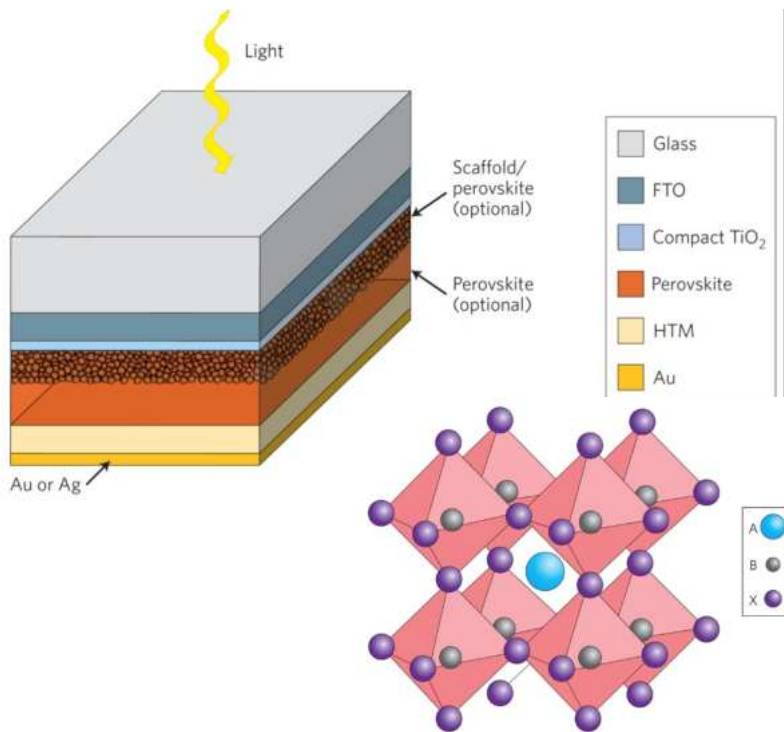
Conductive solution with

- ✓ 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

Coatema Core Technologies in solar technologies

**Dye sensitized
solar cell
(DSSC)**

**Organic
photovoltaics
(OPV)**

Perovskite

**Slot die
coating/
Printing
processes**

**Process inline
control**

**Drying/
Annealing**

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



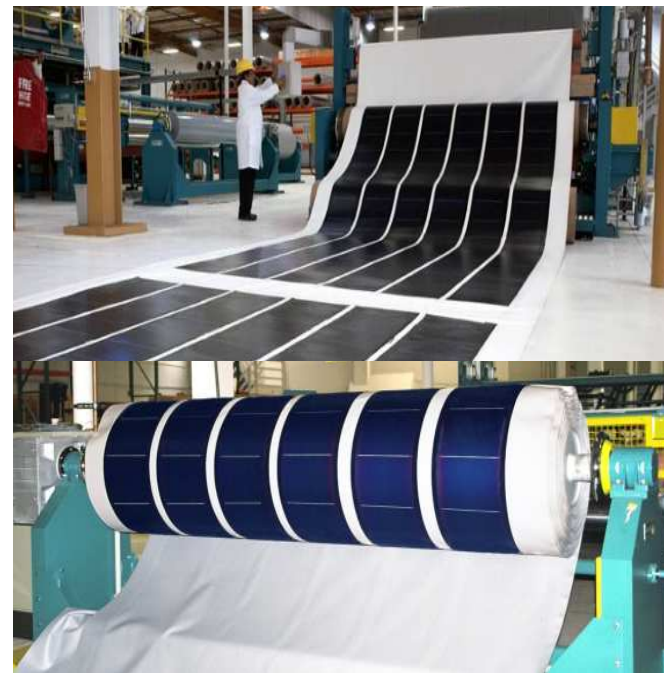
Worlds Largest flexible Amorphous Silicon Photovoltaic Cell Production Line. A Three year, \$100 million dollar commitment

3rd Gen solar technology

1999 – flexible PV on roofing membrane



Production facility in Los Angeles



Vision on flexible roofing integrated PV on roofing membrane



3rd Gen solar technology

Vision on flexible roofing integrated PV on roofing membrane



3rd Gen solar technology

1999 – flexible PV on roofing membrane



Solar cell projects at Coatema



2005 – 2023

Process upscaling – Developing 3rd Gen PV at Coatema



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

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

OPV equipment outside of funded projects

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

Process feasibility study – function & design study

Lab scale



A4

Process specification

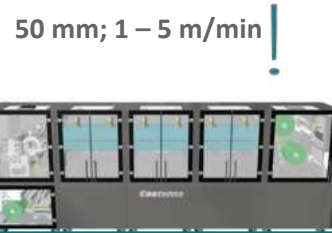
- Machinery
- Fluid

- 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

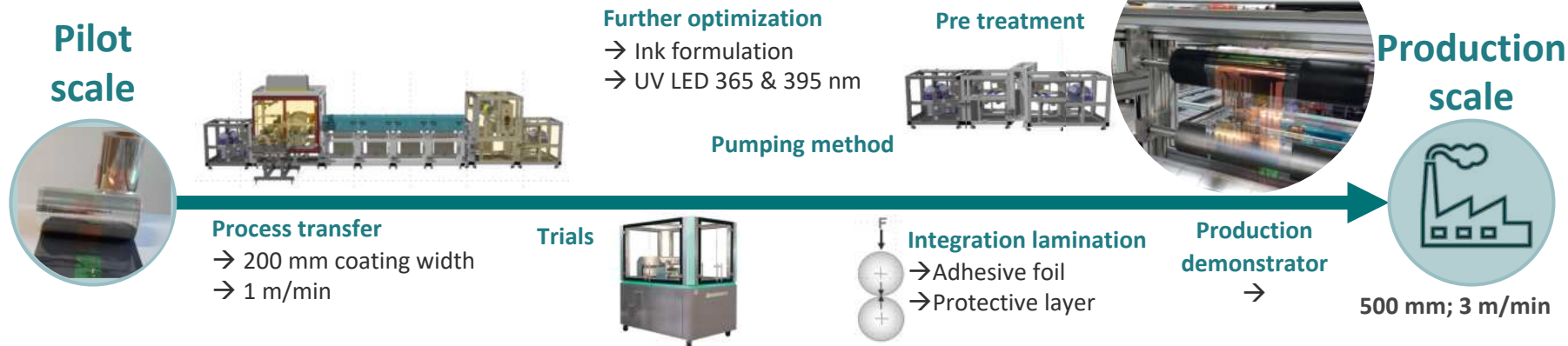
Process & Equipment specifications

- ✓ 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



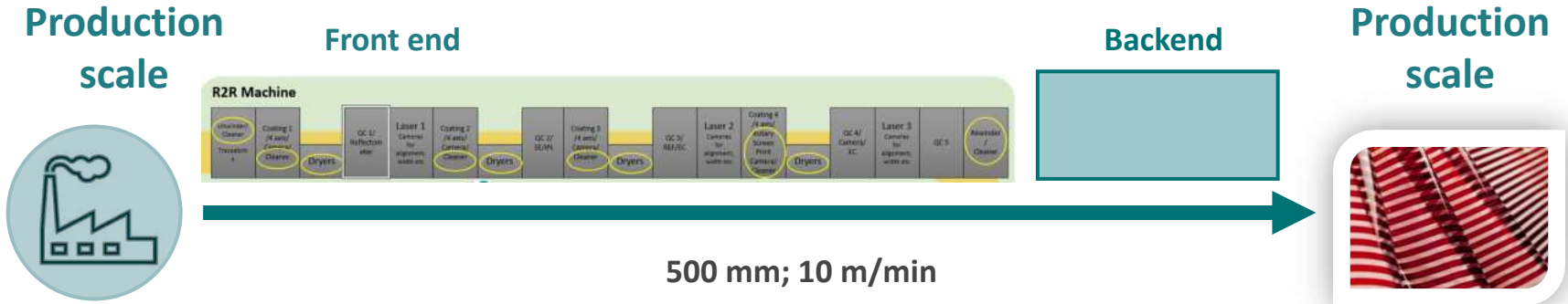
Process integration

- ✓ 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



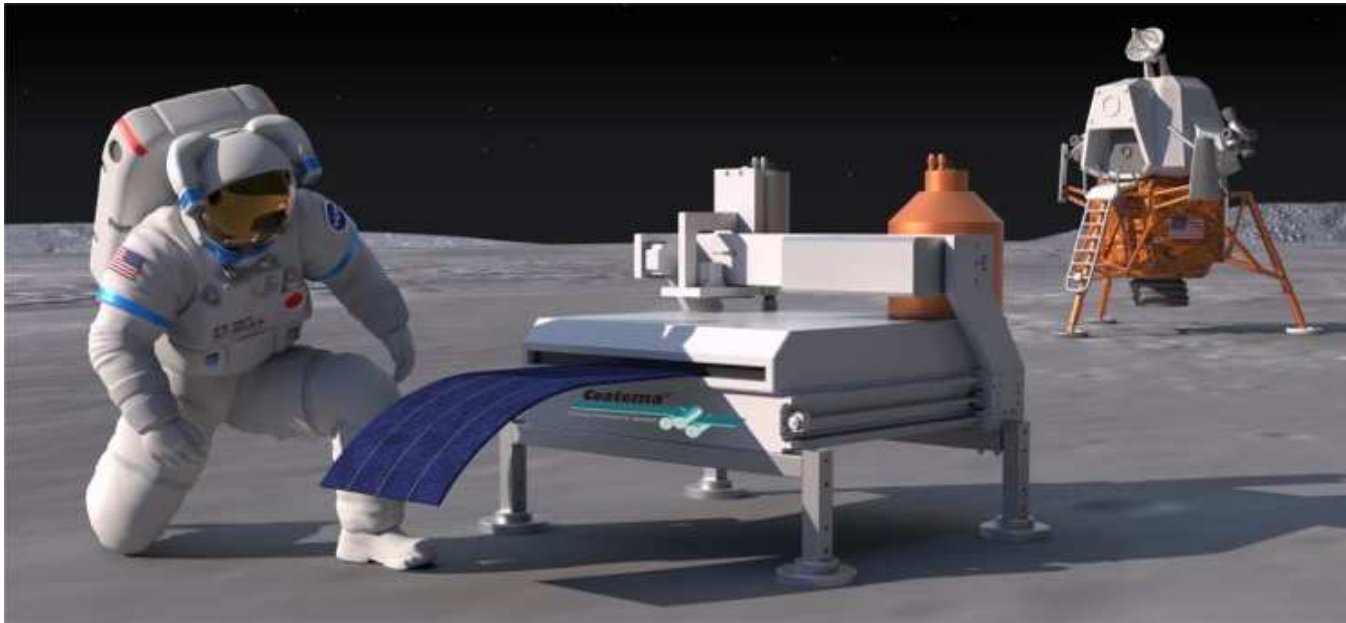
Process integration as industrial standard

- ✓ 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

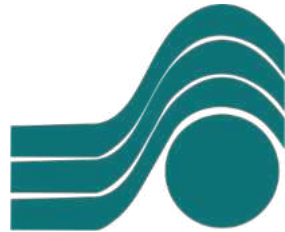


What would it take to manufacture Perovskite Solar Cells in space? | ACS Energy Letters

3.

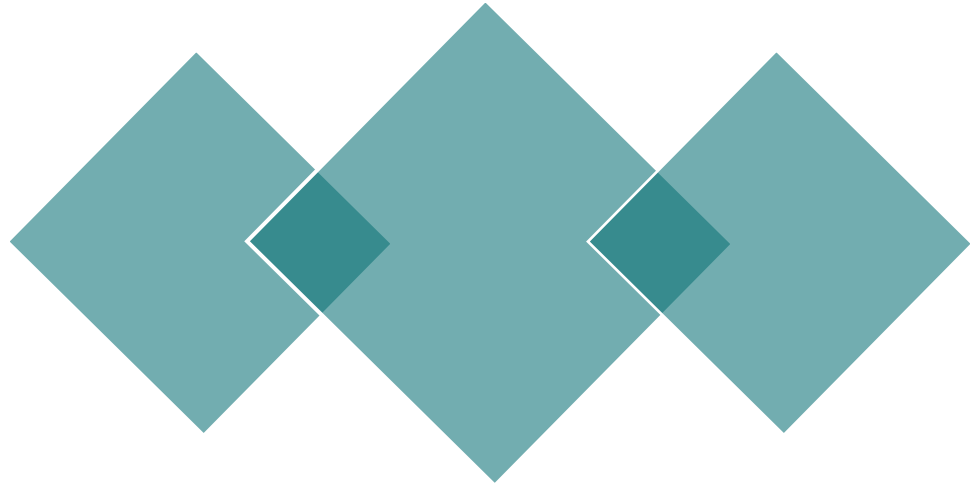
Flex2Energy Project





FLEX2ENERGY

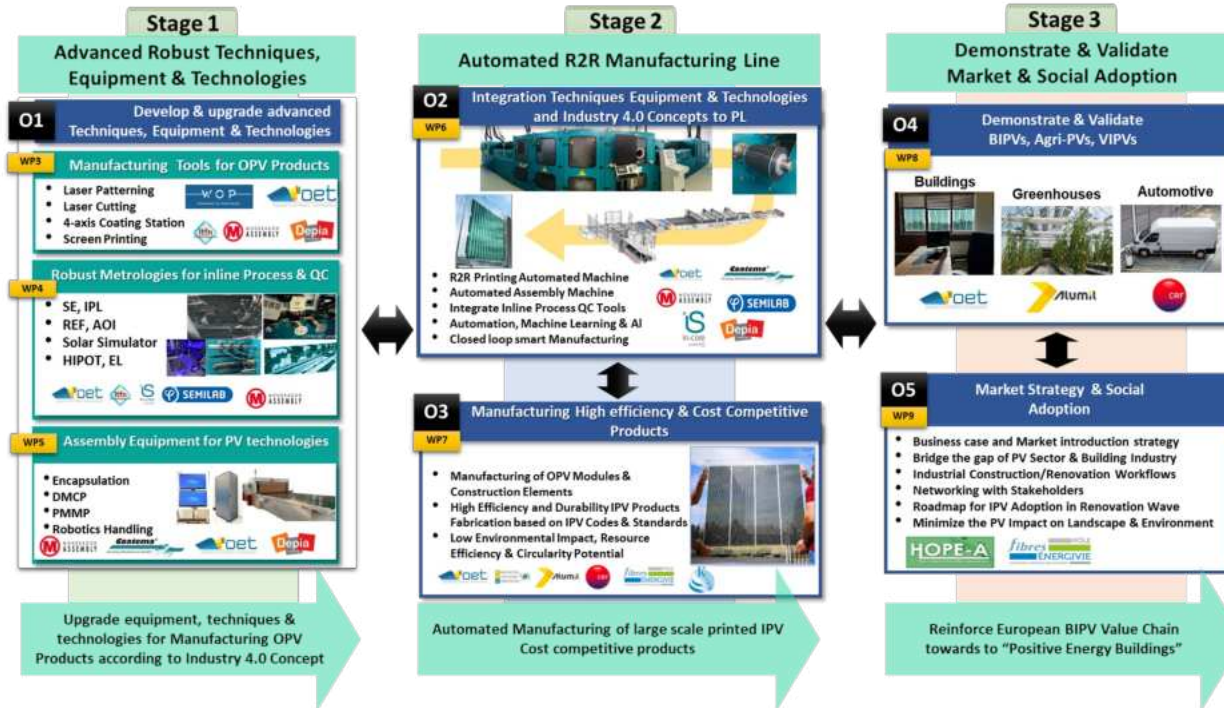
AUTOMATED MANUFACTURING
PRODUCTION LINE FOR IPVS



Consortium partners



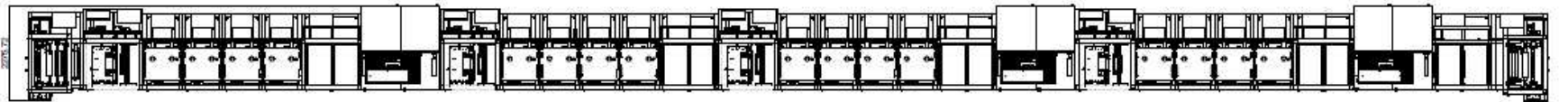
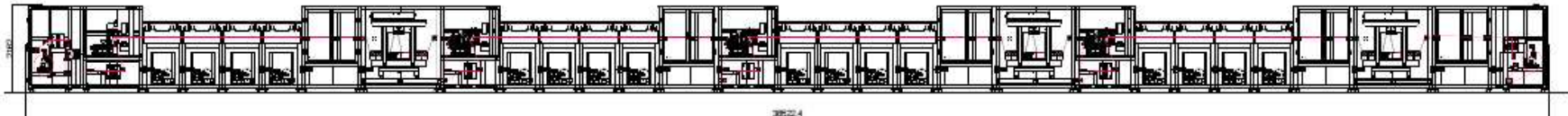
Flex2Energy Concept: The 3 Stages in relation with the Obs & WPs





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

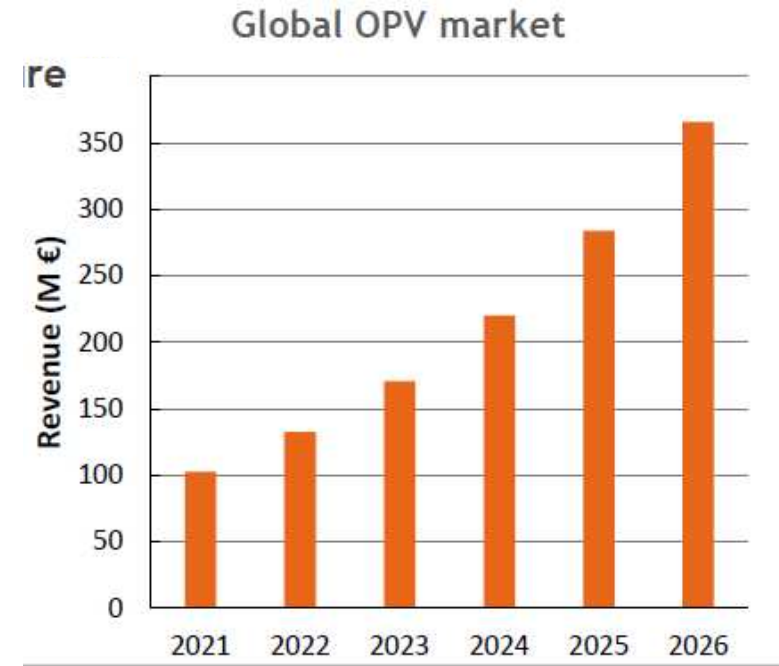
✓ Partners



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 tunable 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>

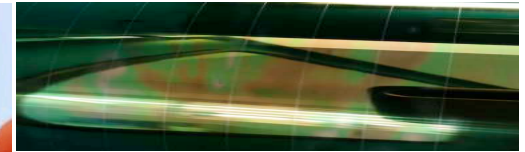
State of the art – OPVs

- ✓ 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)

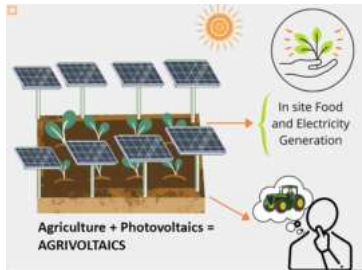
- ✓ No optical transparency
- ✓ High weights (~20 kg), heavy structure
- ✓ Not Applicable in Greenhouse roofs due to limited Transparency
- ✓ Efficiency is reduced abruptly in vertical-90° placement
→ can not cover the energy demands of building



2nd Generation (PV)

- ✓ Optical transparency but limited up to 30 %
- ✓ High weight increases CO2 footprint
- ✓ High fabrication costs due to current production technology (Vacuum deposition)
- ✓ 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**



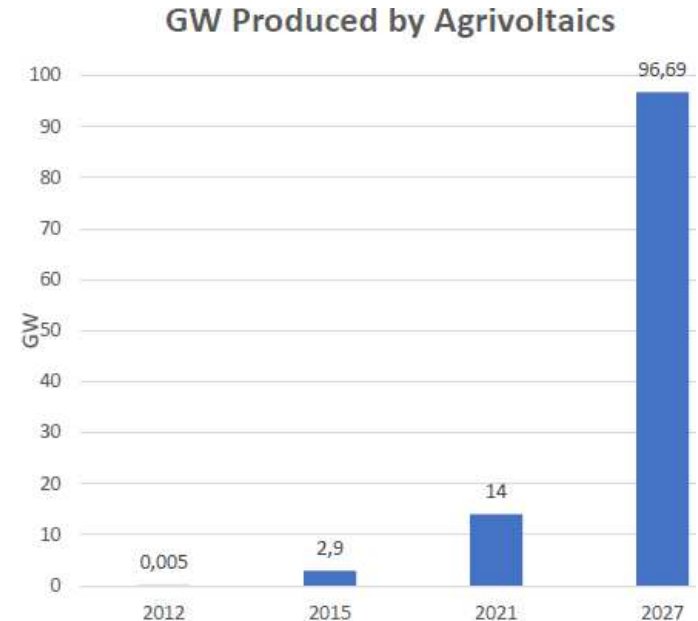
Argivoltaics
Sustainable Green Development

- 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

nanotechnology NANOTECHNOLOGY 2022 Special Workshop: Agrivoltaics 07/07/2022

Expected market grow for Agrivoltaics

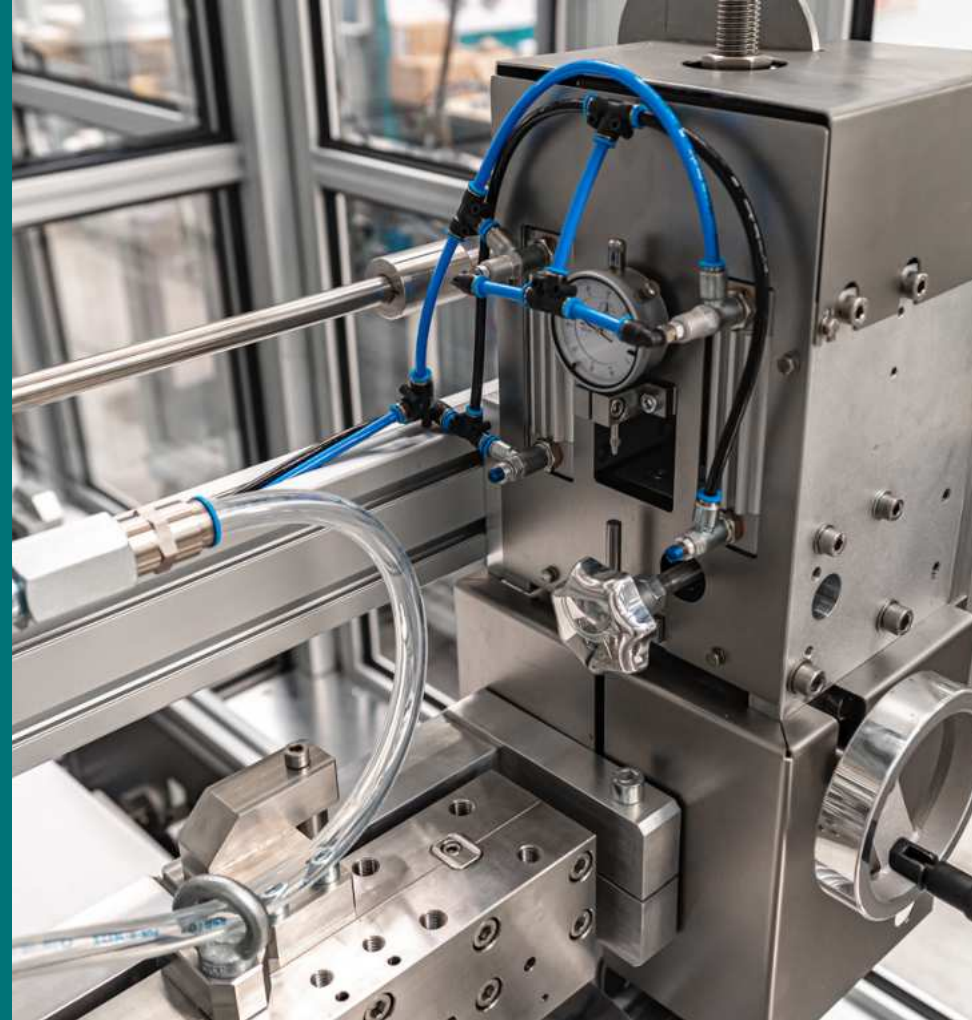
- ✓ Global installed Agri-PV capacity has increased exponentially from 5 MW in 2012 to 14 GW in 2021 (Expected reach of 97 GW in 2027)
- ✓ The global agrivoltaic market will grow at a CAGR of ~38 % (2022 – 27)
- ✓ Due to rapid climate changes create huge challenges for energy & agriculture worldwide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



Source: MarkNitel 2021

4.

Process control

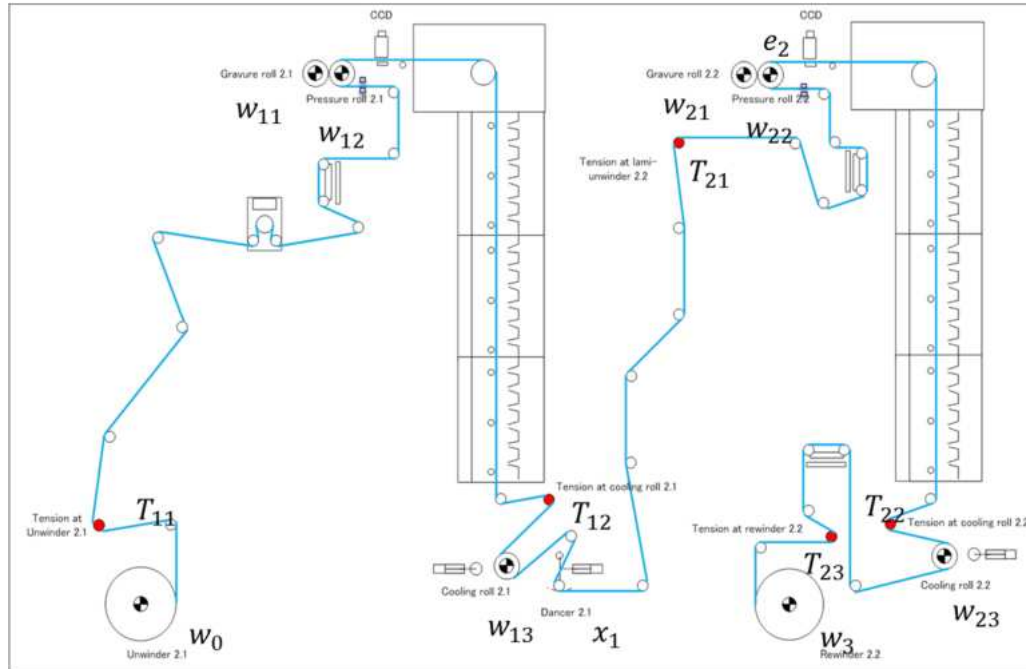


Technologies & processes – process parameters

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



Inline process integration

Tension control

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

Registration control

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

Edge guide control

- ✓ Different sensors
- ✓ Mechanical stress
- ✓ Data collection

Process analysis

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

Quality control

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

Inline process integration and measuring points

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

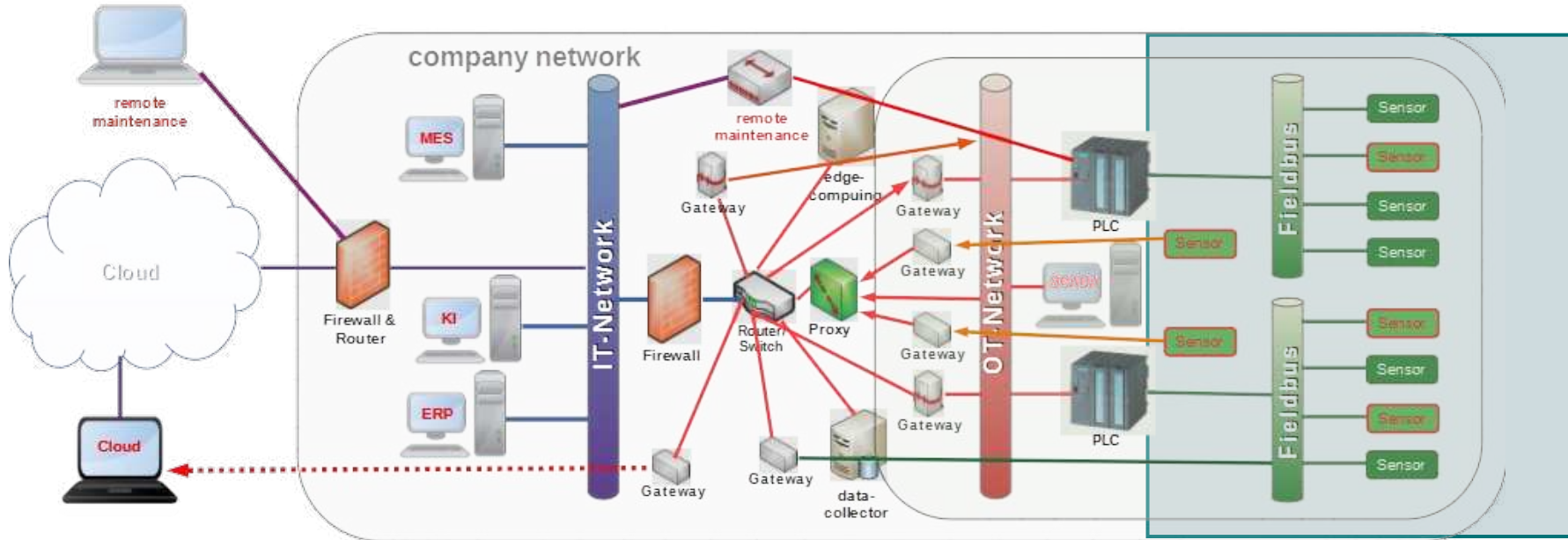


Unwinder	OET 4 Axis system	3m dryers	ps laser	OET 4 Axis system	Ink jet	3m dryers	IPL	In-line optical metrology (SE, Raman)	LBIC	Rewinder
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- Number of measuring points
- Amount of measurements per time

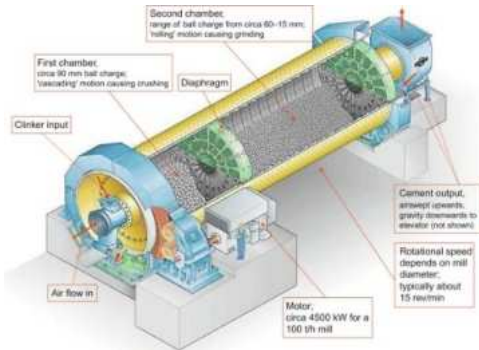
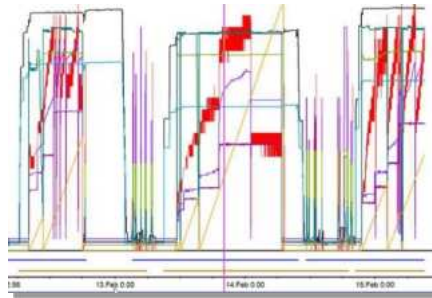


Complexity introduced through connectivity



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

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)

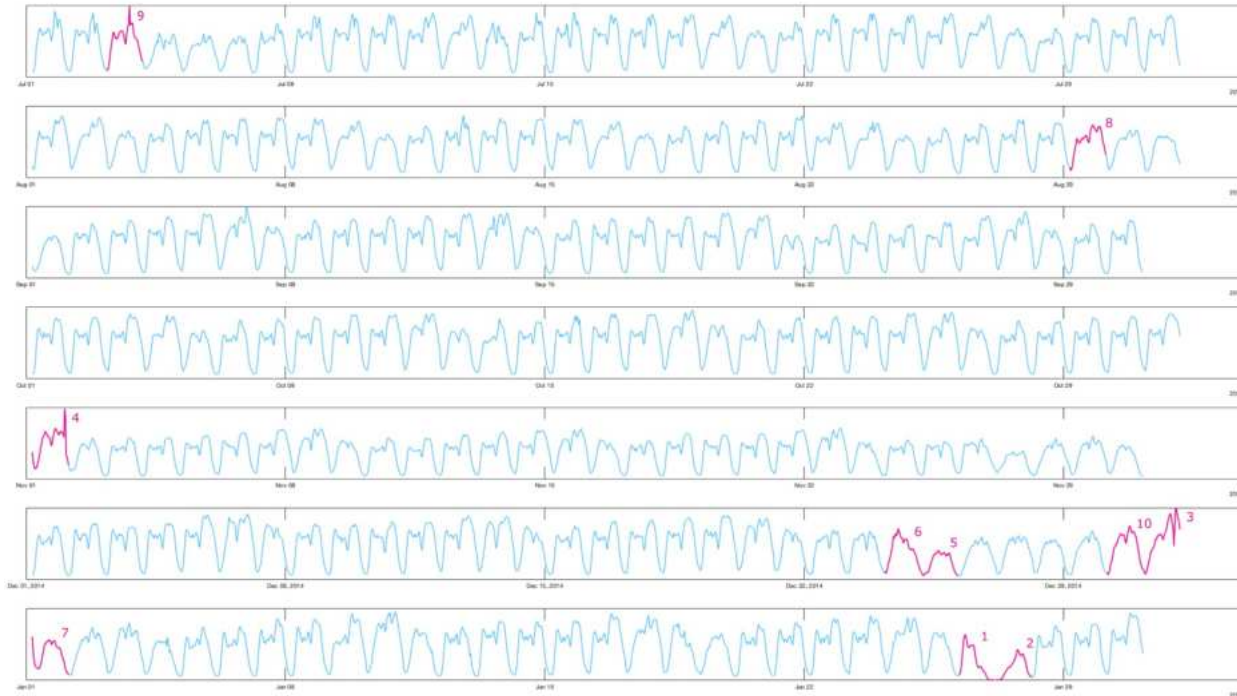
Diagnostics
Root cause analysis (e.g. damaged bearings, clogged filter, ...)

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

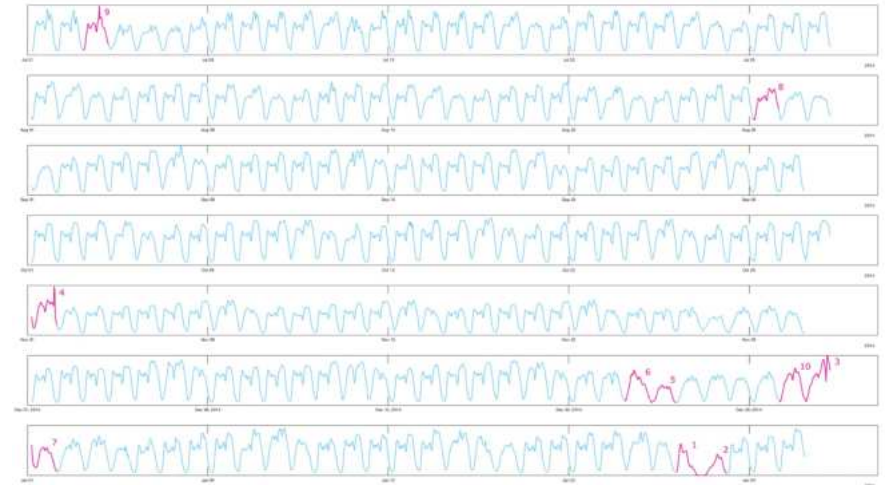
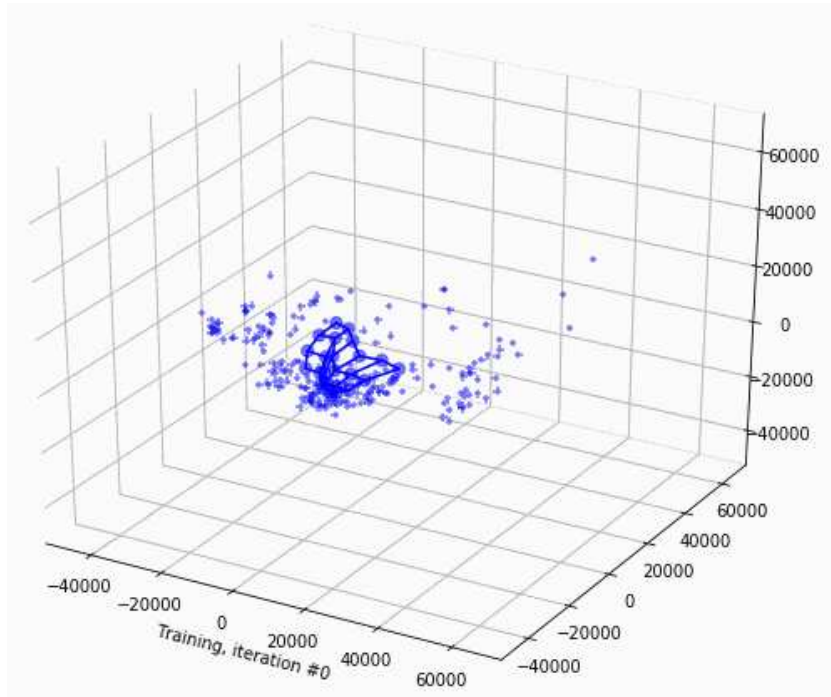
Control
Maintaining productivity (e.g. increasing viscosity)



Automatic anomaly detection for time series

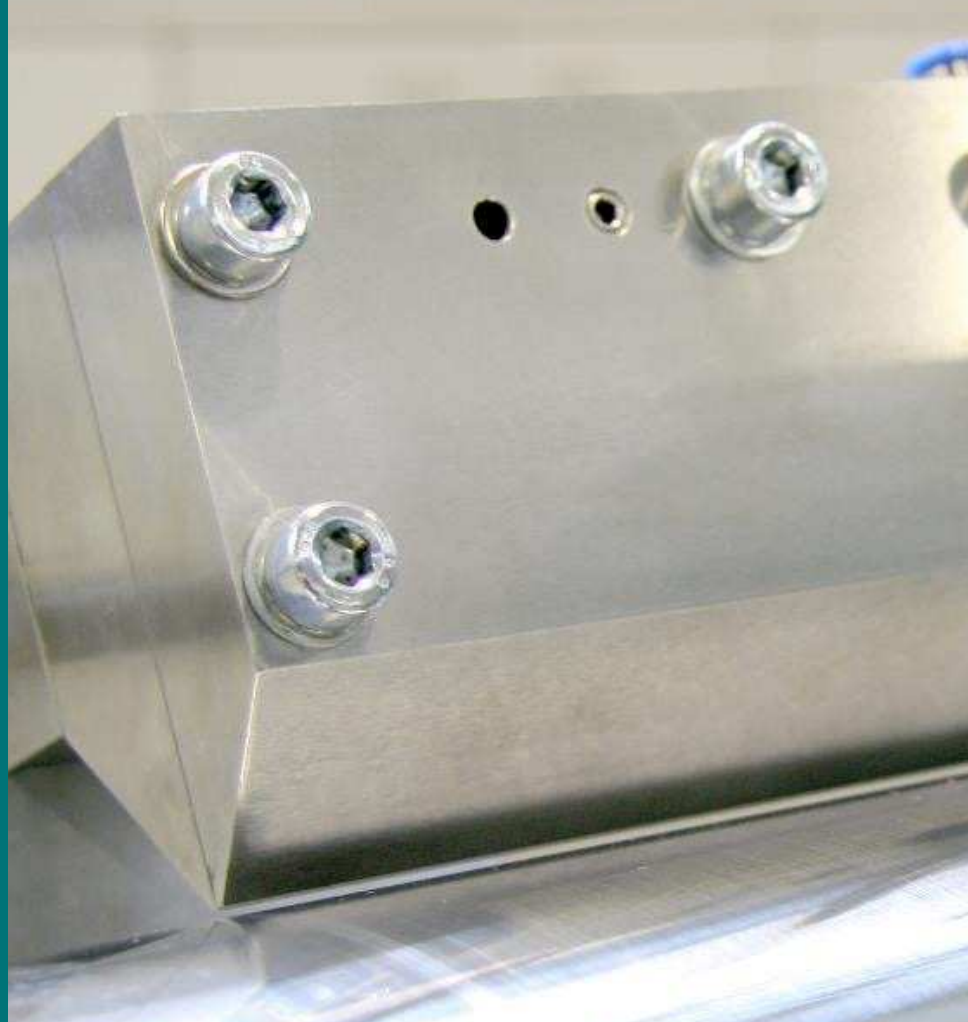


... what the algorithm is doing



5.

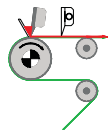
Slot die coating for 3rd Gen PV



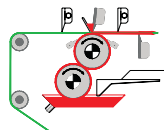
Coating parameters

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

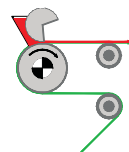
Coating systems



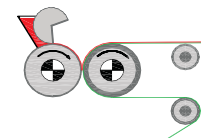
Knife system



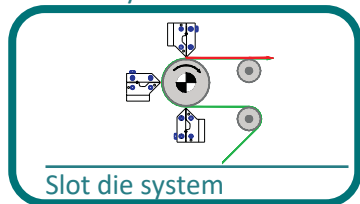
Double side coating system



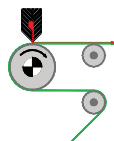
Commabar system



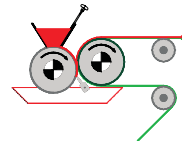
Reverse commabar system



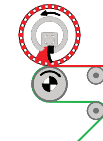
Slot die system



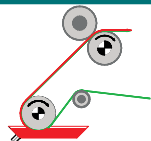
Curtain coating system



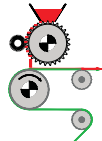
Case knife system



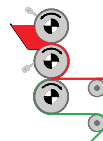
Rotary screen system



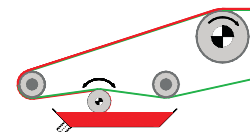
Dipping system (Foulard)



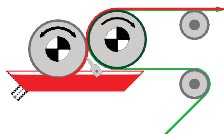
Powder scattering system



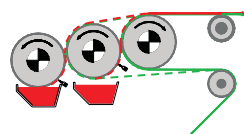
Reverse roll coating system



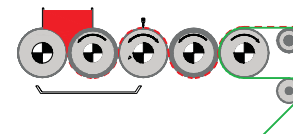
Micro roller coating system



2-roller coating system

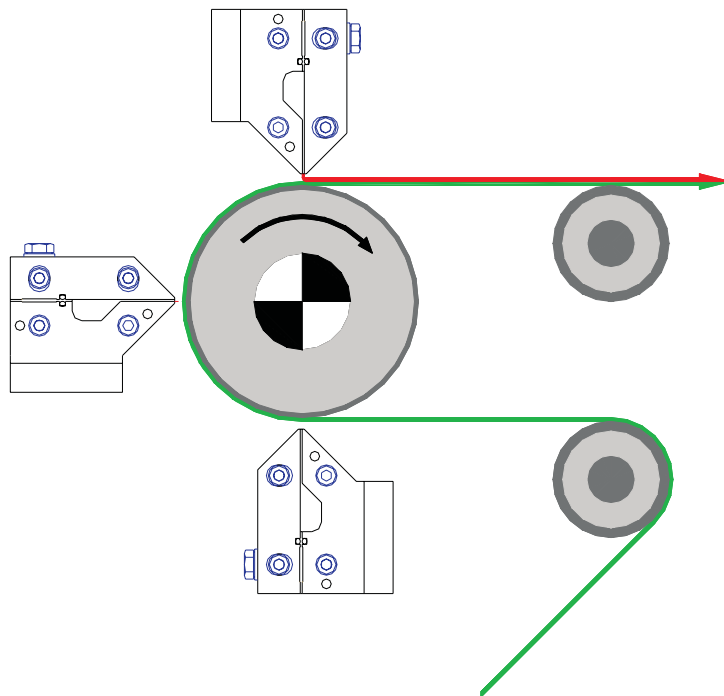


3-roller combi coating system



5-roller coating system

Basics of slot die coating – range of parameters



Coating speed

✓ 0.1 – >1000 m/min

Ink viscosity

✓ 1 – 300 000 mPas

Layer thickness (dry)

✓ 0.1 – >200 μm

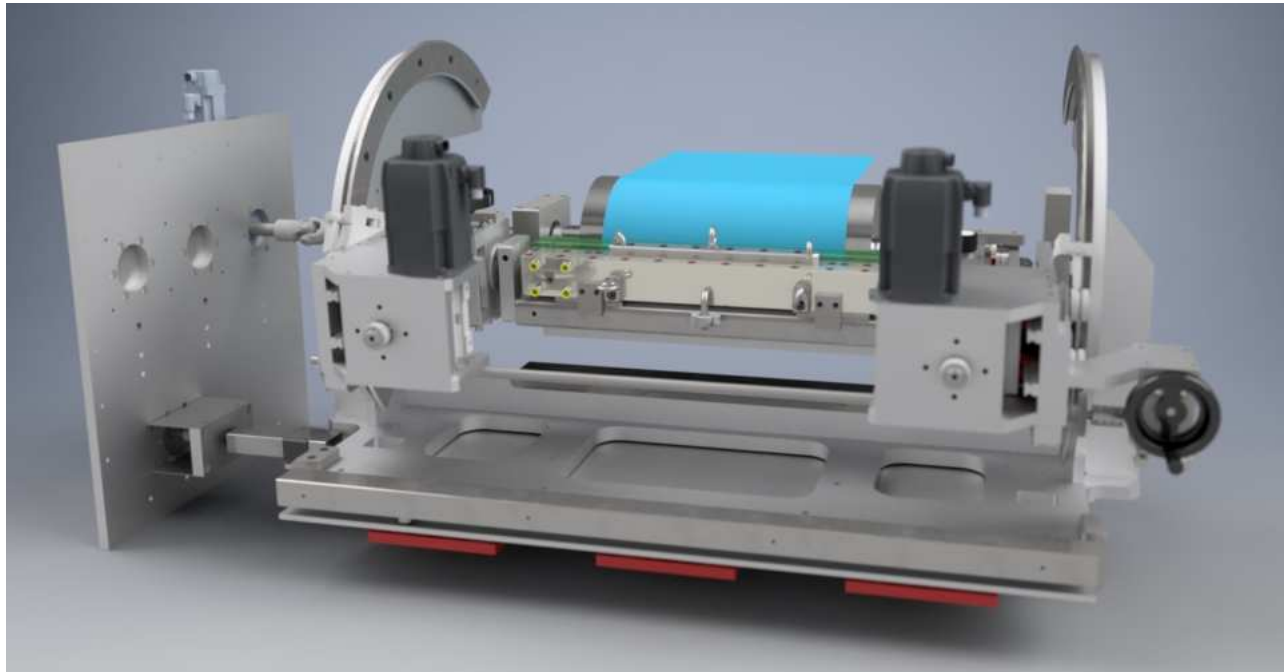
Coating accuracy

✓ <1% (2 – 5%)

Coating width

✓ up to approx. 3 m

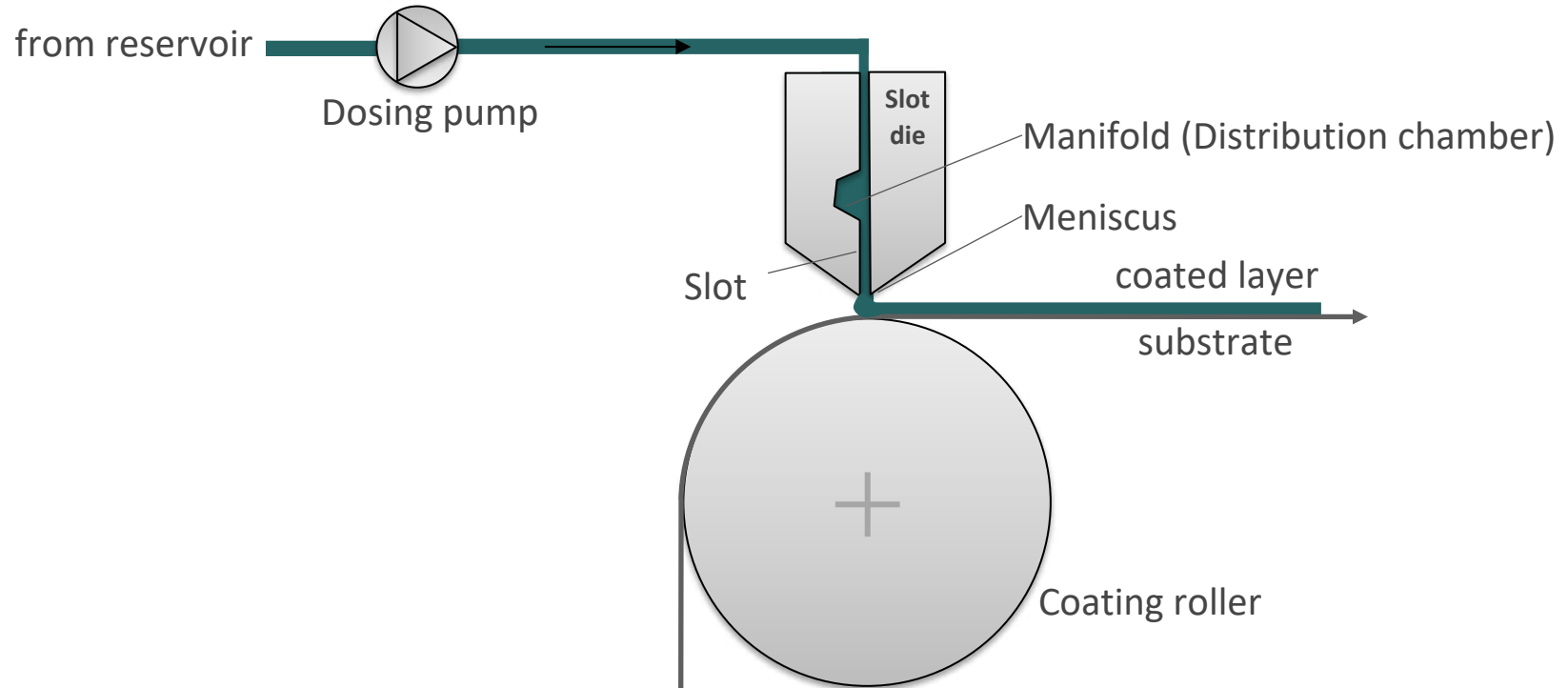
Basic principle



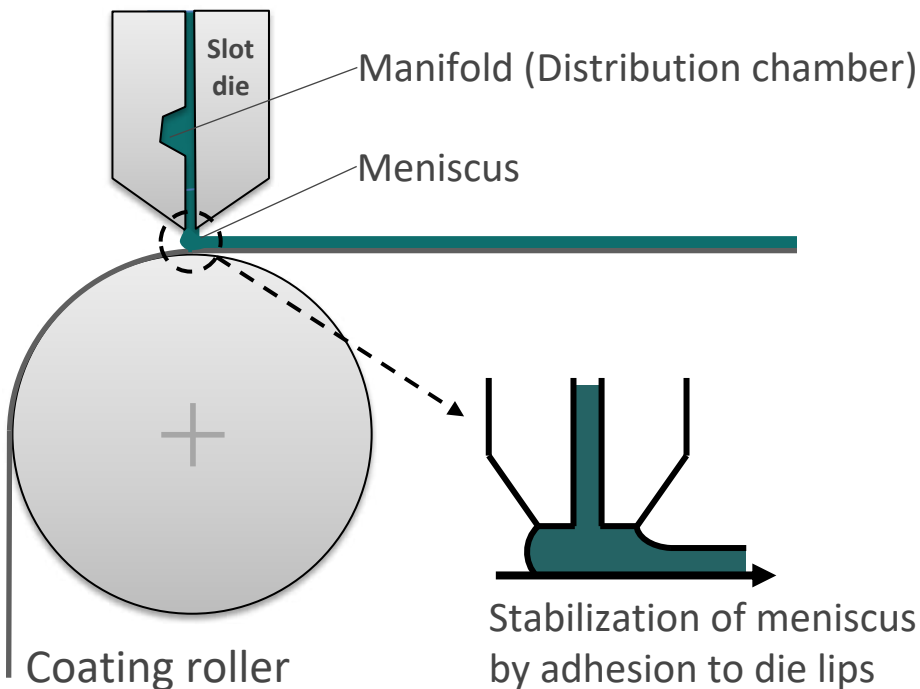
Basic principle



Basic principle

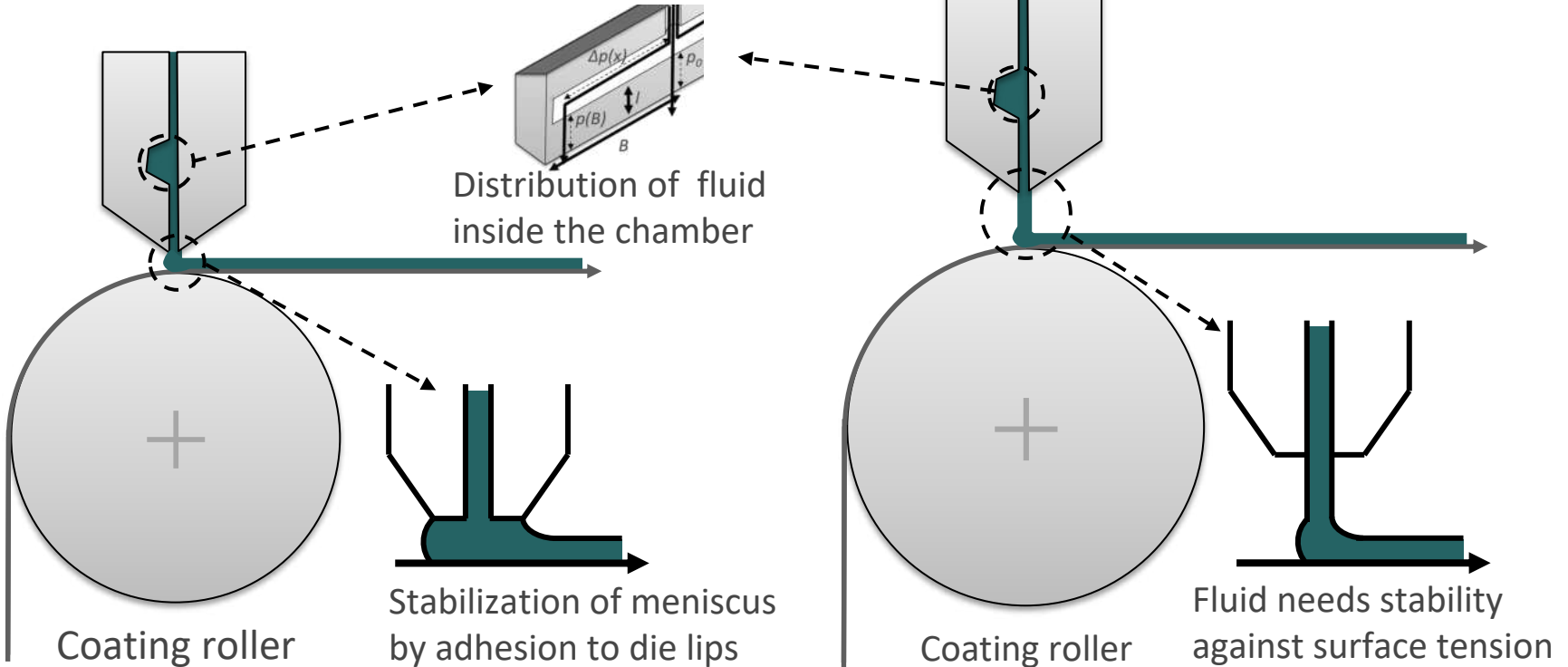


Bead mode

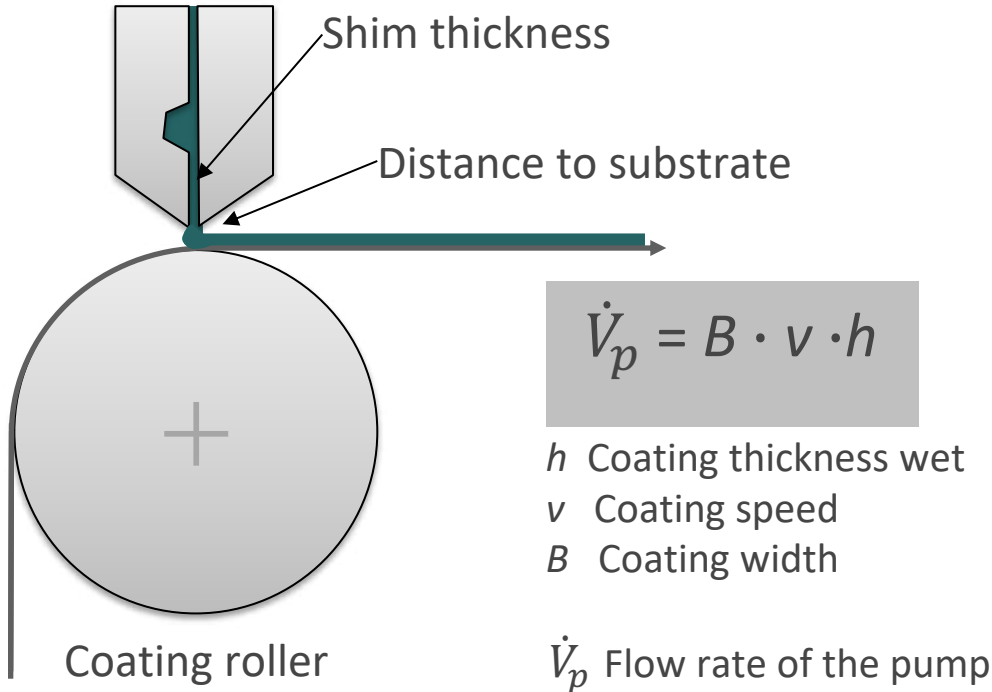


- ✓ Meniscus is formed between die lips and substrate
- ✓ Adhesive stabilization of meniscus by die lips
- ✓ Very low minimum flow rate possible
- ✓ For a stable process the range of rheological parameters is limited
- ✓ Preferably for low coating speed

2 + 2 = 3 aspects of slot die coating



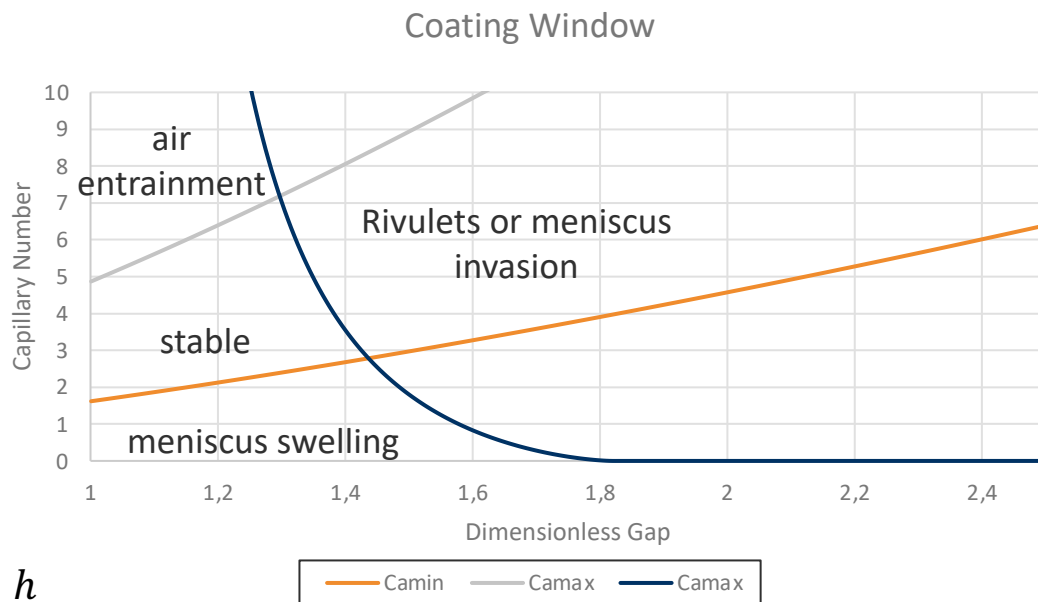
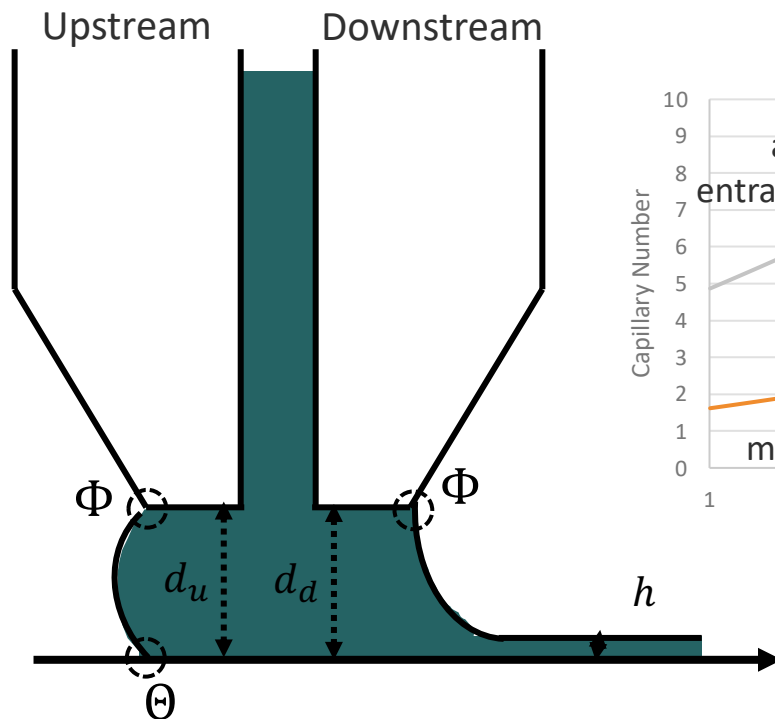
Theoretical background



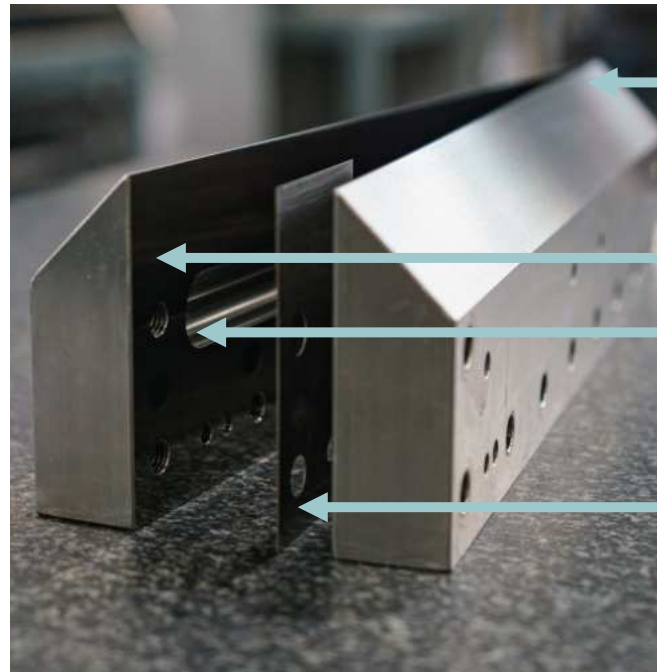
Contrary to a widespread misunderstanding the wet coating thickness does not depend on the shim thickness.

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

Calculation of the meniscus stability



Coatema standard layout – one design among many available







Lips

Slot area

Manifold

Shim

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

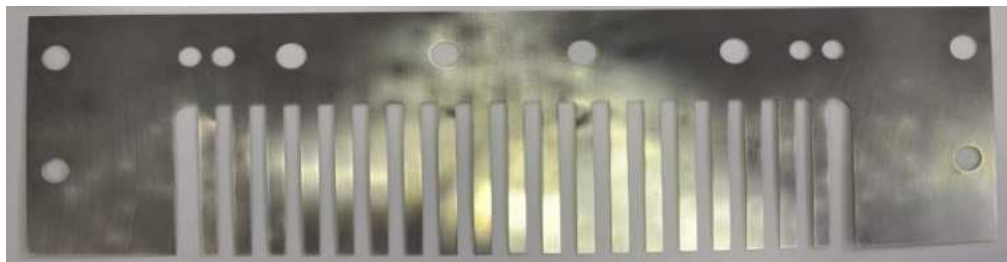
Level 2 – downweb stripes



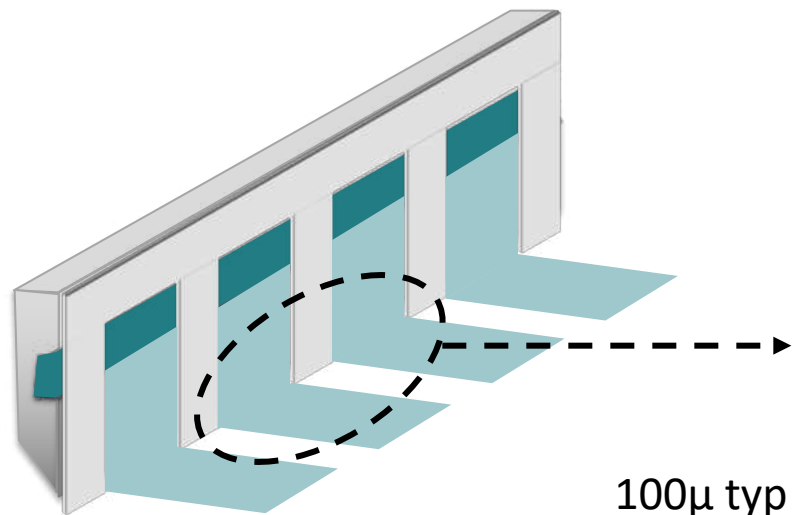
Downweb stripes of different width ...



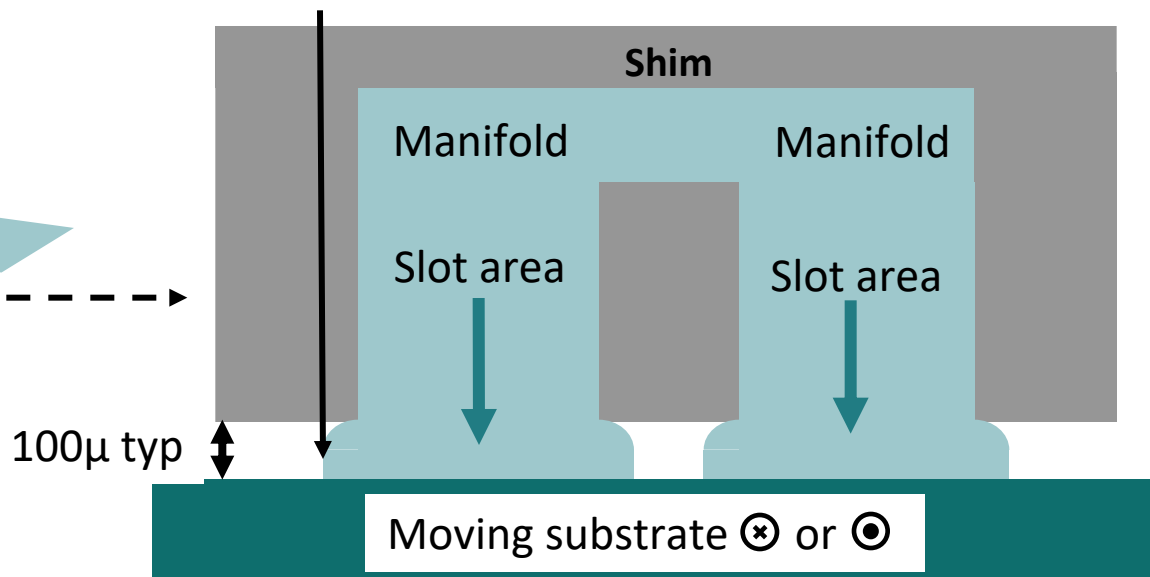
... are made by appropriate shims, lasercut from steel or kapton



Level 2 – downweb stripes

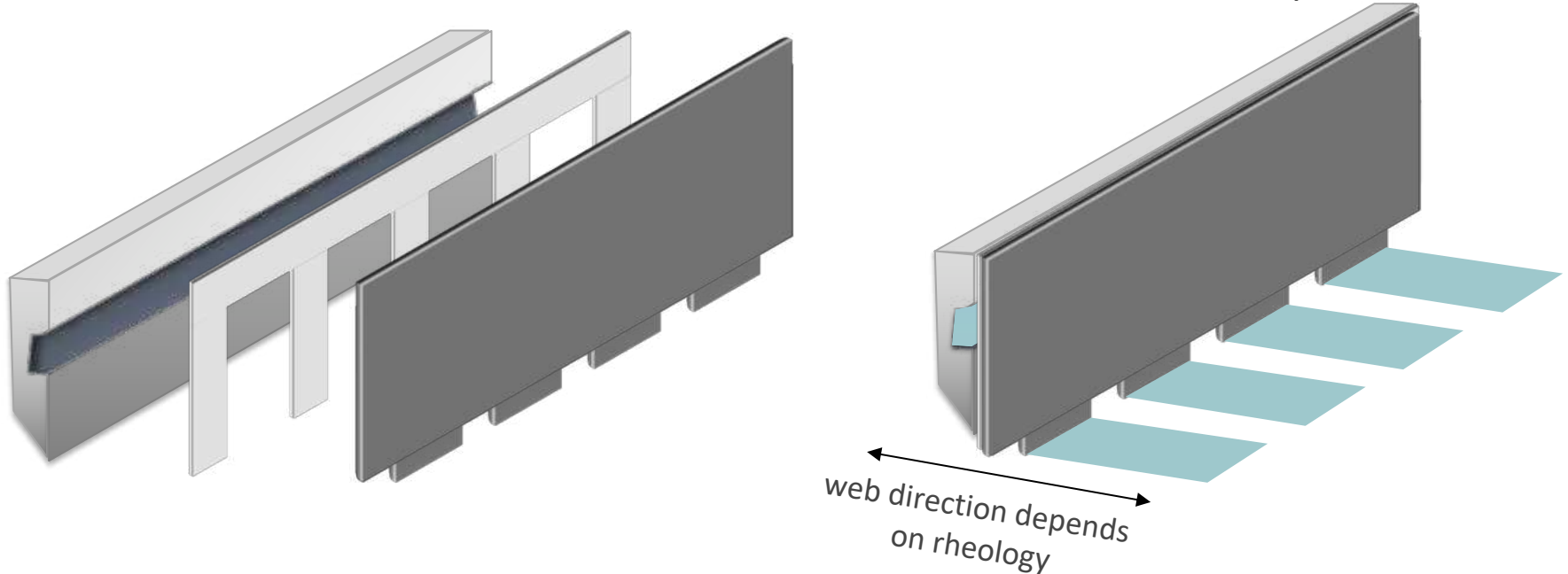


Problem:
Stripe widening by capillary forces at the edges of the shim teeth

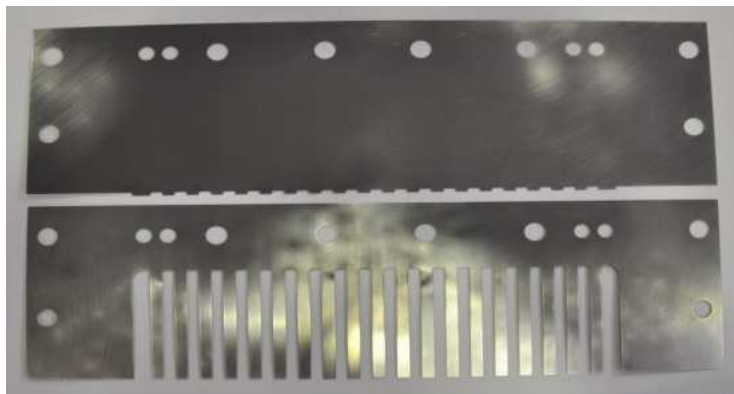


Level 2 – downweb stripes

Manifold + Shim + Meniscus guide = well defined stripes

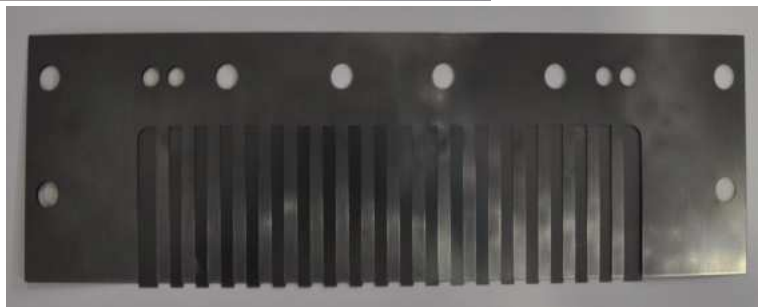


Level 2 – downweb stripes

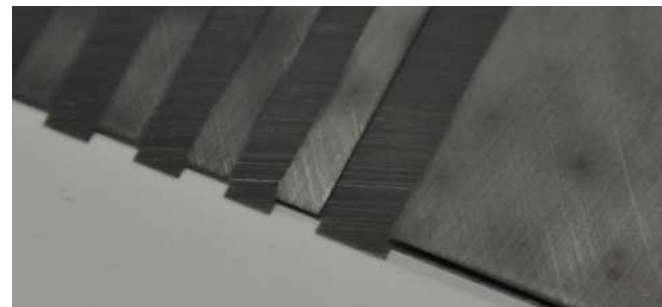


Meniscus guide

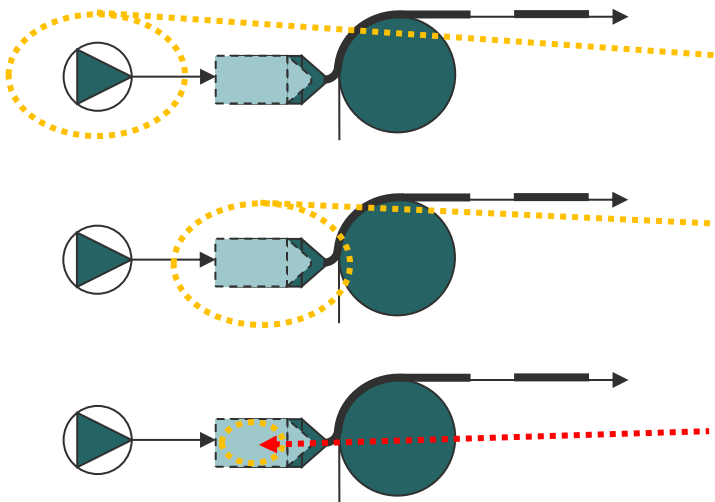
Shim



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)

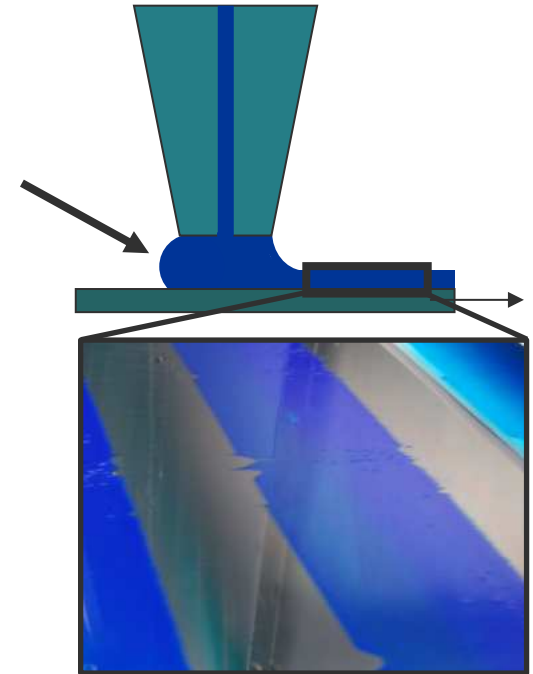
Slot die internal:

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

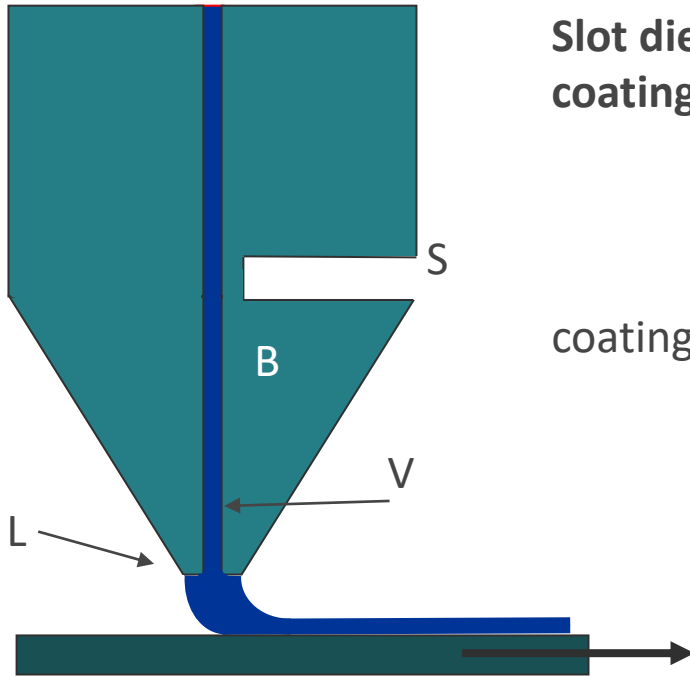
All 3 techniques (single or in combination) work quite well, if the viscosity is rather high and the required edge definition is not more precise than around 1 mm. All techniques may be combined with a vacuum pump upstream to stabilize the meniscus and suck away residual liquid.

Structured coating – reason for bad edges at low viscosity

- ✓ Meniscus has to be interrupted
 - ✓ Low viscous liquids do not break along a straight line
 - ✓ Meniscus has to be sucked back and restored
 - ✓ Speed is of essence
- For low viscosity, all of the three methods are too slow and too indirect



Structured coating – the switching slot die lip

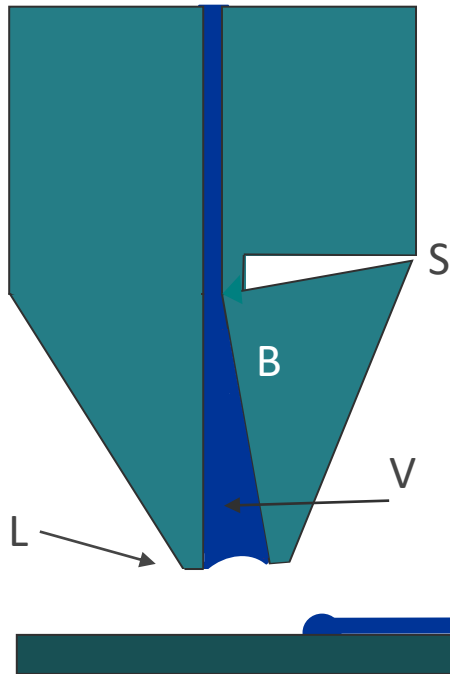


Slot die with movable lips:
coating mode

coating works as usual

- L lip
- V slot volume
- B bendable lip
- S bending slot

Structured coating – the switching slot die lip



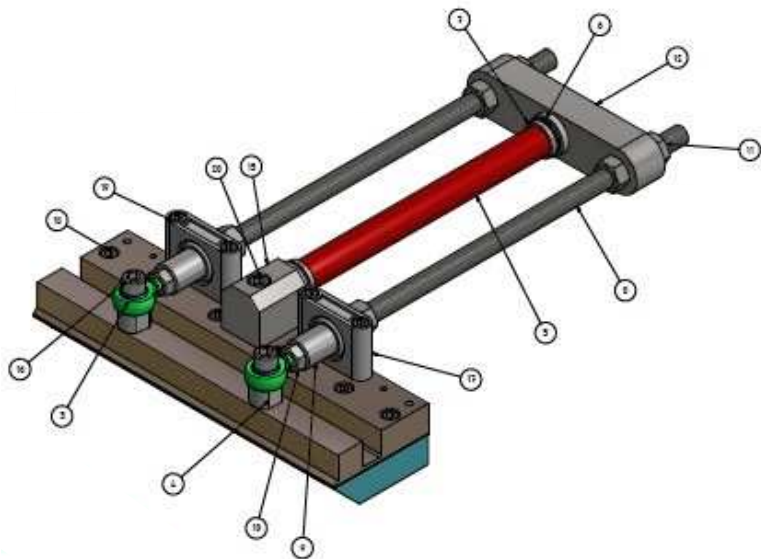
Slot die with movable lips:
stop mode

Bendable lip B flips open

Volume V increases and sucks
away the meniscus

- L lip
- V slot volume
- B bendable lip
- S bending slot

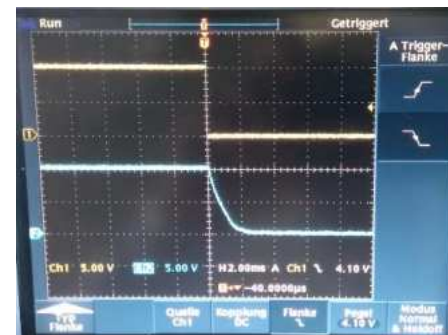
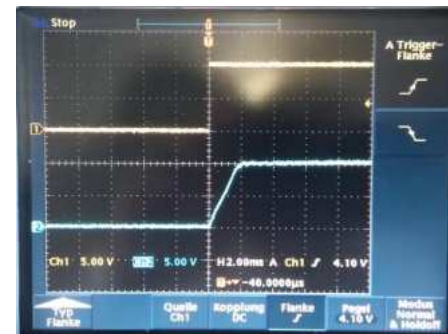
Structured coating – technical implementation with Piezo-Drive



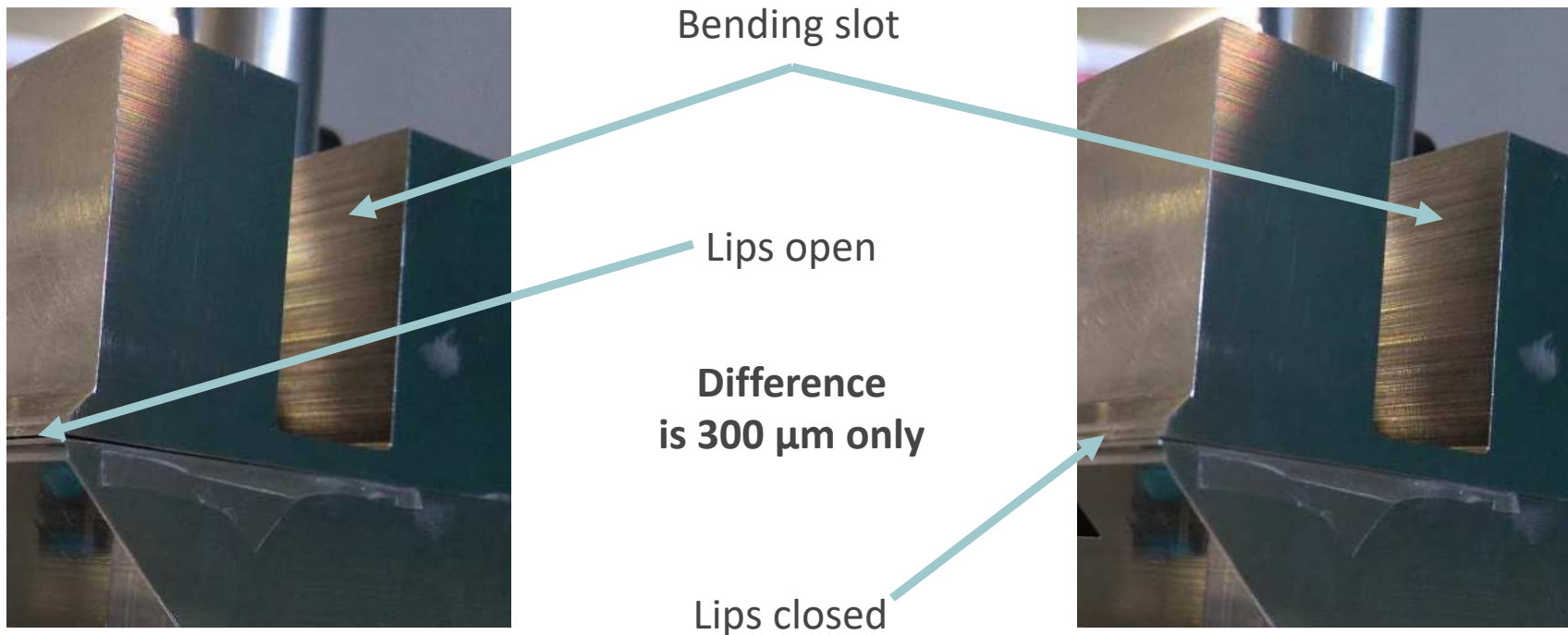
Extremely fast action:
within few ms from coating to
stop mode and vice versa

Control
Voltage

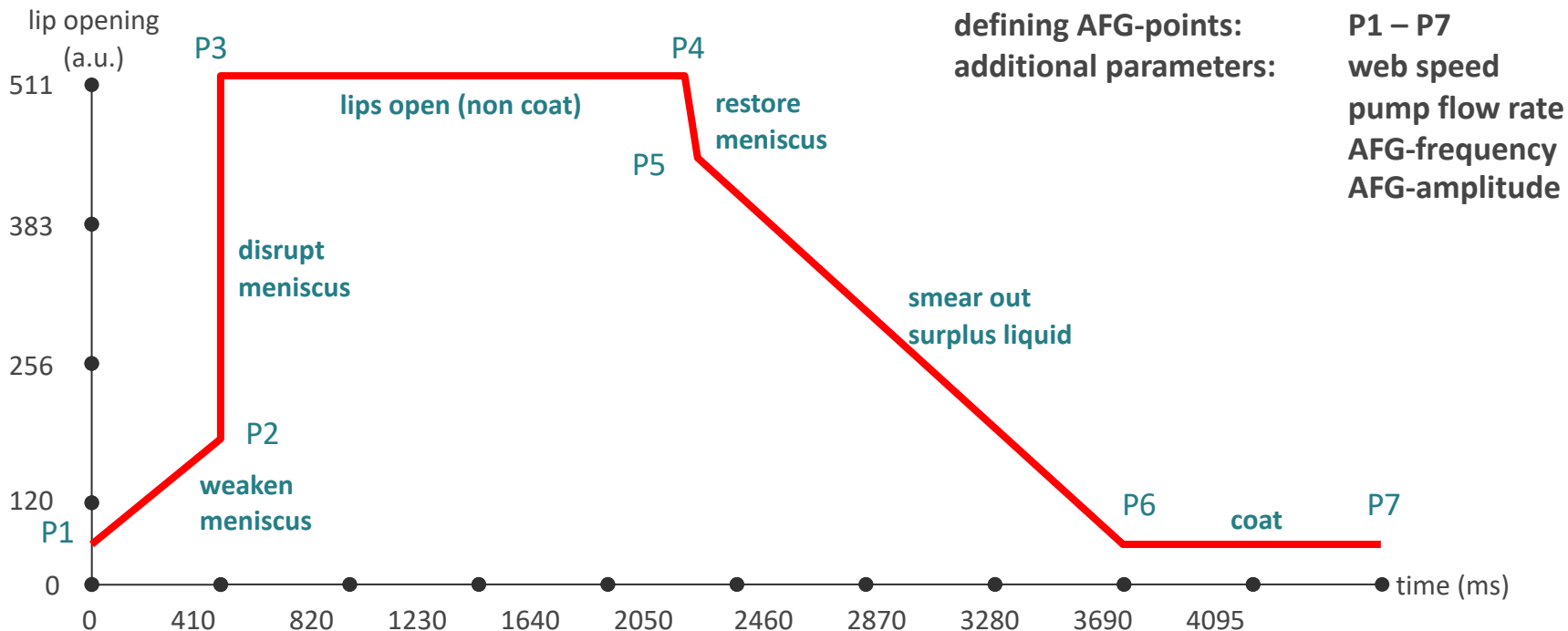
Piezo
Response



Structured coating – technical implementation with bendable lips

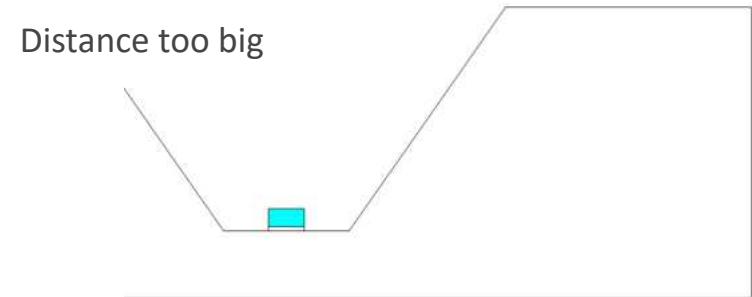
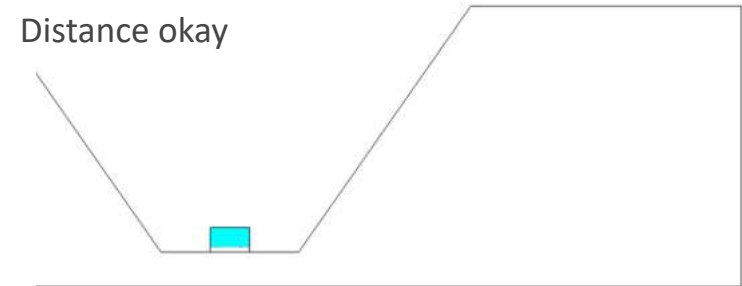


Structured coating – stages of lip motion



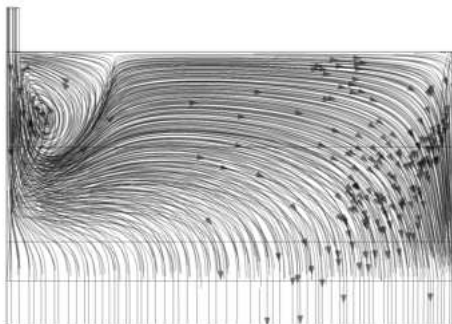
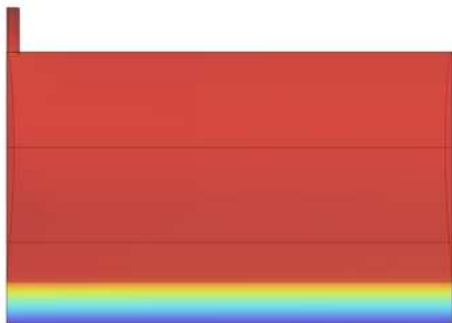
Slot die chamber – Simulation of anode Coating

- ✓ 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

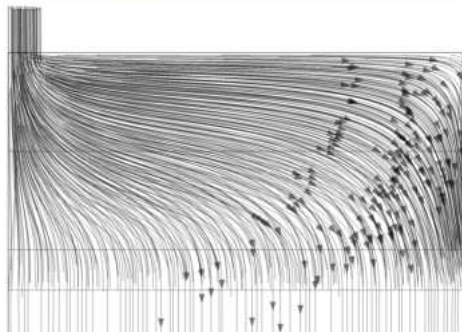


Slot die chamber – Streamlines and pressure distribution

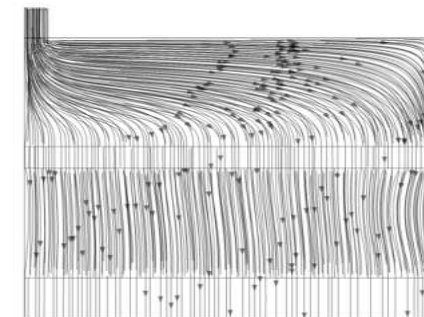
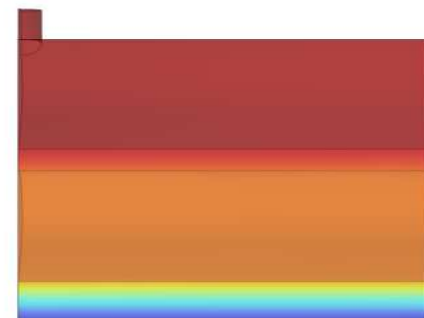
Single Chamber with too small inlet (4 mm)



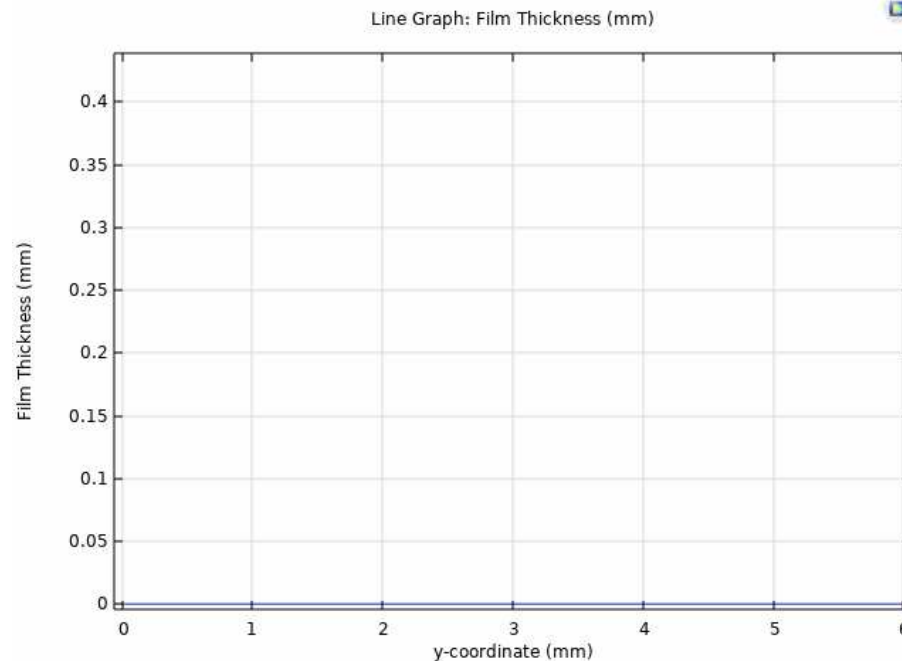
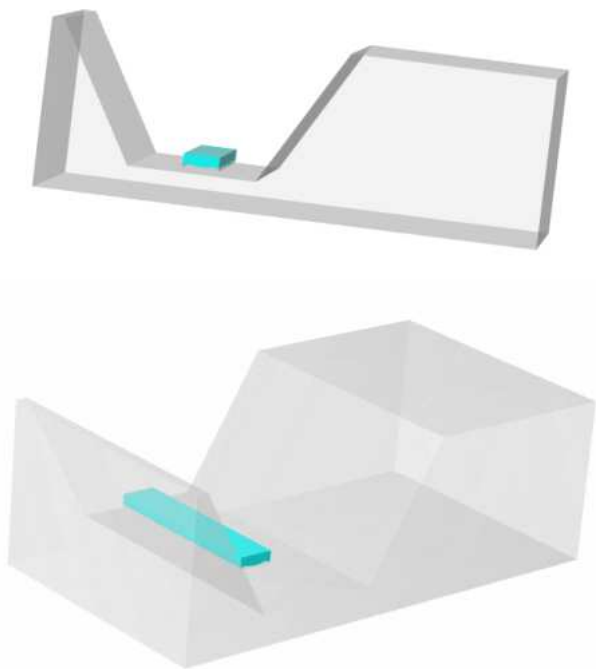
Single Chamber with correct chamber layout (10 mm inlet)



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

Dryer specs needed for the layout

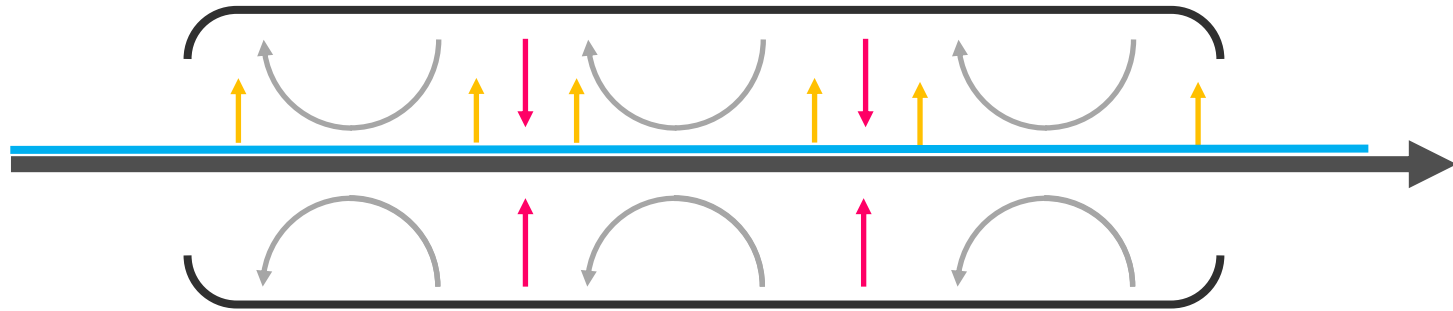
Information about the substrate

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



Source: Drytec

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



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



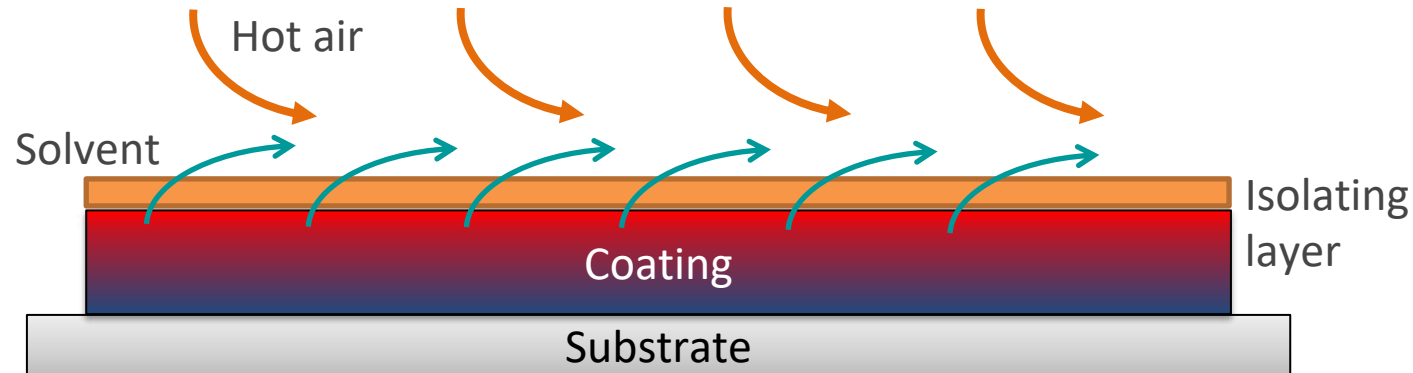
Substrate
Coating
Heat transfer
Evaporating solvent
Solvent vapor transfer



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

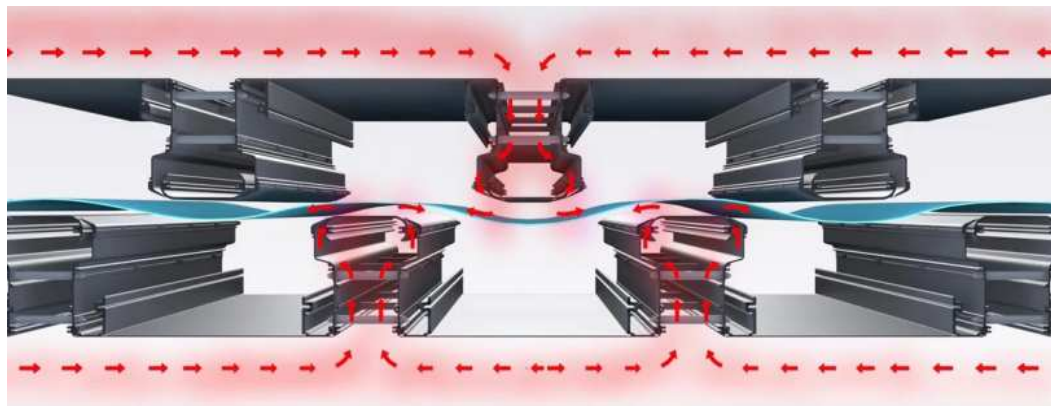


Industrial drying systems

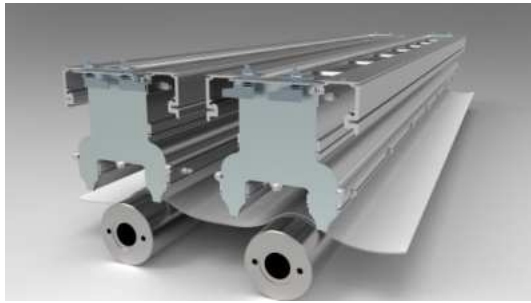
Coatema slot
nozle and
circulation
dryer on small
scale



Drytec Click&Coat™ dryer prinziple



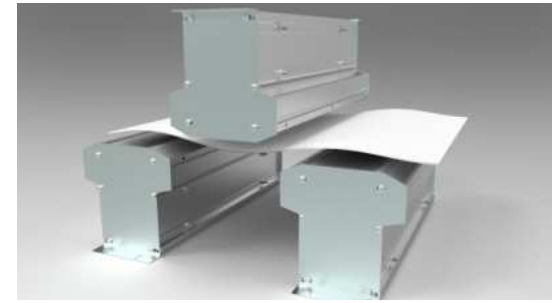
Industrial drying systems: Nozzle shapes 1



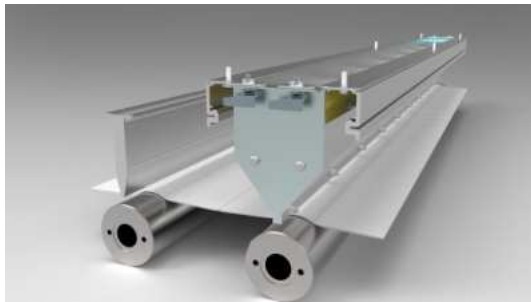
Impingement nozzles with two jets



Flotation nozzles with adjustable air direction



Flotation nozzles

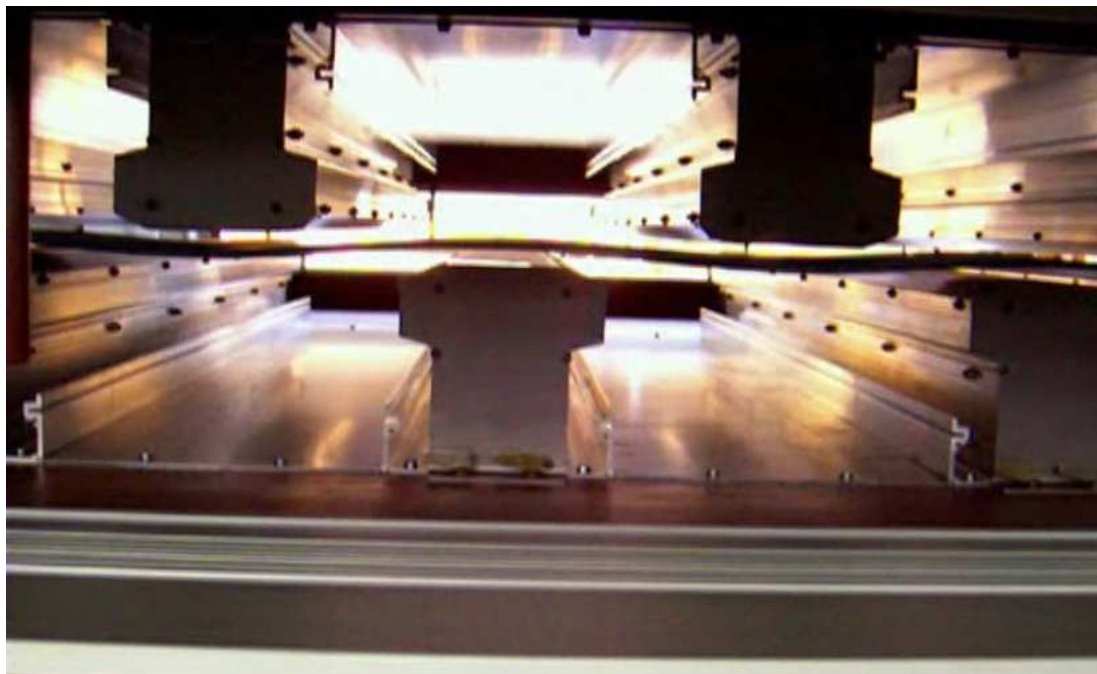


Impingement nozzles with one jet



Flotation nozzles with Contec 3 roller nozzle

Drying topics – drying technologies: HighDry HD500



Web behaviour in a
flowtation dryer

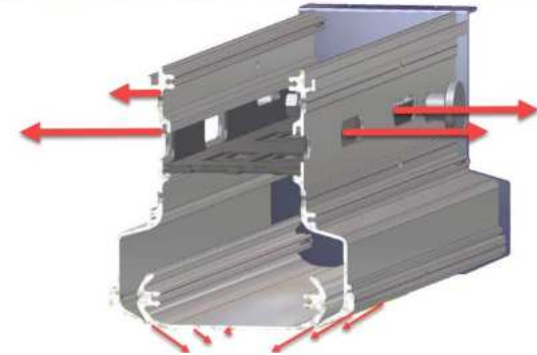
Click on the picture to show the video

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.

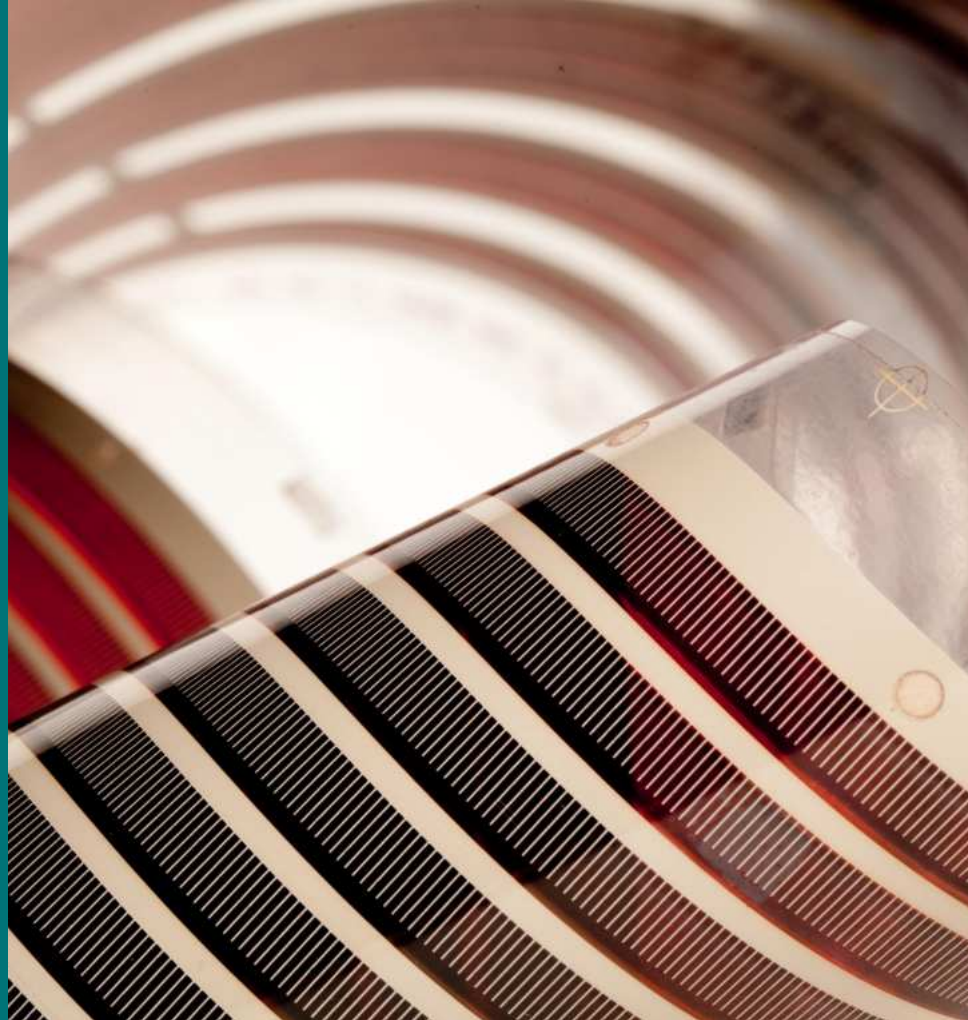
This function is often used, for example, in processes with low-viscosity coatings.

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

Ink testing



Easycoater

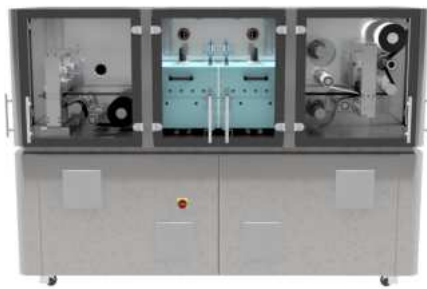
First sample product



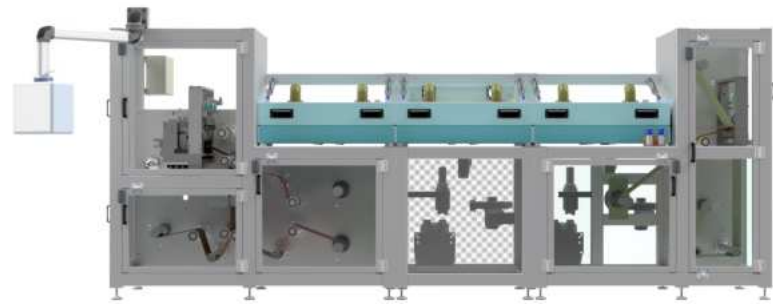
Easycoater Evolution

First pilot as S2S

R2R lab systems



Test Solution R2R



Basecoater R2R



Smartcoater R2R

Today`s equipment for 3rd Gen PV

R2R pilot



Basecoater Pilot R2R

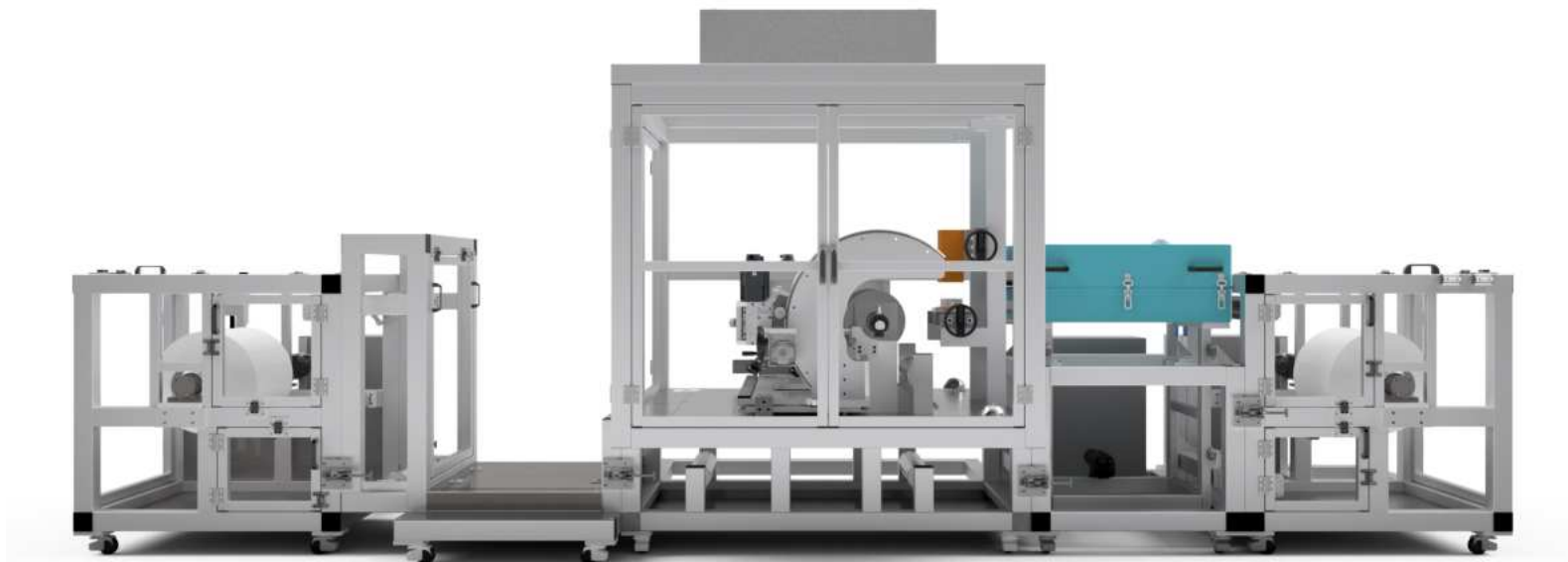
Today`s equipment for 3rd Gen PV

The Basecoater



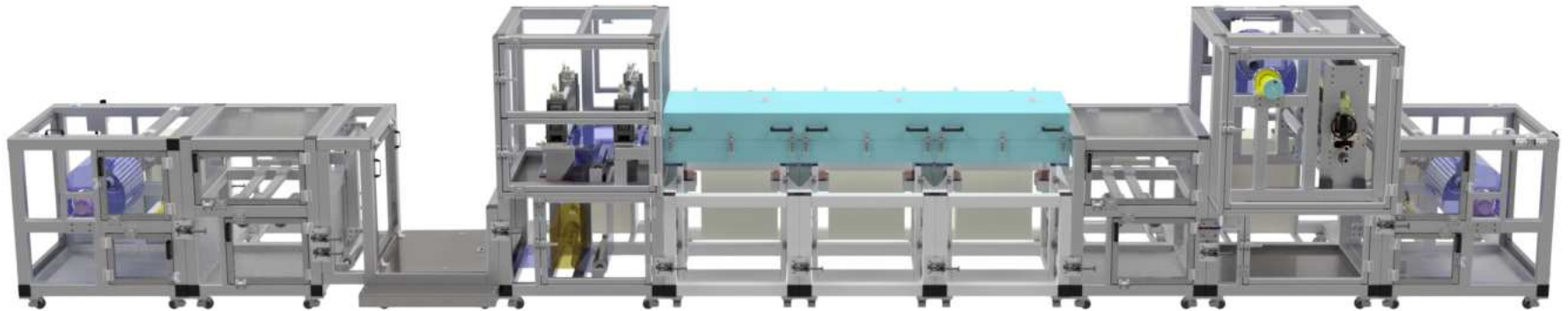
Today`s equipment for 3rd Gen PV

The Click&Coat™



Today`s equipment for 3rd Gen PV

The Click&Coat™



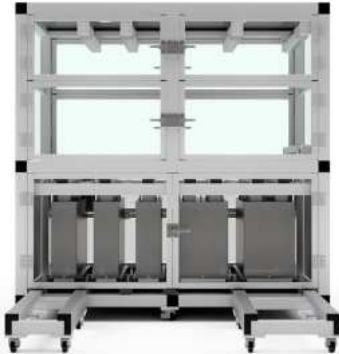
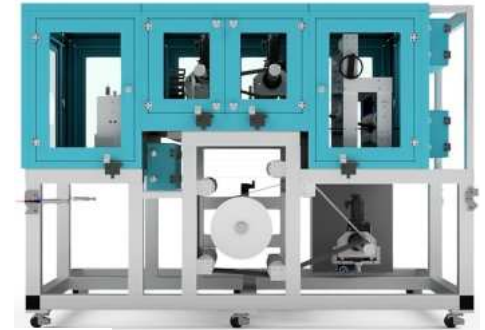
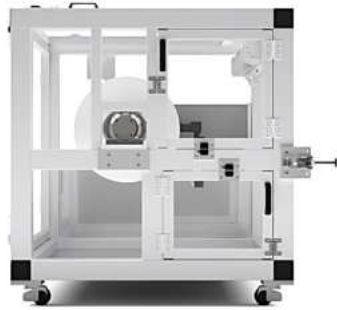
Today`s equipment for 3rd Gen PV

The Click&Coat™



Today`s equipment for 3rd Gen PV

The Click&Coat™ single modules



Today`s equipment for 3rd Gen PV

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



Today`s equipment for 3rd Gen PV

The Click&Coat™ in production scale



Today`s equipment for 3rd Gen PV

The Click&Coat™ in production scale



Today`s equipment for 3rd Gen PV

The Click&Coat[™] in production scale



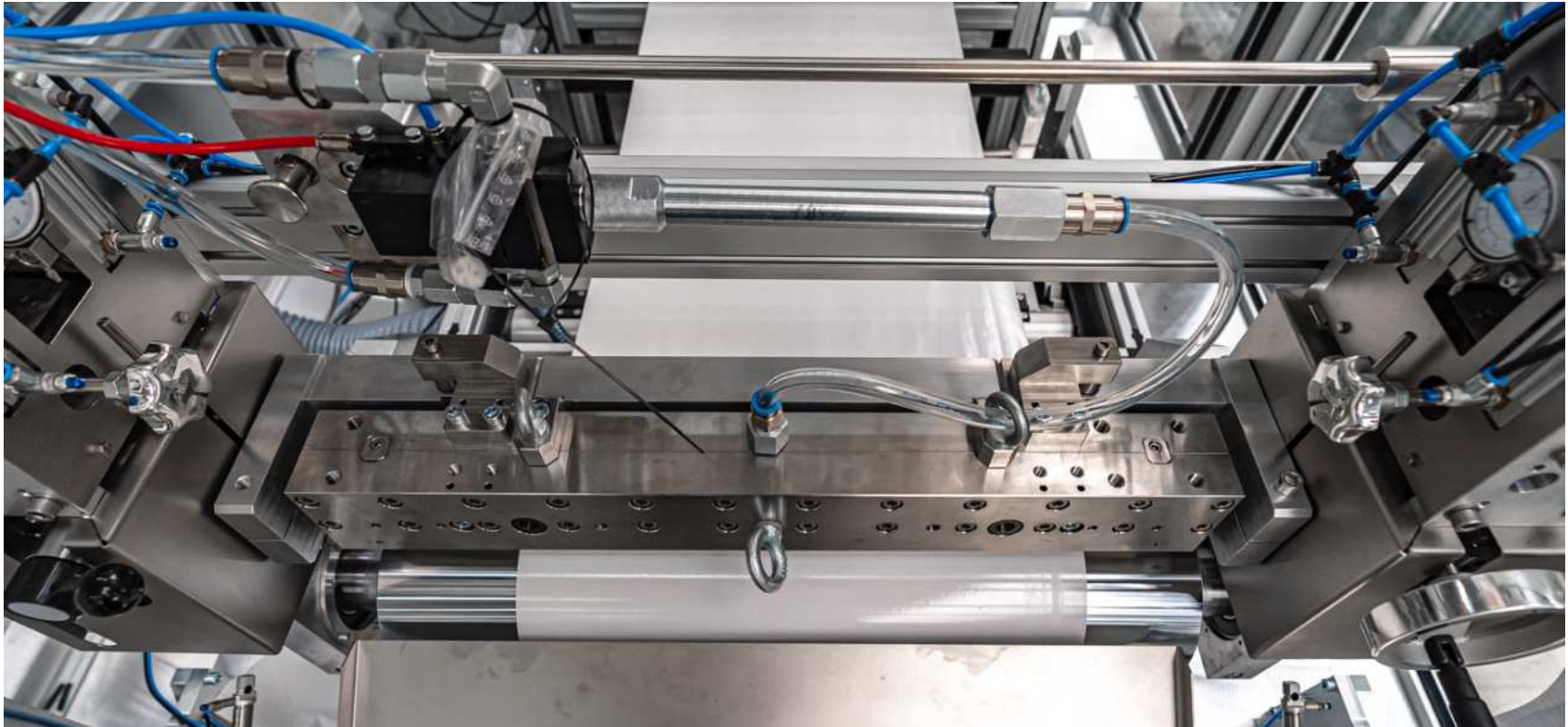
Today`s equipment for 3rd Gen PV



Today`s equipment for 3rd Gen PV



Today`s equipment for 3rd Gen PV



Today`s equipment for fuel cells

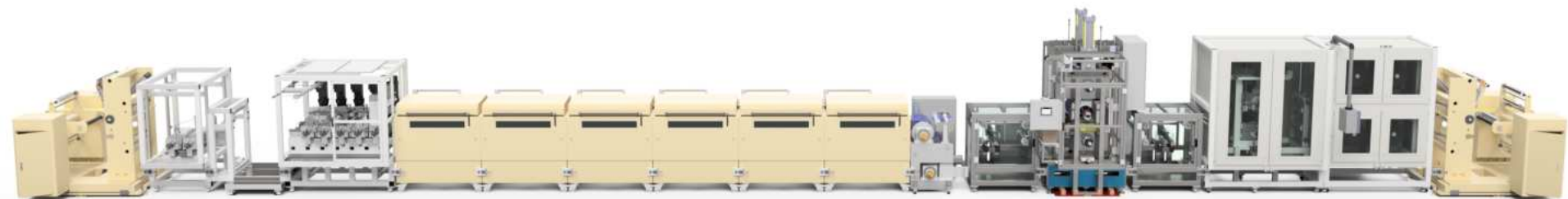


Today`s equipment for 3rd Gen PV



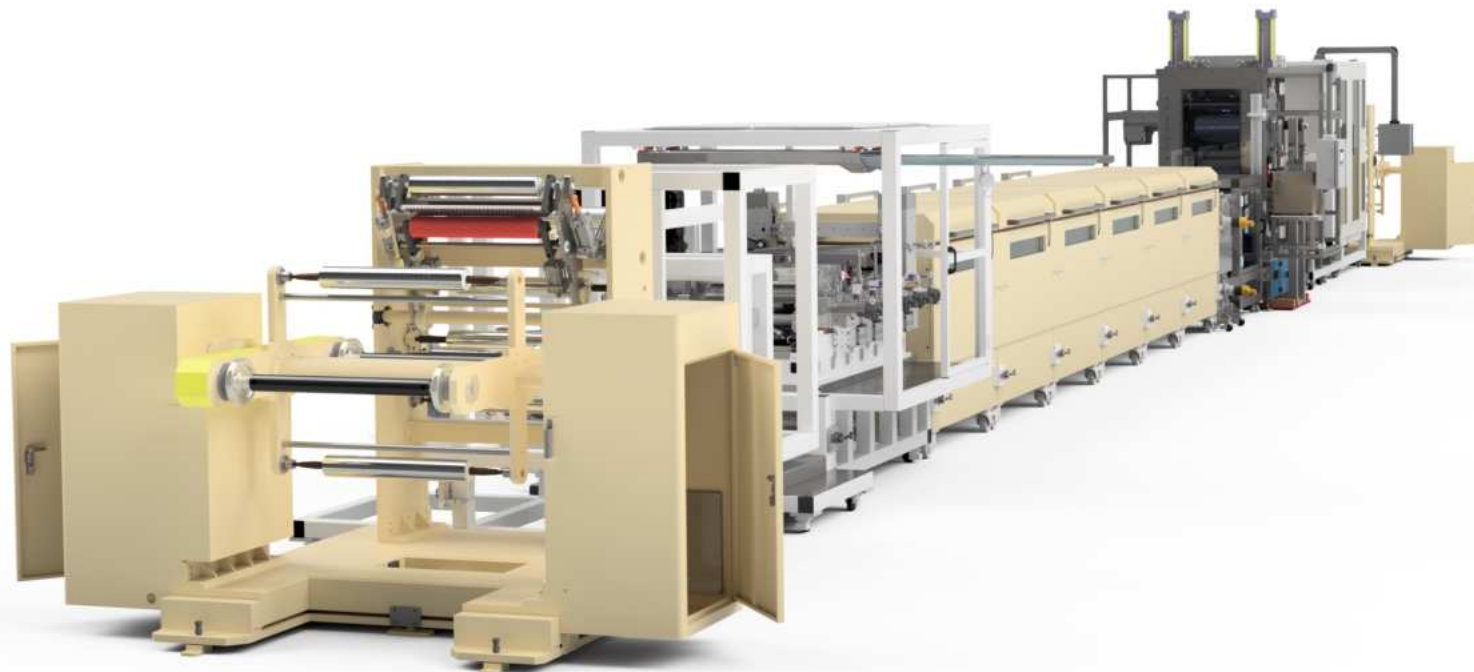
Today`s equipment for 3rd Gen PV

The Click&Coat[™] in production scale



Today`s equipment for 3rd Gen PV

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!

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