

*Hochfunktionelle Oberflächen
für bio(basierte) Materialien
mittels industrieller
Atmosphärendruck-
Plasmabeschichtung*

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Gefördert mit
Mitteln des
Österreichischen
Waldfonds

Mit Unterstützung vom

 Bundesministerium
Land- und Forstwirtschaft,
Regionen und Wasserwirtschaft

Bio(basierte) Materialien als Funktionswerkstoffe durch Beschichtung mit atmosphärischem Plasma

2

nachgiebig, abriebbeständig,
brandbeständig, antimikrobiell



elektrisch leitfähig

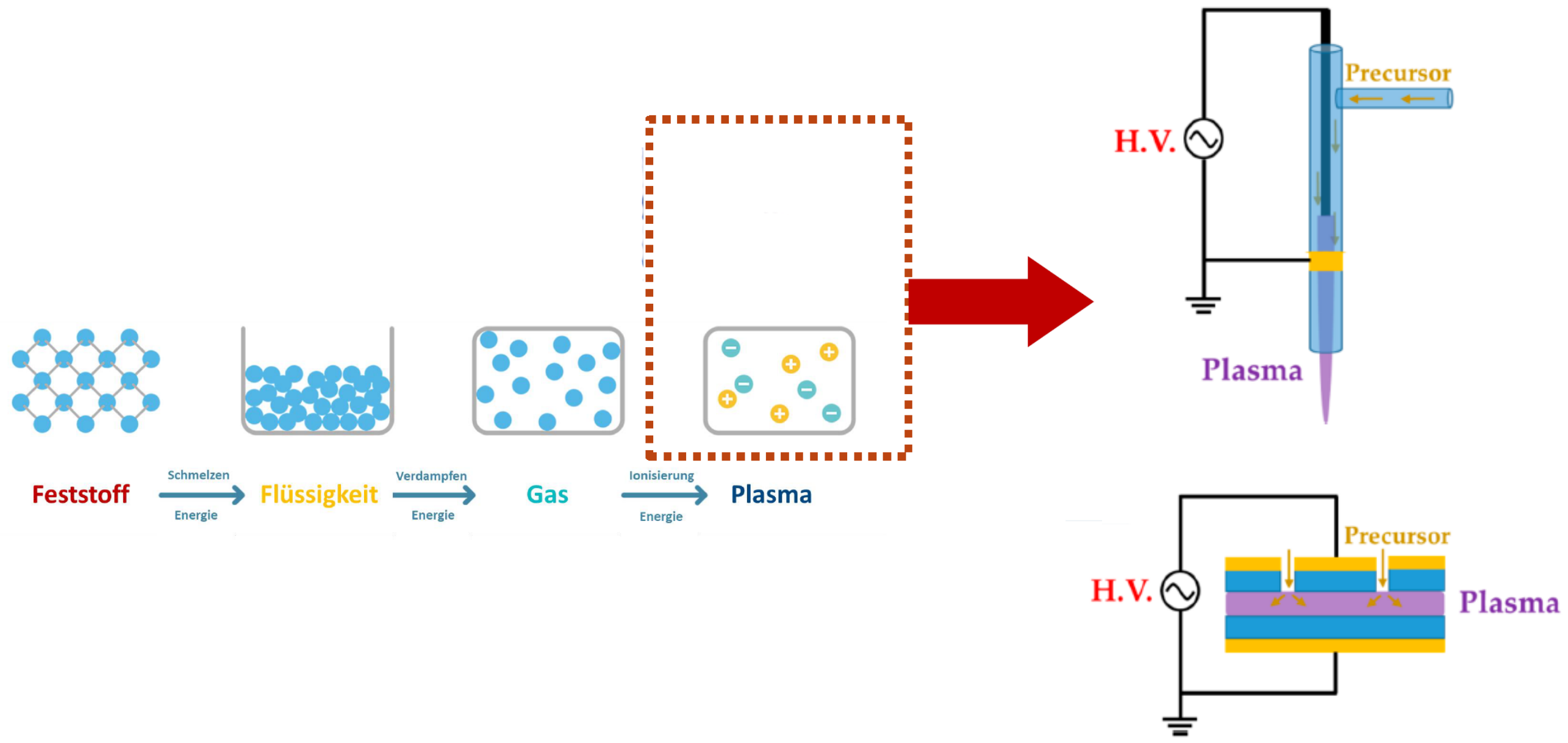


verschleißbeständig,
reibung reduziert



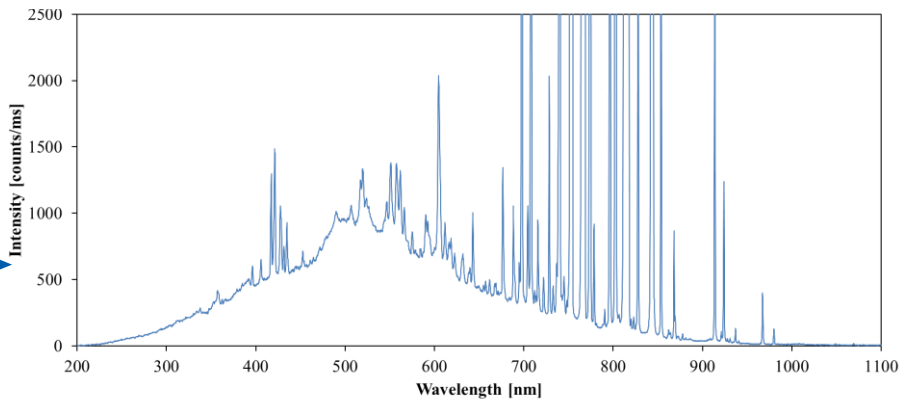
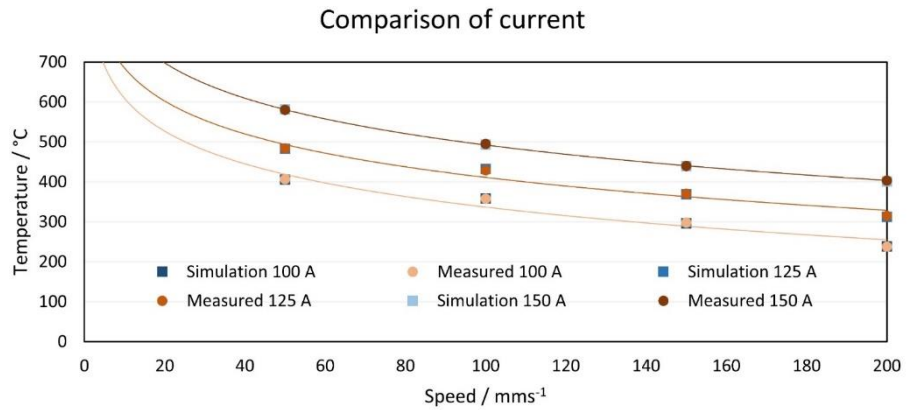
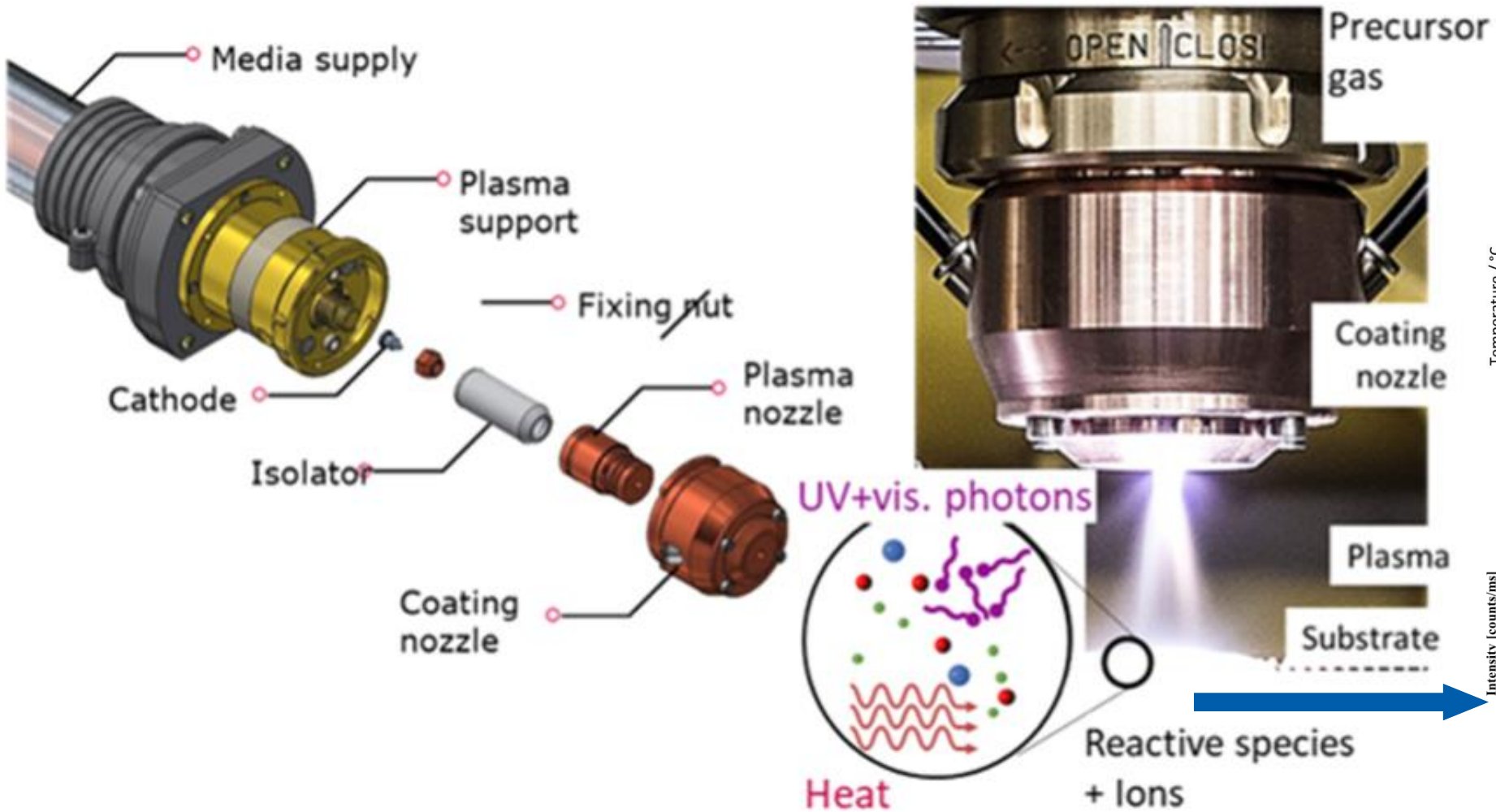
What is Plasma?

How to technically use plasma in atmospheric conditions?



Atmospheric pressure plasma: a high-energy source

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Plasma jet technology for coating deposition

PACVD

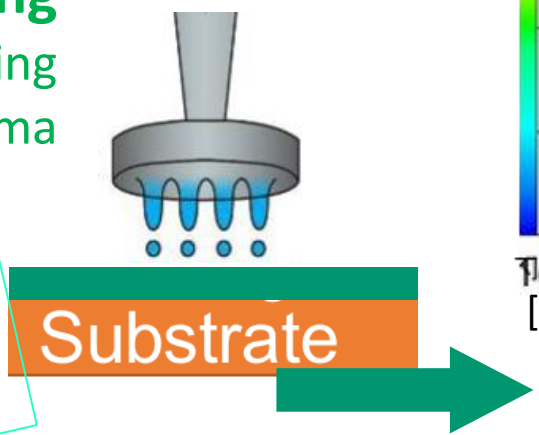
aerosol feed
(H₂O & alcohols + salts or nanoparticles)

plasma spray

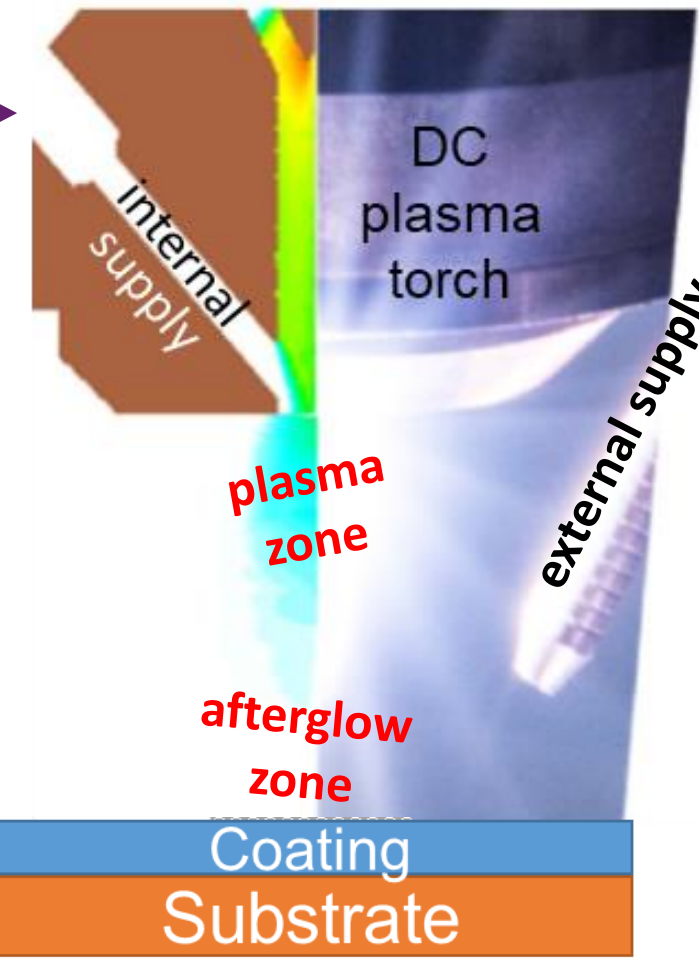
powder feed
(micro- to nanopowders)

pre-coating
for subsequent curing or sintering in plasma

plasma curing & sintering

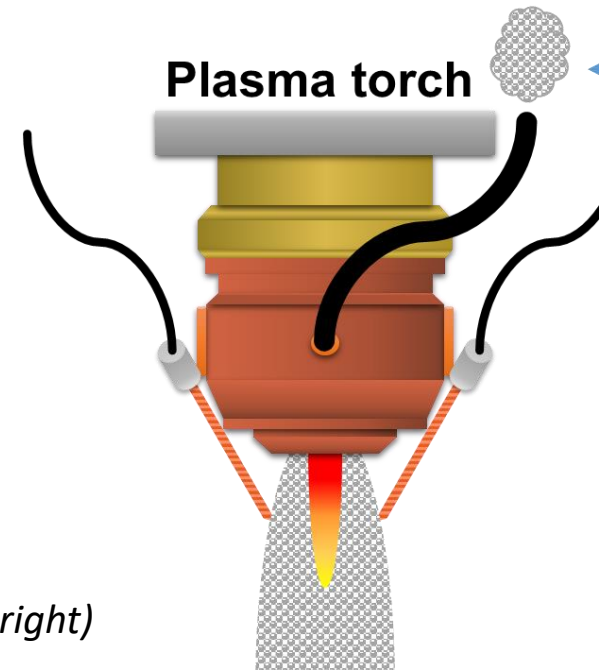


CFD simulation pic during operation



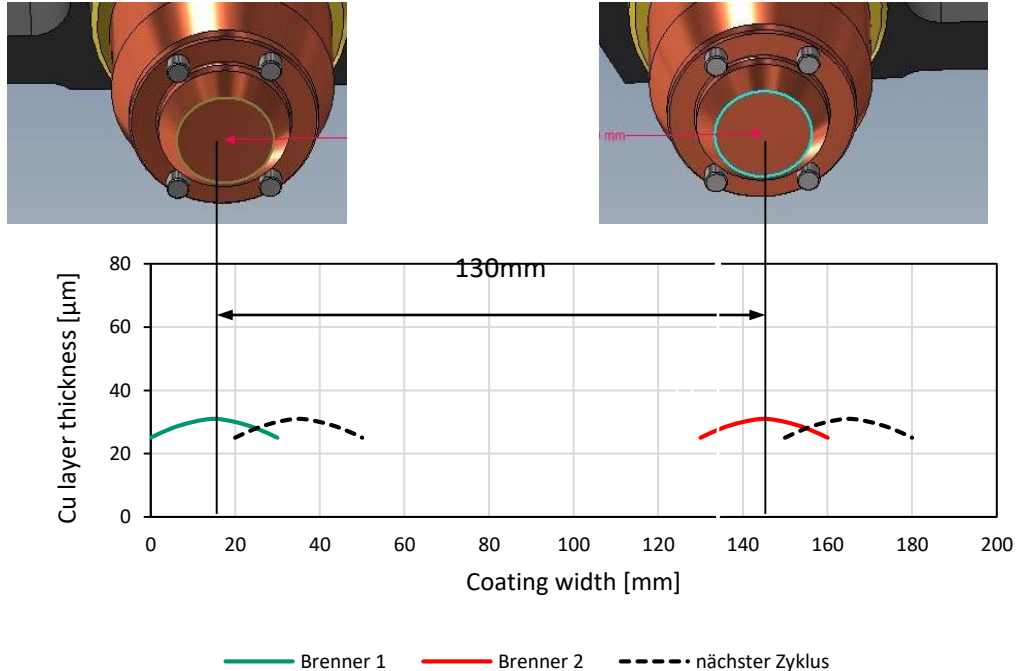
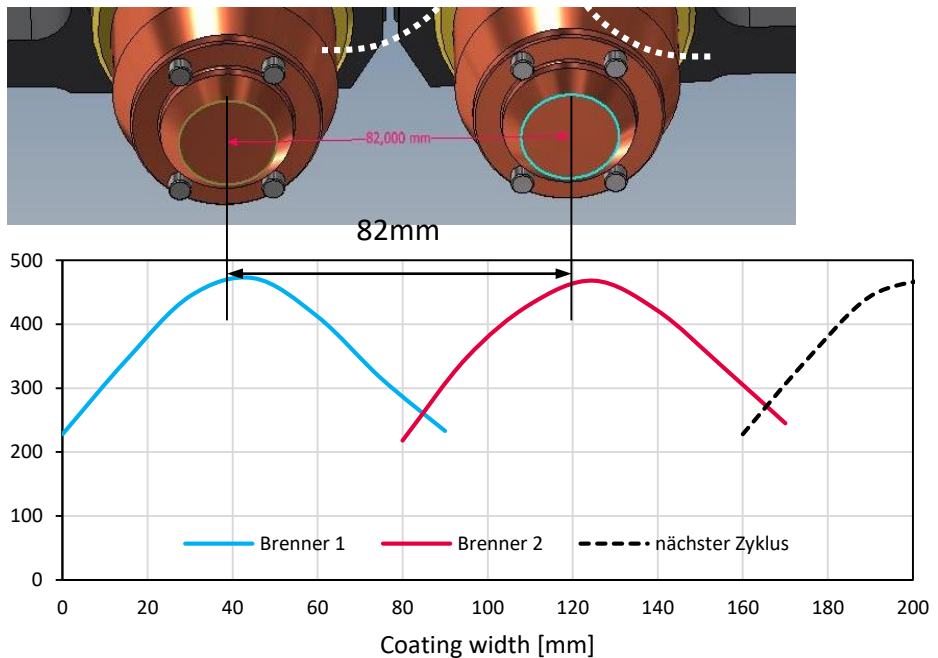
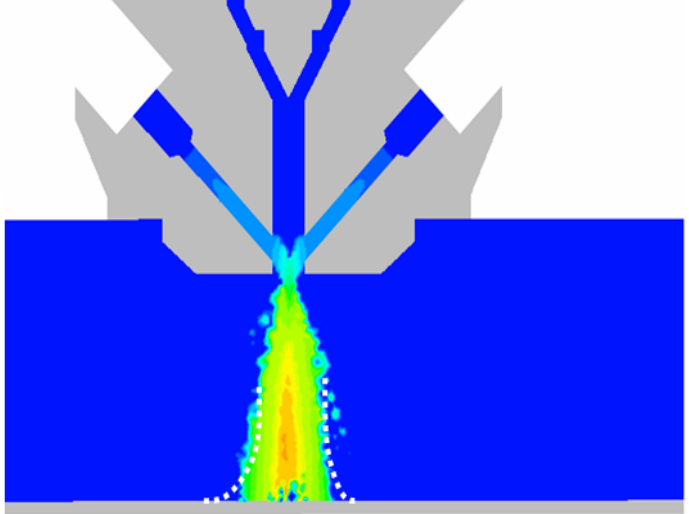
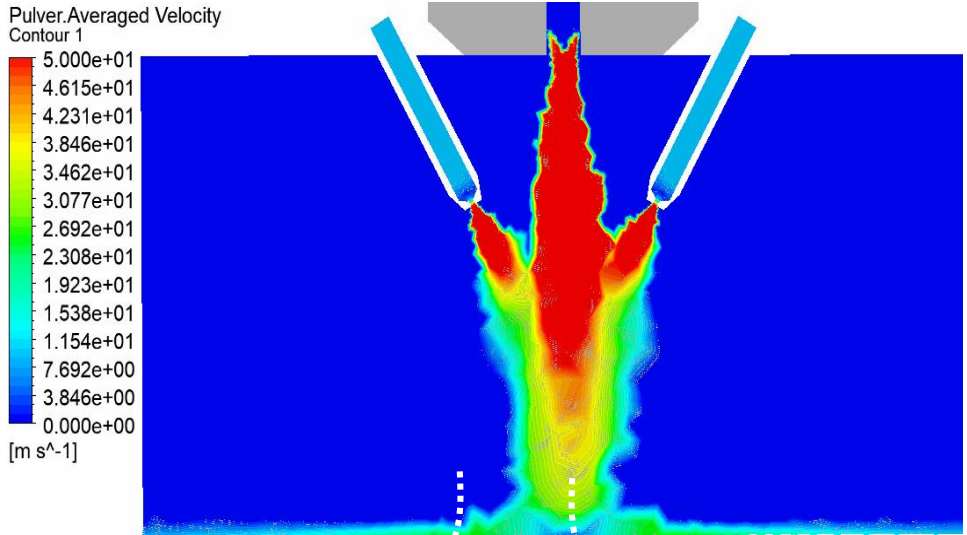
PACVD

vapour feed
(evaporated precursor, e.g. HMDSO)

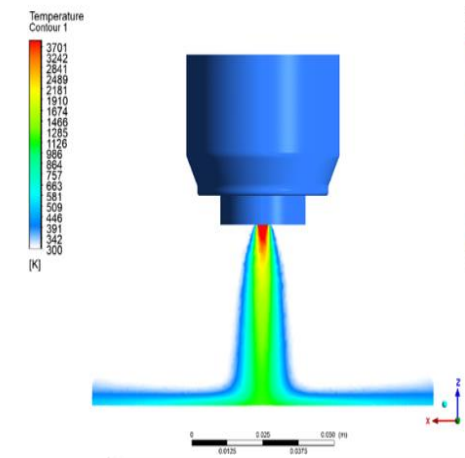
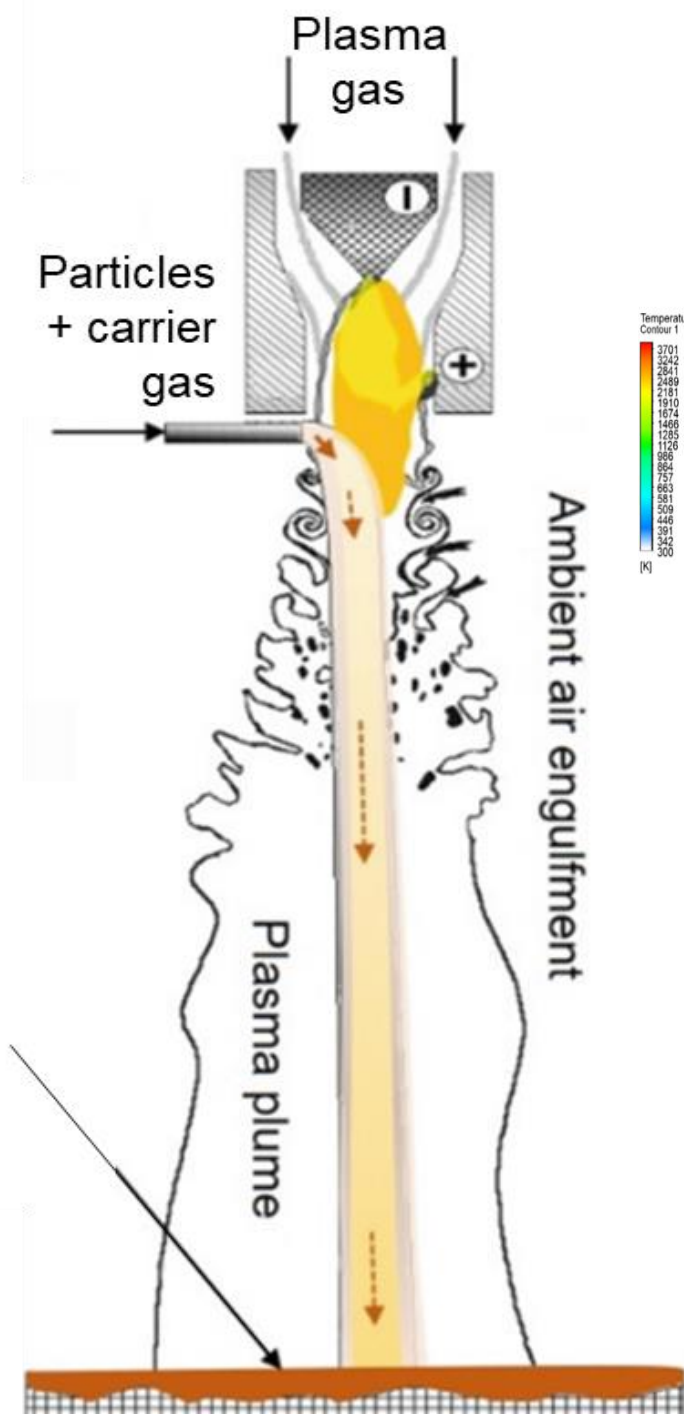


InoCoat 3[®] plasma jet with external nozzles for feedstock supply into afterglow region – (right) in operation and (lower left) in CFD simulation of gas temperature (digital process twin).

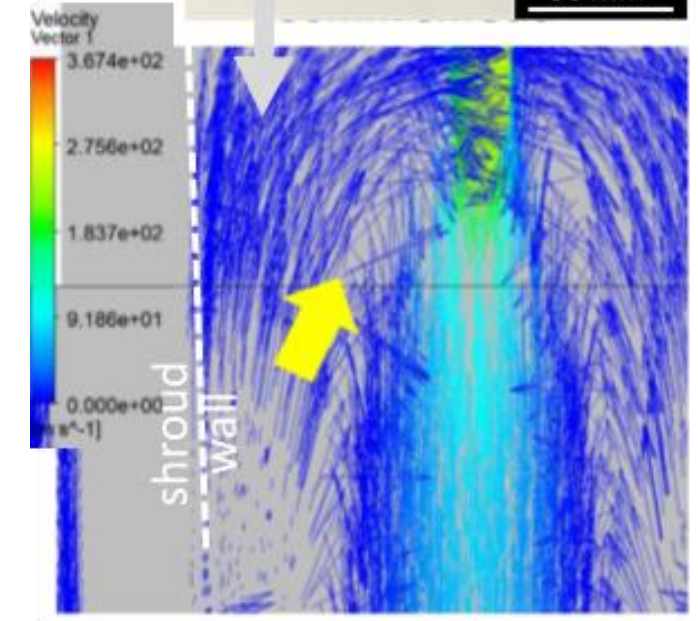
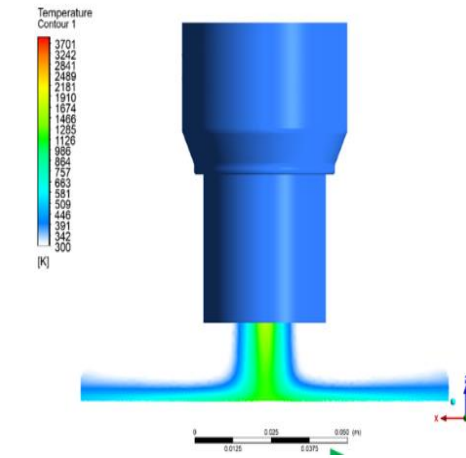
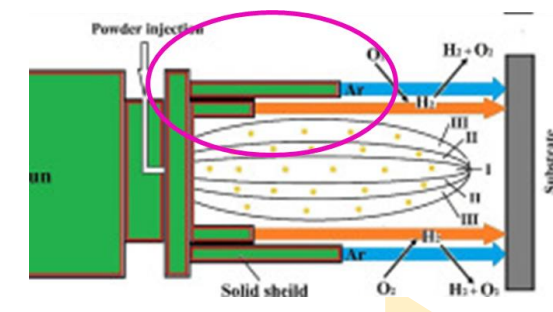
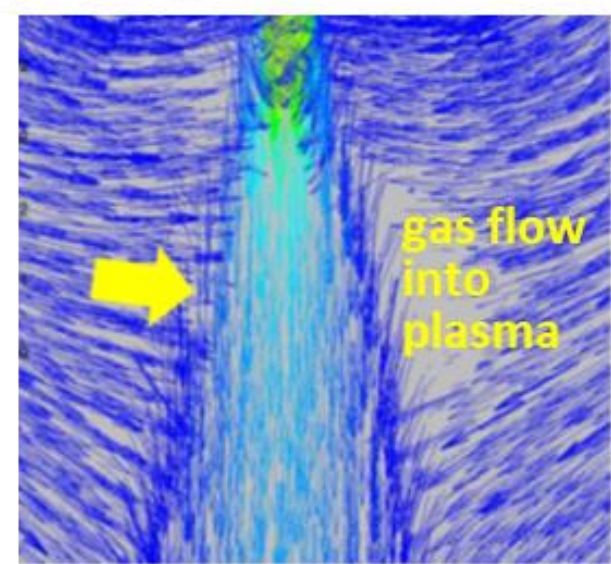
Plasma cone size: PACVD with HMDSO vs. Plasma spray with Cu



Preventing oxygen from mixing in atmospheric plasma: Shrouding



plasma jet without shroud

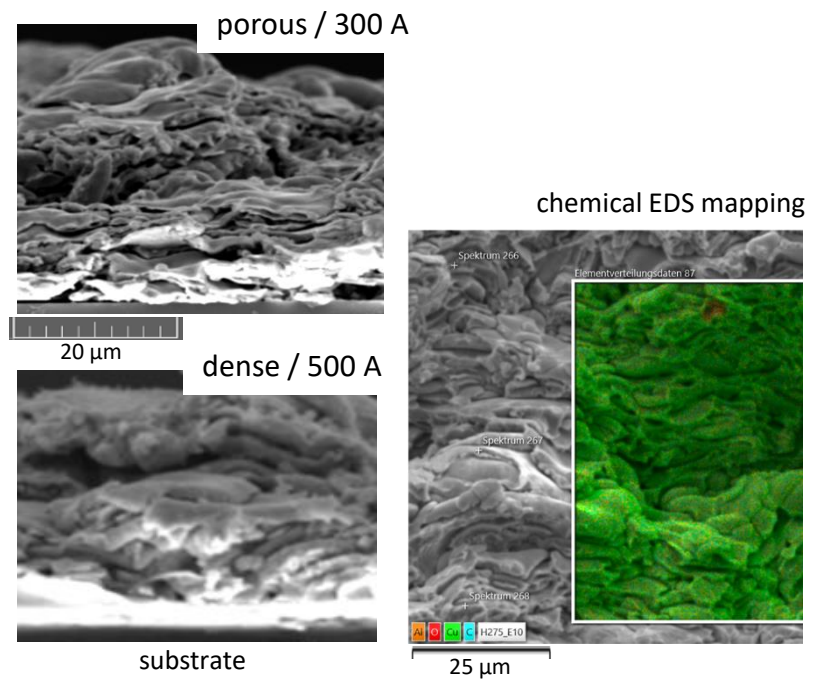
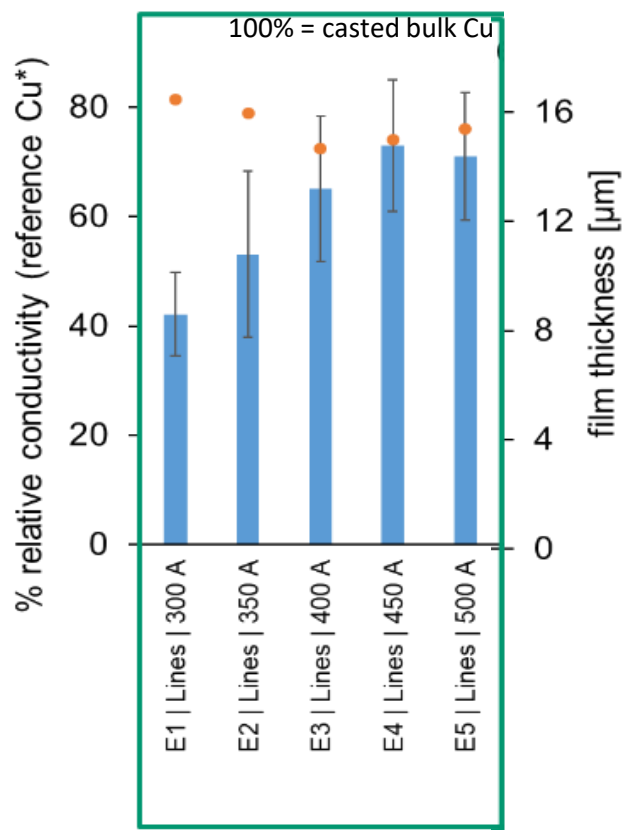


CFD-based optimization (particle vectors) for preventing oxidation of plasma by ambient atmosphere using shrouds

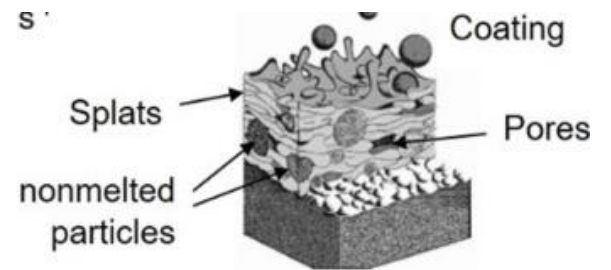
Direct & selective APPD metallization (plasma spray) for highly electrical conductive coatings - Cu & Zn

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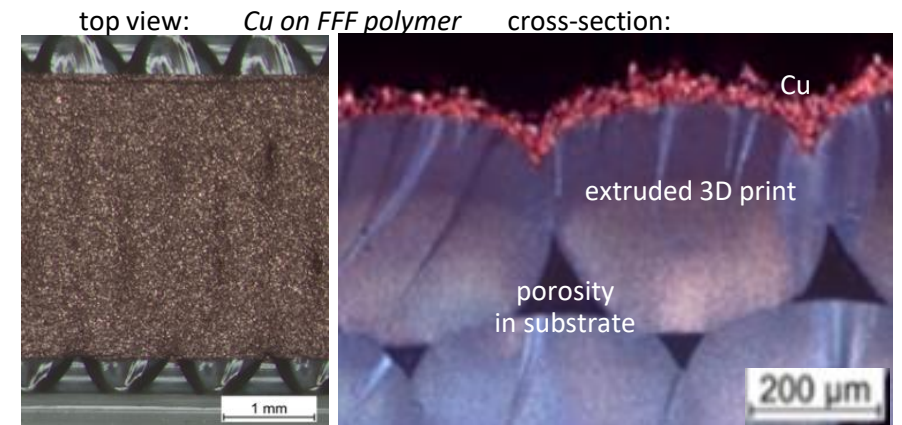
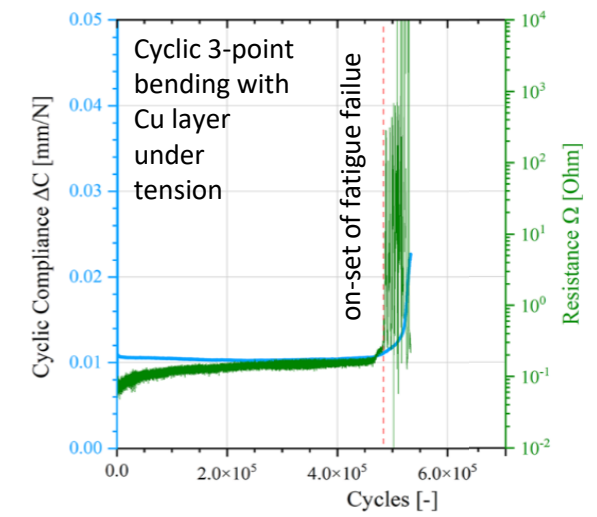
Optimization of electrical conductivity of APPD copper coatings shown by increasing deposition current and given in correlation to bulk Cu conductivity.



Effect on current on formed porosity in cross-section SEM analysis and EDS elemental mapping

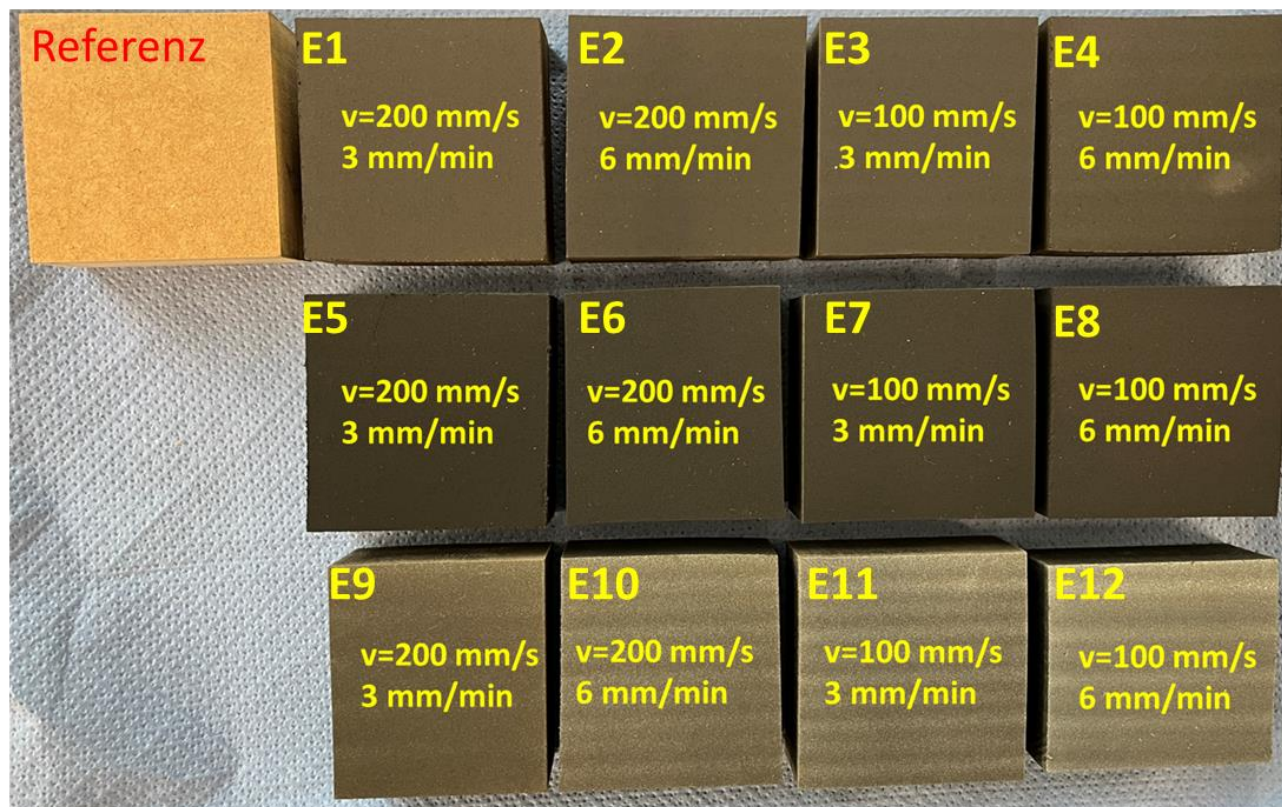


Cyclic bending testing incl. surface conductivity measurement of APPD Cu coated FFF printed polymer substrates (as substitute for wood) to assess fatigue failure. Top view and cross-section imaging of coated porous FFF polymer samples.



Direct & selective APPD metallization (plasma spray) for highly electrical conductive coatings

Partly biobased concepts with admixture of carbonized wood flour



Mixture 1 (E1-E4):

- Carbonized wood flour 50 g
- Lignin 50 g
- Aerosil 200 1 g

Mixture 2 (E5-E8):

- Carbonized wood flour 50 g
- Polyamide 50 g
- Aerosil 200 1 g

Mixture 3 (E9-E12):

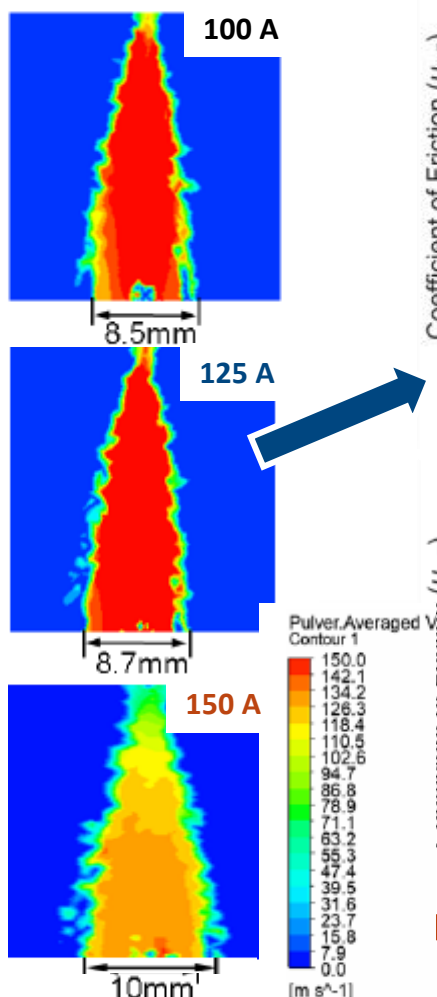
- Carbonized wood flour 70 g
- Zn (40 µm) 30 g
- Aerosil 200 1 g

E1: 9,8E9 Ohm	Lignin
E2: 9,0E9 Ohm	
E3: 12,6E9 Ohm	
E4: 6,7E9 Ohm	
E5: 3,3E9 Ohm	PA
E6: 174E6 Ohm	
E7: 264E3 Ohm	
E8: 79E3 Ohm (Multimeter)	
E9: 4,3E9 Ohm	Zn
E10: 2,8E9 Ohm	
E11: 3,2E6 Ohm	
E12: 0,7 Ohm (Multimeter)	

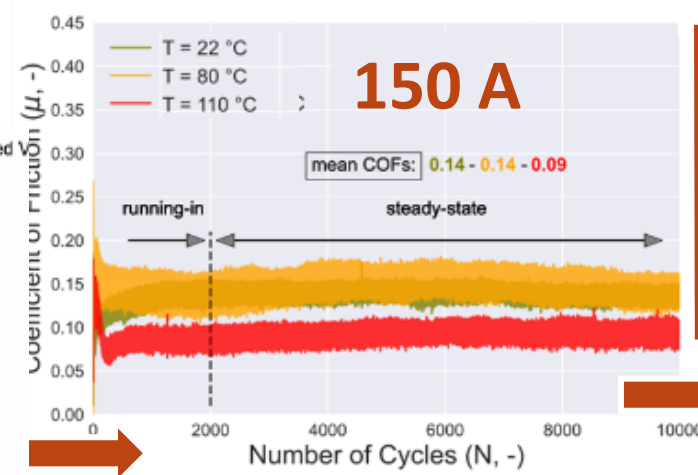
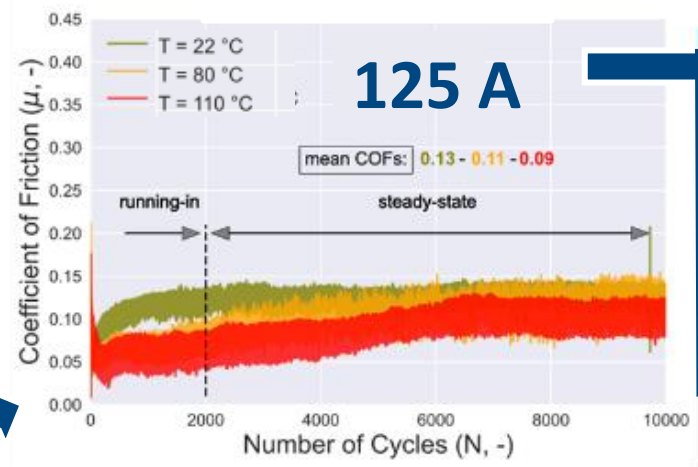
Comparison: Zn: 0.8-0.9 Ohm

Wear protective MoS₂-C-Zn APPD coatings (plasma spray) on biobased polymers and wood

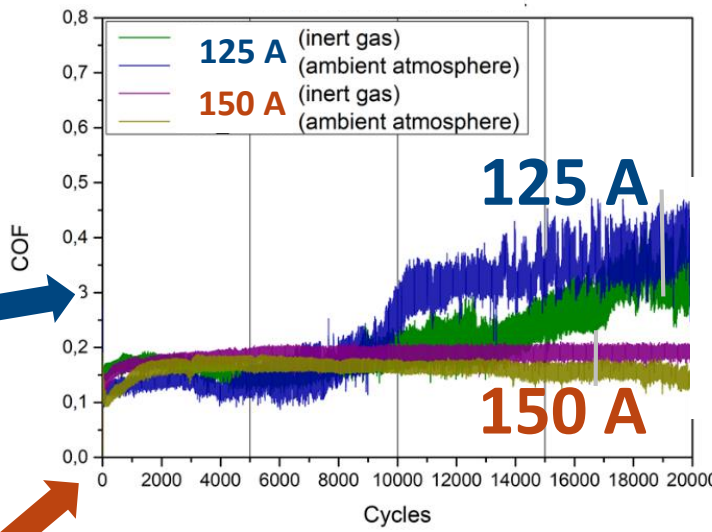
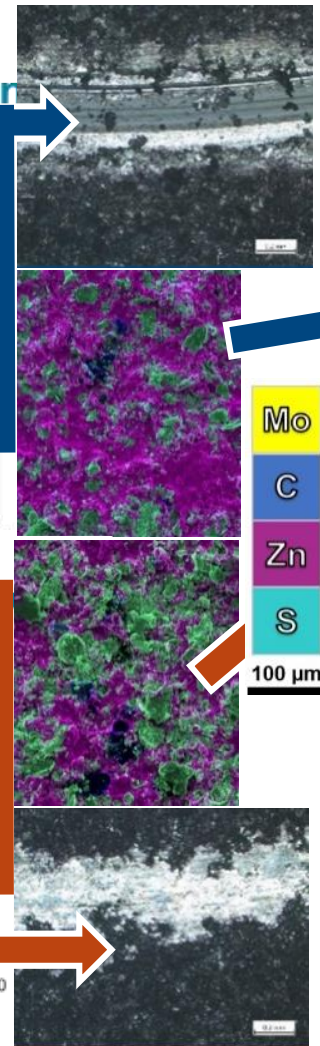
CFD plasma simulation of powder particle velocity in dependency on APPD discharge current



Dry, unlubricated friction curves (pin-on-disc test) for 30 μm thick MoS₂-C-Zn coatings (125 vs. 150 A current) on biobased PA11 at different ambient temperatures

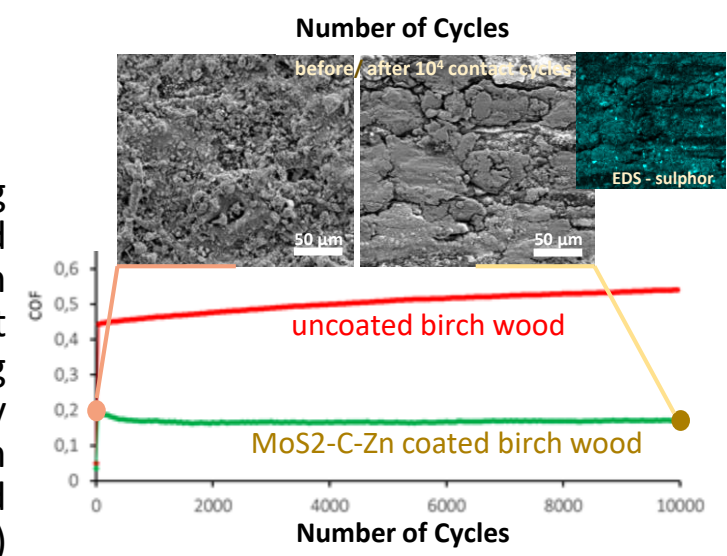


Analysis of occurring wear tracks (grey images: light microscopy, coloured: EDS mapping in SEM).



Testing at doubled sliding distance (typical industrial conditions) indicating for coating deposited at 150 A steady low friction and no damage as well as slightly higher friction for APPD with shrouds ("inert gas

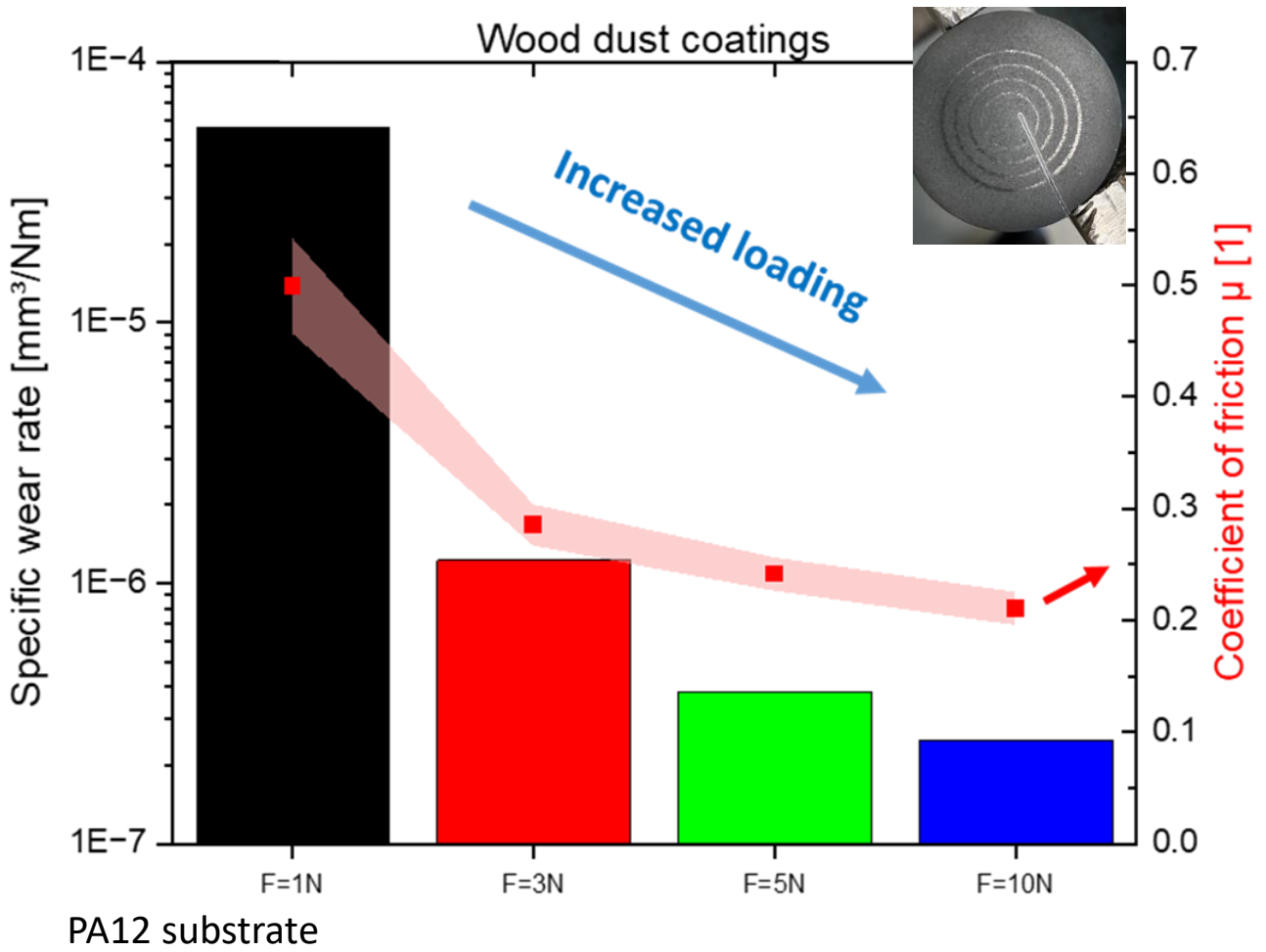
Transfer of the 150 A coating system to birch wood indicating similar friction behaviour without delamination of the coating (SEM images: only fragmentation in pads with self-healing of the pad borders)



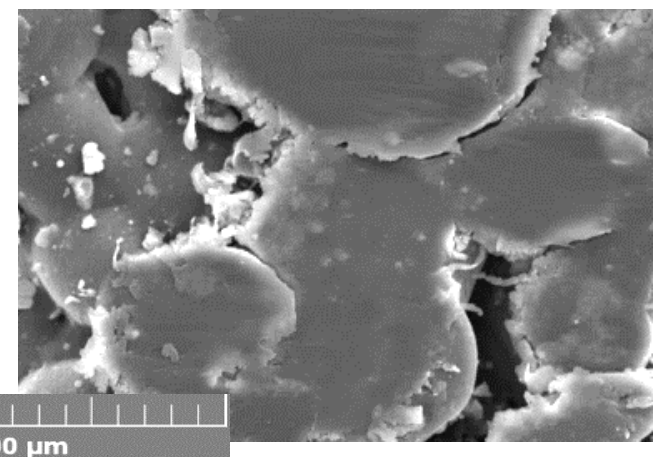
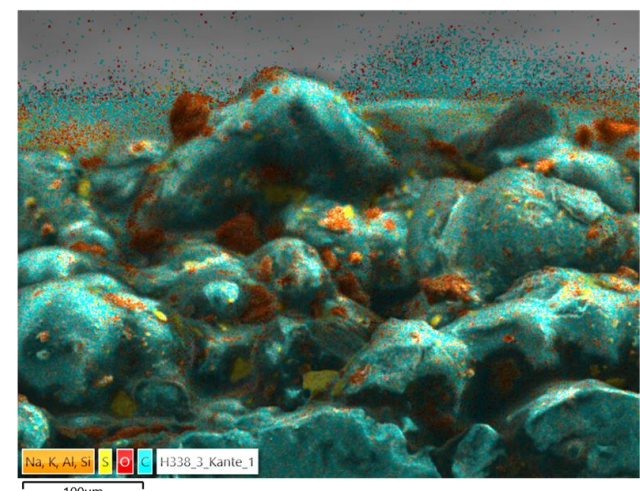
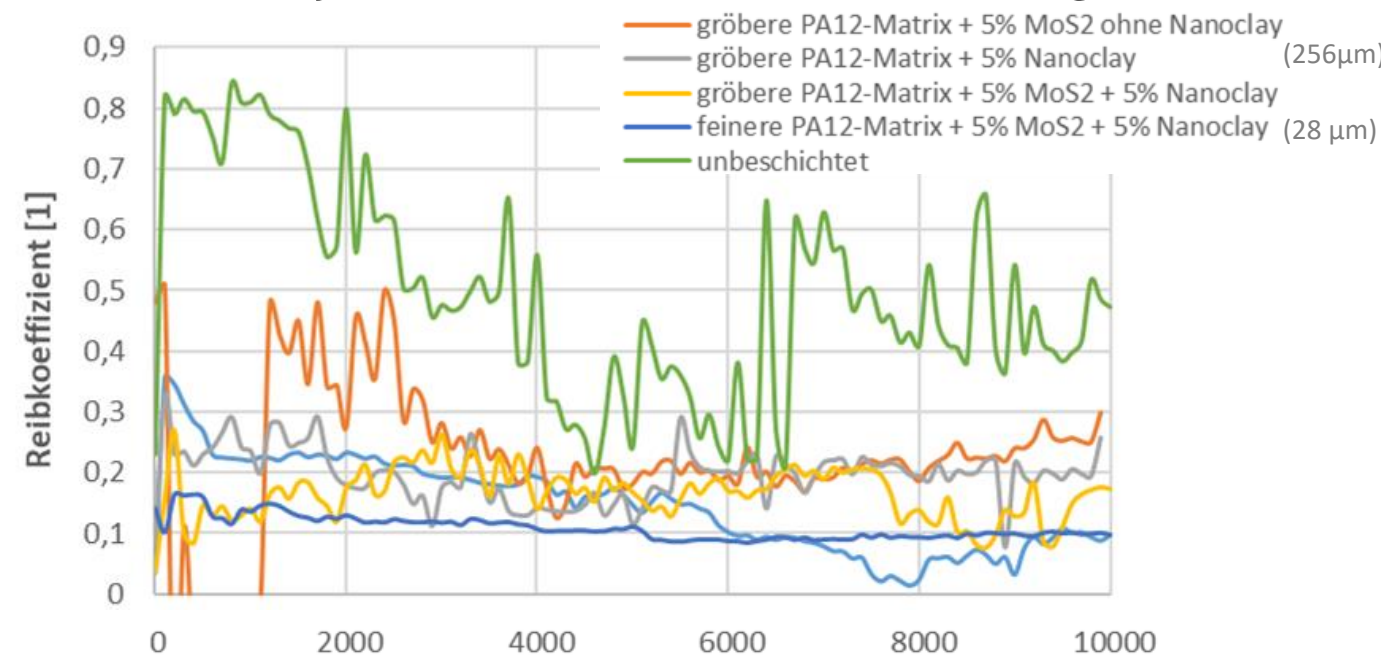
Partly bio-based concepts for wear protective coatings (plasma spray) on biobased polymers and wood

Carbonized wood flour coatings

Nanoclay admixture to PA coatings

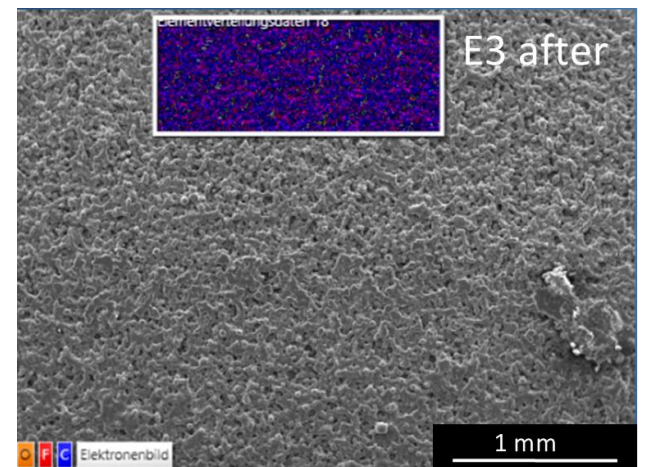
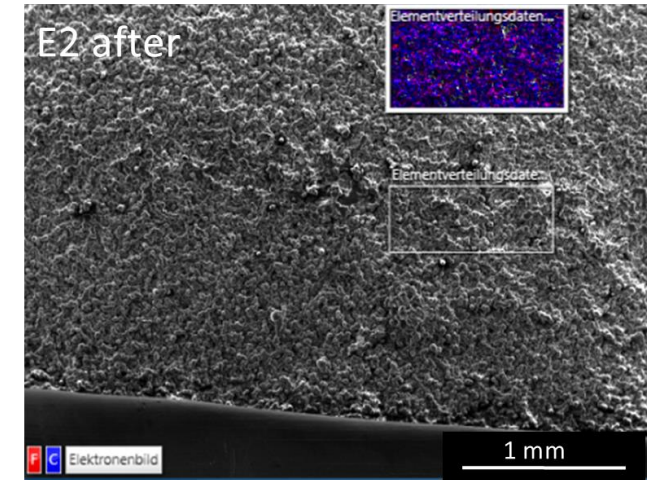
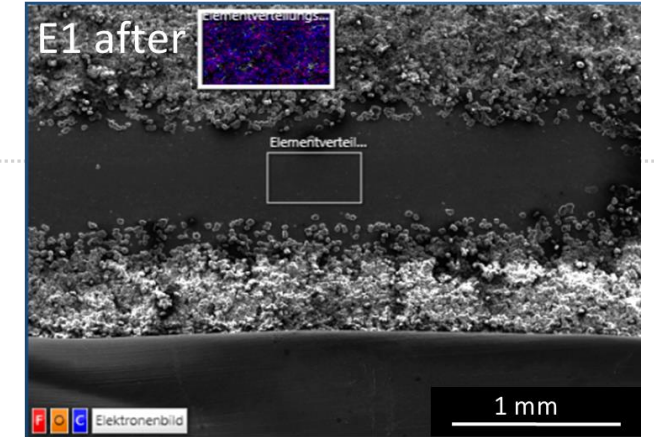
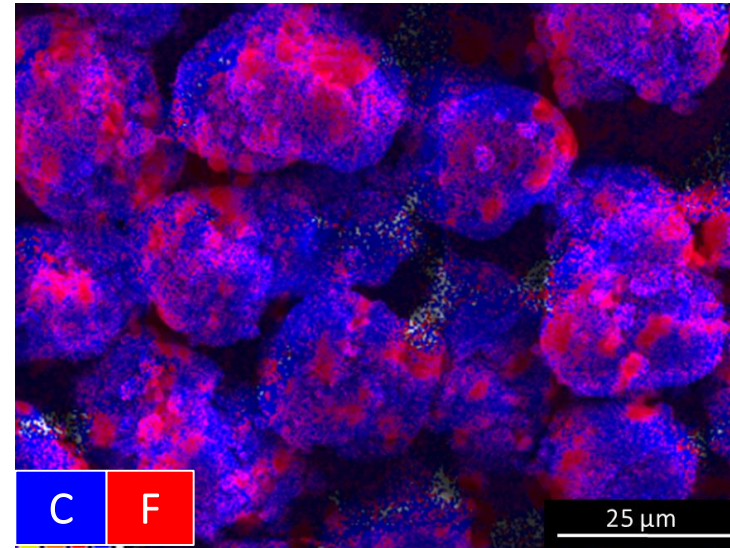
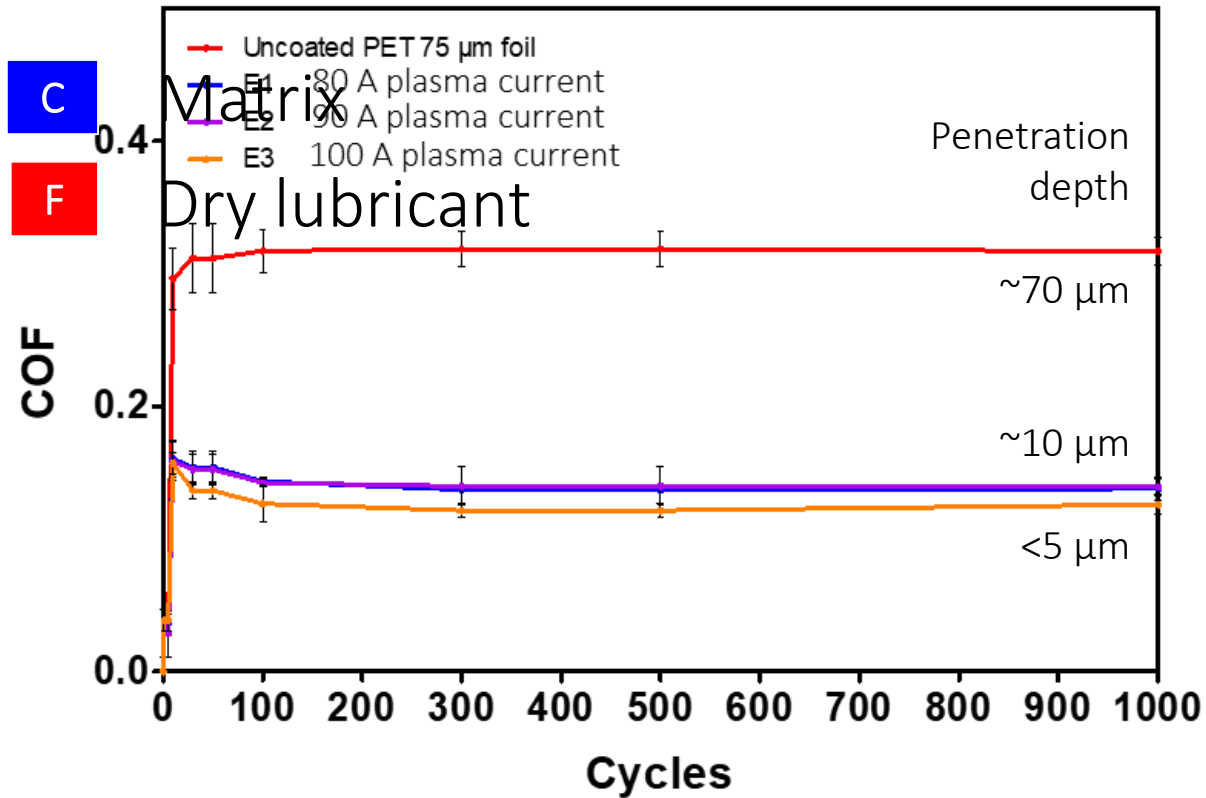


coarse PA12-Pulver + 5 % MoS2 + 5 % Montmorillonit-Nanoclay



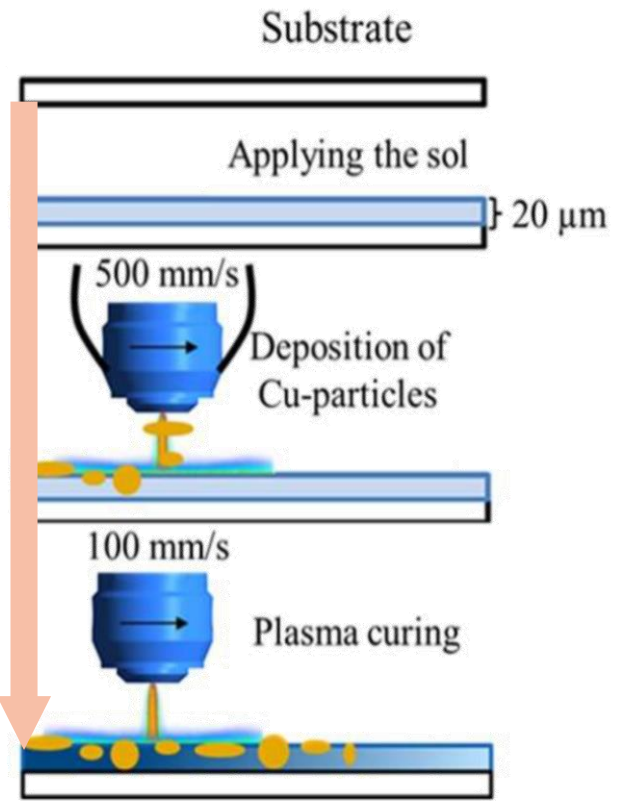
Partly bio-based concepts for wear protective coatings (plasma spray)

PA11-PTFE coating on PET foil

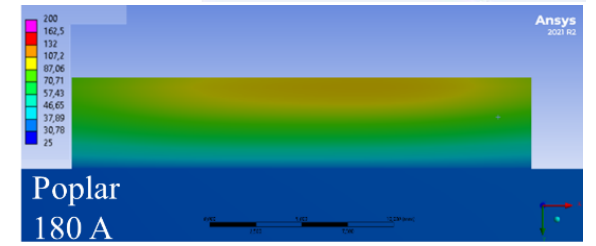
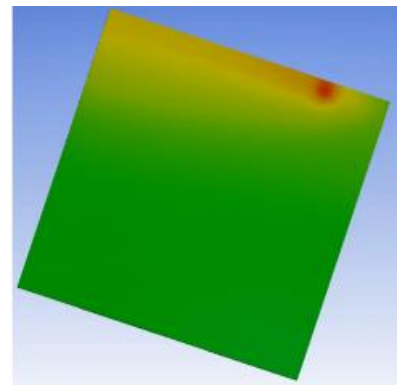
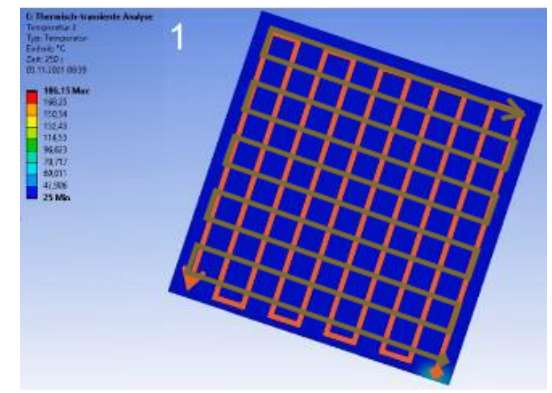


Plasma curing of sol-gels: antimicrobial & intumescent coating

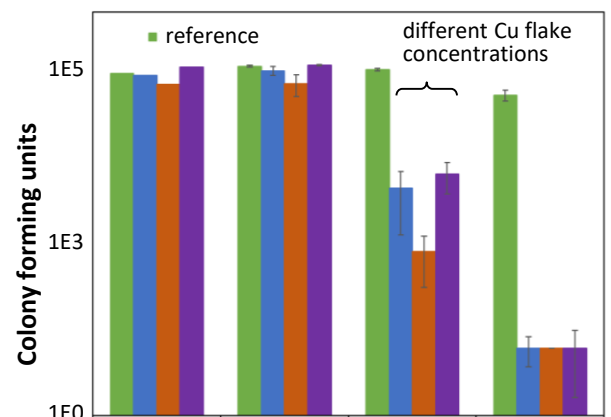
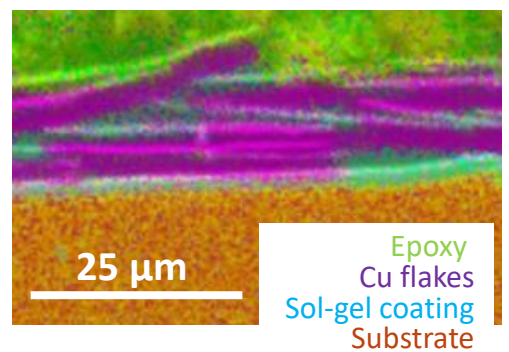
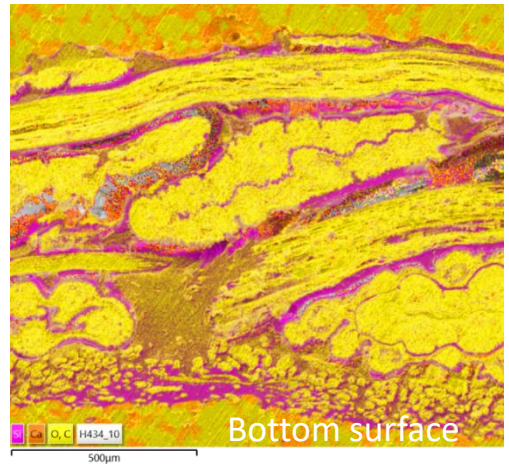
Principle of APPD sol-gel curing incl. antimicrobial modification by microparticles



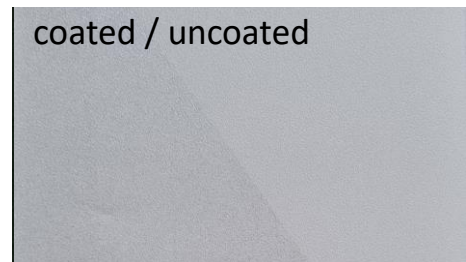
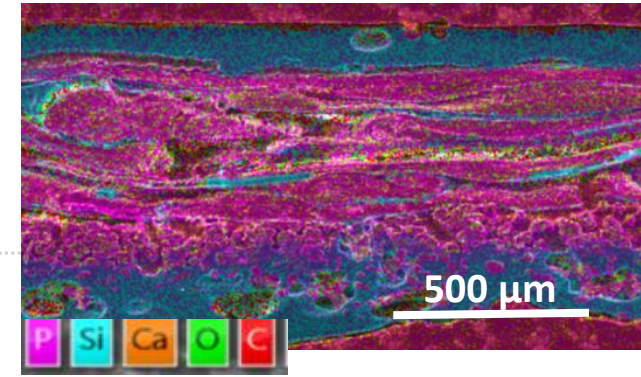
Optimized sol-gel system:
 (trimethoxysilyl)propyl methacrylate +
 ebecryl + (3-aminopropyl) triethoxysilane,
 1-hydroxy cyclohexyl phenylketone +
 benzophenone as photoinitiator



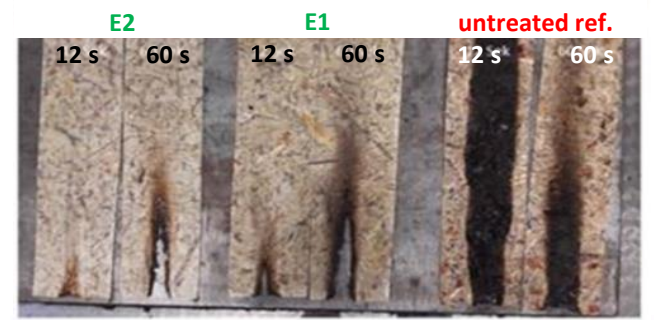
Heat flow simulation on poplar wood substrate for preventing wood damage by overheating during cross-wise APPD curing to



Cross-section after full infiltration & curing in ORGANOID natural materials without and with flame-retardant

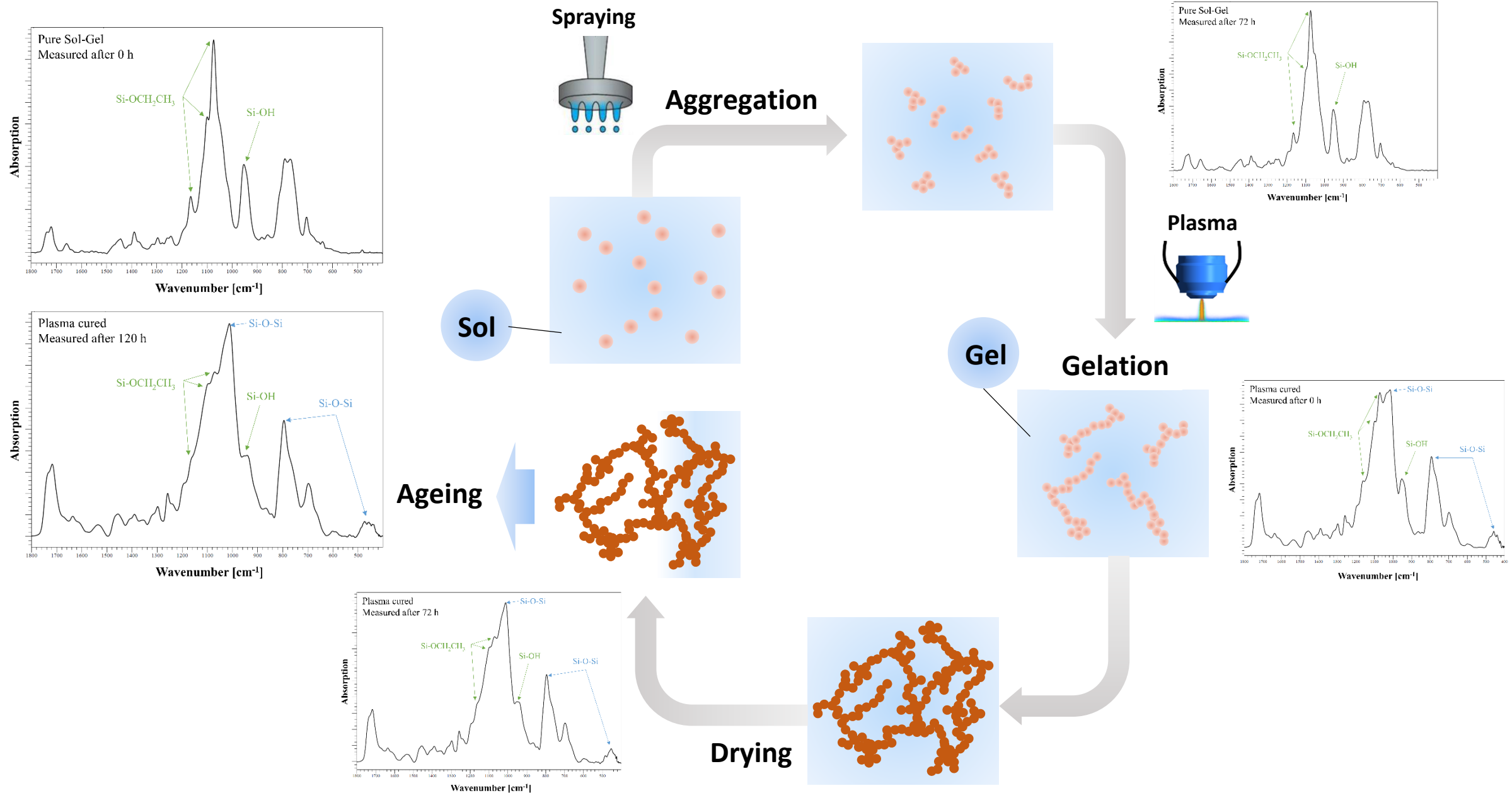


Vertical burn tests for sol-gel infiltrated ORGANOID natural materials with extreme intumescence effect (charring) in comparison to untreated reference (right)



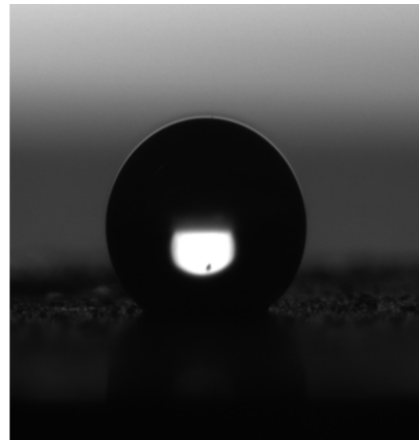
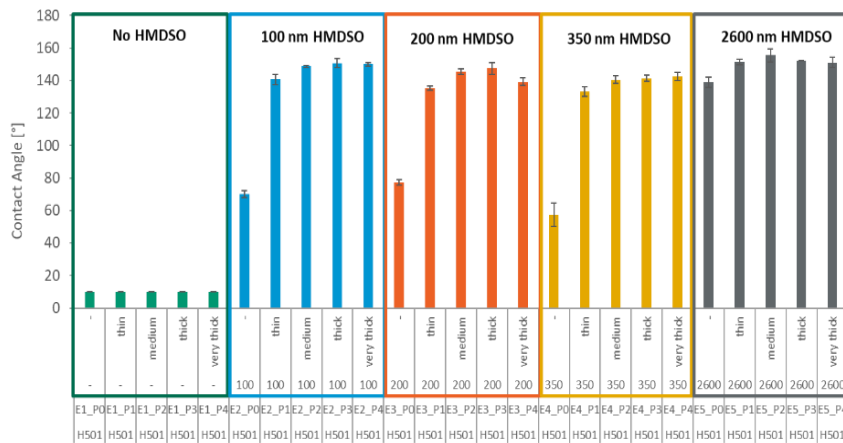
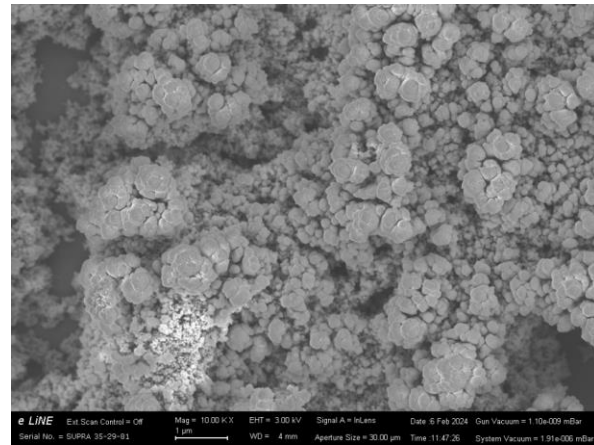
	Sample	Abbrand [mm]	Nachbrand [Sek.]	Drips	Pass/ Fail
12 Sek	E1 (low conc. flame retardant)	40	5	0	Pass
	E2 (high)	20	0	0	Pass
	REF	∞	∞	∞	Fail
60 Sek	E1 (low conc. flame retardant)	110	0	0	Pass
	E2 (low)	80	0	0	Pass
	REF	160	∞	∞	Fail

Sol-Gel curing - technological background of INO/JR patent



Super-hydrophobic layers on wood & fully biobased precursors for future R&D

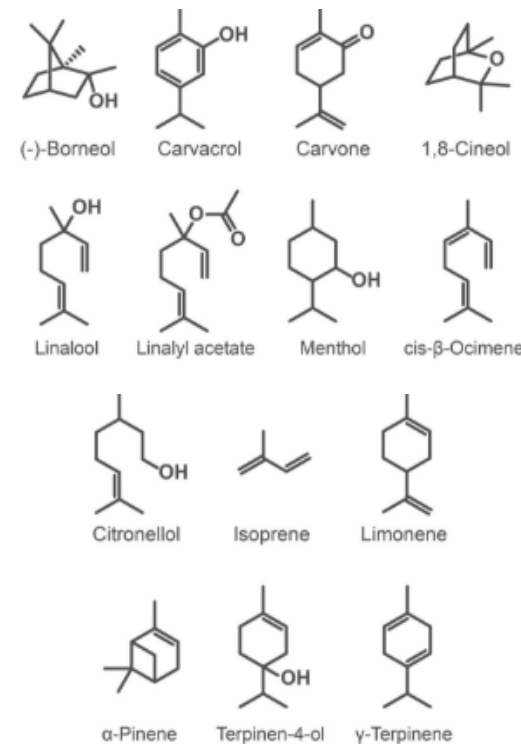
TiO₂/HAp + HMDSO cover on spruce and larch (water contact angle up to 150°)



PECVD of essential oils & extractives

20-60 different components with antimicrobial effect in nature

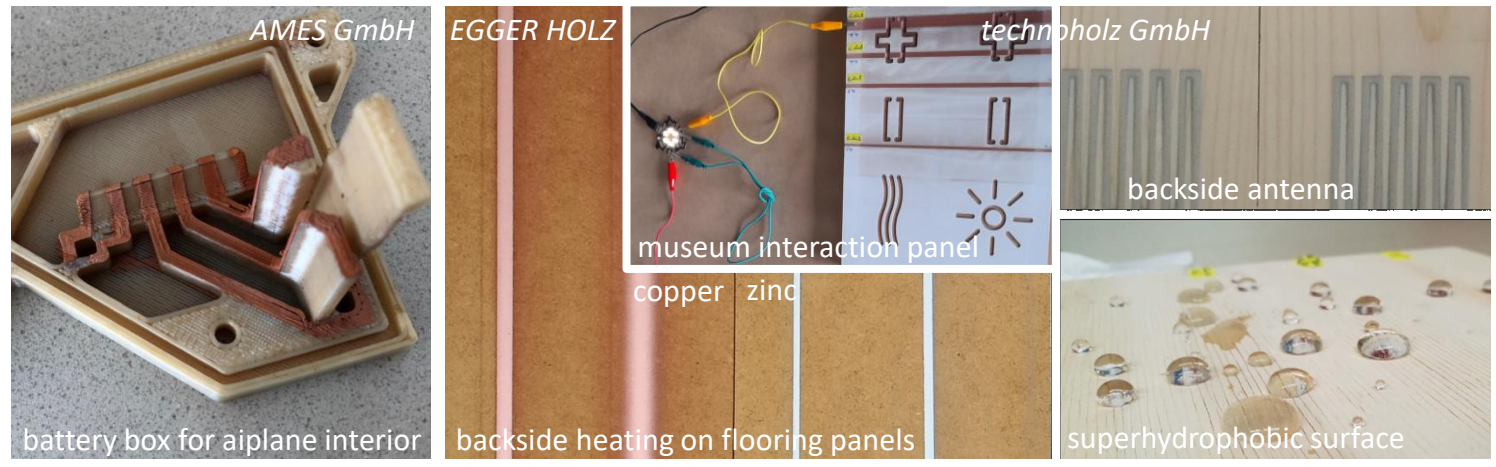
- Terpenes and terpenoids
- Aromatics and aliphatics



Demonstrators - prototypes - product transfer

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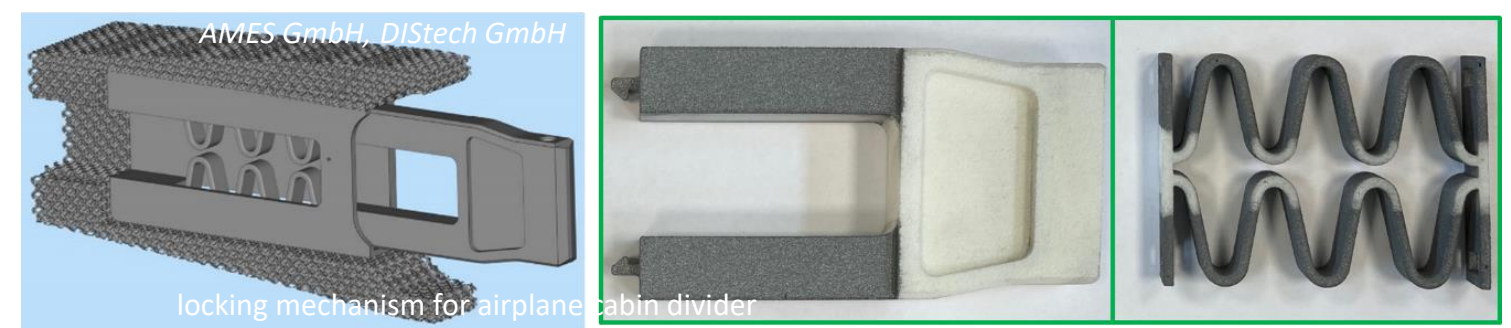
selective metallization (brown: Cu, grey: Zn) for conductor tracks



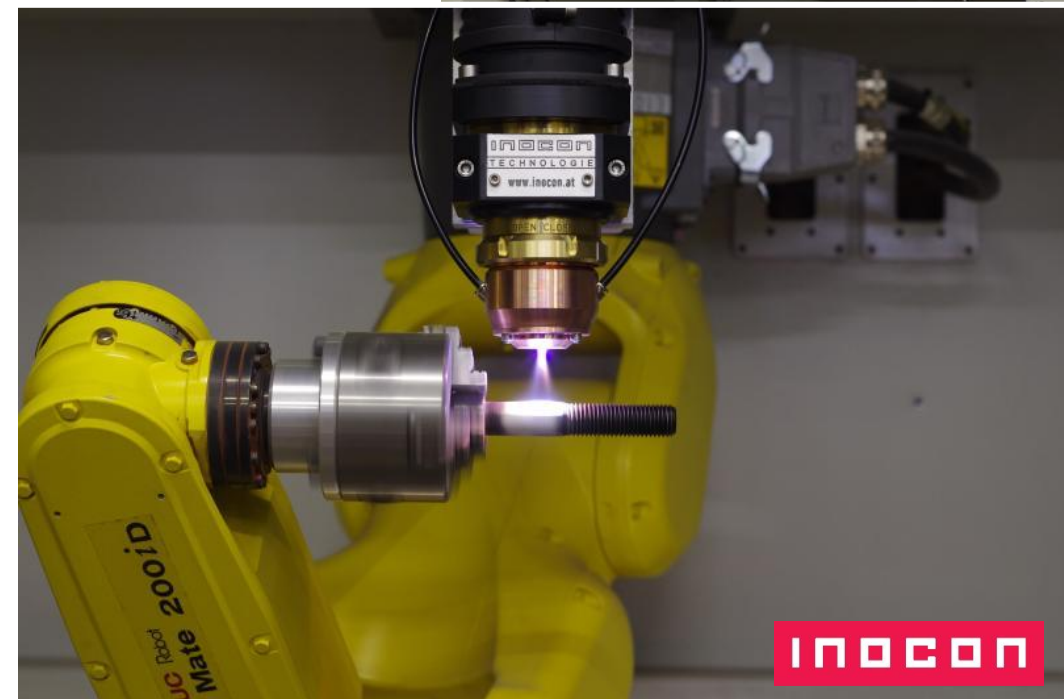
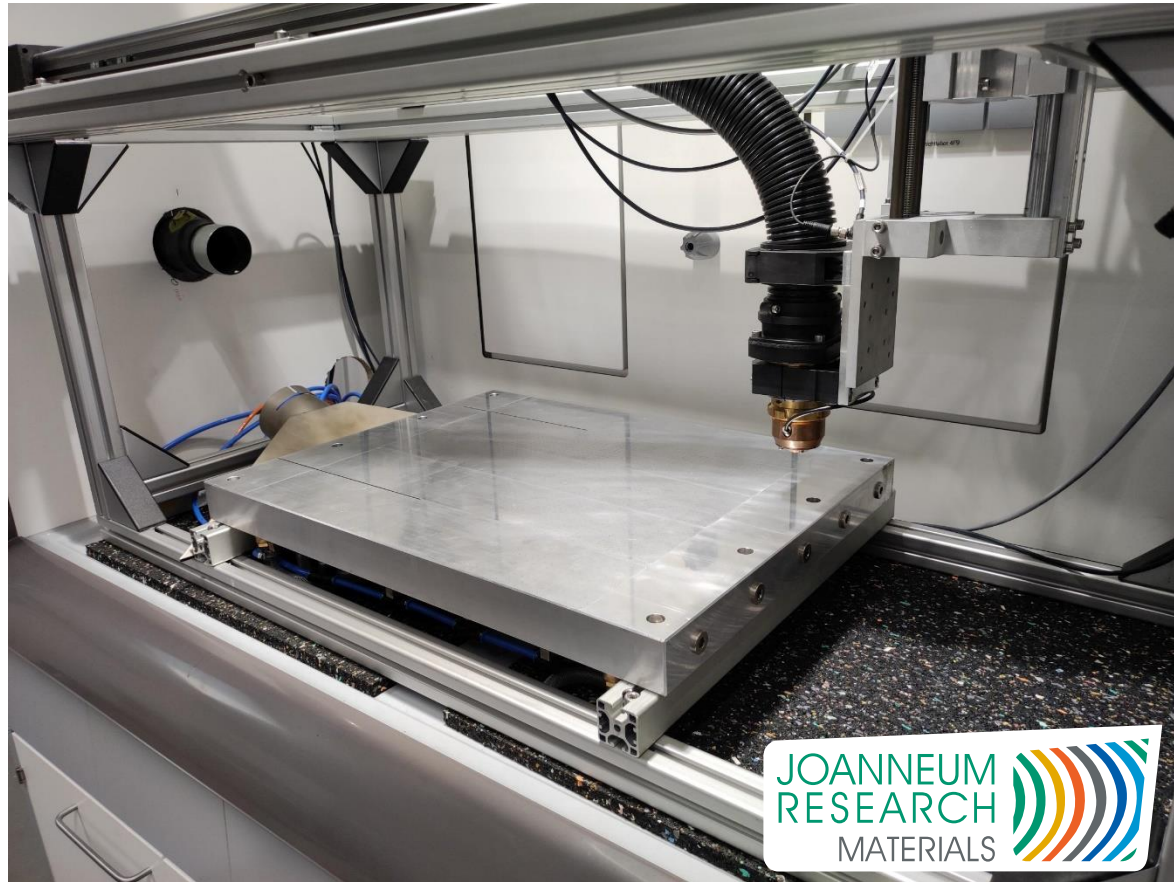
antimicrobial, flame-retardant APPD cured sol-gel route



low-friction coatings for easy-sliding

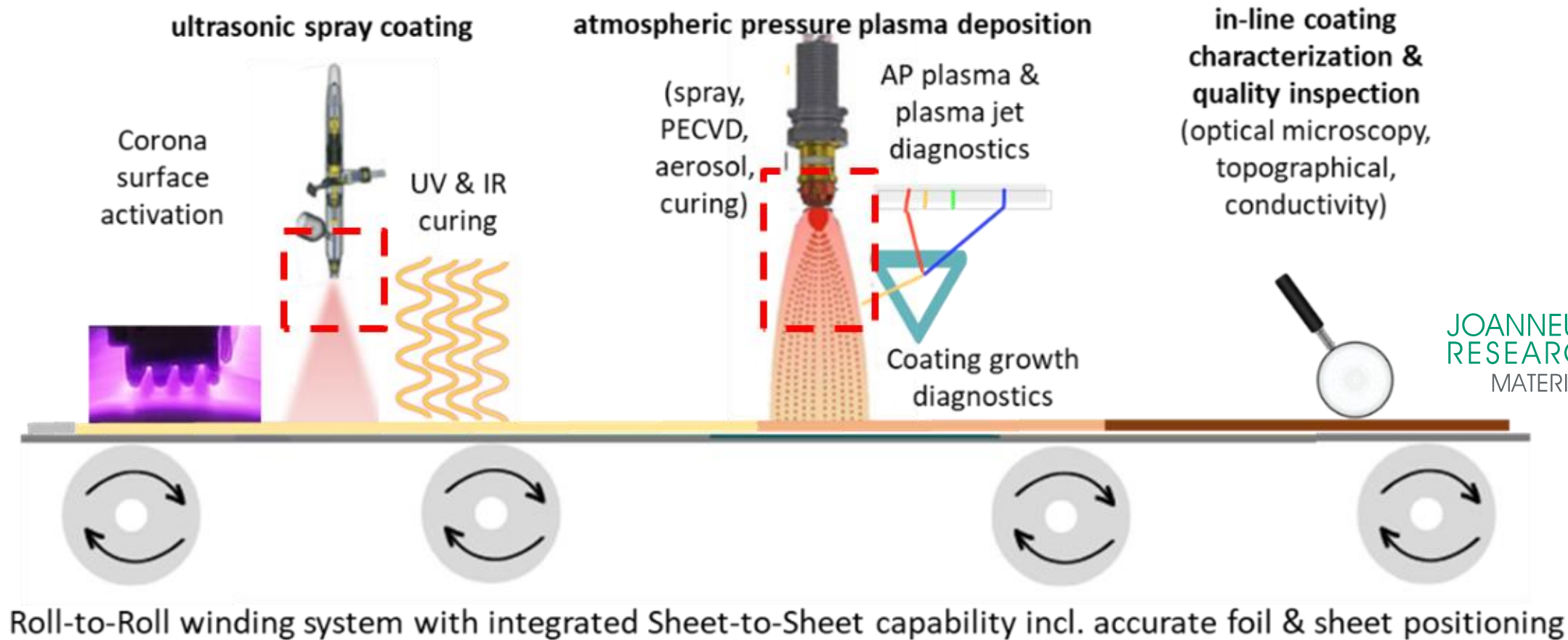


Robot based coating

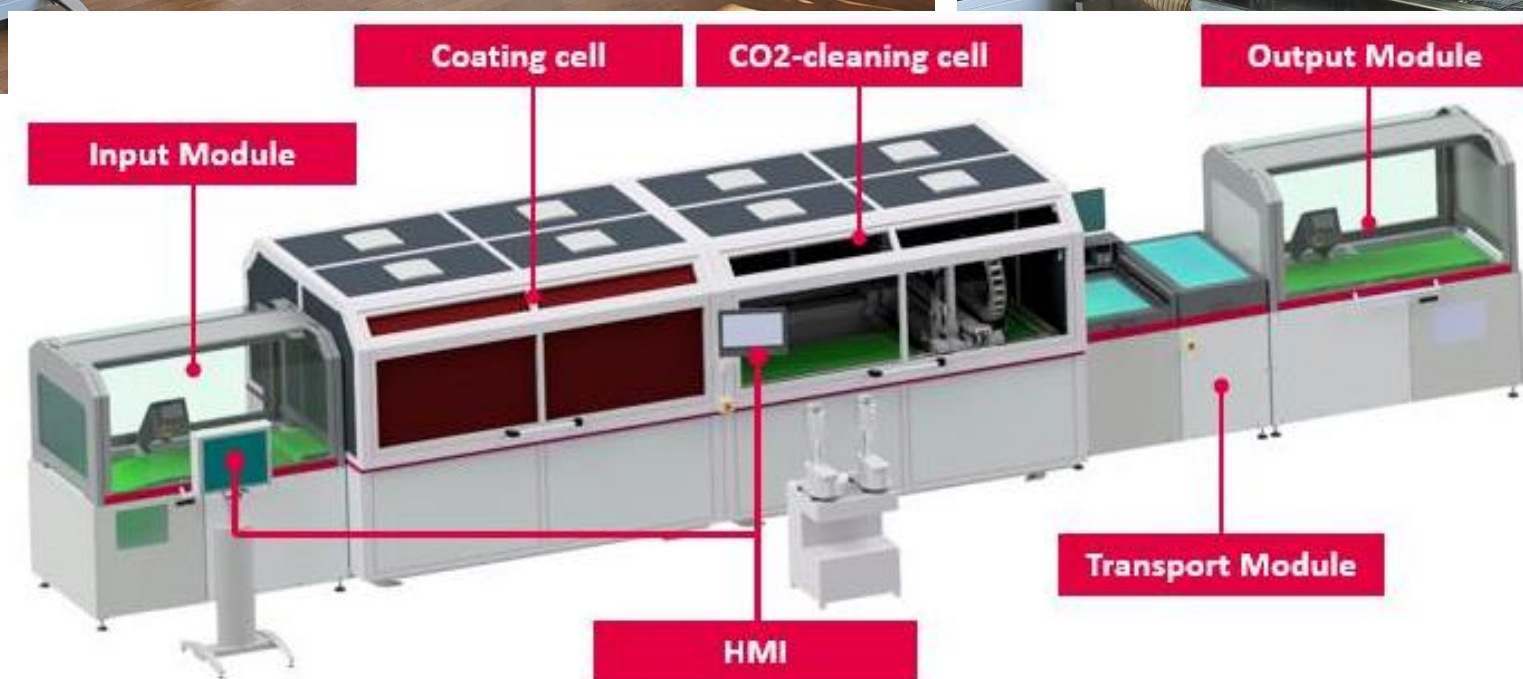
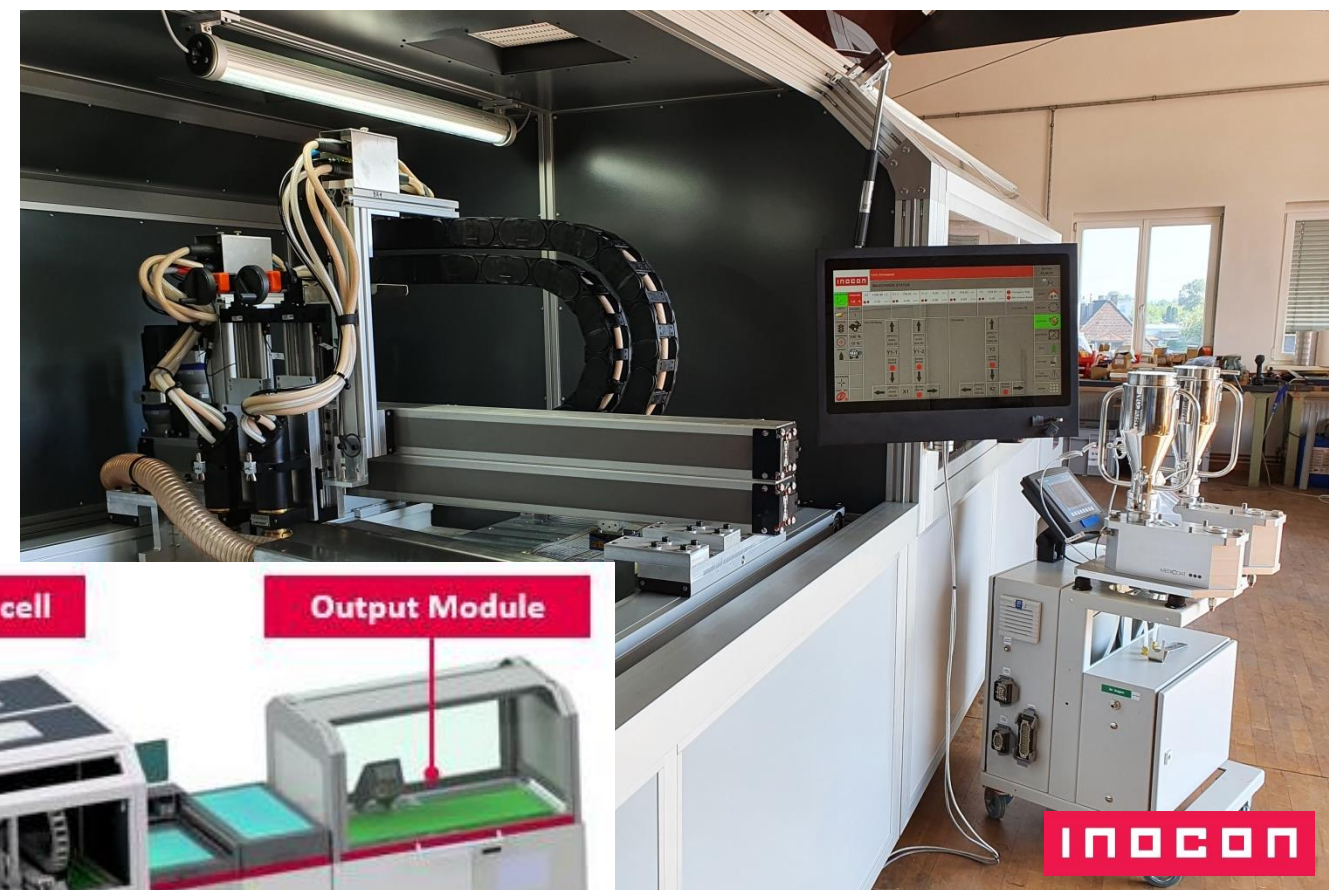


3- to 5-axis plasma jet + substrate handling

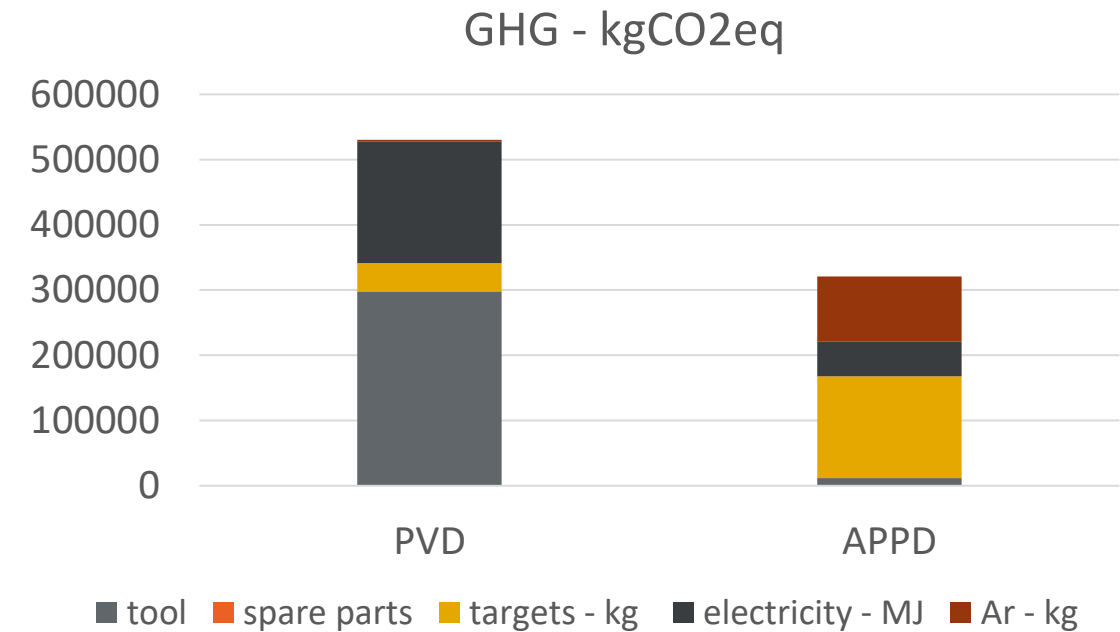
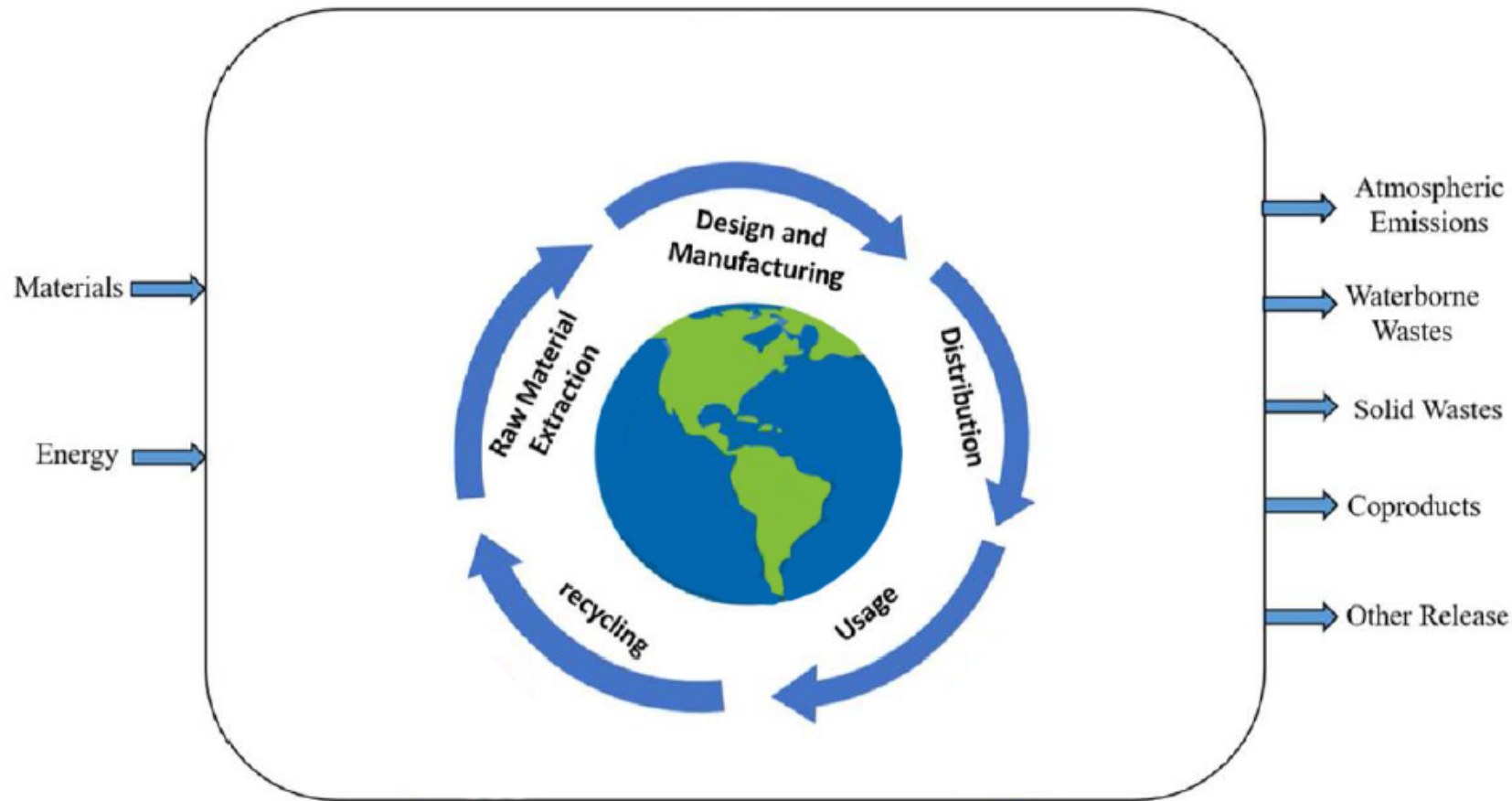
Roll-to-roll coating - lab-scale



Industrial roll-to-roll coating



Green fingerprint of atmospheric plasma - Life Cycle Analysis: APPD vs. PVD (sputtering)



- Deposition of 1000 m²/year over 10 years
- Film with a friction coefficient of $\sim 1E-13$ m³/N m on PA12 (APPD: 50 μ m C-MoS₂-Zn, PVD: 4.7 μ m C-MoS₂)
- Material efficiency: APPD: 70%, PVD: 10 % %

composition	GHG emission - kg	ADP-fossil (MJ)	ADP-minerals (kgSbeq)	Water use (m3eq)
PVD - 94 % C 6 % MoS ₂ , 1 kg	10.27	176.50	1.23E-03	5.87
APPD - 25% Zn+25%MoS ₂ C+50%	44.61	700.34	1.11E-02	44.42

Thank you for your attention!

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together*



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