MaxPhase™ coatings on bipolar plates deposited by magnetron sputtering techniques in a high throughput industrial coating system

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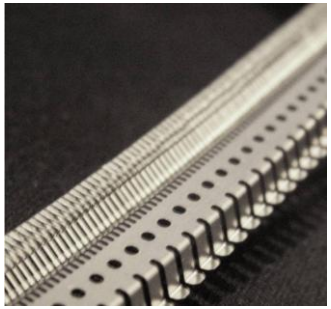
Impact Coatings

- PVD coating systems for mass production of individual parts
- Functional and decorative coatings for connectors, mobile phone shells, frames for glasses, decorative coatings for car interior, surgical devices, EMI shielding, etc.
- Unique architecture provides short cycle times (1-2 min) that match continuous production flows



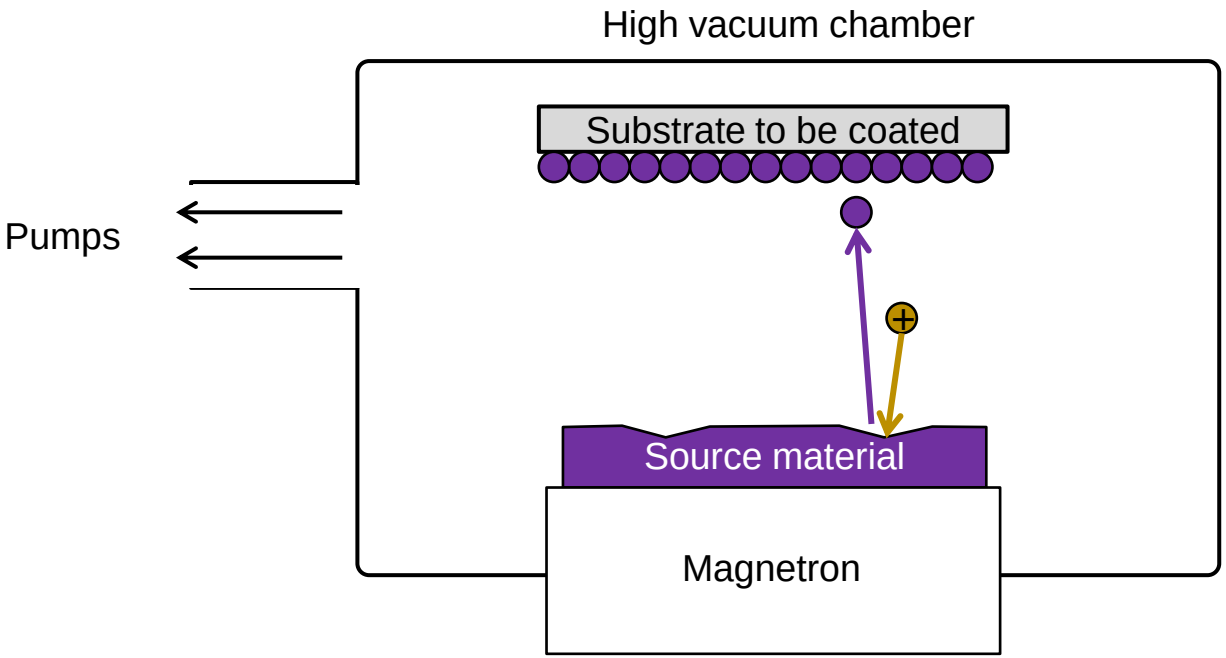
Impact Coatings

Industriverktøy AS in Leksvik, 30 km from Trondheim

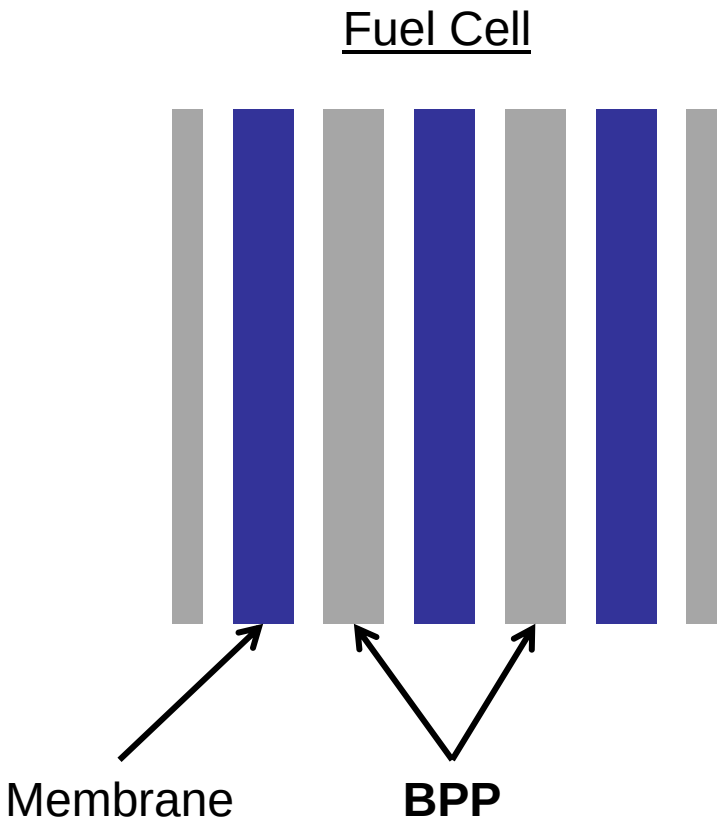
"New and revolutionary technique for metalizing plastic parts"

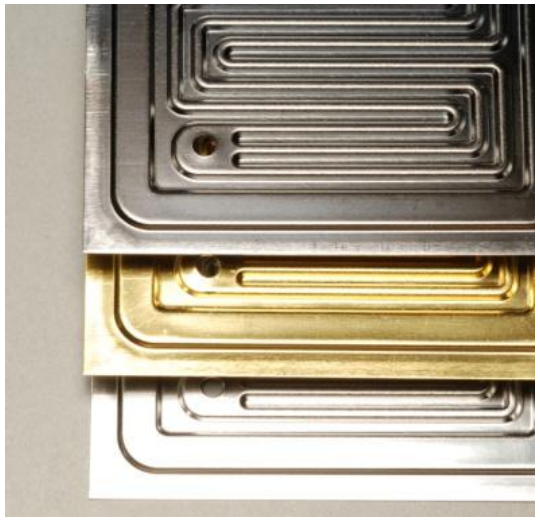
"But most of all, it cuts production time by close to 70%"

PVD - Physical Vapor Deposition
Magnetron sputtering



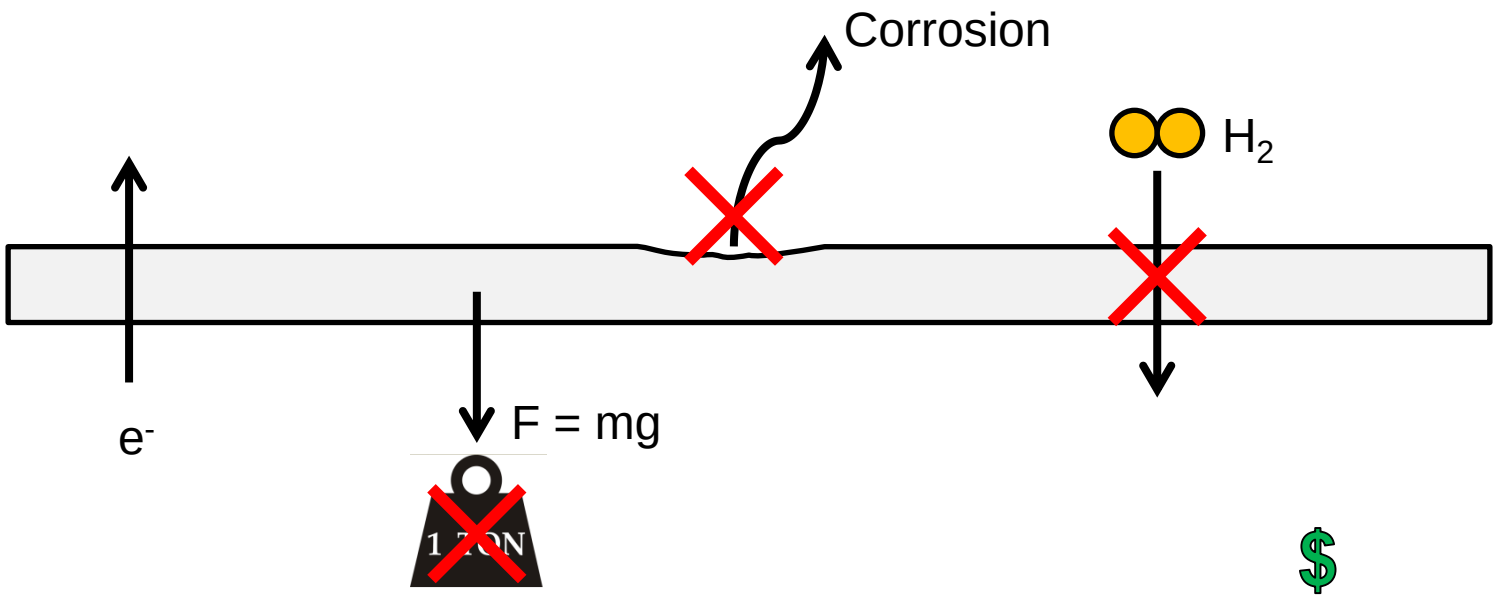
Bipolar plates (BPP)





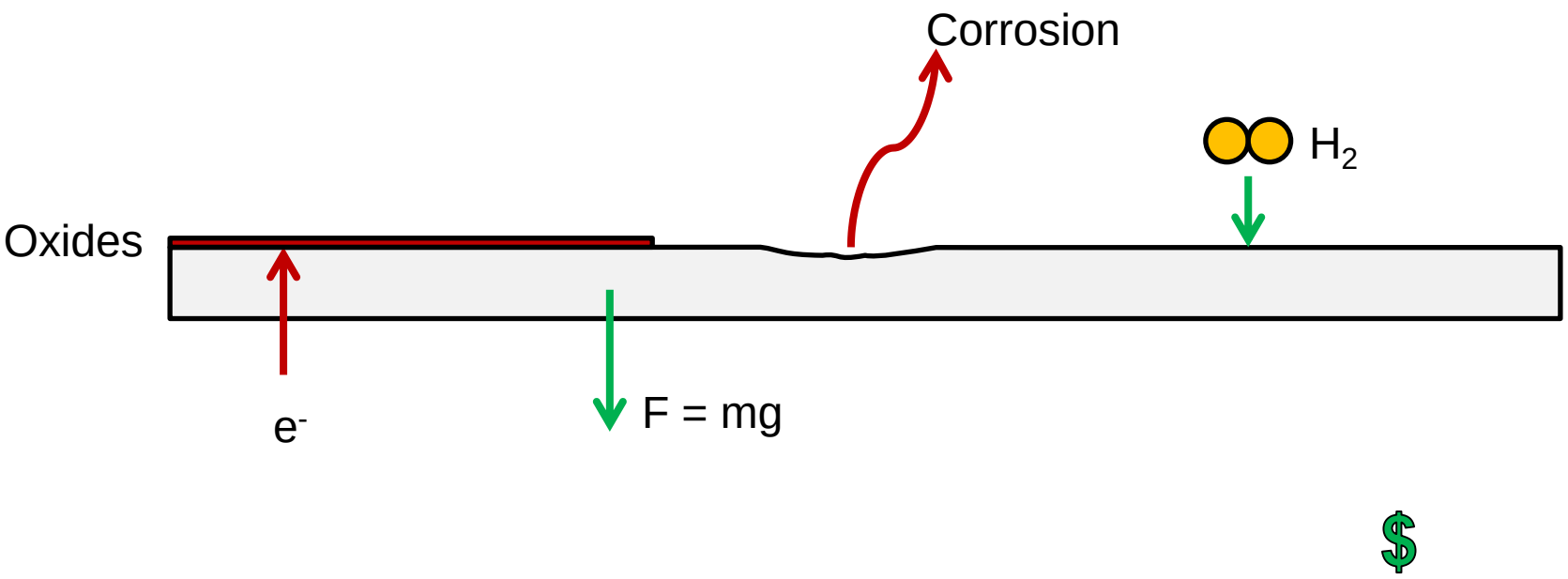
Coated BPP

Bipolar plates



Graphite, polymer, graphite+polymer, metallic

Metallic bipolar plates



The challenge is the surface.

Can we enhance the surface properties with a coating?

Coating Design Strategy

Including, but not limited to

Group → / Period ↓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo
Lanthanides				57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinides				89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

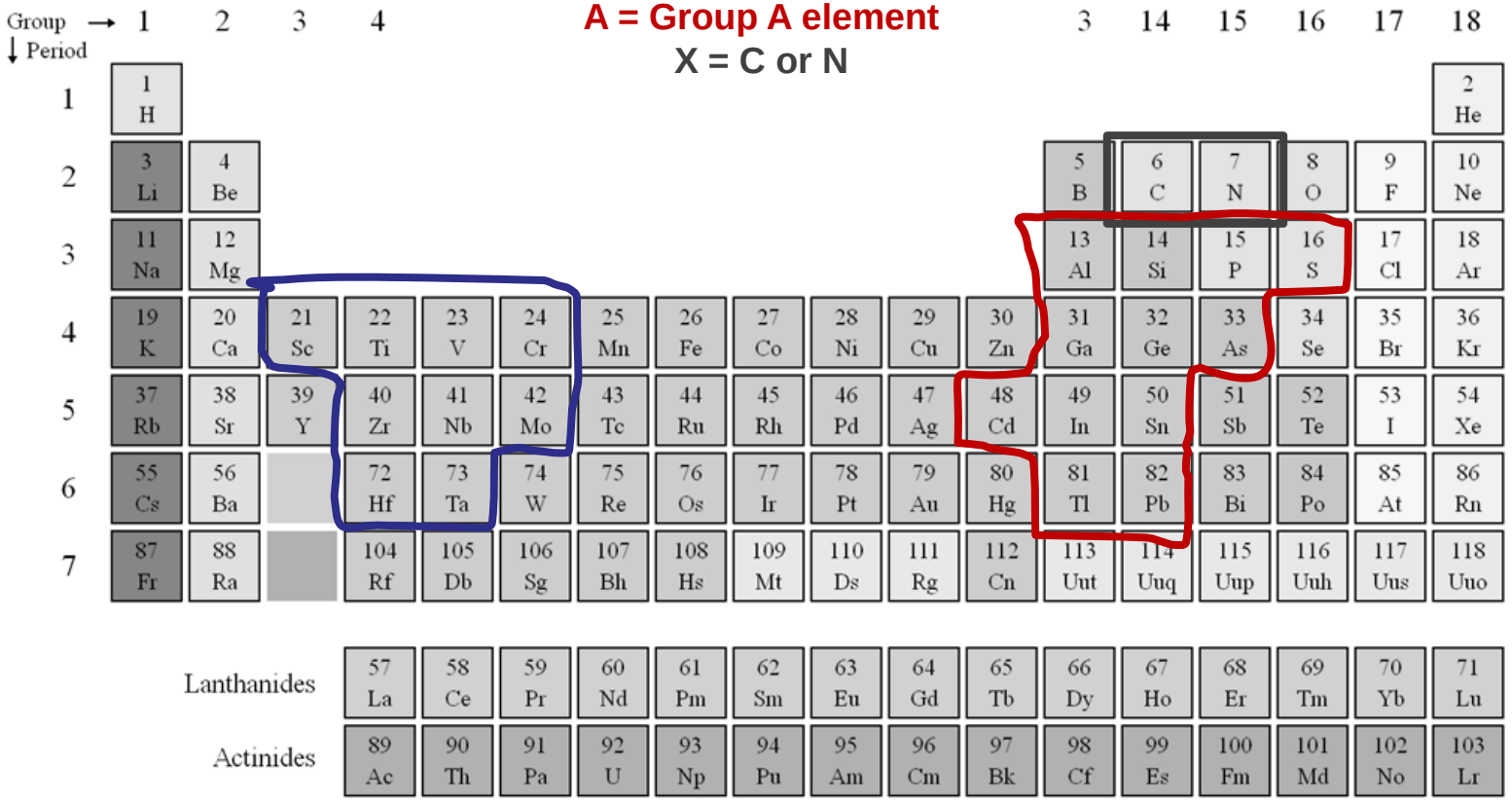
Coating Design Strategy

MAX phases

M = Early transition element

A = Group A element

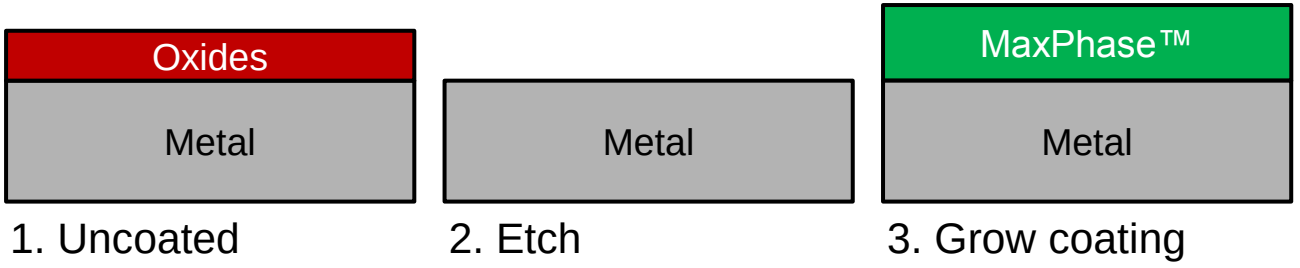
X = C or N



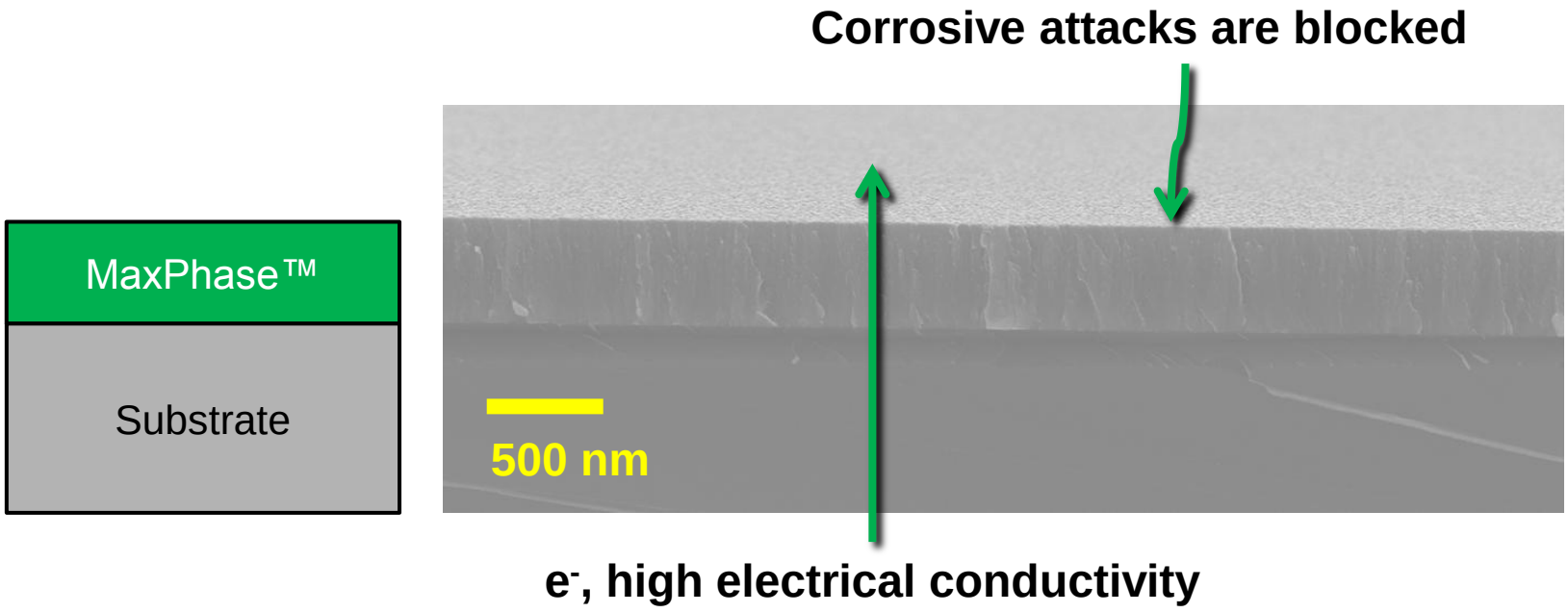
Introducing MaxPhase™ coatings for stainless steel bipolar plates

The coating is

- **a ceramic alloy** producible by PVD
- **corrosion resistant**
- **electrically conductive**
- **economic** and **environmentally sound**



Introducing MaxPhase™ coatings for stainless steel bipolar plates

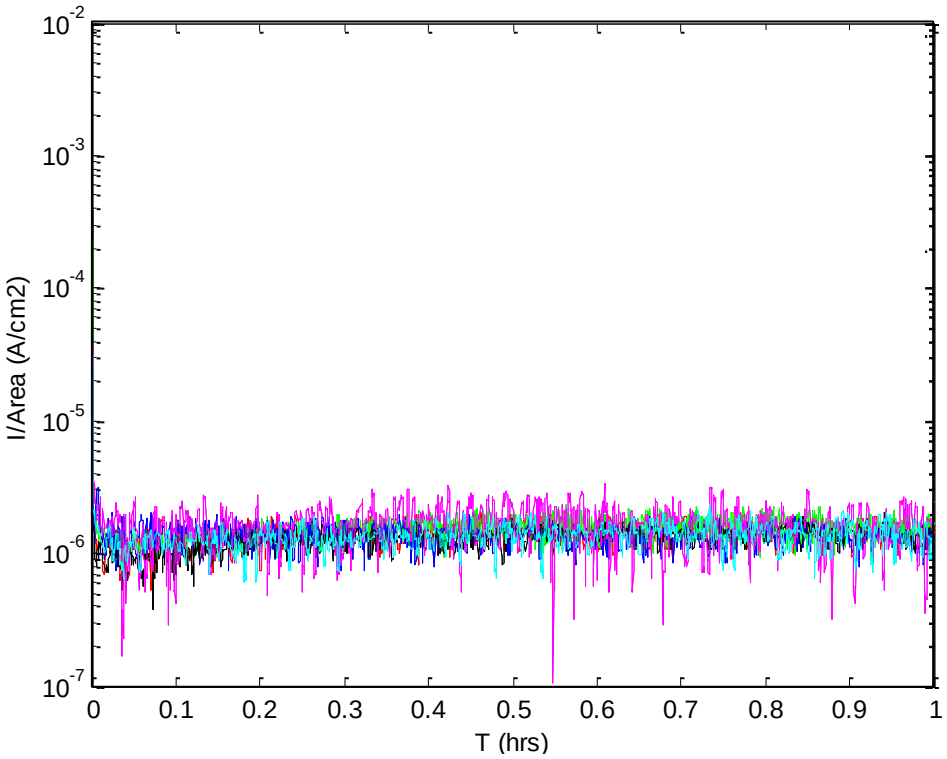


Ex Situ Corrosion Resistance

- 1 hour test
  SS316L + 300 nm MaxPhase
  SS316L + 150 nm MaxPhase

- Low corrosion currents and no detectable levels of substrate metal ions in the electrolyte

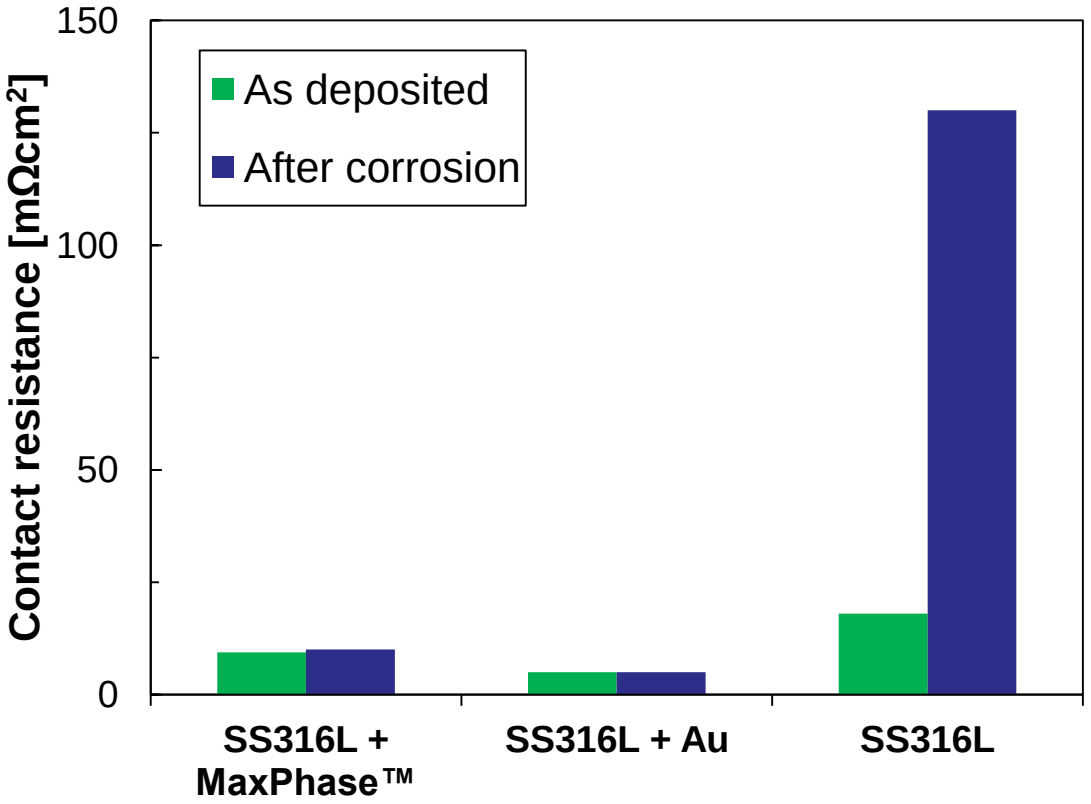
  Very thin coatings work well!



Potentiostatic 1 hour experiments
(80 °C, 1 mM H_2SO_4, 0.643 V vs Ag/AgCl)

Ex Situ Electric Contact Resistance

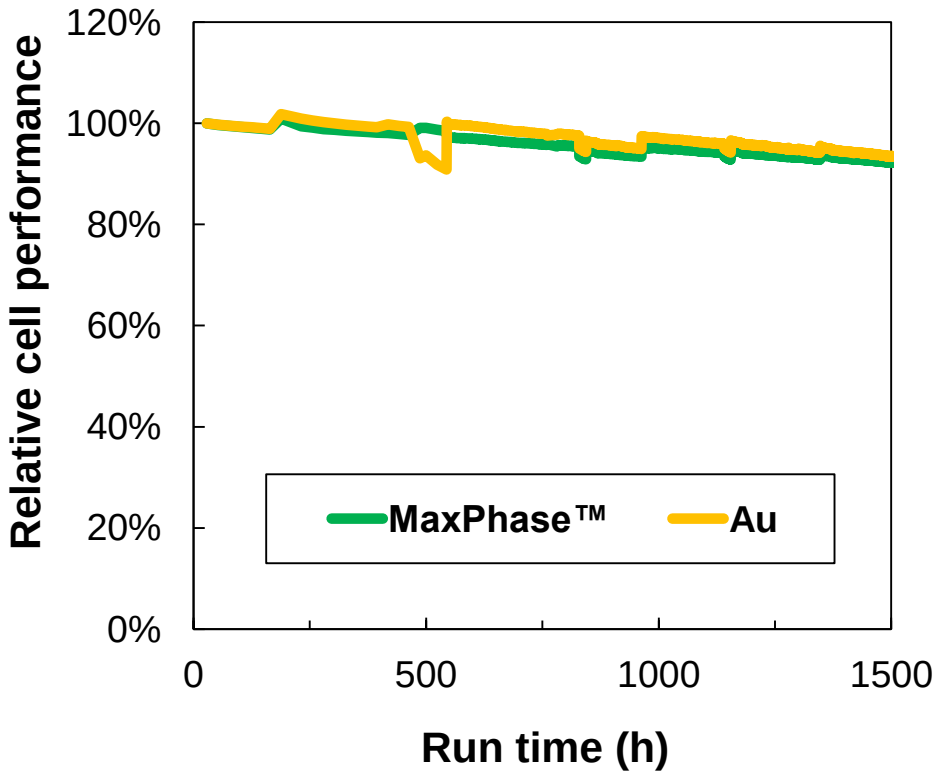
- The oxide layer grows thick on uncoated SS316L and the contact resistance increases as a result
- The electrical properties of the gold and MaxPhase™ coatings are unaffected by the corrosion tests



Pressure 200 N/cm²

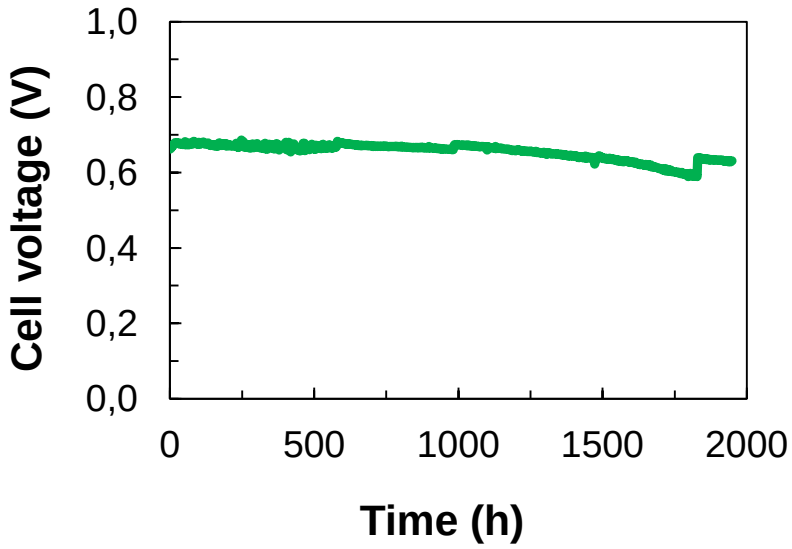
In Situ Stack test

- Performance after 1500 hours 93 %
- The MaxPhase coated BPP provide similar performance as the gold coated BPP



In Situ Stack Test: 2000 hours

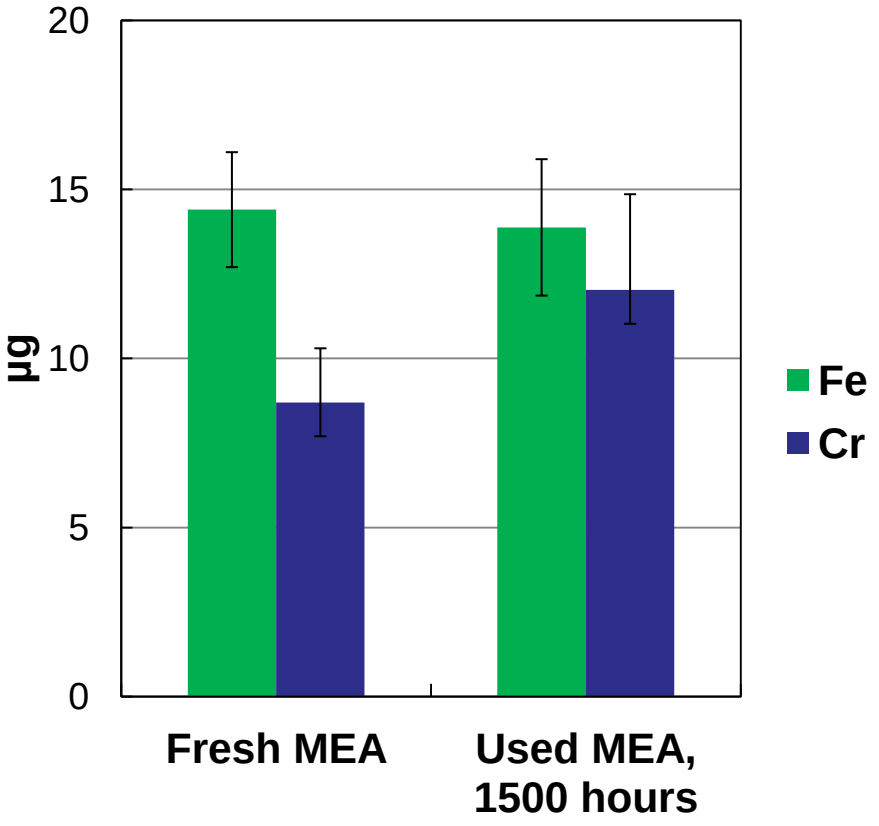
- Test performed by PowerCell Sweden AB
- S1-series short stack with MaxPhase coated BPP
- Stable performance for 2000 hours



- Reformate fuel with 25 ppm CO
- Galvanostatic 500 mA/cm^2 operation
- 70 °C operating temperature
- 80% RH

Post-analysis of metals in membrane

- No detectable difference in Fe and Cr content in the membrane between a fresh one and one used for 1 500 hours

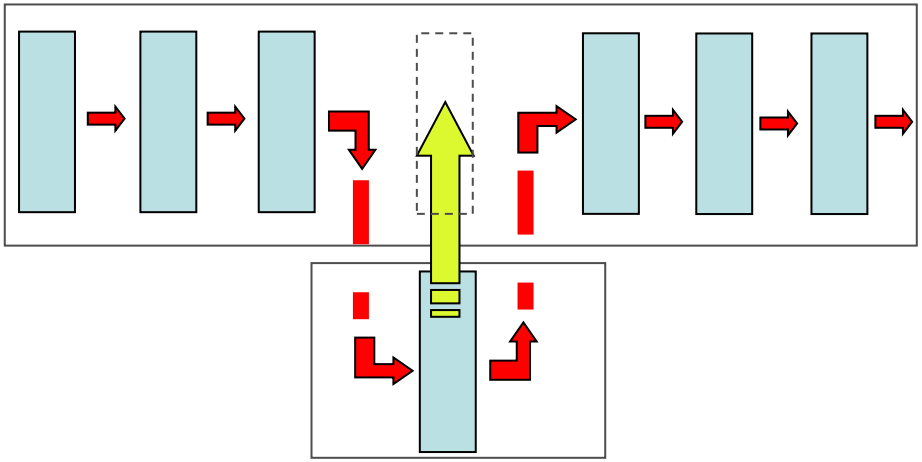


ICP-AES, 6 samples, 95 cm2

Lean Production

Traditional PVD
Out-source the coating step
Lead time: **Weeks**
Produce to storage

Inline PVD
Do it yourself
Lead time: **Minutes**
Produce to order



Two systems

INLINECOATER™

Post-coating of formed BPP

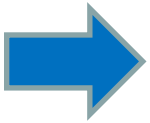
REELCOATER™

Pre-coating steel reel to reel

Production and cost analysis

Detailed cost analysis for different coating scenarios:

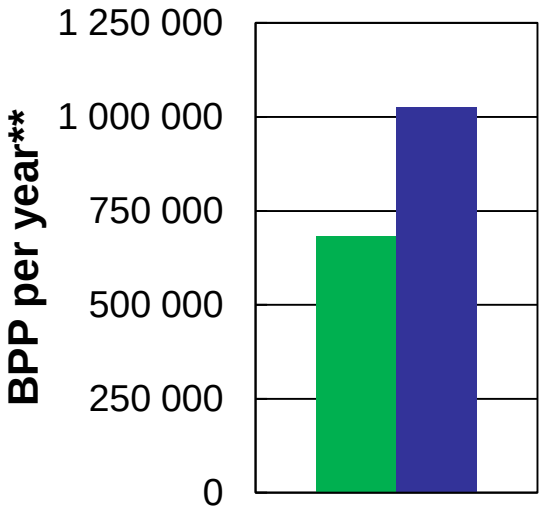
- Initial investment
- Personnel (Swedish salary)
- Taxes
- Operation
- Service
- Materials
- Interest
- ..



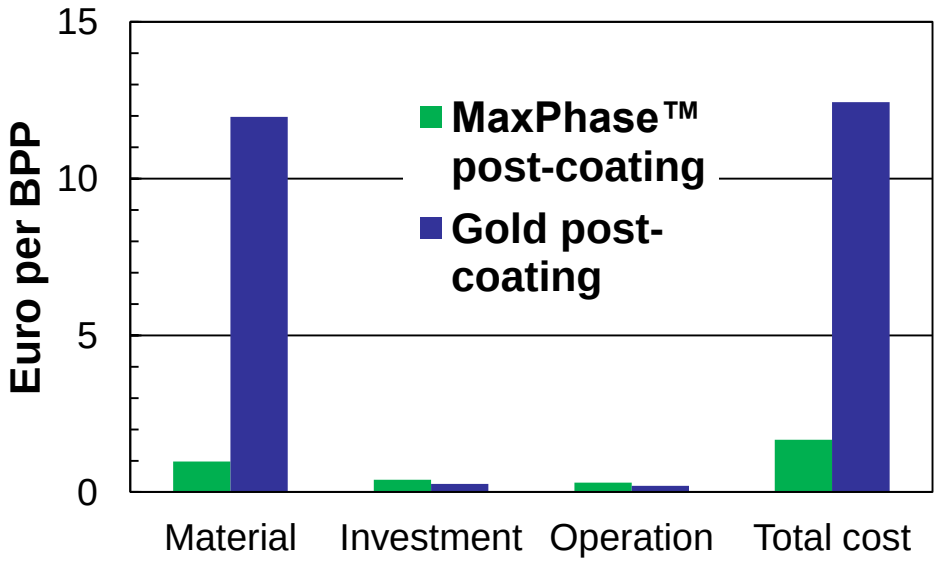
Let's highlight the results!

Post-coating of formed BPP today

Maximum capacity*



Production cost



Au: 12 EUR/BPP

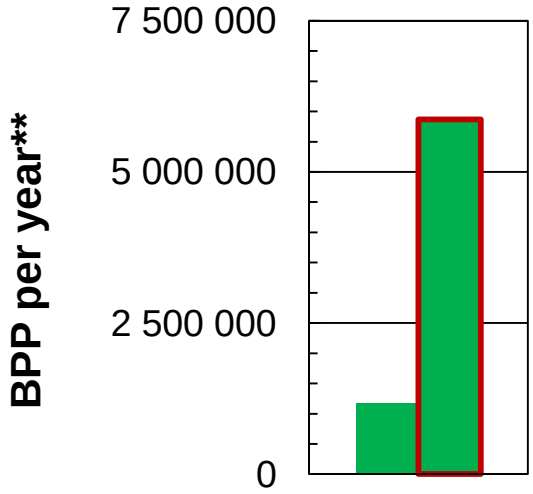
MaxPhase: 2 EUR/BPP

* Capacity of 1 InlineCoater™ 500
** 1 BPP = 700 cm^2

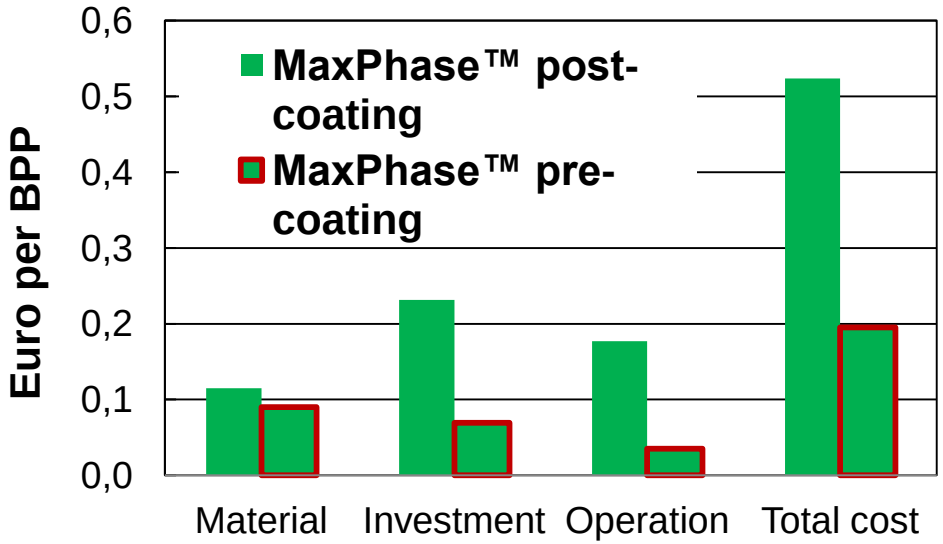
A future outlook

Reduced coating thickness & pre-coating reel-to-reel

Maximum capacity*



Production cost



Post-coat: 0.5 EUR/BPP

Pre-coat: 0.2 EUR/BPP

* Capacity of InlineCoater™ 500 and modified ReelCoater™
** 1 BPP = 700 cm^2

Conclusions

- **MaxPhase™ coatings perform as gold coatings**
  2,000 hours in stack test
- **Coating costs: 2 EUR/BPP** (700 cm^2/BPP, volume production)
  Further cost reduction up to 90 % possible
- We offer job coatings and entire PVD systems for integrated production lines

Acknowledgments

SINTEF

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VTT

POWERCELL

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Nordisk InnovationsCenter

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