

SILICONE-LIKE RELEASE, MINIMAL TRANSFER

Nanometre-scale XIMO® coatings deposited by roll-to-roll atmospheric-pressure PECVD for casting, transfer and composite process liners

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1–10 nm

XIMO® thickness,
continuous layer (TEM)

< 5 ng/cm²

extractable siloxane,
CPI plasma liner [1]; wet
silicones 40–128

> 100 days

no measurable change
in release force

**2 m × 2,000
m**

production run, uniform
release

ABSTRACT

Release liners for casting, transfer and composite moulding must hold the product during processing, then separate cleanly without leaving residues. We describe XIMO®, a silicone-like plasma polymer deposited at 1–10 nm by roll-to-roll atmospheric-pressure plasma-enhanced chemical vapour deposition (AP-PECVD) from a single organosilicon precursor in nitrogen (residual O₂ < 50 ppm). TEM shows a continuous layer; at 10 nm on 50 µm PET it represents < 0.02 wt% of the liner. Surface energy falls from 48–56 to 17–21 mN/m between 0 and 5 nm. Release of cast PU and 2K epoxy decreases with thickness, reaching 0.017 and 0.005 N/25 mm at 5 nm. In a published benchmark, a CPI plasma release coating combined < 5 ng/cm² extractable siloxane with 93.8 % subsequent adhesion and solvent resistance. Release was unchanged after > 100 days of storage and uniform along a 2 m × 2,000 m production run, while matt-film gloss and PET reprocessing properties were preserved.

Keywords: release liner • atmospheric-pressure plasma • AP-PECVD • plasma polymer • siloxane extractables • PU casting • composite liner • roll-to-roll

1

INTRODUCTION: THE RELEASE FUNCTION

A process liner has a two-sided task: **hold first, separate cleanly**. It must be wetted by the resin, adhesive or cast polymer; keep it in place through curing, cutting and winding; then release it smoothly without marking; and leave nothing behind that would compromise printing, painting or bonding of the product. The required release force is therefore a window defined by the application, not a universal minimum.

Wet-coated silicones meet the force requirement with a cured polydimethylsiloxane (PDMS) network applied at typically 0.3–1.5 g/m², cured by catalysed hydrosilylation, condensation or radiation. Unreacted oligomers and cyclic siloxanes in that network form the extractable fraction that migrates to the counter-surface, where it acts as a weak boundary layer. Non-silicone alternatives (carbamates, acrylics) reduce transfer but generally lose solvent resistance. Scrutiny of residual siloxanes is also increasing, for example through the REACH restriction on D4, D5 and D6 [10]. The aim of CPI's work is a release layer that keeps the functional benefits of silicone at a fraction of its thickness and with virtually no extractables.

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CONTROLLED-ATMOSPHERE AP-PECVD

Corona is a plasma in air: although air is about 80 % nitrogen, its surface chemistry is dominated by reactive oxygen species, which oxidise and progressively degrade the polymer. It cannot deposit a coating. CPI's atmospheric plasma instead runs in a nitrogen atmosphere purged of oxygen and water; residual O₂ must stay **below 50 ppm** for the chosen dopants, rather than oxygen, to govern the chemistry [1]. Non-polymerisable dopants (e.g. H₂, NH₃, CO₂) graft functional groups for adhesion [8, 9]; polymerisable precursors grow a thin plasma-polymer film. This is AP-PECVD, the route used for XIMO® [4, 5].

AP-PECVD has a narrow process window (Figure 1). Too high an effective reactivity nucleates particles in the gas phase and yields a powdery deposit; too low leaves an under-crosslinked, oily film that transfers; deposition on the electrodes (fouling) degrades the process over time [1, 4].

Controlled N₂ atmosphere, residual O₂ < 50 ppm

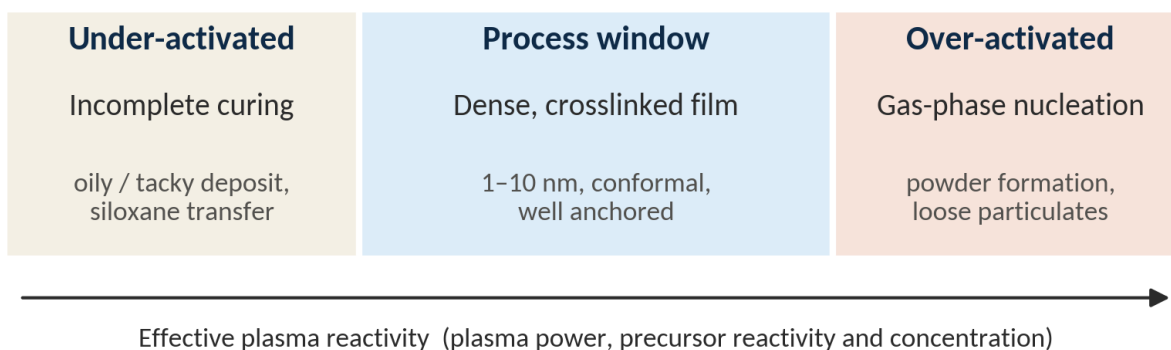


Figure 1. Conceptual process window for AP-PECVD release layers.

CPI's Bluemach reactors address this window through a patented electrode and gas-diffuser assembly that keeps precursor concentration low near the electrodes and uniform across the web, multi-zone treatment in one pass, and continuous control of up to 89 interconnected process parameters [3]. The result is a homogeneous 1–10 nm coating over 2 m width without plasma-generated powder. Coating runs at tens of m/min; grafting treatments reach hundreds of m/min [1].

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THE XIMO® LAYER

XIMO® is deposited from **one organosilicon precursor and the plasma gas**, with no solvent, catalyst, crosslinking agent or controlled-release additive [3]. In the discharge the precursor fragments and recombines into a crosslinked $\text{SiO}_x\text{C}_y\text{H}_z$ network [6]. Oxidising conditions drive such films towards hydrophilic SiO_x ; CPI's conditions retain methyl groups and yield a hydrophobic, silicone-like surface. The layer is two to three orders of magnitude thinner than a wet silicone coating (Figure 2); at 10 nm on 50 μm PET it represents < 0.02 wt% of the liner [3].

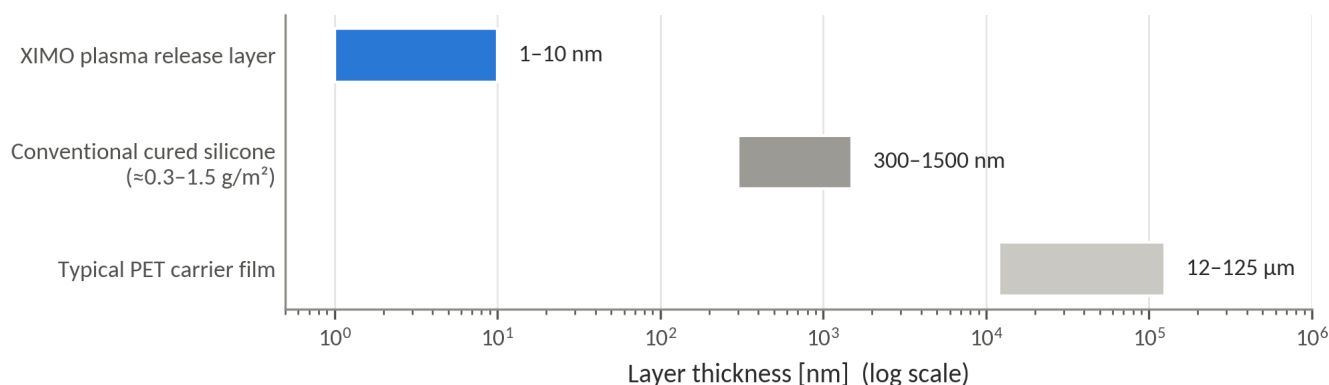


Figure 2. Thickness of the XIMO® layer compared with a conventional cured silicone coating (typical coat weight 0.3–1.5 g/m²) and the carrier film. Log scale.

TEM cross-sections show a continuous layer of uniform contrast at the PET interface, without particulate inclusions, in the imaged sections (Figure 3).

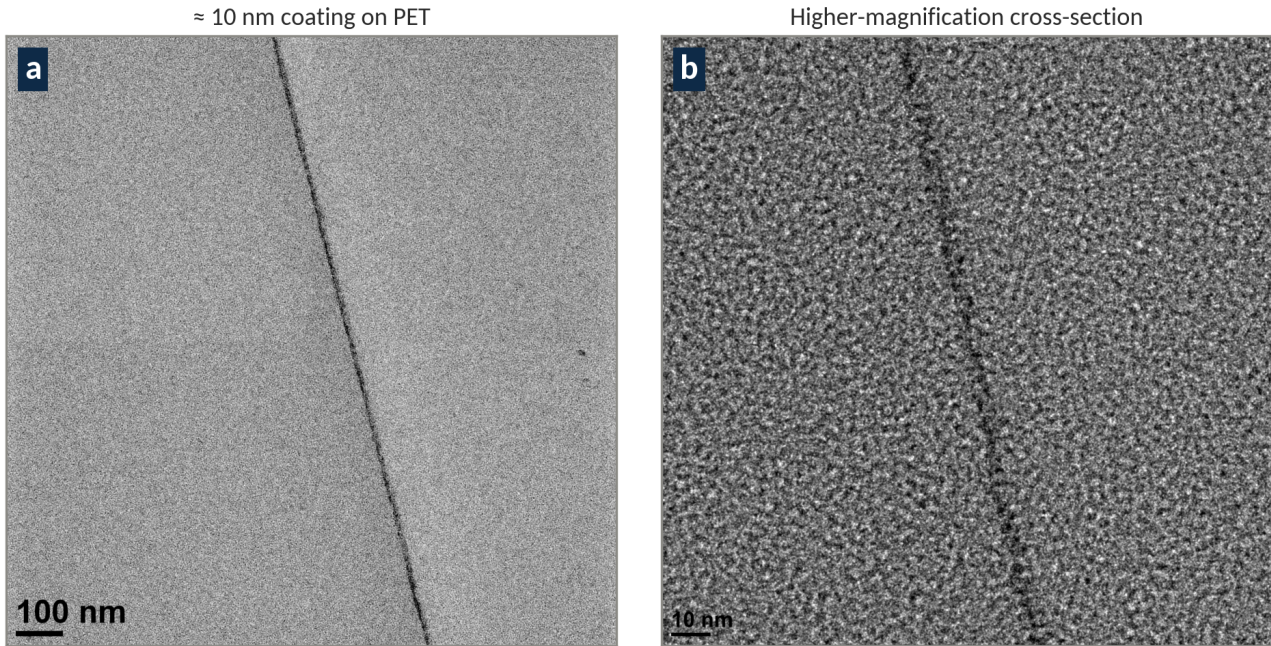


Figure 3. TEM cross-sections of XIMO®-coated PET embedded in resin; the coating is the dark interfacial line. (a) ≈ 10 nm layer; (b) higher-magnification cross-section from the same TEM series. Data: [1, 3].

Surface energy (water/diiodomethane, OWRK) was measured on four PET grades including two matt films (Figure 4). The first nanometre produces the largest drop, from 48–56 to 25–28 mN/m; values then approach 17–21 mN/m at 5 nm, a range comparable to cured PDMS. The response is independent of PET grade, which makes surface energy a practical **quality-control metric**. It is not a qualification test: adhesion and release cannot be predicted from surface energy alone [1].

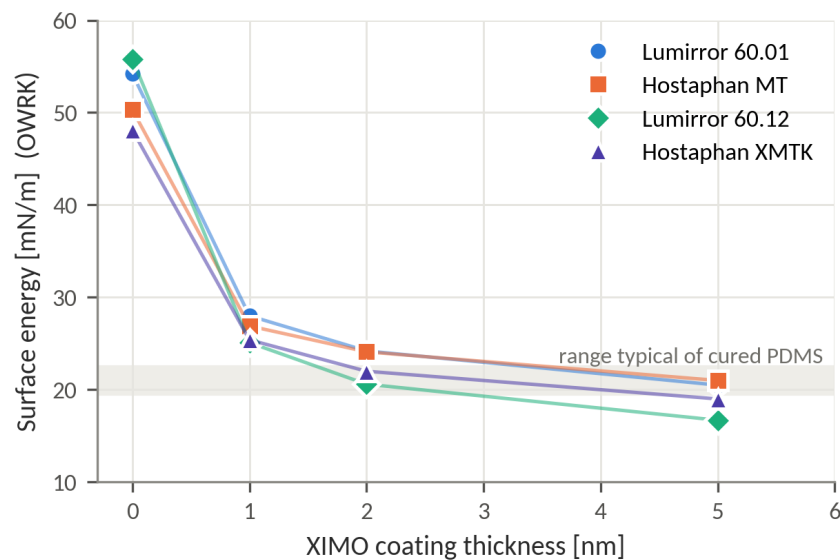


Figure 4. Surface energy of four PET grades versus XIMO® thickness. Shaded band: range typical of cured PDMS (literature value). Data: [3].

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RELEASE PERFORMANCE

4.1 Application release against cast resins

Against cast polyurethanes and a 2K epoxy, release force decreases monotonically with thickness, so the thickness set-point is the tuning parameter (Figure 5a). At 5 nm, release reaches 0.038 N/25 mm (solvent-based PU), 0.017 N/25 mm (solventless PU) and 0.005 N/25 mm (epoxy). The response is resin-specific: thickness sets the level, but the target must be established with the customer's own resin.

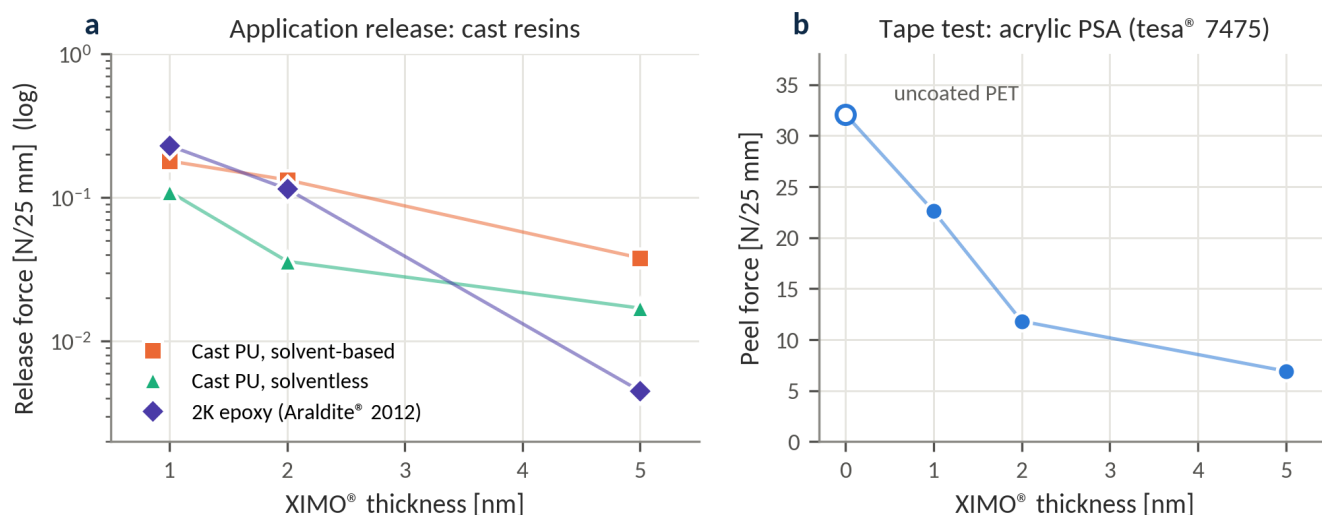


Figure 5. Release force versus XIMO® thickness. (a) Cast PU and 2K epoxy (log scale). (b) Tape test with an aggressive acrylic PSA; the open symbol is uncoated PET [3].

4.2 Tape tests are a different measurement

With tesa® 7475, peel force falls from 32 N/25 mm on uncoated PET to 22.6, 11.8 and 6.9 N/25 mm at 1, 2 and 5 nm (Figure 5b). These values illustrate tunability and are used for quality control. They should not be compared with resin release. In the 2020 benchmark (Section 5), the CPI plasma liner gave 0.21 N/25 mm with a different acrylic PSA and protocol [1]. Every release value belongs with its adhesive and test conditions.

4.3 Smooth, zip-free release

Peel traces of cast PU show a steady plateau without stick-slip at both 1 nm (≈ 0.18 N/25 mm) and 5 nm (≈ 0.04 N/25 mm) (Figure 6). No marking of the PU was observed [3].

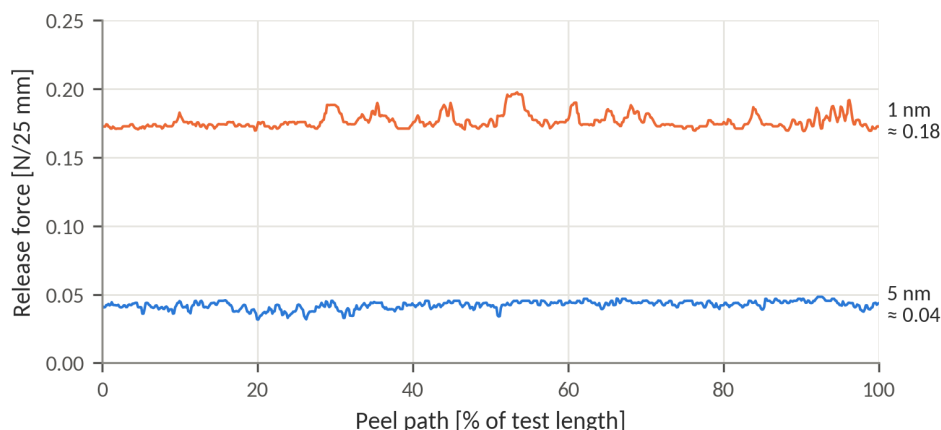


Figure 6. Peel traces of cast PU from 1 nm and 5 nm XIMO® liners. Curves digitised from the source record. Data: [3].

4.4 Composite moulding

For pre-preg and curing liners, a 5 nm XIMO® liner combines low release against 2K epoxy with low volatile and non-volatile extractables (Table 1) [3]. The composite application requires stability during cure at up to 180 °C; this must be qualified for each resin and cure schedule.

Table 1. Release and extractables of a 5 nm XIMO® liner (composite qualification) [3].

Thickness	Peel, tesa® 7475 [N/25 mm]	Release, 2K epoxy [N/25 mm]	Volatile [ng/cm ²]	Non-volatile [ng/cm ²]
5 nm	6.10	0.005	2.15	6.65

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CLEANLINESS AND ANCHORAGE

Release without transfer was assessed through extractable siloxane (procedure adapted from IDEMA M7-98), subsequent adhesion (SA) of a reference tape after contact with the liner, and repeated peels. In the 2020 benchmark (Table 2) [1, 2], three wet silicone liners released at 0.05–0.07 N/25 mm but carried 40–128 ng/cm² of extractable siloxane. The CPI plasma liner reduced this to **< 5 ng/cm²**, at the level of the best non-silicone (carbamate) liner, while remaining solvent resistant, unlike all non-silicone liners tested. Its SA of 93.8 % exceeded that of the three silicone liners. Its release force was higher, consistent with its positioning as a process liner.

Table 2. Benchmark of commercial wet-coated release liners (RL) and a CPI plasma release liner, 2020. Peel: acrylic PSA, 180°, 300 mm/min. SA: Nitto 31B. Extractables: adapted from IDEMA M7-98. Data: [1, 2].

Liner	Chemistry	Peel [N/25 mm]	SA [%]	Extractables [ng/cm²]	Solvent resistant
Commercial RL 1	Silicone	0.07	85.5	127.7	Yes
Commercial RL 2	Silicone	0.05	90.3	39.7	Yes
Commercial RL 3	Silicone	0.05	86.6	50.5	Yes
Commercial RL 4	Carbamate	0.17	97.2	3.4	No
Commercial RL 5	Acrylic	0.18	84.9	n/a	No
Commercial RL 6	Vinyl acrylic	0.10	88.1	n/a	No
CPI plasma liner	Silicone-like	0.21	93.8	< 5	Yes

On XIMO® liners, a second peel on an already-peeled area gives the same force as the first within measurement error (Figure 7a): 20.4 vs 20.9 N/25 mm at 1 nm, 5.9 vs 6.0 N/25 mm at 5 nm. No delamination or coating transfer was detected, and SA (Nitto 31B) exceeded 95 % in this series [3]. If the coating had transferred to the first tape, the second peel would meet bare PET and give a higher force; its absence is consistent with a well-anchored coating.

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STABILITY AND INDUSTRIAL REPRODUCIBILITY

Deposition under non-oxidising conditions avoids the low-molecular-weight oxidised material that drives ageing after corona. XIMO® liners stored for more than 100 days show no detectable change in release force (Figure 7b). After 20 h at 50 °C against the PSA, release is similar on PET, BOPP and HDPE; the larger scatter on HDPE reflects the carrier (Figure 7c) [3].

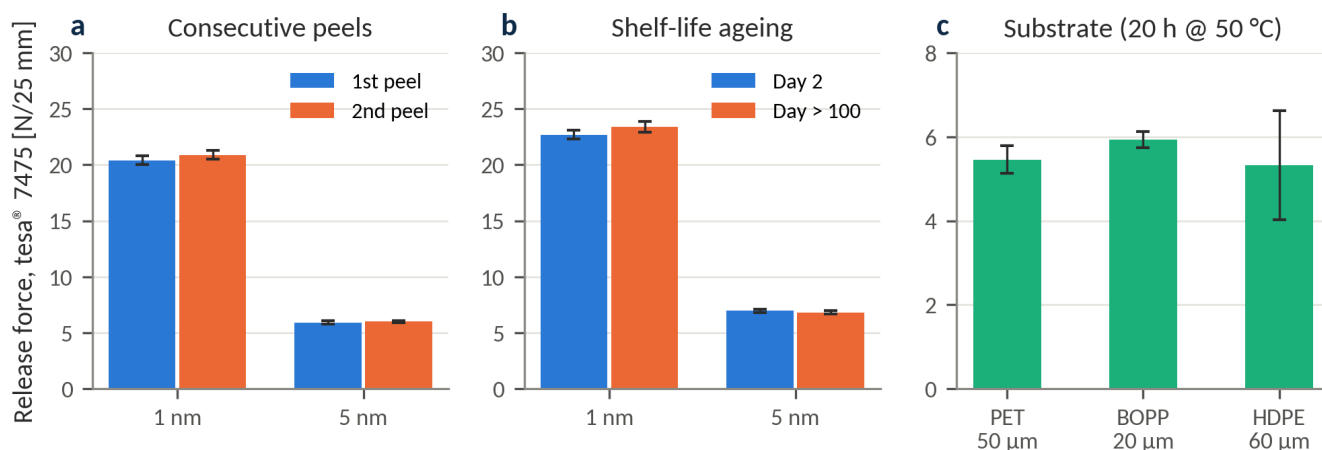


Figure 7. Release against tesa® 7475: (a) consecutive peels on the same area; (b) liner storage > 100 days; (c) carrier films, 20 h at 50 °C. Data: [3].

On a production run of 36 μm PET coated over **2 m width and 2,000 m length**, each point averages three measurements across the web (Figure 8a) [1]. The mean release force is 5.87 N/25 mm, with no point more than 0.35 N/25 mm from the mean and no drift along the roll. Surface energy of the 1 nm grade measured in December 2021, March 2022 and April 2022 was 26.9, 26.9 and 27.1 mN/m (Figure 8b) [3].

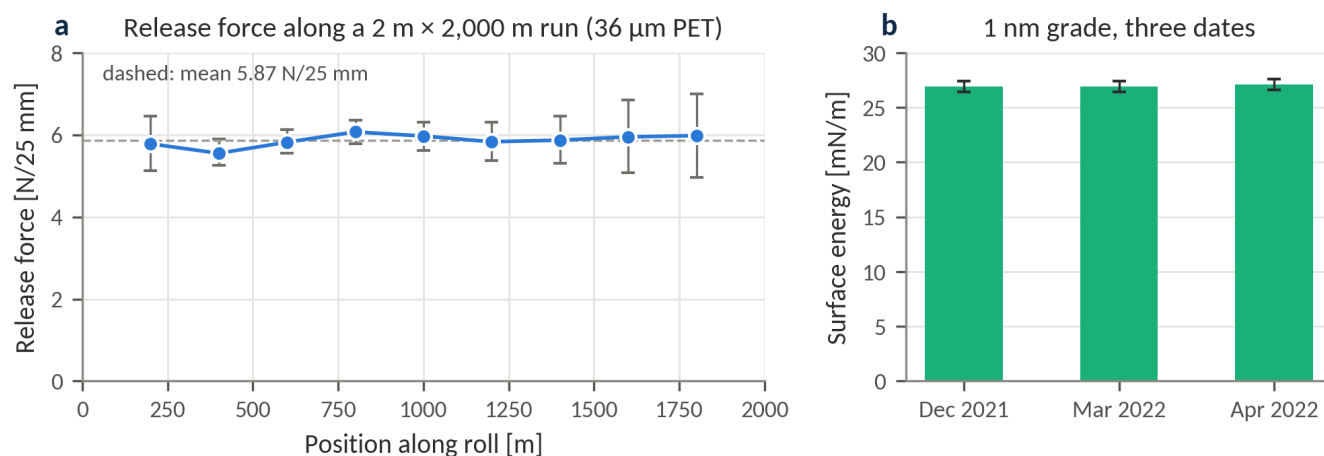


Figure 8. (a) Release force along a 2,000 m roll (36 μm PET, 2 m wide); each point is the mean of three across-web measurements; error bars as reported. Data: [1]. (b) Surface energy of the 1 nm grade at three dates. Data: [3].

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SURFACE FINISH AND REPROCESSING

A casting liner imprints its topography on the product. Wet siliconisation raises the 75° gloss of matt Hostaphan® MT from 21 to 34 GU. A XIMO® layer, much thinner than the surface texture, leaves gloss unchanged within error on MT and XMTK films (Figure 9), so matt transfer is preserved. On these films release against tesa® 7475 was 23 N/25 mm (1 nm) and 6 N/25 mm (5 nm), versus 0.1 N/25 mm for the siliconised reference [3].

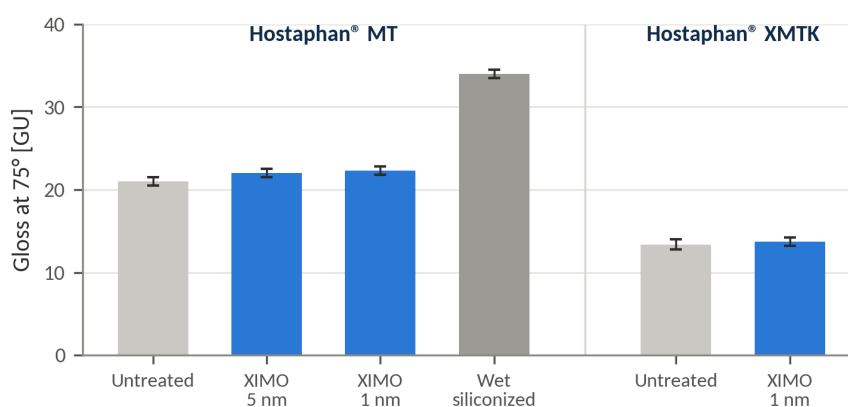


Figure 9. 75° gloss of matt PET films before and after XIMO® coating, compared with wet siliconisation. Data: [3].

In a reprocessing trial, coated and uncoated PET films were extruded into pellets and moulded into test bars. Viscosity number, flexural properties and Charpy impact strength are indistinguishable within scatter (Table 3) [3]. The trial shows that the coating does not measurably degrade the PET. Acceptance in a given recycling stream still depends on the used liner and the collection route.

Table 3. Properties of PET recycle from uncoated and XIMO®-coated film. Data: [3].

Property	Uncoated PET	XIMO®-coated PET
Viscosity number [cm ³ /g]	59.6	58.2
Flexural modulus [MPa]	2,220 ± 20	2,230 ± 60
Maximum flexural stress [MPa]	85.4 ± 1.1	86.2 ± 0.4
Charpy impact strength [kJ/m ²]	1.44 ± 0.15	1.39 ± 0.03

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APPLICATIONS AND QUALIFICATION

Release is always qualified with the customer's own materials. CPI follows a six-step pathway from the release window to supply (Figure 10), run on industrial-scale equipment so that the customer can qualify before any capital investment. Table 4 summarises the main application fields.

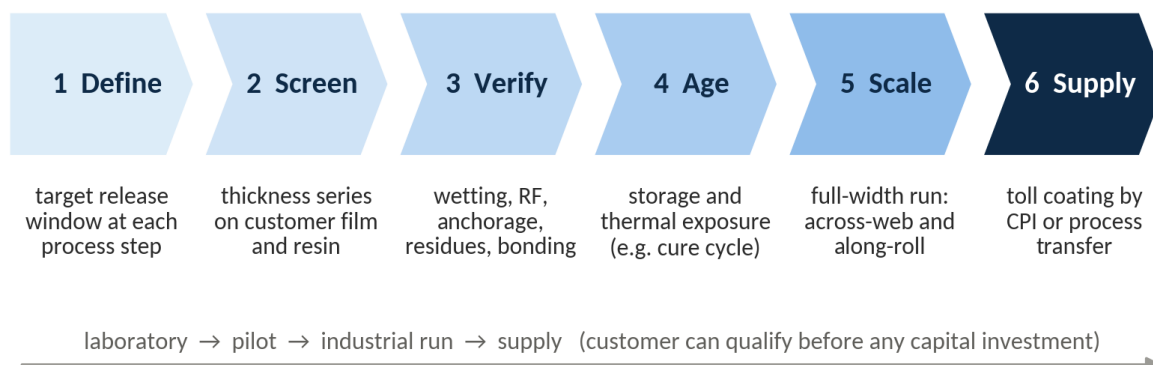


Figure 10. Qualification pathway for a XIMO® release application.

Table 4. Principal release applications of XIMO® [3].

Segment	Problem to solve	XIMO® contribution
Automotive: casting films for PU skins	Hold for handling, release without marking; no residue on a part that is later painted or printed; wetting during casting	Tunable release and surface energy; low transfer; base-film gloss preserved; reusable and reprocessible liner
Apparel: thermal transfer, textile printing	Hold through handling and cutting, clean release at transfer; coating matt surfaces without changing texture	Nanometre layer on matt films; smooth, zip-free release; no silicone layer to transfer to the textile
Composites: pre-preg and curing liners	Silicone residue from conventional liners causes delamination; liner must withstand cure (up to 180 °C)	Crosslinked silicone-like layer with low extractables; one liner for pre-cure and cure (to be qualified per cure cycle)

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VALIDATED SCOPE

Table 5. Status of XIMO® release claims.

DEMONSTRATED	QUALIFIED PER APPLICATION	OUTSIDE CURRENT SCOPE
1–10 nm continuous layer; < 0.02 wt% at 10 nm - Thickness-tunable release vs PU, epoxy, acrylic PSA - Low extractables and high SA (2020 benchmark) - No ageing > 100 days; uniform 2 m × 2,000 m run - Gloss and PET reprocessing properties preserved	- Release window for each resin and process step - Cure-cycle stability (e.g. 180 °C) and post-cure extractables - Downstream printing or bonding of the product - Recycling of the used liner in a specific stream	- Very easy release against standard PSAs, as delivered by classical silicone liners [1, 3] - Porous or 3D substrates (served by the Group's vacuum plasma platform)

CONCLUSIONS AND WORKING WITH CPI

Controlled-atmosphere AP-PECVD produces a 1–10 nm silicone-like release layer that is continuous, thickness-tunable, stable in storage and reproducible at industrial width and length. In benchmark testing, the plasma liner combined solvent resistance with extractables at the level of non-silicone liners. Its best fit is process liners (PU casting, thermal transfer, composite moulding), where clean separation and surface fidelity matter more than ultra-low release.

CPI is the Plasmalex Group's competence centre for atmospheric roll-to-roll plasma and operates under ISO 9001. Its test and job-coating park includes atmospheric roll-to-roll units 60–200 cm wide for reels up to 80 cm diameter and 1,000 kg. Trials run on the customer's film and resin; supply follows by toll coating or process transfer on a Plasmalex-built line.



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TEST METHODS

Table 6. Summary of test methods.

Property	Method
Release / peel force	25 mm strips. 2020 benchmark: 180°, 300 mm/min, acrylic PSA [1]. tesa® 7475, cast PU (solvent-based, solventless), Araldite® 2012: CPI internal protocol [3]
Subsequent adhesion	Nitto 31B after contact with the liner, relative to a non-release reference
Extractable siloxane	Adapted from IDEMA M7-98 (Table 2); volatile / non-volatile fractions (Table 1)
Surface energy	Water and diiodomethane contact angles, OWRK model
Thickness / morphology	TEM of resin-embedded cross-sections
Gloss	75° geometry, matt Hostaphan® MT and XMTK
Reprocessing	Extrusion to pellets, injection moulding; viscosity number; three-point bending (support radius 5 mm, span 16 × thickness); Charpy impact

All results obtained on CPI Bluemach atmospheric-pressure plasma reactors. tesa®, Araldite®, Hostaphan®, Lumirror® and Nitto are trademarks of their respective owners.

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