EUROPLASMA

WHITE PAPER · MEMBRANES

NANOMEMBRANES: THE SURFACE DECIDES

Nanofiber and nanoporous membranes in medical, environmental, industrial and energy applications, and the role of PFAS-free vacuum plasma nanocoatings

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0.1 nm – 10 µm	≈ 20 nm	10–200 nm	Halogen-free
pore scale spanned by membrane classes, RO to MF	pore rating of virus-retentive filters for biologics	typical plasma nanocoating, through the membrane depth	repellent and wetting functions, one dry step

ABSTRACT

Membranes with nanometre-scale fibres or pores sit at the core of biologics manufacturing, water treatment, air filtration, batteries and fuel cells. Pore size sets their selectivity; the surface sets their behaviour in service: wetting, fouling, flux decline and chemical resistance. We review the main applications of nanofiber and nanoporous membranes across four sectors and identify the surface function each one requires. Two findings emerge. The hydrophobic and oleophobic functions of air, venting and membrane-distillation membranes rely largely on fluorinated materials covered by the proposed universal EU PFAS restriction. Any added layer must also stay well below the pore it lines, which places 10–200 nm nanocoatings in the nanofiber, microfiltration and membrane-distillation range, not in nanofiltration. Low-pressure plasma-enhanced chemical vapour deposition (PECVD) meets both constraints, depositing halogen-free functional nanocoatings in one dry step through the depth of porous media.

Keywords: nanofiber membrane · nanofiltration · PFAS-free · low-pressure plasma · PECVD · hydrophobic · oleophobic · hydrophilic · filtration

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1 INTRODUCTION: TWO KINDS OF NANOMEMBRANE

The term nanomembrane covers two different objects that are often confused. Nanofiber membranes are nonwoven mats of electrospun or melt-blown fibres with diameters of tens to hundreds of nanometres; their pores, formed between fibres, are typically 0.1 µm to a few micrometres, with high porosity and low pressure drop [1, 2]. Nanoporous membranes (nanofiltration, ultrafiltration and virus-retentive filters) are dense or asymmetric films whose pores themselves measure 1 to 100 nm [3, 4].

Both separate by size, and both are governed in service by their surface. Pore size sets what a membrane can retain. Surface chemistry sets whether it wets, how fast it fouls, whether it keeps its flux or its electrostatic charge, and whether it survives the process fluid. This paper reviews where each membrane type is used, what its surface must do, and where vacuum plasma nanocoatings can contribute.

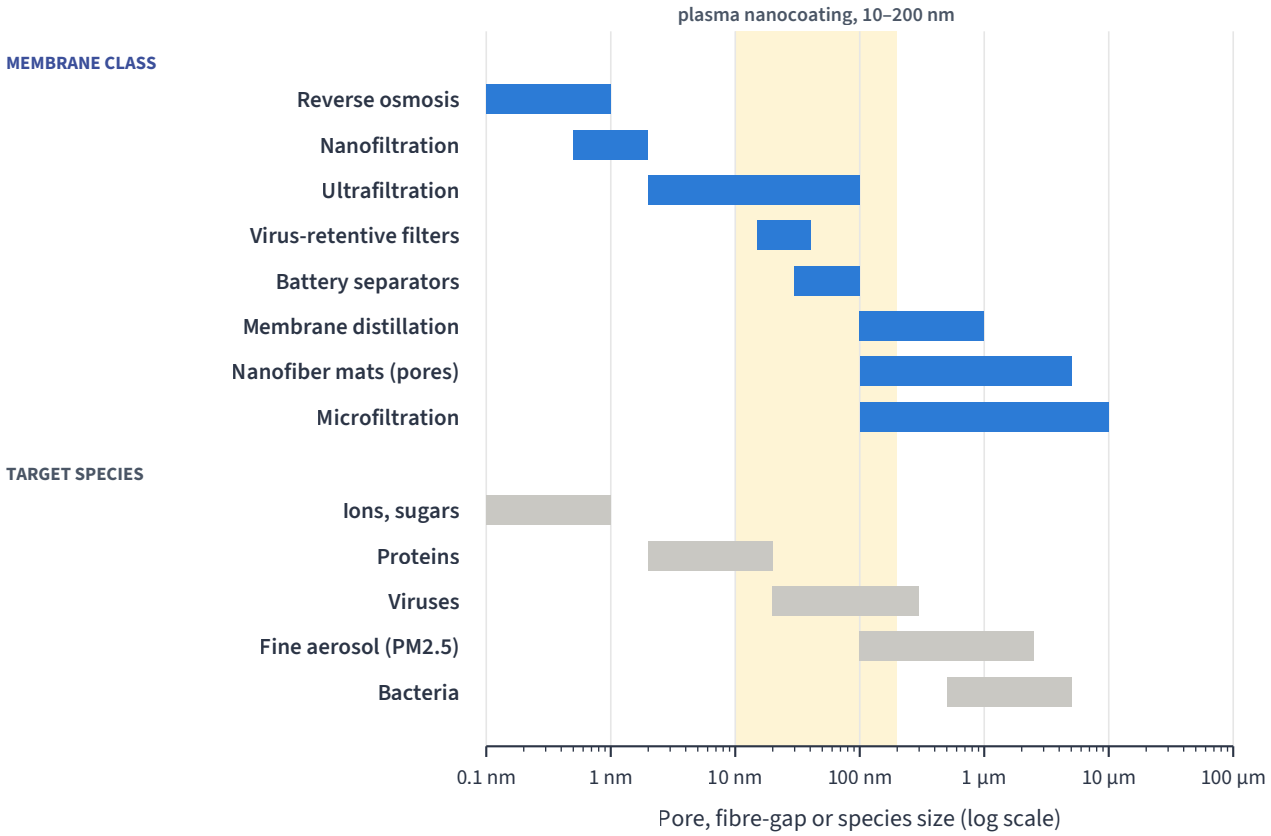


Figure 1. Pore or fibre-gap scale of the main membrane classes, compared with target species and with the typical thickness of a plasma nanocoating (shaded band). Log scale; ranges indicative [1–7].

The shaded band in Figure 1 is the main design rule for any surface treatment: a coating must stay well below the pore it lines. For nanofiber mats, microfiltration and membrane-distillation membranes, a 10–200 nm layer leaves the pore structure in place. For battery separators and virus-retentive filters, pores and coating overlap, so thickness becomes a design parameter kept at the low end of the range. For nanofiltration and reverse osmosis, a deposited layer would close the pores; there, only grafting of the selective skin is relevant.

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2 MEDICAL AND BIOMEDICAL MEMBRANES

In healthcare, membranes protect products and patients: they clear viruses from biologics, purify active ingredients, filter blood, and carry cells or drugs. Contact with proteins, blood and tissue makes low protein binding, controlled wetting and biocompatibility the dominant surface requirements (Table 1).

Table 1. Medical and biomedical membrane applications.

Application	Membrane and pore scale	What the surface must do
Virus filtration of biologics and plasma products	Asymmetric polymer membranes, ≈ 20 nm pore rating [5]	Wet fully and fast; low protein adsorption to keep flux and yield
API purification	Solvent-stable NF (OSN), ≈ 1 nm [8]	Resist organic solvents; keep rejection stable
Haemodialysis	Hollow fibres (e.g. polysulfone), nano- to mesoporous	Haemocompatibility; controlled wetting; low fouling by plasma proteins
Wound dressings and tissue scaffolds	Electrospun nanofiber mats, pores 0.1–10 µm [2]	Hydrophilic or cell-adhesive surface; drug or antimicrobial loading
Diagnostics and lab-on-chip	Track-etched, silicon or nanofiber membranes [9]	Defined capillary flow; low non-specific binding

Atomically thin membranes show where the field is heading: nanoporous graphene has separated small molecules from proteins in dialysis-type tests with permeances well above those of commercial dialysis membranes, so far at laboratory scale [10].

3 ENVIRONMENT: WATER AND AIR

Water treatment uses the full pore range of Figure 1. Nanofiltration removes hardness, multivalent ions and organic micropollutants at lower pressure than reverse osmosis; ultrafiltration and microfiltration remove

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particles, bacteria and viruses upstream [3]. In air, nanofiber layers add fine-particle efficiency to filter media at low added pressure drop [1] (Table 2).

Table 2. Environmental membrane applications.

Application	Membrane and pore scale	What the surface must do
Drinking water and wastewater reuse	NF ≈ 1 nm; UF 2–100 nm; MF 0.1–10 µm [3]	Hydrophilic, low-fouling surface; tolerance to chlorine and caustic cleaning
Air filtration: HVAC, HEPA, face masks	Nanofiber layers on nonwoven or electret media [1]	Hydrophobic and oleophobic surface to keep efficiency and charge against oily aerosols
Remediation and leachate	NF and photocatalytic (e.g. TiO_2) membranes	Chemical resistance; anti-fouling or self-cleaning
Agriculture and resource recovery	NF on drainage water and digestate	Fouling resistance in high-organic streams

Fouling is the common limit across water applications: protein, organic and biofilm deposits reduce flux and raise the cleaning frequency. A hydrophilic, low-fouling surface is the main lever, provided it survives the cleaning-in-place cycle. In air filtration the limit is the opposite: oily aerosols wet the media and discharge electret fibres, which calls for hydrophobic and oleophobic surfaces.

4 INDUSTRIAL AND CHEMICAL PROCESSING

In industry, membranes replace or shorten thermal steps such as evaporation and distillation, and recover value from effluents [3, 8]. Organic solvent nanofiltration (OSN) separates catalysts and impurities from non-aqueous mixtures under mild conditions [8] (Table 3). Zeolite and ceramic nanomembranes extend separation and catalysis to high temperature and aggressive media, outside the range of polymer membranes.

Table 3. Industrial and chemical membrane applications.

Application	Membrane and pore scale	What the surface must do
Dairy, sugar, wine and juice	NF for whey demineralisation, syrup purification, cold concentration	Low fouling; food-contact compliance; cleanability
Fine chemicals and pharma synthesis	OSN for catalyst and solvent recovery [8]	Solvent stability; no extractables
Textile, plating and mining effluents	NF for dye and metal recovery, water reuse	Chemical resistance; anti-fouling
Bioprocess downstream	UF and NF fractionation of enzymes, amino acids, antibiotics	Low protein binding; operation at ambient temperature

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5 ENERGY AND STORAGE

In energy systems the membrane is often the active component, conducting ions or vapour while blocking everything else (Table 4). Perfluorosulfonic acid (PFSA) ionomers such as Nafion® remain the reference for proton-exchange membranes, owing to nanophase-separated ionic channels in a hydrophobic matrix [11]. Polyolefin separators set the safety and rate capability of lithium-ion cells [6], and hydrophobic microporous membranes carry vapour in membrane distillation [7].

Table 4. Energy and storage membrane applications.

Application	Membrane and pore scale	What the surface must do
Fuel cells and electrolysers	PFSA ionomers, nanophase-separated ionic channels [11]	Proton conduction; chemical stability
Lithium-ion battery separators	Microporous PE/PP, pores ≈ 30–100 nm [6]	Fast, uniform electrolyte wetting; adhesion of ceramic or binder layers
Flow batteries, salinity-gradient power	Ion-exchange membranes	Ion selectivity; low crossover
Membrane distillation	Hydrophobic PTFE, PVDF or PP, 0.1–1 µm [7]	Hydrophobic, ideally omniphobic surface against wetting by surfactants and oils
H_2 and CO_2 separation	Pd-alloy, zeolite, ceramic, graphene	Inorganic selective layers; outside polymer-coating scope

6 THE SURFACE FUNCTION AND THE PFAS QUESTION

Mapping the four sectors against the function each application requires (Figure 2) gives five recurring needs: **hydrophobicity, oleophobicity, hydrophilicity, low fouling, and activation** for bonding or cell adhesion.

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		Hydrophobic	Oleophobic	Hydrophilic	Low fouling	Activation / adhesion
MEDICAL	Virus & sterile filtration			●	●	
	Dialysis membranes			●	●	
	Wound dressings, scaffolds			●		●
	Diagnostics, lab-on-chip			●	●	○
ENVIRONMENT	Water NF / UF / MF			●	●	
	Air filtration, masks	●	●			
INDUSTRY	Food, bioprocess UF/NF			●	●	
	Venting membranes	●	●			
ENERGY	Battery separators			●		○
	Membrane distillation	●	●		○	

● primary requirement ○ secondary requirement

Figure 2. Surface functions required by the main nanomembrane applications, by sector. Assessment based on the requirements in Tables 1–4.

The repellent functions (hydrophobic venting, oleophobic air filtration, wetting-resistant membrane distillation) have so far relied on fluorinated materials: PTFE and PVDF membranes and fluorocarbon finishes for oil repellency. PFSA ionomers are fluoropolymers too. All fall within the proposed universal restriction of PFAS under REACH. ECHA's Committee for Risk Assessment adopted its final opinion on 2 March 2026; the Committee for Socio-economic Analysis agreed a draft opinion supporting a broad restriction with use-specific derogations on 10 March 2026, and its final opinion is expected by the end of 2026 [12]. Membrane makers therefore need repellent and wetting functions that do not depend on fluorinated chemistry, at least for the surface finish.

7 VACUUM PLASMA NANOCOATINGS FOR MEMBRANES

Low-pressure PECVD addresses both constraints identified above: no fluorinated chemistry, and a layer far thinner than the pore. The membrane is placed in a vacuum chamber, a precursor vapour is dosed and activated by the plasma, and a crosslinked plasma polymer grows on every exposed surface [13]. At low pressure the active species travel between fibres and into open porosity, so the treatment reaches the depth of the media and not only its top face (Figure 3).

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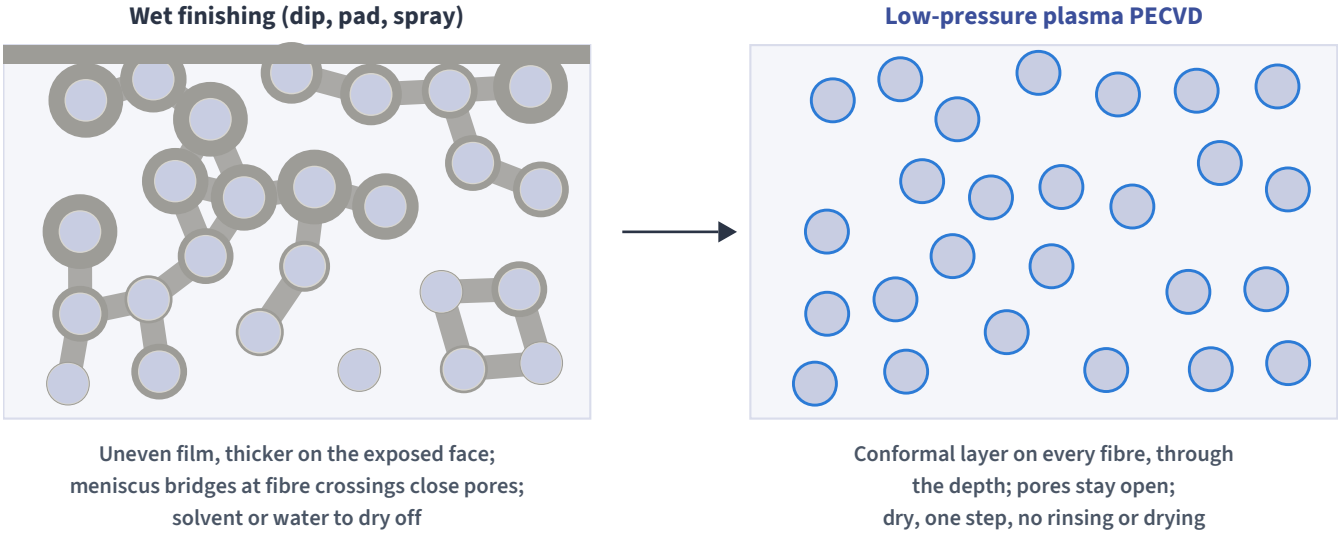


Figure 3. Conceptual cross-section of a fibrous membrane after wet finishing (left) and low-pressure PECVD (right). Not to scale.

Three properties make the process relevant to membranes:

1. **Thickness well below pore size.** Typical layers of 10–200 nm, set by treatment time and power, leave pore structure and air permeability in place.
2. **Chemistry set by the precursor.** Halogen-free precursors give hydrophobic surfaces (PlasmaGuard® S, water contact angle above 105°); oxygen- and nitrogen-containing precursors give hydrophilic and low-fouling surfaces; non-polymerising gases clean and activate before bonding [14].
3. **Dry, low temperature, one step.** No solvent, no water, no drying oven. Depending on the application, Europlasma coating technology reduces coating chemicals by 80 %, water waste by 100 % and energy consumption and CO_2 emission by 50 % compared with wet chemical methods [14].

Measured data confirm the approach on porous media. On two PFAS-free nanofiber membranes, a 25 nm PlasmaGuard® S layer gave average water contact angles of 109° on a membrane that absorbs water untreated, and 131° on a membrane already at 109°. Combined with plasma nanotexturing in the same roll-to-roll process step, the values reached 127° and 145° [15].

Two limits apply. Hydrophilic plasma surfaces can lose part of their effect through surface reorganisation; crosslinked deposited coatings age less than simple activation, but durability must be verified for each membrane and storage condition [16]. Oil repellency without fluorine is the hardest of the five functions, because low-surface-tension oils wet most hydrocarbon and silicone surfaces; the achievable level depends on the oil and is set per application.

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8 APPLICATIONS AND QUALIFICATION

A coating is always qualified on the customer's own membrane, against the customer's own pass criteria. Table 5 summarises where Europlasma treatments address a membrane problem; Figure 4 shows the qualification pathway, run on industrial-scale equipment so that the customer can qualify before any capital investment.

Table 5. Principal membrane applications of Europlasma plasma treatments.

Segment	Problem to solve	Europlasma contribution
Air filtration: HEPA media, face masks	Efficiency loss against oily aerosols; fluorinated finishes being phased out	Halogen-free hydrophobic and oleophobic nanocoating through the media depth
Venting: automotive, electronics	Water and oil ingress while venting; dependence on fluoropolymers	Repellent nanocoating on non-fluorinated membranes or as a fluorine-free finish
Membrane distillation	Pore wetting by surfactants and oils in the feed	Hydrophobic layer on the pore walls; omniphobicity as development target
Biomedical and diagnostic membranes	Slow or uneven wicking; non-specific protein binding	Permanent hydrophilic, low-fouling coating (Actifics)
Tissue engineering: scaffolds	Hydrophobic polymer fibres limit cell attachment	Activation and functional coatings for cell adhesion
Energy: battery separators	Slow electrolyte wetting of PE/PP	Hydrophilic activation, or a coating at the low end of the thickness range

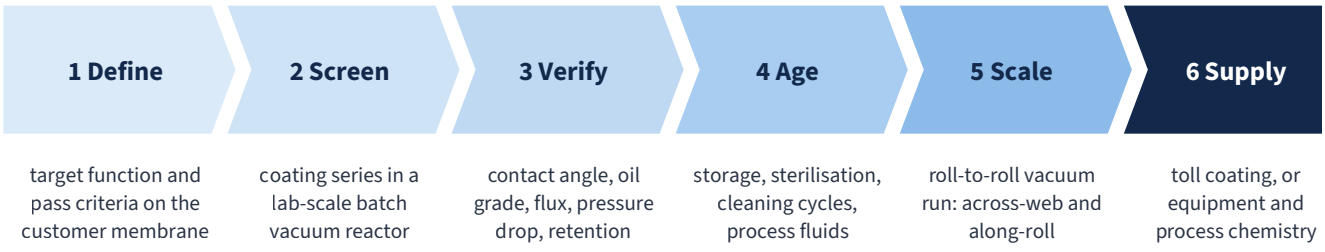


Figure 4. Qualification pathway for a Europlasma membrane coating.

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9 VALIDATED SCOPE

Table 6. Status of Europlasma membrane claims.

DEMONSTRATED	QUALIFIED PER APPLICATION	OUTSIDE CURRENT SCOPE
▪ Halogen-free hydrophobic nanocoating, 10–200 nm (PlasmaGuard® S); 109–145° WCA on nanofiber membranes [15]	▪ Flux, pressure drop and retention after coating	▪ Deposition inside NF and RO pores (< 2 nm)
▪ Treatment through the depth of porous and 3D substrates	▪ Oil-repellency grade for a given oil or aerosol	▪ Membrane manufacture (electrospinning, casting)
▪ Hydrophilic and biofunctional coatings (Actifics)	▪ Durability: ageing, sterilisation, cleaning-in-place	▪ Ion-conducting chemistry (PEM, AEM) and inorganic gas-separation membranes
▪ Batch and roll-to-roll vacuum equipment, process chemistry and toll coating	▪ Biocompatibility and extractables for medical use	▪ Surface-only treatment of films at high line speed (served by the Group's atmospheric roll-to-roll platform)
▪ Lower chemical, water and energy use than wet finishing	▪ Compatibility with process fluids (solvents, electrolytes)	

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10 CONCLUSIONS AND WORKING WITH EUROPLASMA

Nanomembranes are selective because of their pores and reliable because of their surface. Across medical, environmental, industrial and energy uses, five surface functions recur, and the repellent ones depend today on fluorinated chemistry under growing regulatory pressure in Europe. Low-pressure PECVD provides halogen-free hydrophobic, hydrophilic and low-fouling nanocoatings that are thin enough to leave pores open and reach the full depth of the membrane. Its best fit is nanofiber, microfiltration, venting and membrane-distillation membranes, where the coating is far thinner than the pore.

Europlasma is the Plasmalex Group's competence centre for low-pressure plasma, with more than 30 years of PECVD process, chemistry and equipment development. Trials run on the customer's membrane in batch and roll-to-roll vacuum units; supply follows by toll coating or by a turnkey system with qualified process chemistry.

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— ABBREVIATIONS

Table 7. Abbreviations.

Abbreviation	Meaning
AEM / PEM	Anion- / proton-exchange membrane
MD	Membrane distillation
MF / UF / NF / RO	Micro-, ultra-, nanofiltration / reverse osmosis
OSN	Organic solvent nanofiltration
PECVD	Plasma-enhanced chemical vapour deposition
PFAS	Per- and polyfluoroalkyl substances
PFSA	Perfluorosulfonic acid ionomer
PE / PP / PTFE / PVDF	Polyethylene / polypropylene / polytetrafluoroethylene / polyvinylidene fluoride

Pore and size ranges are indicative literature values. Nafion® is a trademark of its respective owner; PlasmaGuard® is a trademark of Europlasma.

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REFERENCES

[1] R.S. Barhate, S. Ramakrishna, "Nanofibrous filtering media: filtration problems and solutions from tiny materials," *J. Membr. Sci.* 296 (2007) 1–8.

[2] Kenry, C.T. Lim, "Nanofiber technology: current status and emerging developments," *Prog. Polym. Sci.* 70 (2017) 1–17.

[3] A.W. Mohammad, Y.H. Teow, W.L. Ang, Y.T. Chung, D.L. Oatley-Radcliffe, N. Hilal, "Nanofiltration membranes review: recent advances and future prospects," *Desalination* 356 (2015) 226–254.

[4] M. Mulder, *Basic Principles of Membrane Technology*, 2nd ed., Kluwer Academic, Dordrecht, 1996.

[5] Parenteral Drug Association, *Technical Report No. 41 (Revised 2008): Virus Filtration*, PDA, Bethesda, 2008.

[6] P. Arora, Z. Zhang, "Battery separators," *Chem. Rev.* 104 (2004) 4419–4462.

[7] A. Alkhudhiri, N. Darwish, N. Hilal, "Membrane distillation: a comprehensive review," *Desalination* 287 (2012) 2–18.

[8] P. Marchetti, M.F. Jimenez Solomon, G. Szekely, A.G. Livingston, "Molecular separation with organic solvent nanofiltration: a critical review," *Chem. Rev.* 114 (2014) 10735–10806.

[9] C.C. Striemer, T.R. Gaborski, J.L. McGrath, P.M. Fauchet, "Charge- and size-based separation of macromolecules using ultrathin silicon membranes," *Nature* 445 (2007) 749–753.

[10] P.R. Kidambi, D. Jang, J.-C. Idrobo, M.S.H. Boutilier, L. Wang, J. Kong, R. Karnik, "Nanoporous atomically thin graphene membranes for desalting and dialysis applications," *Adv. Mater.* 29 (2017) 1700277.

[11] K.A. Mauritz, R.B. Moore, "State of understanding of Nafion," *Chem. Rev.* 104 (2004) 4535–4585.

[12] ECHA, Committee for Risk Assessment final opinion (2 March 2026) and Committee for Socio-economic Analysis draft opinion (10 March 2026) on the proposed universal restriction of per- and polyfluoroalkyl substances (PFAS), European Chemicals Agency, Helsinki, 2026.

[13] J. Friedrich, "Mechanisms of plasma polymerization – reviewed from a chemical point of view," *Plasma Process. Polym.* 8 (2011) 783–802.

[14] Europlasma NV, PlasmaGuard® product data and process comparison with wet chemical finishing, company data.

[15] Europlasma, "PFAS-free water repellency for nanofiber membranes: a 25 nm PlasmaGuard® S coating combined with plasma nanotexturing in a single roll-to-roll vacuum process step," white paper, Plasmalex Group, 2026.

[16] M. Vandenbossche, D. Hegemann, "Recent approaches to reduce aging phenomena in oxygen- and nitrogen-containing plasma polymer films: an overview," *Curr. Opin. Solid State Mater. Sci.* 22 (2018) 26–38.

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