

BATTERY SEPARA- TOR FILM

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STAGE. FOR EVERY CHALLENGE.**

EXECUTIVE SUMMARY

THIN FILM, BIG IMPACT: INDUSTRIALIZING CERAMIC-COATED BATTERY SEPARATORS AT 400 M/MIN

Battery separator films have evolved from passive polymer membranes into safety-critical, performance-defining components of modern lithium-ion batteries. Their transformation – particularly through ceramic coating technologies – has elevated separator coating from a commodity film process to a strategic manufacturing capability central to gigafactory competitiveness.

Ceramic-coated porous polyolefin separators enhance thermal stability, mechanical robustness, and electrolyte wettability, directly influencing abuse tolerance, cycle life, and rate capability. Realizing these benefits at industrial scale, however, demands ultra-low-tension web handling, abrasion-resistant coating systems compatible with ceramic slurries, drying architectures with transport systems not impacting the quality, and automotive-grade inline quality control with full traceability.

Separator coating now sits at the intersection of electrochemistry, thin-film engineering, and high-precision machinery. Producers that successfully integrate PGS™ (Pressurized Gravure System) coating technology, controlled non-contact drying, and ISO/IATF-aligned control systems position themselves as key enablers in the evolving battery manufacturing value chain.

1. SEPARATOR FILMS: MATERIALS AND SAFETY ROLE

Within the cell stack, the separator is a porous electrical insulator between anode and cathode, preventing short circuits while allowing lithium-ion transport through its microporous structure. Industrial separators are predominantly based on polyolefin films (PE, PP, multilayer PP/PE), produced via wet-process PE or dry-process PE/PP routes that generate porosities typically around 40–50% and thicknesses down to the 5–10 μm range.

Because any local defect, shrinkage, or contamination can directly trigger internal shorts and thermal events, the separator is recognized as a primary safety component whose properties strongly influence capacity, cycle life, and abuse tolerance. [1,2]

To improve thermal stability and mechanical robustness, state-of-the-art EV and stationary storage cells increasingly use ceramic-coated separators, where thin layers of inorganic particles (e.g. alumina, boehmite) on the polyolefin substrate reduce high-temperature shrinkage, increase puncture resistance, and improve electrolyte wettability. This makes the coating step itself safety-relevant and shifts the focus from film manufacture alone to the entire coated-separator stack. [3]

2. COATED SEPARATOR STRUCTURES AND EXPECTATIONS

Ceramic-coated separators combine a polyolefin base film with a thin, typically 2–5 μm ceramic layer per side, with coating weights on the order of 4–6 g/m^2 and porosity/permeability tuned to maintain low resistance while enhancing thermal and mechanical performance.

The coated composite is expected to:

- Maintain dimensional stability and low shrinkage under abuse temperatures up to around 180 $^{\circ}\text{C}$, supported by the high modulus and thermal stability of alumina-based layers. [2]

- Provide improved electrolyte uptake and retention, translating into better rate capability and more stable cycling in high-energy cells. [2]
- Increase puncture strength and edge robustness so that mechanical abuse is less likely to initiate catastrophic failure.

These performance expectations are indirectly incorporated in system-level safety frameworks (UN transport tests, vehicle regulations, cell safety standards), which drive tight property windows for thickness, porosity, shrinkage, tensile strength, puncture resistance, and cleanliness for any coated separator qualified into automotive programs. [4]

3. PROCESS CHALLENGES IN SEPARATOR COATING

Separator coating is materially and mechanically more demanding than typical technical film or electrode coating. First, separator films are extremely thin (down to about 5–9 μm) and tension-sensitive; any over-tension, misalignment, or nip pressure can cause wrinkles, neck-in or local thinning. Second, ceramic slurries (alumina, boehmite) are abrasive, shear-sensitive and prone to segregation, placing high demands on gravure rolls, chambers, seals and blade materials; uncontrolled wear can release particles and contaminate the separator. Third, once coated, the separator surface must minimize contact with rolls and guides; accordingly, minimal-contact web handling and drying concepts are required to reduce the risk of scratches, imprints, or flaking.

Drying is another critical step: the coating must be dried uniformly, avoiding skin formation, cracking, or internal stress that could induce shrinkage or delamination of the micrometer-scale ceramic layer.

At gigafactory-scale speeds, this must be achieved with carefully zoned dryers and stable thermal management, without compromising the low-tension, minimized-contact constraints of the web.

4. QUALITY SYSTEMS AND INDUSTRY NORMS

Because separators are safety-critical, coated separator suppliers are expected to operate under automotive-grade quality systems and to match de-facto industry benchmarks set by leading players.

Major separator manufacturers and component suppliers emphasize:

- ISO 9001 and IATF 16949 certification as basis for design and manufacture generally complemented by ISO 14001 for environmental management. [5] [6]
- Structured quality control schemes, monitoring thickness uniformity, coating weight, porosity/permeability, shrinkage, tensile and puncture properties, and surface defects. [5] [7]
- Full traceability from raw materials through coated rolls, with roll-level Certificates of Analysis documenting key parameters and linking them to process data. [8]

At the same time, equipment suppliers are called out in strategic analyses of “Battery Manufacturing 2030+” as key enablers of the structural shift in the battery value chain, where process stability, scrap reduction and throughput become central differentiators. In this landscape, coating lines are expected not only to meet mechanical and thermal requirements, but to embed sensors, data flows, and control logic necessary to support ISO/IATF-compliant, data-driven production. [9]

5. MATTHEWS ENGINEERING: MACHINERY FOR SEPARATOR FILM PRODUCTION

Matthews Engineering develops coating lines specifically for battery separator film, explicitly addressing the combination of safety-critical materials, ultra-thin substrates and gigafactory-level throughput.

Matthews Engineering separator film coating systems support polyolefin and ceramic-coated membranes down to 5 μm at line speeds up to 400 m/min, focusing on no-nip web handling, low-tension threading and tight control of coating thickness.

5.1 COATING WITH PRESSURIZED CHAMBER (PGS™)

For ceramic separator coatings, Matthews Engineering provides a PGS™ (Pressurized Gravure System) specifically engineered for abrasive slurries with a tendency to segregate. The system is based on a gravure coating principle, utilizing an anilox roller with a reduced diameter, enabling precise metering and stable coating at high speeds. The separator-focused PGS™ unit operates in a reverse, kiss-coating mode without a direct impression roller, thereby minimizing mechanical load on the thin web while ensuring highly uniform coating layers (Figure 1.).

A dedicated pressurized chamber enables stable slurry circulation and consistent metering at elevated line speeds (up to 400 m/min). The chamber design and internal flow paths are optimized to suppress foaming and air entrainment, which could otherwise lead to coating defects such as voids or streaks, ensuring stable, high-quality coating performance under demanding process conditions.

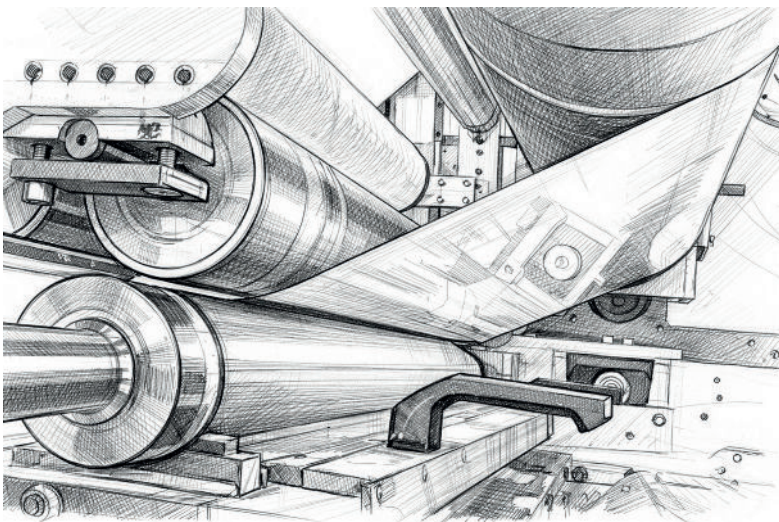


Figure 1. PGS™ coating unit, operating in kiss mode without a direct impression roller. Pressurized chamber enables stable slurry circulation and defect-free coating at speeds up to about 400 m/min.

Abrasive ceramic materials are managed through abrasion-resistant gravure rollers (ceramic-coated) and carefully selected doctor blades to avoid metallic contamination and maintain stable metering over long runs.

5. MATTHEWS ENGINEERING: MACHINERY FOR SEPARATOR FILM PRODUCTION

5.2 WEB HANDLING AND NON-CONTACT DRYING

Matthews Engineering separator coating lines employ no-nip web handling architectures with vacuum-assisted rollers and decoupled tension zones designed to prevent stretching, wrinkling, or edge damage. Web tension is tightly controlled across the line, ranging from ultra-low tension zones of 0–15 N/m during drying to up to ~200 N/m in specific process sections, depending on coating and transport requirements. Matthews Engineering draws on extensive experience in industrial high-speed web handling, including installations operating up to 1000 m/min with ultra-thin films below 5 μm thickness, a capability developed in continuous production environments since 2005.

The coated side is kept free of mechanical contact through a multi-zone drying system providing uniform heat and mass transfer. Adjustable zone drying systems allow tuning of the thermal profile to match different ceramic/binder systems while preserving shrinkage and dimensional targets.

5. MATTHEWS ENGINEERING: MACHINERY FOR SEPARATOR FILM PRODUCTION

5.3 INLINE QUALITY CONTROL AND DIGITAL INTEGRATION

Separator films are safety-critical components in lithium-ion batteries and therefore require 100% inspection after coating to ensure defect-free material before downstream processing.

Matthews Engineering integrates inline inspection systems that monitor the full width and length of the coated web, combining high-resolution optical inspection and thickness measurement. Advanced imaging technologies (e.g. HDR) enable reliable detection and classification of coating-related defects, such as pinholes, thin spots, coating irregularities, scratches, or contamination. These systems provide continuous defect detection, documentation, and traceability, ensuring early identification of defects before further processing.

By linking inspection data with process data and plant-level control systems, the solution enables real-time monitoring and data-driven optimization, supporting ISO/IATF-aligned quality frameworks while improving yield and process reliability.

5. MATTHEWS ENGINEERING: MACHINERY FOR SEPARATOR FILM PRODUCTION

5.4 TOTAL VALUE OF OWNERSHIP

In large-scale separator production, the Total Value of Ownership (TVO) is primarily driven by throughput, which depends on line speed, coating width, and operational uptime. Matthews Engineering evaluated a simplified TVO model comparing a market-standard double-side separator coating line with a Matthews Engineering high-speed coating line (Table 1.).

Both scenarios assume identical operating conditions: 7,600 operating hours per year, 85% line efficiency, and a 15-year plant lifetime. A standard separator coating line typically operates at around 100 m/min with a coating width of 1.2 m, resulting in an annual production of approximately 47 million m². The Matthews Engineering high-speed line, operating at 300 m/min with a 2 m coating width, reaches approximately 233 million m² per year, roughly five times the throughput.

Over a 15-year lifetime this corresponds to ~698 million m² produced on a standard line compared with ~3,488 million m² on a Matthews Engineering high-speed line. Assuming a conservative profit contribution of €0.04 per m² for ceramic double-side coated separator film, the higher throughput can generate approximately €7.4 million additional profit per year, corresponding to ~€111 million over the 15-year lifetime of a single coating line. [10]

More detailed TVO simulations confirm that OPEX is similar between standard and high-speed coating lines, while CAPEX represents less than 10% of total operating cost when distributed over the equipment lifetime. For a more detailed model, please contact Matthews Engineering.

Table 1. Total Value of Ownership Comparison: Standard Separator Coating Line vs. Matthews Engineering High-Speed Line

PARAMETER	STANDARD LINE	MATTHEWS LINE	UNITS
Annual operating hours	7,600	7,600	h/year
Line efficiency	85%	85%	%
Throughput	46.5	232.6	Mm ² /year
Plant lifetime	15	15	years
THROUGHPUT PARAMETERS			
Max line speed	120	400	m/min
Production speed (avg.)	100	300	m/min
Coating width	1.2	2.0	m
Production rate	7,200	36,000	mm ² /h
Production rate	0.0072	0.036	Mm ² /h
Shifts per year	950	950	-
RESULTS			
Annual output	47	233	Mm ²
Lifetime production	698	3,488	Mm ²
Profit vs standard	-	€7,400,000	EUR/year
Incremental profit (15 yrs)	-	€111,000,000	EUR

6. OUTLOOK

As EV and stationary energy storage markets continue to expand, coated separator films will remain a critical determinant of battery safety, performance, and manufacturability. This places separator coating technology at the center of both cell design innovation and gigafactory-scale production strategies.

At the same time, the economics of large-scale separator manufacturing increasingly depend on throughput and capital efficiency. As illustrated by the Total Value of Ownership analysis, higher line speeds and wider web widths can substantially increase annual output. In high-volume production environments, these factors become key levers for improving overall manufacturing competitiveness.

With purpose-designed, high-precision separator coating lines that combine micro-scale material application, ultra-low-tension web handling, driven-roller supported drying, and integrated inline quality control at speeds up to 400 m/min, Matthews Engineering provides equipment platforms capable of translating laboratory-scale separator concepts into robust industrial production. In this context, advanced coating technology becomes an essential enabler for achieving both process reliability and profitable scaling in next-generation battery manufacturing.



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Matthews International GmbH
Gutenbergstraße 1-3
48691 Vreden | Germany
T: +49 2564 120

info@matthews-engineering.com

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