Industrial Application Guide

HTL & ETL Functional Layers

Industrial Materials for Scalable Organic Solar Manufacturing

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Introduction

About this guide

Organic solar cells are rapidly moving from laboratory research towards commercial manufacturing. As production scales, the requirements placed on materials change significantly. High laboratory performance alone is no longer sufficient. Industrial manufacturing demands materials that deliver consistent performance, stable processing and compatibility with high-throughput production.

This guide introduces LayersTech's HTL and ETL solutions developed specifically for industrial organic solar cell manufacturing. It explains the role of transport layers, the challenges they address and how our products can be integrated into existing manufacturing processes.

The purpose of this document is to provide a technical overview of our technology platform and product portfolio. It is intended as a non-confidential introduction and does not contain proprietary process parameters or confidential material formulations.

Who should read this guide

This guide is intended for professionals involved in the development, scale-up and manufacturing of organic photovoltaic devices, including:

- Research & Development Engineers
- Process Engineers
- Manufacturing Engineers
- Product Development Teams
- Technical Directors
- Business Development Managers evaluating new production technologies

Whether your focus is improving device performance, increasing manufacturing yield or preparing for industrial scale-up, this guide provides an introduction to how optimized transport layers can contribute to more robust production.

About LayersTech

LayersTech develops advanced functional transport layers for organic solar cells with one objective: making industrial OPV manufacturing more robust, scalable and economically attractive.

Unlike many transport layer materials developed primarily for laboratory devices, our solutions are designed with industrial implementation in mind. They are developed to support reproducible roll-to-roll manufacturing, simplified process integration and long-term production stability.

Our technology originates from the research conducted at SDU CAPE, one of Europe's leading research environments within organic photovoltaics and functional thin-film materials. Years of research have resulted in a portfolio of patented technologies focused on improving both device performance and manufacturability.

LayersTech offers two complementary approaches for integrating our technology into customer production:

- High-performance HTL and ETL materials for direct integration into existing production lines.
- Ready-to-use functional foils with pre-coated transport layers, reducing processing steps and enabling simplified manufacturing.

By focusing on industrial compatibility rather than laboratory optimization alone, LayersTech helps bridge the gap between promising laboratory devices and commercially viable large-scale production.

From laboratory performance to industrial manufacturing

Over the past decade, organic solar cells (OSCs) have achieved remarkable improvements in power conversion efficiency. Advances in active layer materials, device architecture and coating techniques have demonstrated the significant commercial potential of this technology.

However, success in the laboratory does not automatically translate into successful industrial production.

Laboratory devices are typically fabricated under highly controlled conditions using small substrates, low production volumes and carefully optimized processing parameters. Industrial manufacturing introduces an entirely different set of challenges, where reproducibility, throughput, process robustness and manufacturing cost become equally important as device efficiency.

As production scales, materials must perform consistently over long production runs while remaining compatible with high-speed roll-to-roll processing and industrial quality requirements.

The manufacturing challenge

For many manufacturers, the primary challenge is no longer achieving high cell efficiency in a single laboratory device. Instead, success depends on producing thousands or millions of square meters with consistent quality.

Several factors influence production stability:

- Material compatibility throughout the device stack
- Stable interfaces between functional layers
- Uniform coating over large areas
- Robust processing windows
- High production yield with minimal variation
- Long-term operational stability

Even small variations in material properties or processing conditions can result in significant reductions in yield and increased manufacturing costs.

Consequently, materials developed primarily for laboratory research often require substantial adaptation before they become suitable for industrial production.

Why transport layers become critical

Among the functional layers within an organic solar cell, the Hole Transport Layer (HTL) and Electron Transport Layer (ETL) play a central role in both device performance and manufacturing robustness.

These layers influence:

- Charge extraction
- Interface quality
- Energy level alignment
- Surface morphology
- Layer adhesion
- Device stability

Because transport layers are positioned directly adjacent to the photoactive layer, they also affect the quality of all subsequent coating steps.

As manufacturing scales, transport layers increasingly become a key factor in achieving stable, repeatable production.

The industrial opportunity

Improving transport layers offers an attractive pathway to enhance manufacturing performance without fundamentally changing the overall device architecture.

Rather than redesigning the complete solar cell, manufacturers can often improve production robustness by integrating optimized HTL and ETL solutions that fit within existing process flows.

This approach reduces implementation risk while supporting higher production yield, improved device consistency and a more efficient path towards commercial-scale manufacturing.

Understanding transport layers

Organic solar cells consist of several functional layers, each contributing to the conversion of sunlight into electrical energy. Among these, the Hole Transport Layer (HTL) and Electron Transport Layer (ETL) perform a critical function by enabling efficient extraction and transport of electrical charges.

When sunlight is absorbed in the active layer, electrons and holes are generated simultaneously. To produce electrical power efficiently, these charges must be transported quickly and selectively towards the respective electrodes while minimizing losses caused by recombination.

The transport layers act as selective interfaces between the active layer and the electrodes, ensuring efficient charge extraction and contributing to stable device operation.

Hole Transport Layers (HTL)

The Hole Transport Layer is responsible for collecting and transporting positive charge carriers (holes) from the active layer to the anode.

An effective HTL should:

- Provide efficient hole extraction.
- Block unwanted electron transport.
- Form a stable interface with adjacent layers.
- Support uniform coating of subsequent layers.
- Maintain performance throughout long production runs.

In industrial manufacturing, the HTL also contributes to process robustness by providing a consistent and reproducible surface for further layer deposition.

Electron Transport Layers (ETL)

The Electron Transport Layer performs the complementary function by transporting electrons towards the cathode while blocking holes.

A well-designed ETL helps to:

- Improve electron extraction.
- Reduce charge recombination.

- Enhance electrical contact.
- Improve interface stability.
- Support long-term device performance.

Just like the HTL, the ETL must not only perform electrically but also remain compatible with industrial coating and manufacturing processes.

More than device performance

Although transport layers are often associated with improvements in efficiency, their influence extends far beyond laboratory device performance.

Within industrial production, transport layers affect several key manufacturing parameters, including:

- Process stability
- Coating uniformity
- Layer adhesion
- Production yield
- Device lifetime
- Manufacturing reproducibility

Optimized transport layers therefore contribute not only to better-performing devices but also to more efficient and reliable production.

A small layer with a large impact

Transport layers represent only a small fraction of the total device thickness, yet they influence nearly every stage of device fabrication.

By controlling charge transport, interface quality and process compatibility, HTL and ETL materials can significantly improve both product performance and manufacturing economics.

For manufacturers seeking scalable organic photovoltaic production, transport layers therefore represent one of the most effective opportunities for process optimization without requiring a complete redesign of the device architecture.

The LayersTech Technology Platform

At LayersTech, we believe that the future success of organic solar cells depends not only on achieving high laboratory efficiencies, but on enabling reliable, scalable and cost-effective manufacturing.

While many transport layer materials have been developed with laboratory optimization as the primary objective, industrial production introduces a different set of requirements. High-throughput manufacturing demands materials that deliver consistent performance across large production volumes, integrate seamlessly into existing production lines and support stable processing under industrial conditions.

Our development philosophy therefore begins with the manufacturing process itself. Every material is designed with industrial implementation in mind, focusing on reproducibility, process robustness and compatibility with roll-to-roll production.

The result is transport layer solutions that not only improve device performance but also contribute to a more stable and efficient manufacturing process.

From Research to Industrial Innovation

LayersTech was founded to bridge the gap between advanced research and industrial manufacturing.

Our technology platform is based on years of research within organic photovoltaics and functional thin-film materials carried out at SDU CAPE. This work has generated a portfolio of patented technologies focused on improving charge transport, interface engineering and scalable manufacturing processes.

By combining scientific expertise with an industrial mindset, LayersTech transforms research results into practical solutions that address the real challenges faced by organic solar cell manufacturers.

Our objective is not simply to develop better materials, but to enable more reliable production.

Technology Principles

Every LayersTech product is developed according to the same fundamental design principles.

Industrial Compatibility

Our materials are developed to integrate into existing production environments with minimal disruption, reducing implementation risk and accelerating adoption.

Roll-to-Roll Ready

The technology platform is designed for continuous manufacturing and supports scalable roll-to-roll processing rather than laboratory-scale fabrication.

Simplified Manufacturing

Reducing unnecessary process complexity improves production stability and enables higher manufacturing efficiency.

Stable Interfaces

Carefully engineered interfaces improve charge extraction while contributing to long-term device stability and manufacturing reproducibility.

Scalable Performance

Our solutions are designed to maintain consistent performance from laboratory validation through pilot production and industrial manufacturing.

Two Integration Approaches

Recognizing that manufacturers have different production strategies and technology readiness levels, LayersTech offers two complementary approaches for integrating our technology.

Functional Materials

Customers can integrate our HTL and ETL materials directly into their existing coating process. This approach enables manufacturers to enhance device performance while maintaining their current production architecture.

Functional Foils

Alternatively, LayersTech provides pre-coated functional foils with integrated transport layers. This solution reduces processing steps, simplifies manufacturing and provides a controlled, high-quality interface ready for active layer deposition.

Both approaches are designed to minimize implementation risk while allowing manufacturers to select the integration strategy that best matches their production environment.

Built Around Your Production Line

Implementing new materials should not require redesigning an entire manufacturing process.

Our technology platform has therefore been developed with flexibility as a core principle. Whether manufacturers choose direct material integration or ready-to-use functional foils, the objective remains the same: enabling a smooth transition with minimal disruption to existing production.

This allows manufacturers to validate performance under their own processing conditions before moving towards larger-scale implementation.

By reducing technical uncertainty and supporting gradual qualification, LayersTech helps customers move confidently from evaluation to industrial production.

Product Portfolio

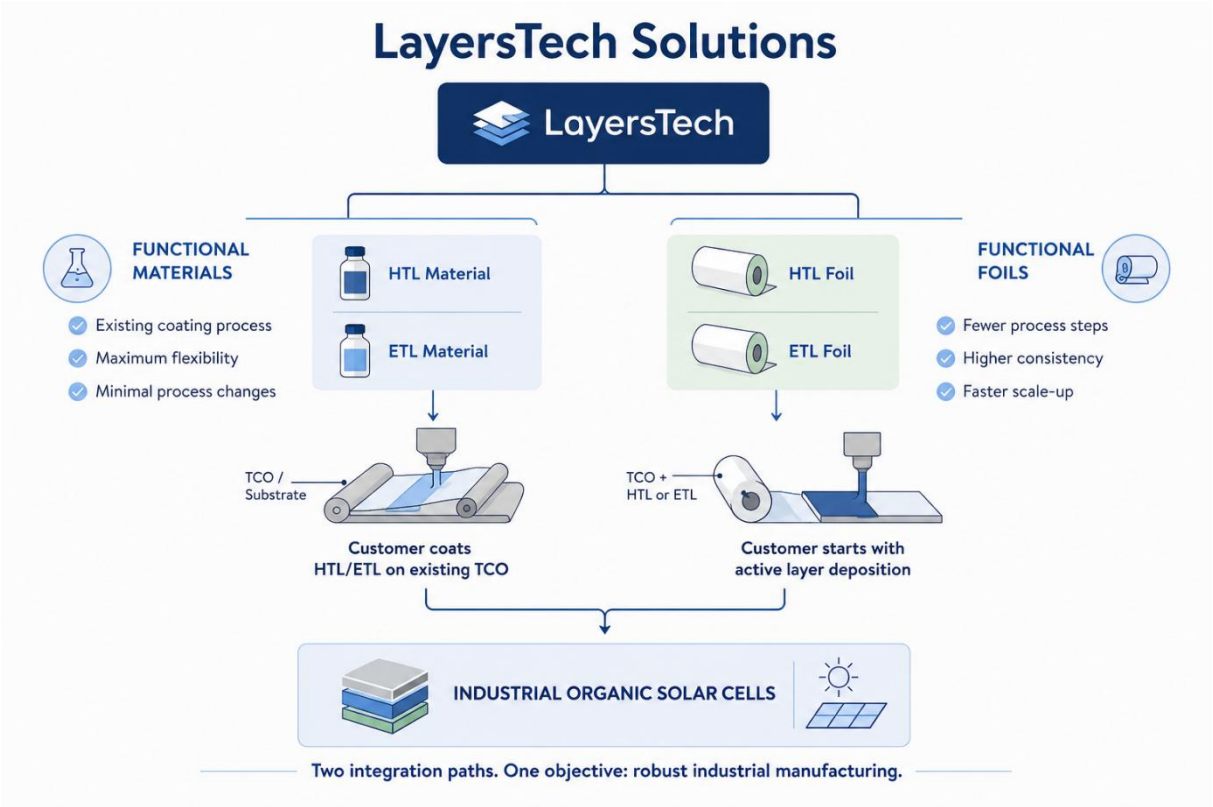
Every organic solar cell manufacturer follows a unique production strategy. Some prefer to integrate new functional materials into existing coating processes, while others seek to simplify manufacturing through pre-functionalized substrates.

To support both approaches, LayersTech offers a flexible product portfolio that enables customers to select the solution best suited to their manufacturing process, technology maturity and scale-up strategy.

Our portfolio currently consists of two complementary product families:

- Functional Transport Materials
- Functional Foils

Both are developed using the same technology platform and are designed to improve production robustness while supporting high-performance organic solar cells.



LayersTech supplies advanced Hole Transport Layer (HTL) and Electron Transport Layer (ETL) materials for direct integration into existing manufacturing processes.

These products are intended for manufacturers who already operate coating equipment and wish to incorporate optimized transport layers without fundamentally changing their production architecture.

Typical benefits include:

- Direct integration into existing coating processes
- Roll-to-roll compatibility
- Simplified qualification
- Improved interface quality
- Reduced process sensitivity
- Support for scalable manufacturing

The materials are supplied in formats suitable for customer evaluation, pilot production and industrial implementation.

Functional Foils

For manufacturers seeking to reduce process complexity, LayersTech also offers pre-functionalized foils with integrated transport layers.

Rather than coating HTL or ETL during production, customers receive a ready-to-process substrate prepared for deposition of the active layer.

This approach offers several potential advantages:

- Fewer coating steps
- Improved layer consistency
- Reduced process variation
- Faster production implementation
- Simplified manufacturing workflow

Functional Foils are particularly attractive for manufacturers aiming to accelerate industrial scale-up while minimizing implementation risk.

Choosing the Right Solution

The optimal integration strategy depends on each customer's production environment.

Manufacturers with established coating capabilities may benefit from integrating LayersTech transport materials directly into their existing process.

Others may prefer Functional Foils as a means of reducing process complexity and accelerating production readiness.

Both approaches are fully supported by LayersTech, enabling customers to choose the solution that best aligns with their manufacturing objectives.

From Evaluation to Industrial Production

Step 1 – Initial Technical Dialogue

Every production environment is unique. We begin by understanding your current device architecture, manufacturing process and technical objectives.

This initial dialogue allows us to recommend the most suitable integration approach, whether through functional transport materials or ready-to-use functional foils.

Step 2 – Material Evaluation

Customers receive evaluation samples for laboratory testing or small-scale process trials.

The objective is to verify compatibility with existing materials, coating methods and production conditions while identifying the most promising implementation strategy.

Step 3 – Process Validation

Following successful laboratory evaluation, the materials are tested under representative production conditions.

During this phase we support process optimization, helping customers establish stable coating parameters and evaluate manufacturing robustness.

Step 4 – Pilot Production

The next step is pilot-scale validation.

Here the focus shifts from individual device performance to manufacturing consistency, process repeatability and production yield.

Pilot production provides valuable insight before large-scale implementation.

Step 5 – Industrial Implementation

Once technical and manufacturing objectives have been achieved, the technology can be introduced into full-scale production.

LayersTech continues to support customers during the implementation phase to ensure a smooth transition into industrial manufacturing.

Supporting Long-Term Success

Qualification does not end when production begins.

As manufacturing evolves, LayersTech works closely with customers to support continuous process optimization, evaluate new product generations and identify opportunities for further improvements in manufacturing performance.

Our ambition is to become a long-term technology partner rather than simply a material supplier.

Let's Start the Conversation

The transition from laboratory innovation to industrial manufacturing is one of the greatest challenges facing the organic photovoltaic industry.

At LayersTech, we believe that successful scale-up requires more than high-performance materials. It requires solutions designed for manufacturing, a structured implementation process and close technical collaboration throughout the qualification journey.

Whether your objective is to improve device performance, increase production yield or simplify your manufacturing process, our HTL and ETL solutions are developed to integrate with your production environment while minimizing implementation risk.

We are committed to supporting our customers from the first technical discussion through evaluation, pilot production and industrial implementation.

How We Can Support You

We invite you to discuss your current manufacturing challenges and explore how our transport layer technologies may fit into your production process.

Typical starting points include:

- Evaluation of existing HTL or ETL solutions
- Integration into current production lines
- Pilot-scale testing
- Functional foil evaluation
- Joint development opportunities

Every manufacturing process is different, and we believe the best solutions are developed through close collaboration.

Get in Touch

Whether you are developing your first pilot line or scaling towards high-volume manufacturing, we would be pleased to discuss how LayersTech can support your next step.

Contact us to:

- Request evaluation samples
- Schedule a technical meeting
- Discuss your manufacturing process
- Explore collaboration opportunities