

How a PV Module Laminator Enhances Solar Panel Quality

Optimizing Panel Durability Through Lamination

Content Partner: J. v. G. technology GmbH

Turnkey solar module production lines — since 1997

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Technical overview of PV lamination thermodynamics



Created as part of the PVKnowHow Knowledge Network



Prepared by J.v.G. Technology GmbH



European specialists in turnkey solar module production lines

Key Project Data

~135–1...

Temperature Range

Operating range for EVA crosslinking and encapsulant bonding

~20 min

Cycle Time

Typical lamination cycle: preheat, vacuum, press, cooling

~600/hr


Peak Throughput

Fully automated systems (IEA reference)

2 Types

Automation Levels

Semi-automatic and fully automated laminators

 Process: PV module lamination · Application: Solar module manufacturing · Source: PVKnowHow / J.v.G. Technology GmbH

What Is a PV Laminator?

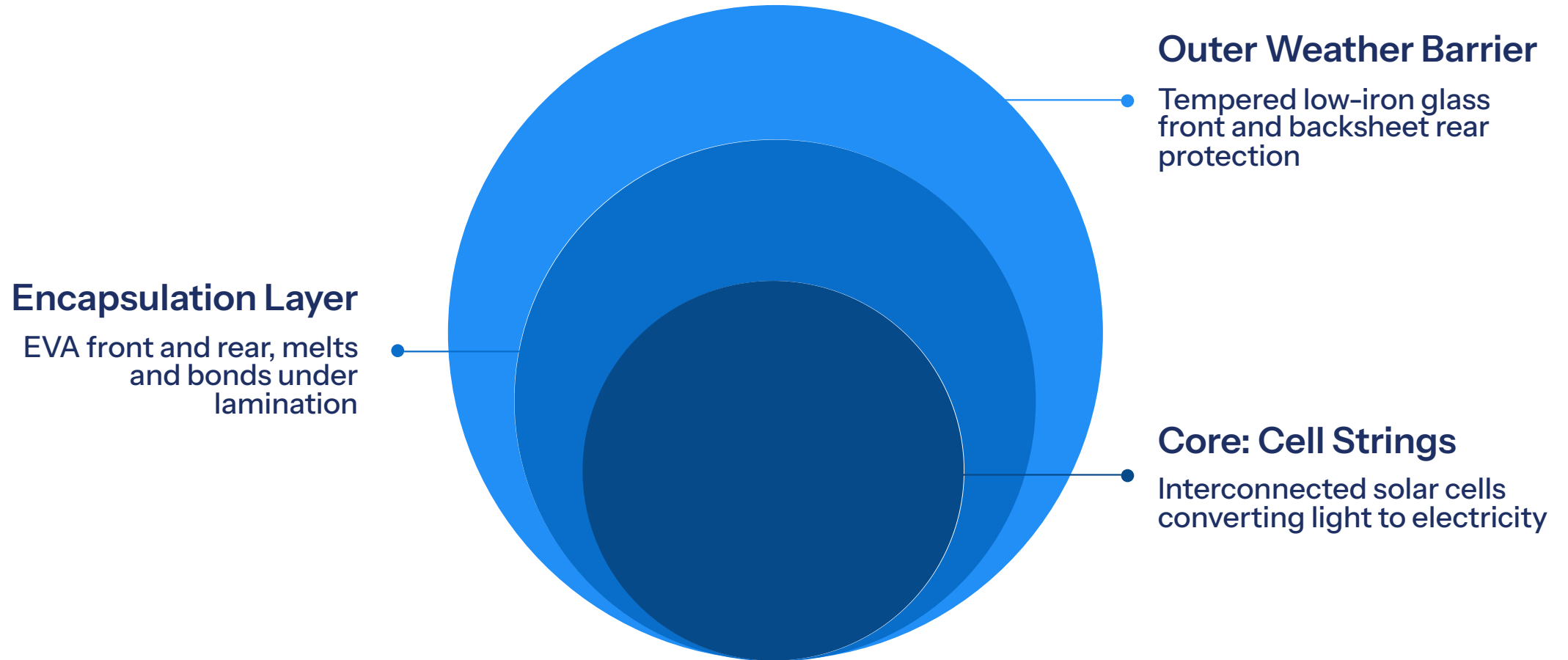
Definition

- A precision machine that bonds solar module layers under heat, vacuum, and pressure
- Operates within a sealed chamber to eliminate air inclusions
- Central step in crystalline silicon (c-Si) and thin-film PV manufacturing
- Produces the permanent, weatherproof laminate structure of a finished module

Why It Matters

- Protects solar cells from moisture, UV, and mechanical stress
- Determines long-term module reliability — 25+ year lifetime target
- Once laminated, rework is extremely difficult — quality must be ensured upstream
- Directly affects power output and certification compliance

Layer Structure of a Standard Solar Module



This five-layer sandwich — glass / EVA / cells / EVA / backsheet — is consolidated inside the laminator under heat and vacuum. The encapsulant melts, flows, and crosslinks to form an airtight, durable bond around the cell strings.

Key Components of a PV Laminator

Heating System

- Oil or electric resistance heating of platens
- Uniform temperature across module surface ($\pm 5^{\circ}\text{C}$ tolerance)
- Operating range: $\sim 135^{\circ}\text{C}$ – 180°C

Vacuum System

- Sealed upper and lower chambers
- Controlled evacuation rate removes air and outgassing
- Alarm monitoring if vacuum cannot be reached in target time

Pressure / Press System

- Pneumatic or hydraulic membrane applies even surface pressure
- Three-step pressing control for consistent laminate quality
- Prevents uneven encapsulation and delamination at edges

Cooling & Control

- Active or passive cooling after lamination cycle
- PLC-based control with HMI touchscreen interface
- Parameters stored safely – manual override mode available

Types of PV Laminators: Semi vs. Fully Automated

Criterion	Semi-Automatic	Fully Automated
Loading / Unloading	Manual by operator	Robotic handling systems
Throughput	~100–300 modules/hour	Up to ~600 modules/hour
Best Suited For	Medium-scale production; lower capex	High-volume lines; minimized unit cost
Initial Investment	Moderate	Higher upfront, lower cost/module at scale
Process Control	Automated temp/pressure; manual loading	Fully integrated, computer-managed
Downtime Risk	Higher (manual load/unload cycle)	Lower (continuous flow possible)

Lamination Process Steps

1

1 — Pre-Inspection

Visual and EL inspection of cell strings before entering laminator

Rework is near-impossible after lamination

2

2 — Lay-Up & Loading

Glass / EVA / cells / EVA / backsheet assembled in sequence

Module loaded onto heated platen (manually or robotically)

3

3 — Heating & Vacuum

Chamber sealed; vacuum applied in controlled stages

EVA softens and begins to flow at ~135°C+

4

4 — Pressing & Crosslinking

Membrane pressure applied; EVA bonds all layers

Full crosslinking achieved at lamination temperature

5

5 — Cooling & Unloading

Module cooled (active or passive) before unloading

Post-lamination inspection: visual check and peel force test

Encapsulant Materials: Technical Comparison

EVA — Ethylene Vinyl Acetate

- Industry standard since the 1980s; well-proven in field
- Good adhesion, long lifetime; requires curing with UV stabilizers and cross-linking agents
- Most cost-effective option; widely compatible with standard laminators

TPO — Thermoplastic Polyolefin

- Growing adoption for glass-glass and bifacial module designs
- Superior UV resistance; water absorption <0.1%; no crosslinking additives needed
- Lower processing temperatures possible — energy savings potential

PVB / TPU — Thermoplastic Alternatives

- Available in sheet form; do not require curing
- Higher melt viscosity than EVA — process cycle times similar
- Used in specialty, architectural, and building-integrated PV applications

Performance & Quality Impact of Lamination

Efficiency Impact

- High-quality lamination can improve panel efficiency by 2–3% (NREL reference)
- Proper bonding reduces optical losses and cell microcracks
- Consistent encapsulation minimizes air bubbles that degrade output
- Platen temperature uniformity of $\pm 5^{\circ}\text{C}$ is sufficient for good gel content and adhesion

Durability & Reliability

- Lamination provides the primary weather barrier — moisture, UV, mechanical stress
- Correct vacuum timing prevents outgassing and bubble formation
- Process control measures (peel force, gel content tests) are critical in production
- Proper crosslinking is essential for 25+ year module lifetime

Benefits of Industrial PV Lamination

Efficiency

- Automated lamination ensures consistent, repeatable quality
- Fully automated systems: up to ~600 modules/hour throughput
- Reduced operator dependency; lower scrap rates

Durability

- Sealed laminate protects against all major environmental degradation factors
- Correct material selection supports 25+ year field lifetime
- Reduced delamination, yellowing, and moisture ingress risk

Cost-Effectiveness

- Higher automation reduces cost per module at volume
- Energy-efficient encapsulants (TPO) lower thermal processing costs
- Process reliability reduces warranty and field failure exposure

Laminator Selection Criteria

Production Volume

- Medium-scale (25–100 MW/yr): semi-automatic provides balance of cost and output
- High-volume (>200 MW/yr): fully automated systems justify higher capex
- Throughput target determines number of laminator units required in line

Material Compatibility

- Laminator must be configured for the target encapsulant (EVA, TPO, PVB)
- Module format (glass-backsheet vs. glass-glass) affects platen and vacuum configuration
- High-efficiency cell types (TOPCon, HJT) may require tighter temperature tolerances

Energy & Budget

- Oil-heated platens offer high uniformity; electric heating offers faster response
- Multi-chamber designs (preheat + laminate + cure) increase throughput and energy efficiency
- Total cost of ownership includes maintenance, consumables (belts, membranes), and downtime

Strategic Importance of Lamination in PV Manufacturing



Quality Gateway

Lamination is the point of no return — all upstream quality decisions are locked in permanently at this step

Line Bottleneck Risk

As the longest cycle-time step (~20 min), the laminator often defines overall line throughput and must be scaled accordingly

Certification Anchor

IEC-compliant lamination process is a prerequisite for module certification and market access in regulated markets (EU, US)

- ❏ An experienced European turnkey provider integrates lamination know-how into full-line process methodology — reducing the learning curve for new manufacturers entering production.

About the Content Partner

J. v. G. technology GmbH – The DESERT Company

Founded in 1997 in Bavaria, Germany. Family-owned engineering company specializing in turnkey solar module production lines.

More than 90 factory projects delivered worldwide.

On-site team training included – no prior manufacturing experience required.

Key areas:

Turnkey PV manufacturing lines | DESERT Technology® |
TÜV-certified module designs | Factory planning to production

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