

# Solar Energy Efficiency and Output

The science behind sunlight-to-electricity conversion

**Content Partner: J. v. G. technology GmbH**

*Turnkey solar module production lines — since 1997*

[www.jvg-thoma.com](http://www.jvg-thoma.com)





# A Technical Overview of Solar Efficiency and Output



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

**15–22%**

**Efficiency Range**

Typical PV module efficiency  
(crystalline silicon)

**~300 ...**

**Peak Power Rating**

Standard  
residential/commercial  
module output

**kWh**

**Energy Unit**

Output measured over time  
(kilowatt-hours)

**3 Types**

**System Types**

Photovoltaic · Thermal ·  
Hybrid

📄 Key influencing factors: temperature · shading · orientation · encapsulation quality · cell type · Source: PVKnowHow / J.v.G. Technology GmbH

# What Determines Solar Panel Output?

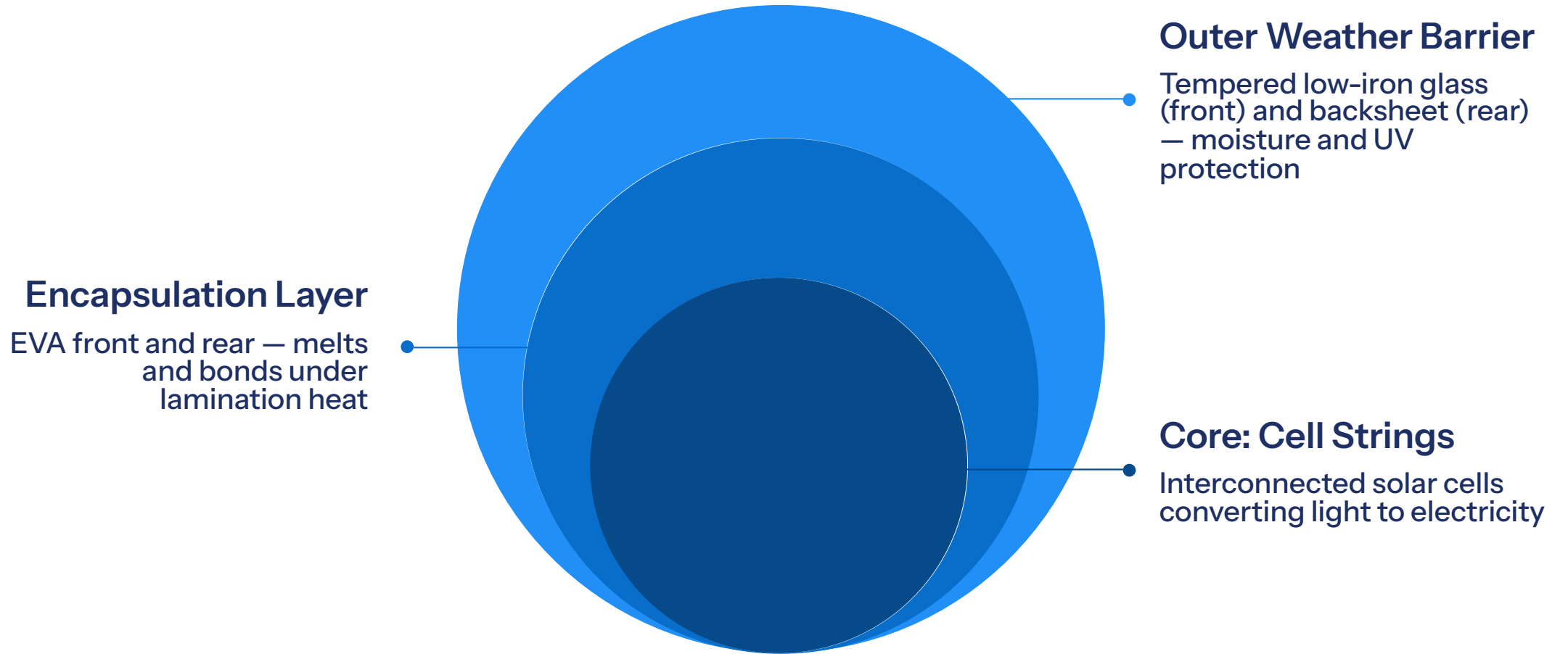
## Intrinsic (Module-Level) Factors

- Cell technology type: monocrystalline, polycrystalline, thin-film
- Encapsulation quality — determines long-term optical and electrical stability
- Anti-reflective glass — reduces surface reflection losses
- Rated efficiency under Standard Test Conditions (STC: 1,000 W/m<sup>2</sup>, 25°C)

## Extrinsic (Site & Environmental) Factors

- Solar irradiance level at installation site
- Module operating temperature (above 25°C reduces output)
- Shading from nearby objects — even partial shading is critical
- Orientation (azimuth) and tilt angle relative to sun path

# Layer Structure of a Standard Solar Module



The five-layer sandwich — glass / EVA / cells / EVA / backsheet — is consolidated under heat and vacuum during lamination. Encapsulant quality and uniformity directly determine optical efficiency and 25-year field lifetime.

# Temperature: The Primary Performance Variable

## Temperature Coefficient

- Crystalline silicon loses ~0.3–0.5% output per °C above 25°C
- A module at 65°C field temperature loses ~15–20% of rated power
- Cell operating temperature is always higher than ambient air temperature

## Thermal Management

- Rear ventilation and mounting gap reduce operating temperature
- Light-colored or reflective backsheets lower heat absorption
- Bifacial modules benefit from rear-side irradiance but require careful thermal modelling

## Manufacturing Relevance

- Lamination temperature uniformity ( $\pm 5^\circ\text{C}$ ) determines encapsulant crosslink quality
- Poor crosslinking degrades optical clarity and bonding — reduces field efficiency
- Operating range during lamination:  $\sim 135^\circ\text{C}$ – $180^\circ\text{C}$  (EVA crosslinking window)

# Shading: Disproportionate Impact on Array Output

## Why Shading Is Critical

- Partial shading of even one cell can reduce output of an entire string
- Bypass diodes limit the impact but do not eliminate losses
- String-level mismatch losses can reach 10–30% of total yield
- Shading analysis (e.g. SolarEdge, PVsyst simulation) is essential at design stage

## Mitigation Strategies

- Module-level power electronics (MLPE): microinverters or DC optimisers
- Careful row spacing to avoid inter-row shading at low sun angles
- Horizon and obstacle surveys before system design
- String configuration optimised for specific shade patterns

# Orientation & Tilt: Optimising Annual Yield

## 1 — Azimuth (Compass Orientation)

South-facing optimal in Northern Hemisphere; North-facing in Southern Hemisphere

East/West deviations reduce annual yield by ~5–15% depending on latitude

## 2 — Tilt Angle

Optimal tilt  $\approx$  site latitude (e.g., 35° tilt at 35°N latitude)

Flat roofs may use ballasted frames at 10–15° for cost-efficiency and wind loading

## 3 — Tracking Systems

Single-axis trackers increase annual yield by 15–25% vs. fixed-tilt

Dual-axis tracking adds further gains; mainly used in utility-scale CPV applications

## 4 — Soiling & Surface Losses

Dust, pollen, and bird soiling can reduce output by 1–5% annually

Steeper tilt angles improve self-cleaning in rain-prone climates

# PV System Types: Technical Comparison

Criterion	Photovoltaic (PV)	Solar Thermal	Hybrid (PVT)
Output Form	Electricity (DC/AC)	Heat (water/air)	Electricity + Heat
Typical Efficiency	15–22% (STC)	50–80% thermal	~10–15% PV + 30–50% thermal
Primary Application	Grid power; off-grid	Domestic hot water; space heating	Combined heat and power; space-constrained sites
Key Metric	kWh electricity/year	kWh thermal/year	Combined kWh yield
Temperature Sensitivity	High (–0.3–0.5%/°C)	Low (benefits from heat)	Moderate (PV cooled by thermal extraction)

# Encapsulant Materials: Impact on Long-Term Output

## EVA — Ethylene Vinyl Acetate

- Industry standard since the 1980s; extensively field-validated
- Good adhesion and long service life; requires UV stabilisers and crosslinking agents
- Most cost-effective option; compatible with standard lamination equipment

## TPO — Thermoplastic Polyolefin

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

## PVB / TPU — Thermoplastic Alternatives

- Sheet form; do not require curing — simpler thermal processing
- Higher melt viscosity than EVA; cycle times broadly comparable
- Used in specialty, architectural, and building-integrated PV (BIPV) applications

# Manufacturing Quality: Direct Efficiency Impact

## Efficiency Impact

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

# Key Factors in Turnkey PV Line Performance

## Efficiency

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

## 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

# Strategic Insights: Maximising Solar Output

1

## Design Phase

Site shading analysis, orientation modelling, and system type selection determine the achievable energy yield ceiling

2

## Manufacturing Phase

Lamination quality, encapsulant choice, and process control lock in module efficiency and 25-year durability performance

3

## Operations Phase

Temperature management, soiling control, and inverter performance monitoring are essential to sustain rated kWh output over time

- ❏ A proven turnkey manufacturing concept integrates process know-how across all phases – reducing the learning curve for new manufacturers entering production.

# Sources & References

## Primary Sources

- PVKnowHow Knowledge Network — [pvknowhow.com](http://pvknowhow.com)
- An experienced European turnkey provider — specialist in solar module production lines since 1997
- NREL (National Renewable Energy Laboratory) — lamination efficiency reference data
- IEA (International Energy Agency) — throughput and automation benchmarks

## Disclaimer

These case studies are based on real figures but are composite scenarios. All data presented reflects publicly available technical references. Efficiency ranges and performance figures are indicative — actual results depend on site conditions, system design, and manufacturing process control.

# 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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