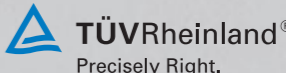


**TONGWEI**



**TONGWEI**



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**QUALITY WHITE PAPER  
OF TW SOLAR**

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## THE ERA OF PV, THE FUTURE BY QUALITY

The global photovoltaic (PV) industry is currently riding the historic waves of the energy revolution and climate action. The overlay of international trade barriers and green new deals has shaped a brand-new competitive landscape, accelerating the regional restructuring of the global PV supply chain. At the same time, large-scale mass production of various emerging solar cell technologies is driving continuous breakthroughs in conversion efficiency. The PV industry is stepping into a new era characterized by high-quality development at its core.

In China, the construction of a new power system has been fully rolled out, and the multi-scenario application of "PV+" continues to deepen. The industry is undergoing a profound transformation from the "accumulation of quantity" to a "leap in quality". Optimization of the leveled cost of electricity (LCOE) across the entire lifecycle, refined management of carbon footprint, and zero-carbon collaboration in the industrial chain have become the golden benchmarks for measuring enterprise competitiveness. In this process, the strategic position of quality management has been elevated to an unprecedented level—product reliability, process consistency, and alignment with international standards are becoming the key pillars for enterprises to weather cycles and win global markets. They are also the "golden key" to gaining access to international markets in the face of green trade barriers.

"Integrity, Trustworthiness, Uprightness and Unity" is TW Solar's consistent business philosophy. TW Solar always regards quality as the eternal theme of enterprise development, and as the foundation and prerequisite for the market and profitability. It always regulates all employees' awareness and behavior with the goal of maximizing customer value, and strictly controls the entire process of product design, manufacturing and use at professional, standardized and large-scale levels to ensure product quality. Against the backdrop of increasingly fierce global competition, we are convinced that only by prioritizing quality can we stand out in a fiercely competitive market and achieve sustainable development amid industry transformations. Quality control is not only a guarantee for the stable operation of enterprises, but also the central hub that drives the efficient operation of the entire value chain.

Based on this profound understanding and continuous practice, TW Solar, with a global vision and full industry chain perspective, has distilled years of quality management experience and innovative achievements to meticulously compile the TW Solar Quality White Paper. This Paper systematically summarizes the opportunities and challenges for the development of the PV industry, comprehensively presenting Tongwei's quality culture, lean management practices, quality methodology and innovative practices. It is not only a panoramic display of our quality system, but also our solemn commitment to the industry, customers and society.

We hope that through this Paper:

—— Enable all employees to strengthen their commitment to "quality first" and to integrate quality awareness into every process, every improvement, and every innovation;

—— Let customers truly perceive Tongwei's relentless pursuit of excellence in quality and its ability to deliver on that commitment;

—— Let industry partners share Tongwei's experience and insights, and work together to promote the overall improvement of PV quality management;

—— Let all sectors of society see a responsible enterprise demonstrate its commitment and dedication to "establishing and growing the business through high-quality development" with concrete actions.

In the future, we will continue to take quality as our foundation and innovation as our sail, work hand in hand with global partners, jointly build trust and consensus, and write a new chapter for the high-quality and sustainable development of the PV industry.

ZHOU HUA  
TW SOLAR CO., LTD.

# DATA-DRIVEN QUALITY MANAGEMENT, INTELLIGENCE POWERS THE FUTURE

Dear Customers, Partners and Industry Colleagues,

In the tide of industrial changes driven by global energy transformation and sustainable development, the photovoltaic (PV) industry has emerged as a core force driving the adoption of renewable energy and supporting the global "dual carbon" goals. In recent years, the PV industry has experienced rapid technological development, with application scenarios continuously expanding and market coverage gradually increasing. However, behind this high-speed growth are challenges such as accelerated technological updates and intensified market competition. As a leader in the global PV industry, Chinese PV companies are in urgent need of shifting from "scale priority" to "quality leadership." They need to build global product competitiveness with excellent quality and truly shoulder the responsibility of leading the sustainable development of the industry.

TW Solar has ranked first in global solar cell shipments for eight consecutive years (Shipping Rankings Source: In foLink), which is not only an achievement in scale but also a result of relentless pursuit of quality. This White Paper systematically presents TW Solar's unique quality culture of "pursuit of excellence". At the same time, it deeply integrates "refined production and digital tools" to form a comprehensive quality management model, providing the industry with a comprehensive, replicable and practical benchmark paradigm in quality strategy formulation, quality culture building, quality talent development and technology route innovation.

It is worth mentioning that the strategic cooperation between TW Solar and TÜV Rheinland is an important cornerstone for the successful completion of this White Paper. From the beginning of their cooperation, both parties, driven by a shared pursuit of quality and value, established the fundamental approach of being "customer-oriented, data-driven, system-optimized, and culture-shaping." During the in-depth promotion and implementation of the Lean Six Sigma Project, we have witnessed the Tongwei team's efficient execution and forward-looking approach to future quality management models. Together, we have explored a clear path from goal setting to overcoming challenges to sharing experiences, ultimately achieving financial gains. We have deeply experienced the value and transformation brought by the culture of "pursuing excellence." This new cooperation model of "joint efforts, knowledge transfer, and capability internalization" has not only helped Tongwei build a self-iterative quality improvement mechanism, but has also provided the PV industry with a globally leading quality management methodology.

In particular, Tongwei has taken the lead in building a digital quality ecosystem in the PV industry. Leveraging innovative applications such as the cell-level traceability system and the AI-driven quality inspection and early warning, Tongwei has successfully made a key leap from exploring the concept of "data-driven" to the mature practice of "digital quality management." This data-driven quality management model has not only significantly improved the efficiency of responding to quality anomalies, but also promoted TW Solar to achieve a full-process upgrade from "discovery and resolution" to "prediction and prevention".

The value of this White Paper lies in the fact that it goes beyond the experience of a single enterprise and, through systematic methodology, detailed case analysis, and forward-looking trend assessment, explores the roadmap for quality upgrades in the PV industry. It also provides crucial support for Chinese PV enterprises to lead global technological innovation and participate in the development of international quality standards.

Looking ahead, quality will undoubtedly become the key tool for PV companies to navigate industry cycles and achieve long-term competitiveness. We hope this White Paper will further inspire the global PV industry to deeply explore quality innovation, and promote the entire industry to advance together towards a new era of high-quality and sustainable development.

Sincerely!

TÜV RHEINLAND (SHENZHEN) CO., LTD.

Although the PV industry is currently experiencing a downturn, its long-term development prospects remain promising under the general trend of global energy transition and the "dual carbon" goals. Compared with other traditional manufacturing industries, the PV industry is very young and develops rapidly. It faces many challenges, such as the transmission of specification tolerance designs, lack of industry consensus on standards and strategies for certain process controls, and a lack of systematic methods and tools for improving product issues.

As an industry-leading company, Tongwei regards quality as its core competitiveness. During challenging times, Tongwei focuses on strengthening its internal capabilities and has put forward the quality concept of "pursuit of excellence." Guided by the characteristics of PV manufacturing and the data-rich environment, we have continuously explored and established a dual-engine strategy of "Systematization + Data-Driven". We deployed and executed a long-term strategic plan, which has yielded substantial financial returns. In this process, we first enhance personnel quality and skills, building deep and robust quality systems. Then, we distill and summarize various methodologies for solving quality issues and departmental "Three Essential Skills," allowing quality to "accumulate deeply and burst forth." This enables more people to more efficiently improve products and processes, which is presented to everyone in this White Paper.

Chapter I introduces TW Solar's quality culture and activities centered around "pursuit of excellence", which can be seen as the "philosophy" and "method" behind the quality. Chapter II, combining the process and quality focus of TOPCon cells, briefly presents the quality methods and tools commonly adopted by TW Solar during its "pursuit of excellence" initiatives, representing the "techniques" and "instruments" of quality. These are the steadfast implementations of TW Solar's long-term strategy of "pursuing excellence" in quality and building deep and robust quality systems.

Chapter III discusses how to harness accumulated strength for breakthrough development when the quality culture reaches maturity. Expand from three dimensions: First, sort out each department's responsibility KPIs, specifying the required job-specific skills, applicable quality tools, and digital intelligence capabilities for future development, so as to achieve universal quality for all employees, while proactively integrating personnel development with enterprise development. Second, summarize the improvements to various types of problems, inductively organizing the systematic methodology of logic chains and tool chains, to enable replicability of similar improvements. Through cases of quality practice, it demonstrates that the organized methodology also possesses replicability across industries. Third, it shows the transition from a "customer demand-centered approach" to organization-wide, multi-departmental, cross-functional quality management, and then to collaborative supply chain improvement, achieving comprehensive quality management.

Chapter IV initiates the third engine of quality improvement—"intelligentization", extending process quality to design quality and digital quality. Explore the "data gold mine", leverage AI large models to empower intelligent manufacturing, and recognize the future trends in quality and technology.

Practice has proven that TW Solar's unique approach of "pursuing excellence" not only provides manufacturing enterprises with a practical model for shifting from "scale expansion" to "quality and efficiency," but also demonstrates the feasibility of upgrading from "cost control" to "value creation." It is hoped that this White Paper can also serve as a reference and model for the quality-oriented and healthy development of the entire PV industry.

WANG HAI

TÜV RHEINLAND GROUP  
SENIOR EXPERT IN PERFORMANCE EXCELLENCE  
SIX SIGMA MASTER BLACK BELT

Chapter I  
TW Solar  
Quality Culture and  
Activities

1.1

# Photovoltaic Market Development and Technical Challenges

At present, the global photovoltaic industry is undergoing structural transformation, with rising trade barriers, rapid technology iterations, increasing overcapacity, and a continuously worsening competitive landscape. As dominant players in the global supply chain, Chinese photovoltaic companies face multiple challenges such as overseas market blockades, cash flow constraints, insufficient supply chain resilience, and geopolitical risks, resulting in unprecedented compression of their room for survival.

In 2025, the global photovoltaic module production capacity is expected to exceed 1TW, while demand will be only about 580GW [1]. The serious imbalance between supply and demand has led to a continual decline in prices—the cell price has dropped below 0.30 yuan/W, and the module price has fallen below the threshold of 0.70 yuan/W, greatly compressing the profit margins of the entire industry. At the same time, energy consumption control, raw material fluctuations and process stability issues on the production side further erode corporate profitability.

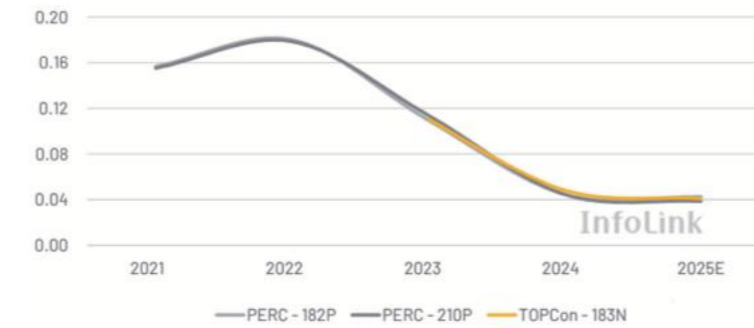


Figure 1.1 China's Cell Price Forecast from 2021 to 2025 (unit: USD/W) [3]

According to InfoLink's research, the global cell production capacity was around 1.130GW in 2024, a year-on-year decrease of about 5% compared with 2023. The growth rate of total production capacity in the cell segment began to slow down [2], ending the trend of rapid growth.

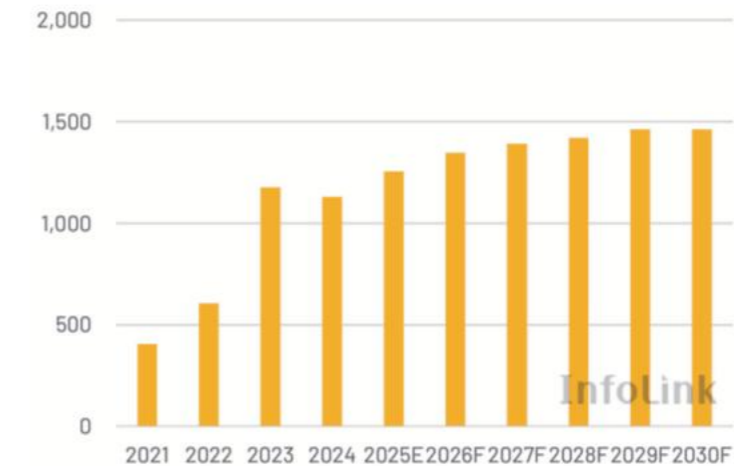


Figure 1.2 Global Cell Production Capacity Forecast from 2021 to 2030 (unit: GW) [3]

Note: Source for Figure 1.1 China's Cell Price Forecast from 2021 to 2025 and Figure 1.2 Global Cell Production Capacity Forecast from 2021 to 2030: Pv infoLink.

## Technology and Route Forecast

Cell manufacturers aim to improve photoelectric conversion efficiency as their primary development goal while seeking ways to reduce costs, thereby driving the ongoing iteration of cell technology. Independent innovation and breakthroughs in new solar cell technologies—from polycrystalline to monocrystalline, from P-type PERC to N-type TOPCon, heterojunction (HJT), back contact (XBC), as well as perovskite tandem—have established China's leading position in the global PV industry.

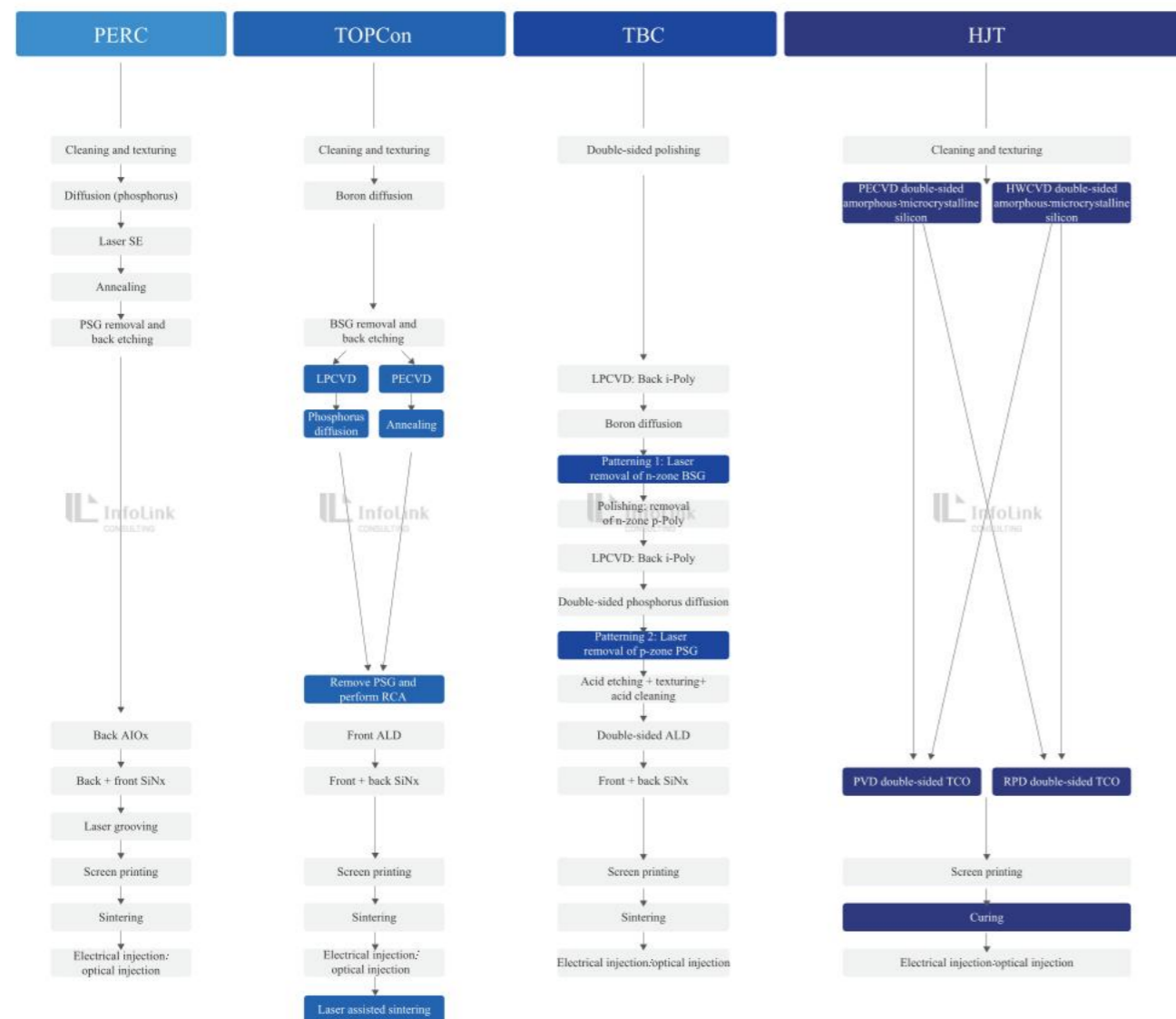


Figure 1.3 Comparison of Cell Processes [3]

As PERC production lines are gradually phased out, TOPCon will be compatible with the original PERC lines. In addition, TOPCon has an efficiency similar to HJT and a theoretical maximum efficiency of up to 28.7%, but its cost is lower than that of HJT, making it a highly competitive technology product in today's market and suitable for use in large-scale centralized projects. [4]

In 2024, the market share of TOPCon has exceeded 70% [6]. Statistics from the first half of 2025 show that TOPCon cells, as the most widely adopted technology route at present, account for 88.3% of shipments. TOPCon modules have become the major products of the world's top ten suppliers and are expected to maintain their leading position as mainstream technology in the next few years [5].

Note: The source of the cell process comparison data is Pv infoLink

## Technology Trends

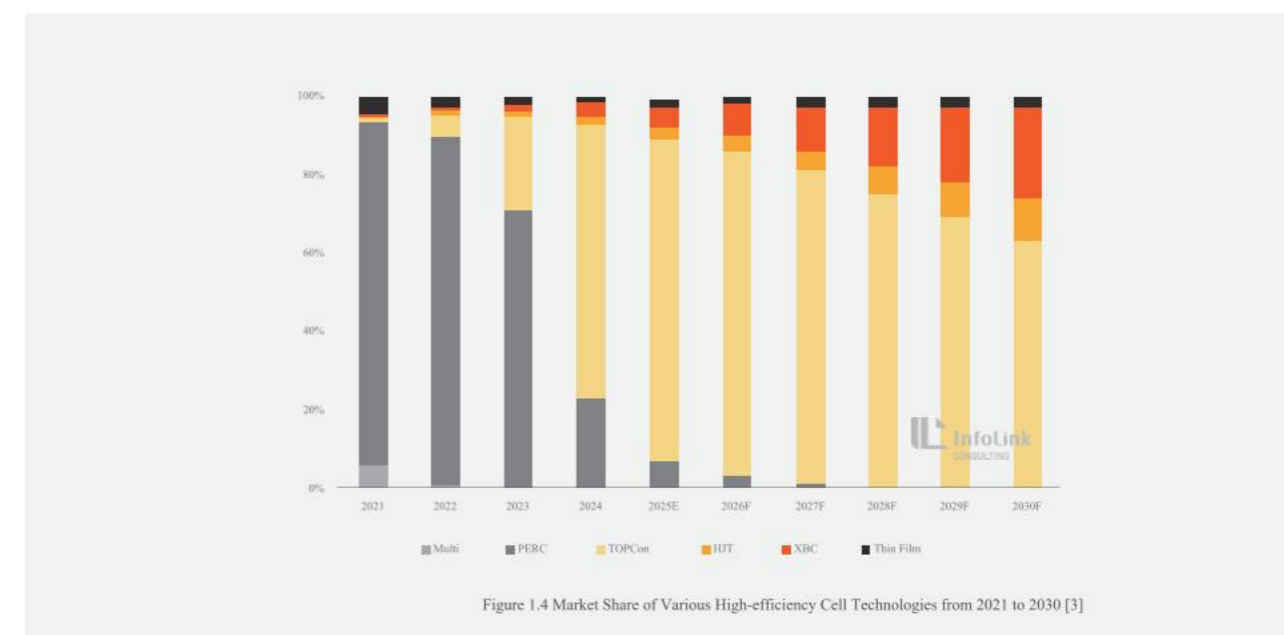


Figure 1.4 Market Share of Various High-efficiency Cell Technologies from 2021 to 2030F [3]

### 1.2

## TW Solar Market and Quality Performance

### Global No. 1 in shipments

In the first half of 2025, TW Solar's cell shipments ranked first in the world.



Solar cell shipments have ranked first in the world for eight consecutive years.

More than 200 intelligent manufacturing production lines



Existing solar cell production capacity 150GW+

The world's first PV 5G application base

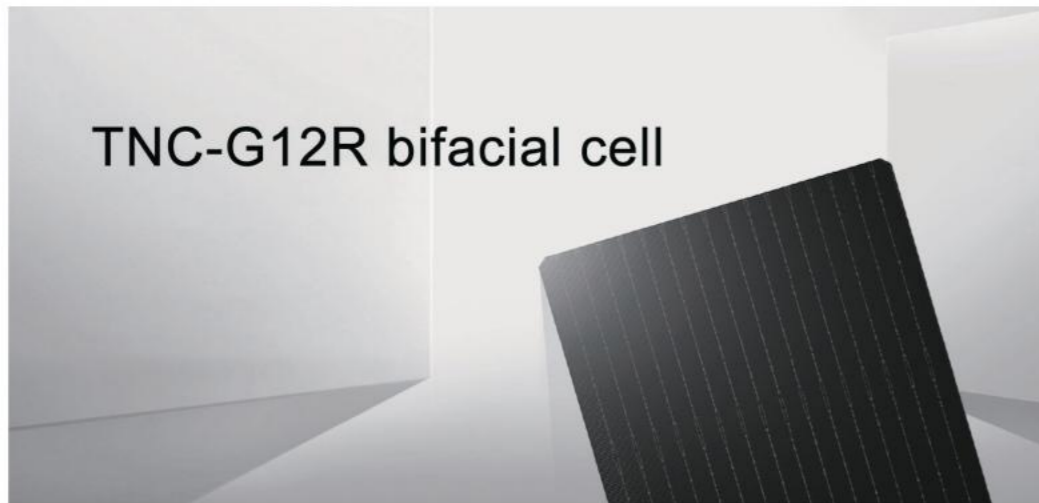
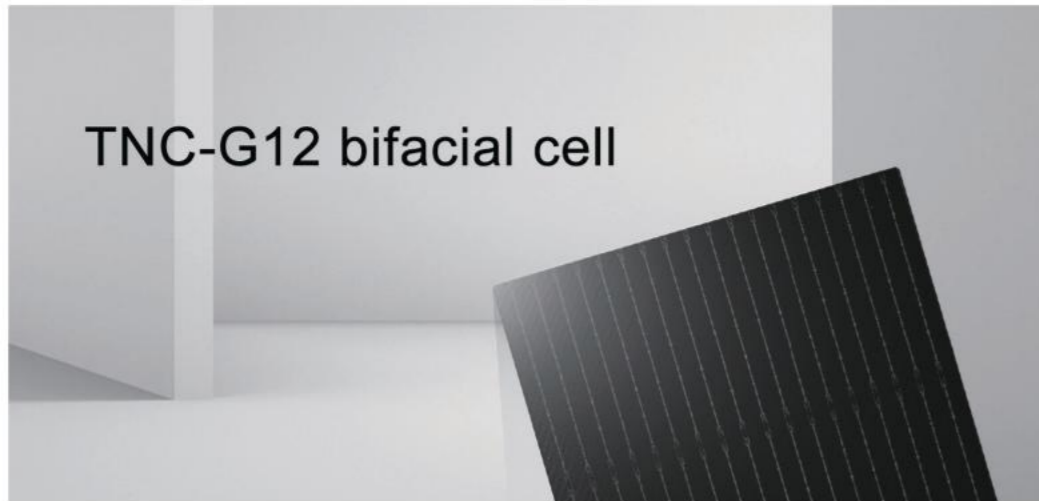


1200+ senior R&D technicians

Note: Solar cell shipment ranking data source: Pv InfoLink

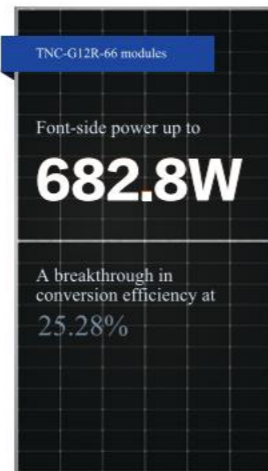
## Industry-leading, Excellence in Efficiency

Tongwei is a leader in the crystalline silicon N-type TOPCon cell manufacturing industry in terms of both production scale and cell manufacturing technology. With the continuous innovation of Tongwei's TNC cell technology and the gradual introduction of cutting-edge cell technologies into production lines, the average conversion efficiency of mass-produced industrialized TOPCon cells has reached 25.7%.



On March 20, 2025, according to the test by TÜV, an international authoritative certification body, under the standard size of 2382x1134mm, the front side power of Tongwei's TNC-G12R module reached 682.8 watts and the conversion efficiency reached 25.28%, which is about 60 watts higher than the mainstream power of mass-produced models of the same type in the current market.

Under the standard size of 2384x1303mm, Tongwei TNC-G12 modules have a power of 778.5 watts and a conversion efficiency of 25.06%. It has established new benchmarks for the efficiency and power of the two mainstream types of TOPCon modules. [7]



### 1.3

## TW Solar Quality Culture of Pursuit of Excellence

### Quality Policy of Tongwei Co., Ltd.

- Quality, market and profitability are the perpetual themes of the company's development, and quality is the foundation and prerequisite for market and profitability.
- Accurately identify the essential needs of customers, always regulate all employees' awareness and behavior with the goal of maximizing customer value, and strictly control the entire process of product design, manufacturing and use at professional, standardized and large-scale levels to ensure product quality.
- Continuously improve the quality management system, strive to create an industrial chain that is leading in efficiency, continuously value-added and irreplaceable, provide safe and stable products for society, and achieve win-win development for the company and its customers.

### Quality Objective

Tongwei adopts and implements ISO9001 quality management, ISO37301 compliance management and various special management systems, abides by national laws and regulations, and strictly controls product quality.

- 100% product qualification rate upon factory delivery
- Zero quality and safety incidents
- 100% customer complaint resolution rate

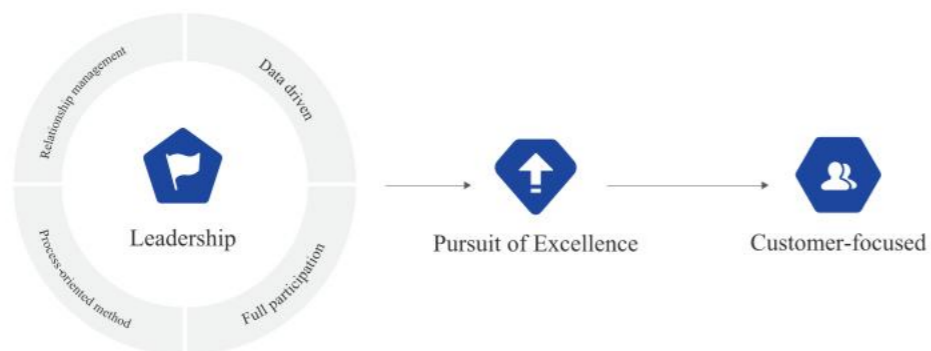


The market recovery still needs time, but industry competition has never ceased. TW Solar has established a systematic quality optimization methodology. With its unique core quality advantage of "striving for excellence," it has become a key lever for photovoltaic companies to break through industry bottlenecks.

This White Paper systematically presents TW Solar's unique "striving for excellence" quality culture and its implementation, the application of quality methodologies and tools, and future trends in quality practices. It focuses on key areas such as quality improvement, cost optimization, process enhancement, and product efficiency, and integrates industry best practices to provide actionable and replicable solutions, thus helping build sustainable competitive advantages in the context of industry reshuffling.

## TW Solar's Relentless Pursuit of Excellence in Quality Management Culture

Build a systematic model of "pursuing excellence" in quality management with TW Solar's unique characteristics, achieving comprehensive management from strategy (management) to execution (employees), from internal (process) to external (customers, suppliers), and from static (current quality) to dynamic (continuous improvement). Not being satisfied with product quality and workflow, continuously making breakthroughs and pursuing excellence in execution and innovation, thereby improving customer satisfaction and strengthening its position as a global leader.



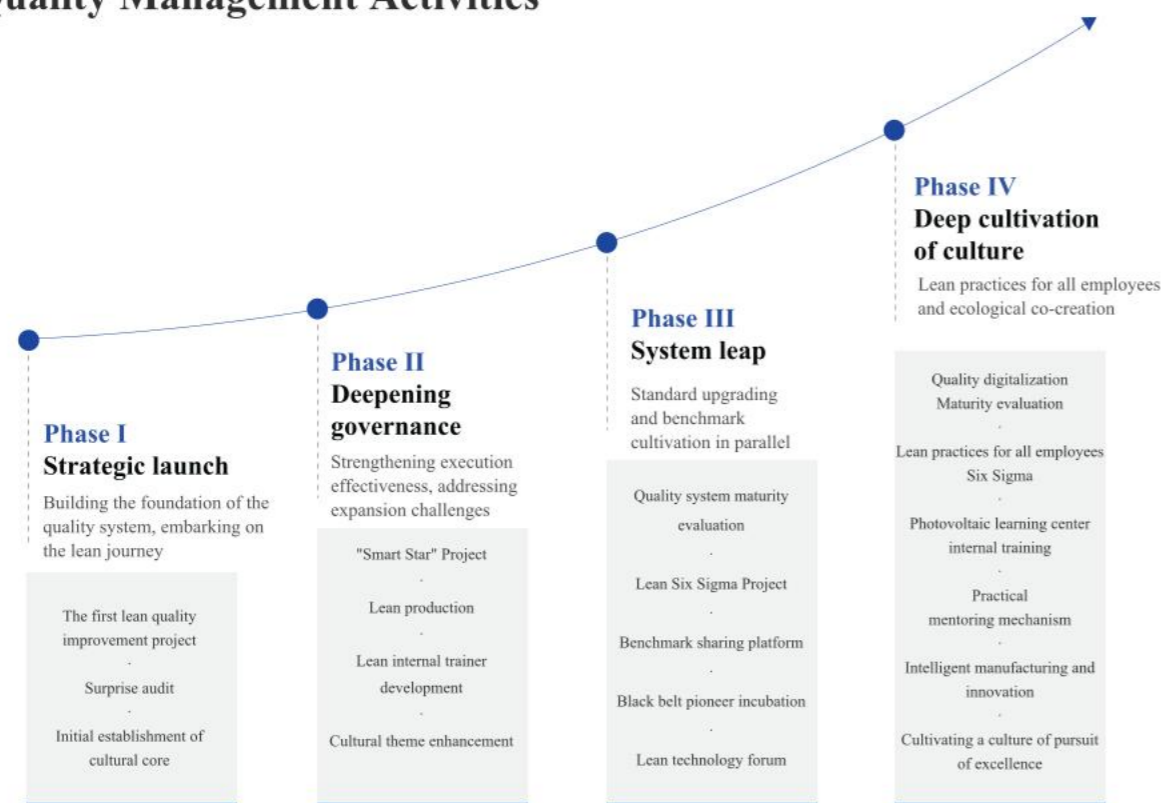
Since implementing its distinctive "pursuit of excellence" quality management strategy, TW Solar has consistently focused on long-term goals, advancing steadily and deepening its exploration step by step:

**Foundation stage:** Initially concentrating on system establishment and talent development to lay a solid groundwork for lean management.

**Breakthrough stage:** During its growth, leveraging targeted measures and innovation-driven approaches to effectively overcome bottlenecks and challenges hindering development.

**Deepening stage:** With ongoing practice, continuously advancing the upgrade of management standards, process optimization, and technological innovation, achieving iterative enhancements in the lean management system and driving sustained quality improvement.

## TW Solar's Relentless Pursuit of Excellence in Quality Management Activities



Through a strategic focus on its distinctive "pursuit of excellence" culture, TW Solar has systematically advanced quality management reform. Driven by a three-pronged approach of "supervision and audit + lean projects + benchmarking leadership," the company has undergone four stages of transformation: "Foundation (2022) → Breakthrough (2023) → Benchmarking (2024) → Co-creation (2025)." This has shaped a quality ecosystem characterized by "standards-driven leadership + intelligent innovation" in the spirit of "pursuit of excellence," achieving a leap from basic capability building to collaborative industry ecosystem development.



- Rationalization Proposals - Golden Idea Initiative
- Quality Month Activities
- Total Quality Management (TQM)
- QC Circle Activities
- Quality Knowledge Forum
- Lean Six sigma Management
- Quality Bulletin
- Quality Awareness Training
- Quality Star Evaluation
- Total Productive Maintenance (TPM)
- Quality digitalization Maturity evaluation
- Lean Culture Salon

2.1

# Tongwei TOPCon Cell Process and Quality

Traditional TOPCon cell manufacturing primarily utilizes the LPCVD process. Since 2020, Tongwei has been developing TNC cells, and possesses the industry's first large-size PECVD Poly deposition technology route, which fills the gap in tubular PE-Poly technology for China's cell manufacturing. Tongwei has achieved innovative breakthroughs and industry leadership in TOPCon cell manufacturing technology. [8]

## Chapter II TW Solar Quality Management Methodology

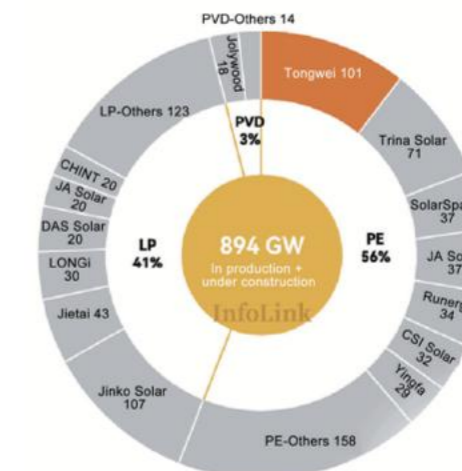


Traditional TOPCon Cell Manufacturing Process

PECVD	LPCVD + phosphorus diffusion	LPCVD in-situ doping
Texturing	Texturing	Texturing
Boron diffusion	Boron diffusion	Boron diffusion
Etching: BSG removal + alkali polishing	Acid or alkali polishing	Acid or alkali polishing
PECVD deposition and in-situ doping of polysilicon	LPCVD deposition of intrinsic polysilicon	LPCVD deposition and in-situ doping of polysilicon
Annealing	Phosphorus diffusion	Annealing
PSG removal + RCA cleaning	PSG removal + RCA cleaning	RCA cleaning
ALD, PECVD front side coating	ALD, PECVD front side coating	ALD, PECVD front side coating
PECVD back coating	PECVD back coating	PECVD back coating
Screen printing + sintering	Screen printing + sintering	Screen printing + sintering

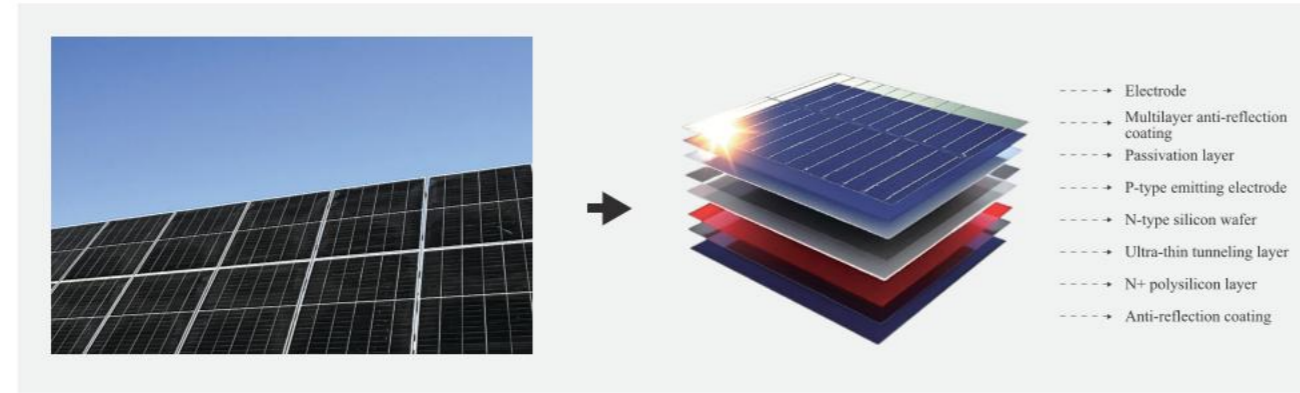
Tongwei leads the development of the PECVD technology route. According to PV InfoLink statistics, the PE-Poly route accounts for 56% and has become the mainstream mass-production technology for TOPCon.

Proportion of backside Poly deposition capacity, Unit: GW; %



Source: InfoLink Technology Trend Research

# Introduction to Process Flow of TOPCon Cell and Quality Concerns



■ Wafer   
 ■ BSG   
 ■ P+   
 ■ SiOx   
 ■ SiNx   
 ■ AlOx   
 ■ n+-Poly   
 ■ PSG

Description of process functions	Film layer structure of cell	Quality concerns	
		Critical to Process CTP	Critical to Quality CTQ
Remove impurities from the silicon wafer, form a textured surface structure on the N-type silicon wafer, reduce surface reflectivity, and increase light absorption.	Texturing	Texturing tank Solution ratio	Weight loss Reflectivity
Boron is doped into the front side of the N-type silicon wafer to form a P+ layer and establish a PN junction. An ultrathin oxide layer is also formed on the surface as the basis for the passivation layer.	Boron diffusion	Deposition step gas flow Junction drive temperature Number of uses of quartz boat	Sheet resistance Sheet resistance uniformity
Polish the back side to remove edge and back BSG, retaining front BSG in preparation for alkaline polishing	Alkaline etching	Conductivity of BSG removal tank Solution ratio of alkaline polishing tank	Weight loss Reflectivity Appearance
Forming a passivated contact structure	SiO <sub>2</sub> /n+-Poly:SiO <sub>x</sub>	Tunnel oxide layer Gas flow rate of amorphous silicon layer Deposition time	Film thickness Uniformity of film thickness Appearance
Dopant activation	Annealing	Annealing	Sheet resistance Non-uniformity of sheet resistance
Remove the front PSG and edge n+-Poly layer, then remove the front BSG and back PSG	Remove PSG and perform RCA	Conductivity of PSG removal tank Initial preparation and replenishment of alkaline polishing tank	Weight loss Appearance
1. Atomic deposition is used to form an AlOx film layer for field-effect passivation of the cell, suppressing electron recombination. 2. Silicon nitride is deposited on the front side, such as SiNx, SiOxNy, and SiOx stacks, which have the effects of reducing light reflection, improving light absorption and hydrogen passivation	Front AlO <sub>x</sub> :SiNx	Chamber temperature TMA flow Pulse time Number of cycles	Alumina thickness SiNx film thickness
Deposit silicon nitride (SiNx) on the back side to reduce parasitic absorption, increase bifacial ratio, and prevent oxidation.	Back film SiNx	Silane and ammonia flow Silicon-nitrogen ratio of bottom film Deposition temperature	SiNx film thickness Refractive index Appearance
1. Double-sided metallization, forming front and back electrodes by printing the main and fine grid. 2. High-temperature sintering forms an ohmic contact to achieve carrier collection and transmission 3. Passivation treatment using light-controlled hydrogen 4. Laser-assisted sintering enhances contact between metal and cell 5. Appearance sorting, defect testing, and electrical performance binning	Metallization (Screen printing, sintering, photoinjection, laser-assisted sintering)	Printing pressure Printing height offset Drying oven temperature	Paste weight Printing pattern accuracy Aspect ratio of grid lines EL, efficiency and appearance defects

# TOPCon Cell Inspection Technology

**Automatic silicon wafer sorting**

Compatible with inspection of silicon wafers in the full size range of 156-230mm, it integrates test modules for size, appearance, resistivity, PL, color difference, and more, and supports automatic data analysis and statistics.

**QE test (Quantum Efficiency)**

Provide full-spectrum sunlight simulation (300-2500nm), enabling comprehensive analysis of cell spectral responsivity, internal and external quantum efficiency, reflectivity, surface uniformity, etc.

**Cell EPL inspection**

Through innovative dual-system collaboration of "EL dynamic prediction + PL secondary imaging", along with PL re-inspection and a score integration algorithm, a "double assurance" grading model is provided for cell EL inspection, effectively solving the bottleneck of misjudgment caused by single imaging.

**Screen AOI inspection**

Drawings can be imported and automatically analyzed to generate inspection strategies, compatible with various screen formats. Support defect detection and graphic comparison; one-click automatic detection takes less than 5 minutes.

**Offline & online sheet resistance test**

Equipped with an automated load/unload system, it enables fully automated measurement and features mapping software, as well as thickness, edge, and temperature compensation functions. Test data is automatically integrated into the SPC system to enable dynamic monitoring of key product characteristics.

**Cell & module reliability test**

Comprehensive reliability testing capabilities for cells and modules are available, strictly aligned with IEC international standards and customer requirements. Systematic and advanced validation programs are implemented to provide solid assurance for ultimate reliability and long product lifespan.

# Cell AOI Defect Inspection and Core Technology

Defect type	Test principle	Technical methods
Subfissure / microcrack	Destruction of crystal structure in photoluminescence (PL) subfissure regions Changes in carrier recombination characteristics Abnormal dark or bright stripes in PL images	PL imaging + AI classification
Chipping/defect	Geometric deviation of profile Abnormal pixel contrast	Edge detection + template matching
Color difference/contamination	Uneven hue distribution in HSV space Local grayscale discontinuity	Block scanning + differential operation
Grid breakage	Grid line continuity interruption	Morphological analysis + connected component detection
Paste leakage	The ring-shaped LED illuminates with red light. The reflectivity of the paste is higher than that of the silicon substrate, resulting in high brightness in abnormal areas.	Multi-light source fusion comparison

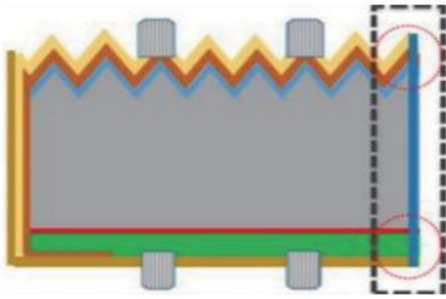
2.2

# Tongwei TOPCon Cell Future Technical Advantages <sup>[9]</sup>

Tongwei's TNC1.0 and TNC2.0 cells have achieved major technological breakthroughs. Both adopt the independently developed and industry-leading PECVD polysilicon deposition technology route, which lays a solid foundation for the high efficiency performance of cells. At the same time, by combining efficient secondary sintering technology, high-quality metal contact is successfully achieved without damaging the passivation layer in the non-contact areas, effectively enhancing the electrical performance of the cell.

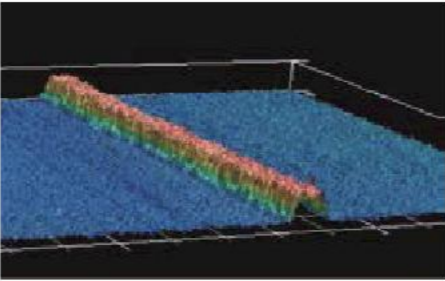
Certified by Germany's TÜV Rheinland, Tongwei Global Innovation and R&D Center has achieved the latest technological breakthrough: The bifaciality of cells based on TOPCon technology has exceeded 94.3%, and the bifaciality of TNC2.0 modules has reached over 88% at the R&D level. These results mean that under the same lighting conditions, their bifaciality is 5-10 percentage points higher than conventional TOPCon modules in the market, effectively boosting overall power generation and delivering superior performance.

## Technical Structure: Tongwei TNC 2.0 Integrates Four Key Processes



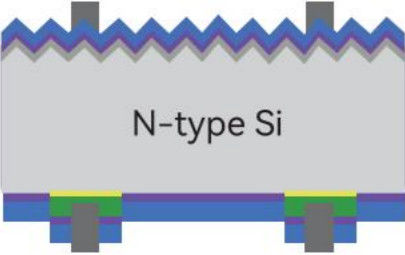
**TPE Technology**  
TPE technology, improving quality and efficiency

Repair cell edge defects and reduce recombination centers to improve half-cell efficiency by 0.2%+



**Stencil Printing**  
Precision printing for enhanced electrical performance

Utilizing a 100% aperture ratio stencil to replace traditional screens, effectively reducing the shading area of front-side grid lines. This strengthens current collection capability and reduces power loss by 3.3%.



**Poly Tech**  
Higher bifaciality, higher overall energy generation

Optimize the contact performance of the passivation layer, reduce optical loss, increase bifaciality to 88%+, and obtain TÜV Rheinland and CGC certifications, achieving 5%-10% higher than conventional modules.



**908 Cell Interconnect Technology**  
Tongwei's 0BB technology

Through the low-temperature interconnection process, organic silicone gel is used to replace traditional pad points, reducing the cell shading area by 30%, lowering the risk of subfissures, and significantly improving module reliability.

2.3

# TW Solar Quality Methods and Tools for Pursuit of Excellence

In today's fiercely competitive market environment, excellent quality management is the key for enterprises to achieve sustainable development. TW Solar flexibly and thoroughly integrates various quality management methods into the company's quality management and strategic planning, and builds a synergistic mechanism of "CTQ (Critical to Quality)-financial benefits" to ensure the coordinated optimization of quality control and business performance. The following introduces the commonly used methods and tools in TW Solar's distinctive pursuit-of-excellence quality management:

### PDCA Cycle

Also known as the Deming Cycle, it divides quality management into four stages: Plan, Do, Check, and Act.

### 8D Problem Solving Tool

It includes 8 steps, plus a preparation step, which are used to objectively identify, define and solve problems and prevent similar problems from recurring.

### QC Seven Tools

Use a Check Sheet to gather data; Apply Stratification to identify differences; Follow the Fishbone Diagram to trace root causes; Rely on the Pareto Chart to focus on the critical issues; Observe distribution patterns with a Histogram; Examine correlations through a Scatter Diagram; Maintain process stability with a Control Chart. These seven tools form the foundation of quality.

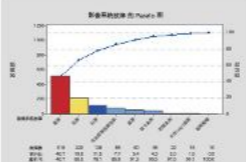
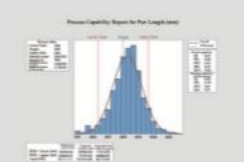
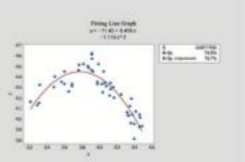
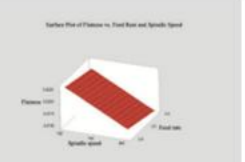
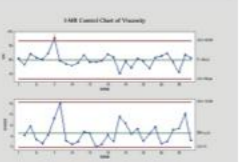
### Lean Six Sigma to Digital Six Sigma

Six Sigma is derived from statistical principles and aims to reduce variation and improve quality and efficiency through rigorous processes and scientific methods, with decisions driven by data and facts. It is a systematic and structured business improvement and innovation model for enhancing customer and stakeholder satisfaction.

Its specific implementation process consists of five stages: Define, Measure, Analyze, Improve, and Control, collectively referred to as DMAIC.

Lean is a philosophy and methodology focused on identifying and eliminating waste and non-value-added activities in products, services, and processes through continuous improvement.

Lean Six Sigma is the combination of "doing things faster (Lean)" and "doing things better (Six Sigma)."

Define Phase <b>D</b>	Measure Phase <b>M</b>	Analyze Phase <b>A</b>	Improve Phase <b>I</b>	Control Phase <b>C</b>
What is the current main problem?	What is the current situation? What are the potential causes?	Reason verification	What improvement measures need to be taken?	How do we keep up the performance?
<ul style="list-style-type: none"> <li>- Determine Y</li> <li>- Set objectives</li> <li>- Estimated financial benefits</li> <li>- Define the scope of process</li> <li>- Establish a project team</li> </ul>	<ul style="list-style-type: none"> <li>- Analysis of measurement systems for key outputs</li> <li>- Current performance of key outputs</li> <li>- Conduct a preliminary search for the cause and identify quick win opportunities</li> </ul>	<ul style="list-style-type: none"> <li>- Preliminary analysis of causes</li> <li>- Verify the root cause</li> <li>- Current situation analysis of X</li> </ul>	<ul style="list-style-type: none"> <li>- Generate candidate solutions</li> <li>- Evaluate candidate solutions</li> <li>- Validate candidate solutions</li> </ul>	<ul style="list-style-type: none"> <li>- Monitor Y and X</li> <li>- Standardize</li> </ul>
				

#### TW Solar's Full-process Six Sigma Model

- Introduction period (Years 1-2): Cultivate Yellow Belt and Green Belt teams to focus on high-benefit projects (such as quality, energy consumption, efficiency improvement, and silver paste cost reduction).
- Expansion period (Year 3): Cultivate Black Belt teams to cover design and supply chain, and establish a culture of independent improvement.
- Maturity stage (Year 4): Combine with digital tools to form a closed loop of "data-analysis-decision".

Note: All data in the project cases of this unit are desensitized.

# DFSS Design For Six Sigma

Design quality determines the inherent quality of the product. Only by giving the product a high inherent quality at the design stage can it be possible to achieve the quality goal of Six Sigma.

Through rigorous processes and scientific methods, focused on customer or stakeholder needs, robust design is implemented at the source of product, service, and process development to eliminate defects and reduce waste. This is the process to achieve high-quality products and services.

## Typical Six Sigma Design Process (IDDOV)

Stage	I Identify	D Define	D Develop	O Optimize	V Verify
Main works	Find market opportunities, identify customer needs, and conduct project validation.	Determination and development of customer needs; product concept evaluation and design.	Design of full-size prototype (specimen), manufacturing process design, and supporting resource design.	Optimization of product and process design parameters; design of nominal samples.	Development of prototypes; verification of the correctness of product design schemes and achievement of quality standards.
Main technical methods	<ul style="list-style-type: none"> <li>·QFD</li> <li>·Kano Model</li> <li>·Seven new QC tools</li> <li>·Risk analysis</li> </ul>	<ul style="list-style-type: none"> <li>·QFD</li> <li>·System design</li> <li>·DFX</li> <li>·Functional FMEA</li> <li>·Seven new QC tools</li> <li>·Risk analysis</li> <li>·LCC analysis</li> </ul>	<ul style="list-style-type: none"> <li>·System design</li> <li>·QFD</li> <li>·DFX</li> <li>·DOE</li> <li>·Parameter design</li> <li>·Tolerance design</li> <li>·CAD:CAM</li> <li>·R&amp;D test</li> <li>·FRACAS</li> <li>·LCC analysis</li> <li>·DFSS scorecard</li> </ul>	<ul style="list-style-type: none"> <li>·DOE</li> <li>·Parameter design</li> <li>·Tolerance design</li> <li>·DFX</li> <li>·FMEA</li> <li>·LCC analysis</li> <li>·CAD:CAM</li> <li>·Simulation</li> <li>·Optimization test</li> <li>·FRACAS</li> <li>·DFSS scorecard</li> </ul>	<ul style="list-style-type: none"> <li>·Simulation test</li> <li>·V&amp;V test</li> <li>·Reliability test</li> <li>·Life test</li> <li>·Qualification test</li> <li>·SPC ATP of small samples</li> <li>·FRACAS</li> <li>·MTBF</li> <li>·S/N ratio</li> <li>·DFSS scorecard</li> </ul>
Main design outputs	<ol style="list-style-type: none"> <li>1. Project feasibility study report</li> <li>2. DFSS project charter</li> </ol>	<ol style="list-style-type: none"> <li>1. Product design scheme</li> <li>2. Technical specification</li> </ol>	<ol style="list-style-type: none"> <li>1. Drawings and process documents for prototype production</li> <li>2. Product specification (provisional version)</li> <li>3. Initial draft of the design scheme for after-sales support system</li> </ol>	<ol style="list-style-type: none"> <li>1. Product production drawings and process documents</li> <li>2. Product specifications</li> <li>3. Design scheme for after-sales support system</li> </ol>	<ol style="list-style-type: none"> <li>1. Design verification test report</li> <li>2. Design appraisal report</li> <li>3. Process capability analysis report</li> <li>4. DFSS project performance report</li> </ol>

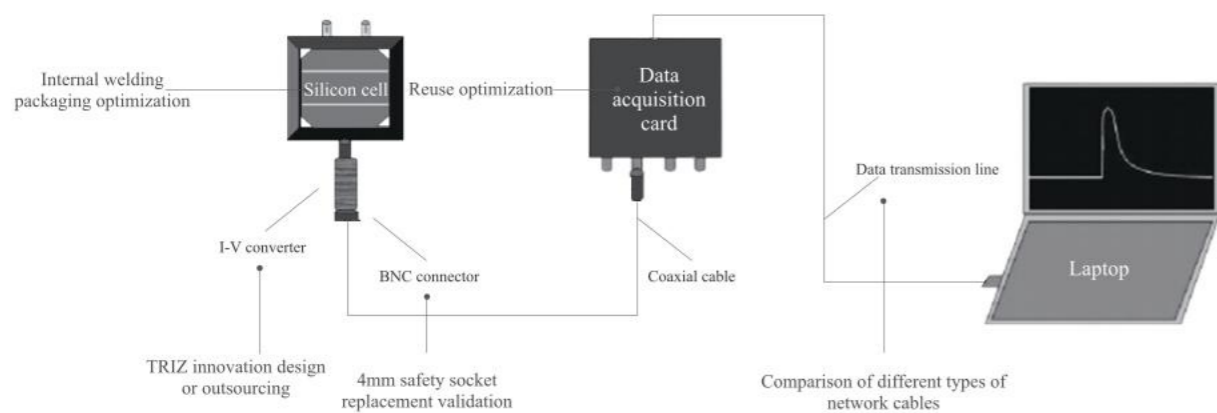


Figure 2.1 Design of Solar Simulator Detection System

# QFD Quality Function Deployment

A customer-oriented, systematic product planning and development method. Its core idea is to start from the design stage and systematically transform customer (or market) needs into product design, component characteristics, process requirements, and production control through a multi-level deployment and analysis method. QFD forms a precise, step-by-step control chain through four interconnected "Houses of Quality" (HOQ): Customer Requirements (VOC) → Critical to Quality Attributes (CTQs) → Critical Design Parameters (CDPs) → Critical Process Parameters (CPPs) → Critical Process Controls (CPCs).

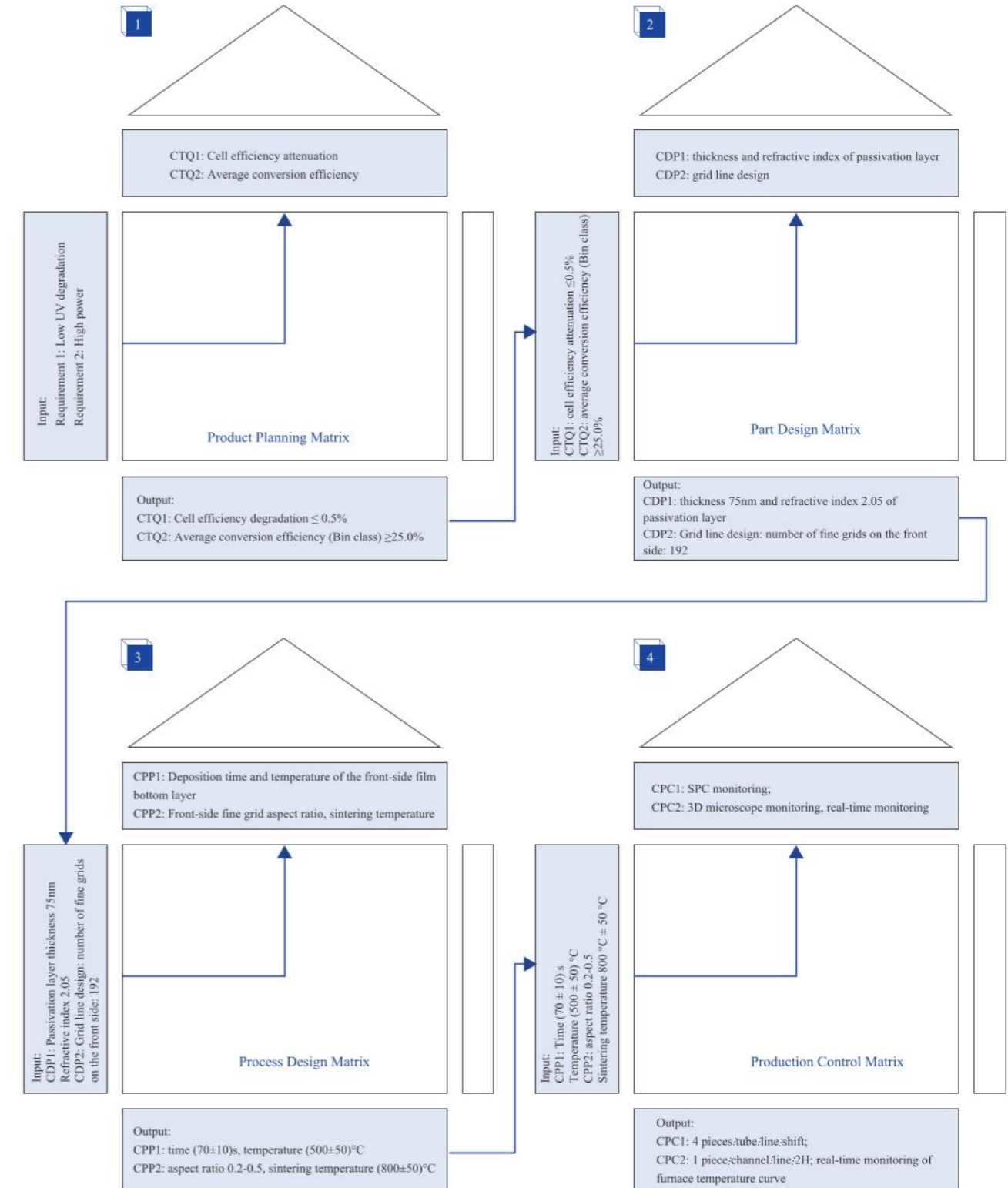


Figure 2.1 QFD Case of 4 Houses of Quality for a Certain TOPCon Product

# TRIZ - Theory of Inventive Problem Solving

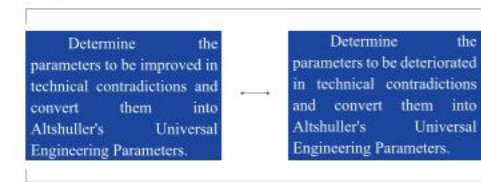
The basic problems people face in solving invention problems are the same, and the contradictions they need to solve are essentially the same. The same principles of technological innovation and corresponding problem-solving solutions are also applied in subsequent inventions. The Theory of Inventive Problem Solving (TIPS) and its methodological system are generally applicable to newly arising invention problems, helping to quickly and effectively find solutions.

TRIZ's solution to technological contradictions is the "40 invention principles." First identify the improving and deteriorating parameters, then consult the contradiction matrix to find possible solutions based on the suggested invention principles.

## General steps for resolving technical contradictions

### Issues:

Describe the key problem to be solved, not the initial problem encountered.



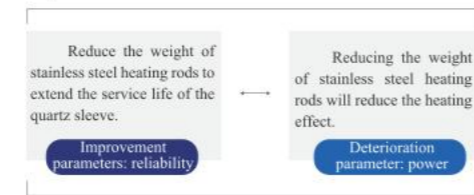
Find the contradiction matrix and determine the invention principle

### Specific solutions

## Practical issues application

### Issues:

The heating rod is heavy, and the evacuation process causes the quartz tube to break.



Refer to the contradiction matrix: the invention principles corresponding to reliability & power are 11:21/26/31.

### Specific solutions

Figure 2.2 Optimization and Innovative Improvement of the Upper Auxiliary Heating Rod Weight Problem using TRIZ Tools

		Deteriorating parameters									
		21	22	23	24	25	26	27	28	29	
Improving parameters	<b>Contradiction matrix</b>	Power	Energy loss	Material loss	Information loss	Time loss	The quantity of a substance or an item	Reliability			
	23	Material loss	28,27 18,38	35,27 2,31			15,18, 35,10	6,3 10,24	10,29 39,35	16,34 31,28	35,10 24,31
	24	Information loss	1,019	1,910			24,26 28,32	24,28 35	10,28 23		
	25	Time loss	35,20 10,6	10,5, 18,32	35,18 10,39	24,26 28,32		35,38 18,16	10,30 4	24,34 28,32	24,26, 28,18
	26	The quantity of a substance or an item	35	7,18 25	6,3, 10,24	24,28 35	35,38 18,16		18,3 28,40	13,2 28	33,30
	27	Reliability	21,11, 26,31	10,11, 35	10,35 29,39	1,028	10,30 4	21,28 40,3		32,3, 11,23	11,32, 1
	28	Measurement accuracy	3,6 32	26,32, 27	10,16, 31,28		24,34 28,32	26,32	5,11, 1,23		
	29	Manufacturing accuracy	322	13,32, 2	35,31, 10,24		32,26, 28,18	3,230	11,32 1		

Figure 2.3 Suggested Innovative Invention Principles Obtained by Searching the Contradiction Matrix

## Invention principle

S/N	Invention principle	Guiding principles
11	Precautions taken beforehand	Adopt pre-prepared emergency measures to compensate for the relatively low reliability of the object
21	Rapid passage	Perform dangerous or hazardous processes or steps at high speeds
26	Copy	1. Replace complex, expensive, inconvenient, fragile, or hard-to-obtain objects with simple and cheap replicas. 2. Use optical replicas (images) instead of physical objects or systems, allowing images to be enlarged or reduced in proportion as needed. 3. If a visible light replica has been used, use an infrared or ultraviolet light replica instead.
31	Porous material	Make an object porous or introduce a porous object

# 5WHY

5WHY analysis method: It is a structured and iterative root cause analysis tool. The core lies in continuously asking "why" to conduct in-depth exploration of the root causes behind the identified problems or faults.

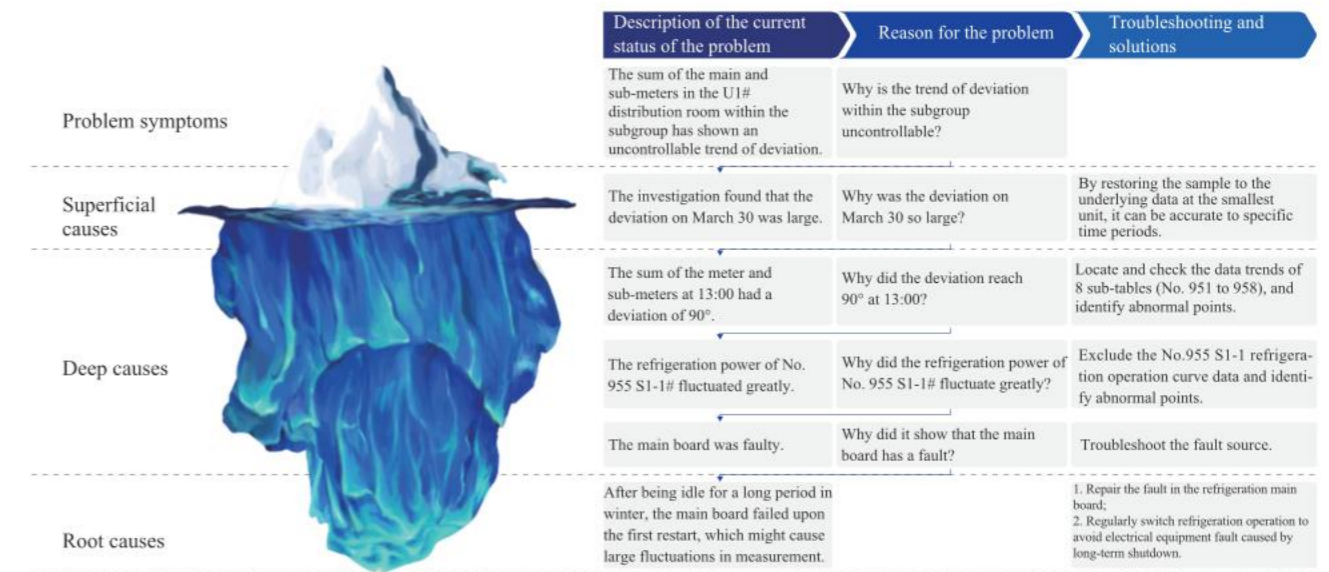


Figure 2.4 Iceberg Model : 5WHY Problem Analysis and Solutions

# Design Of Experiments (DOE)

Design of Experiments (DOE): a scientific method for planning and conducting experiments to determine the true causal relationship between key X variables and the Y variables of interest. DOE allows experimenters to study the effects of a large number of input variables that simultaneously influence products or processes, including possible interaction effects (such as synergistic effects). Many experimental results are ultimately described as mathematical formulas.

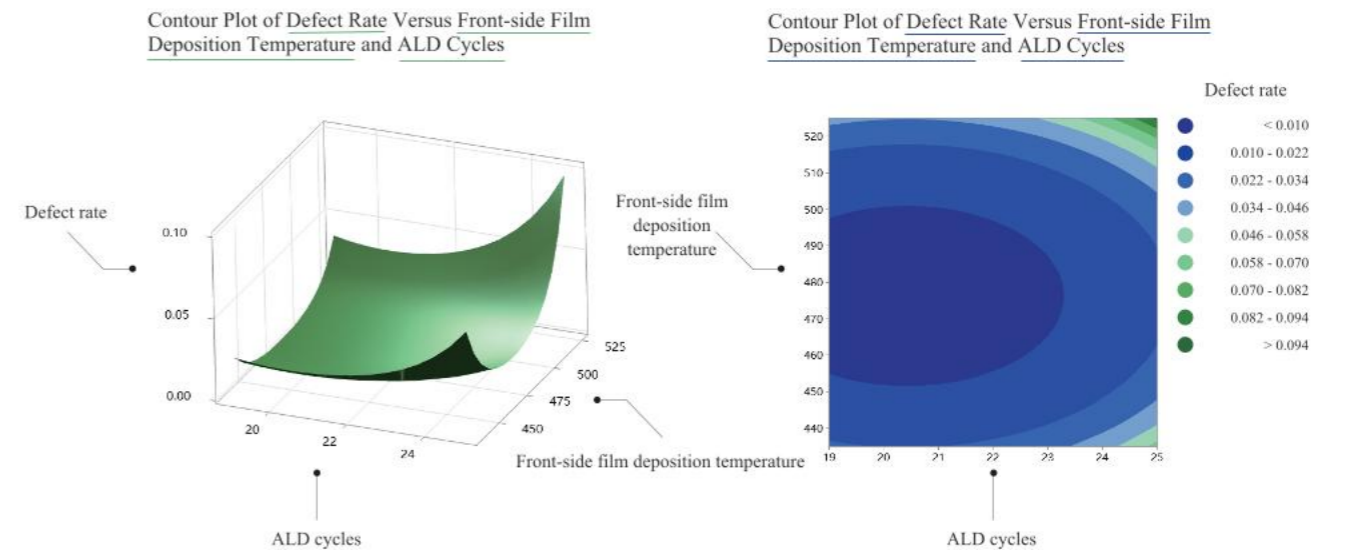


Figure 2.5 Model of Defect Rate Y with Front-side Film Deposition Temperature X1 and ALD Cycles X2

Orthogonal experimental design is a design method for studying multiple factors and levels. It selects some representative points from comprehensive experiments based on orthogonality for testing. These representative points are characterized by "uniform dispersion, neatness, and comparability". Orthogonal experimental design is the main method of fractional factorial design and is an efficient, fast, and cost-effective experimental design method.

The invention principle 26,1 is adopted for this case  
Improvement plan: Replace the upper auxiliary heating stainless steel heating rod with a short-wave infrared heating filament. Improvement effect: The heating effect after improvement is comparable to that before improvement, and the breakage frequency of the upper auxiliary heating quartz sleeve is reduced by more than 80%.

## Talent Development

Through its Phase III Project, TW Solar has trained and certified 1,863 Yellow Belts, registered 119 Green Belts, and 12 Black Belts, forming an internal "pool of improvement experts." It has pioneered a "mentoring mechanism," enabling knowledge transfer through project proliferation.



## Organizational Change

After four years of practical validation, TW Solar has not only achieved breakthroughs in specific problems by integrating and applying lean methods and tools, but has also successfully built an enterprise-level strategic engine that is "data-driven and focused on continuous improvement". Its unique lean paradigm provides a practical example for the manufacturing industry to transition from "scale expansion" to "quality and efficiency," while also validating the feasibility of elevating from "cost control" to "value creation."

Amidst the accelerated evolution of intelligent manufacturing, digital Six Sigma—deeply integrating AI and industrial Internet—is becoming a strategic methodology for the photovoltaic industry to address the triple challenges of quality bottlenecks, cost difficulties, and technology iteration. It drives enterprises toward sustainable development and fosters high-quality productive forces.

TONGWEI

TÜVRheinland®  
Precisely Right.

# Chapter III Part Pursuing Excellence in Quality Management



3.1

# Total Quality Management: "Three Essential Skills" Required for Different Positions

For TW Solar, total quality management is not a short-term initiative, but about embedding the spirit of 'pursuit of excellence' into the organization's DNA. Full participation is at the core of Tongwei's pursuit of excellence and is key to the company's quality culture, because it turns quality from "control" to "collaborative development", and shifts from 'passive compliance' to 'proactive improvement'.

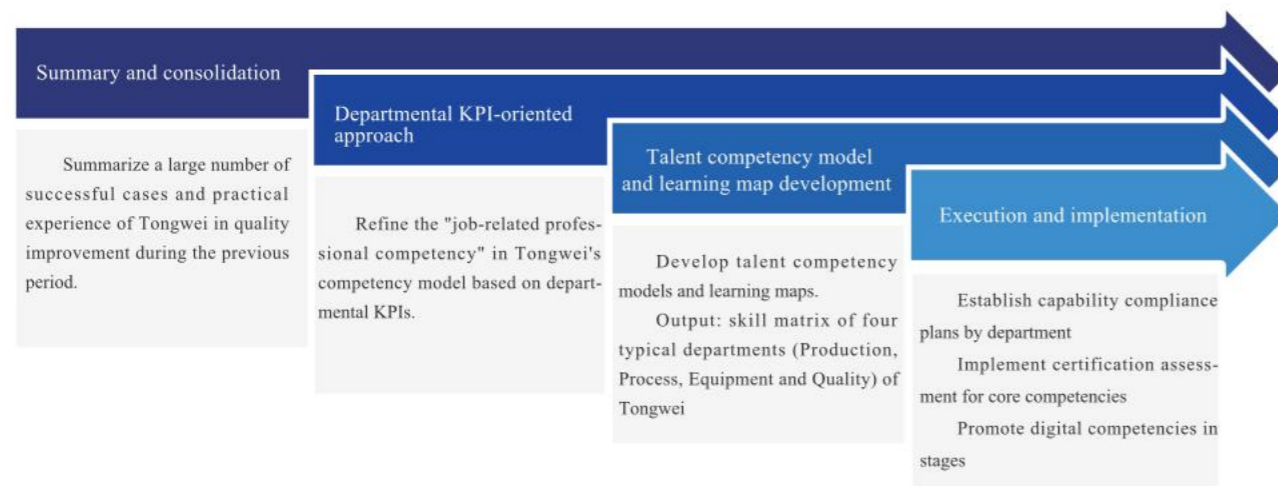
## Ability and Competency Model for Tongwei Technicians



Figure 3.1 Tongwei Technician Competency Model

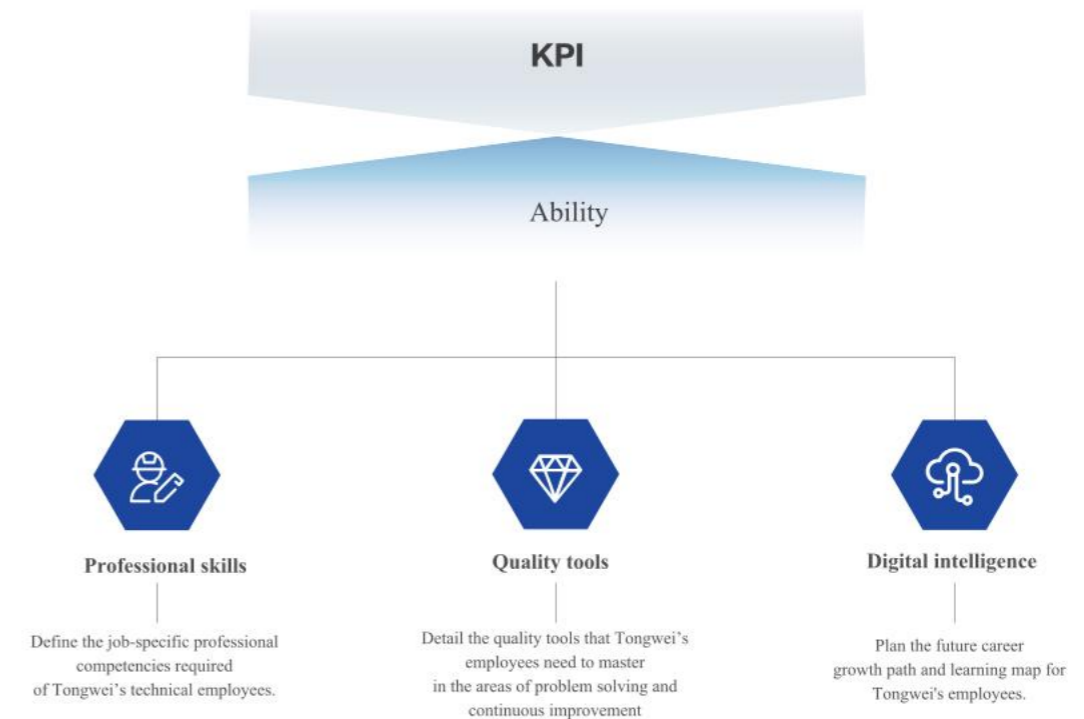
By empowering employees, breaking down departmental walls and shaping a culture of excellence, the organization can achieve continuous optimization and ultimately gain competitive advantages in cost, efficiency and customer satisfaction.

The specific procedures are as follows:



## Introduction and Explanation of Tongwei's Personnel Skill Matrix for Continuous Quality Improvement

The skill matrix consists of two parts: KPI and ability:  
The abilities required to meet KPIs are broken down into three parts: professional skills, quality tools, and digital intelligence.



The following takes the technical sequence engineer as an example to demonstrate the application of the skill matrix of four typical departments (Production, Process, Equipment and Quality):

Symbol	Level	Definitions
	Awareness	Familiar with the theory
	Proficient	Understand the theory and are capable of practical application
	Expert	Deep understanding and proficient use of the theory; able to mentor others

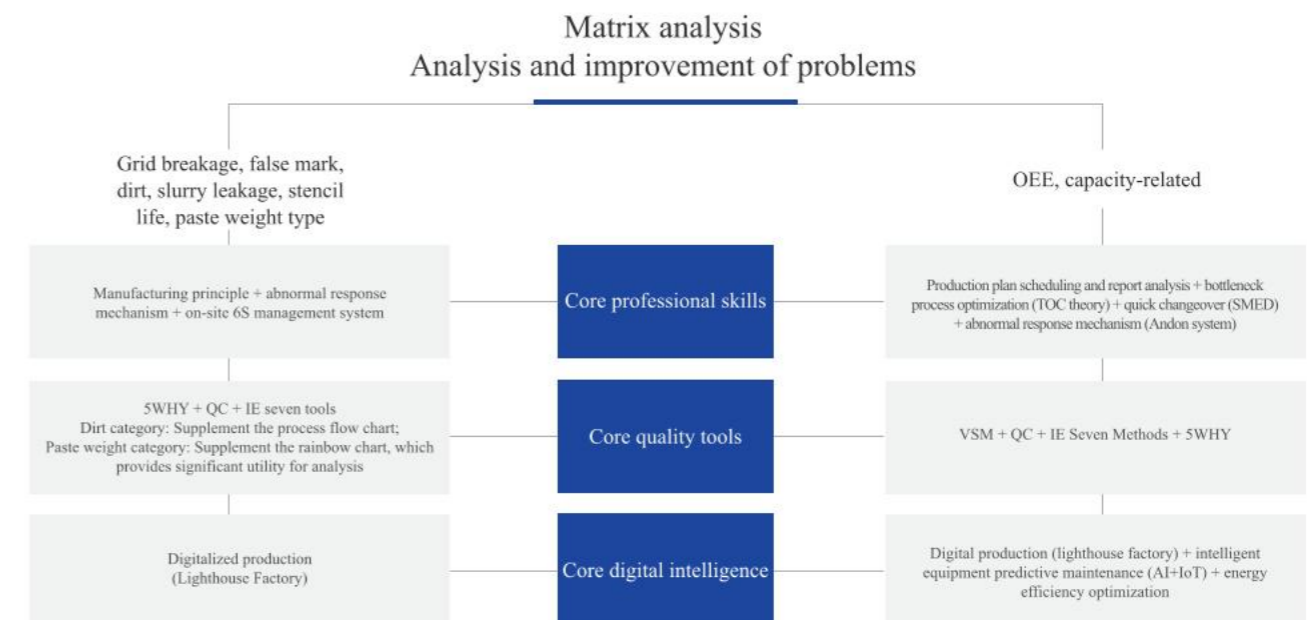
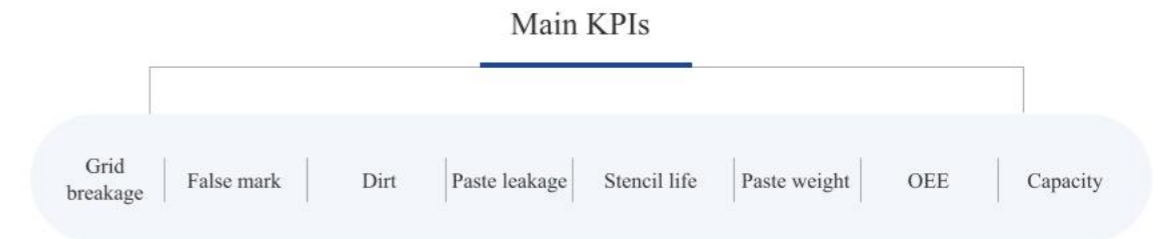
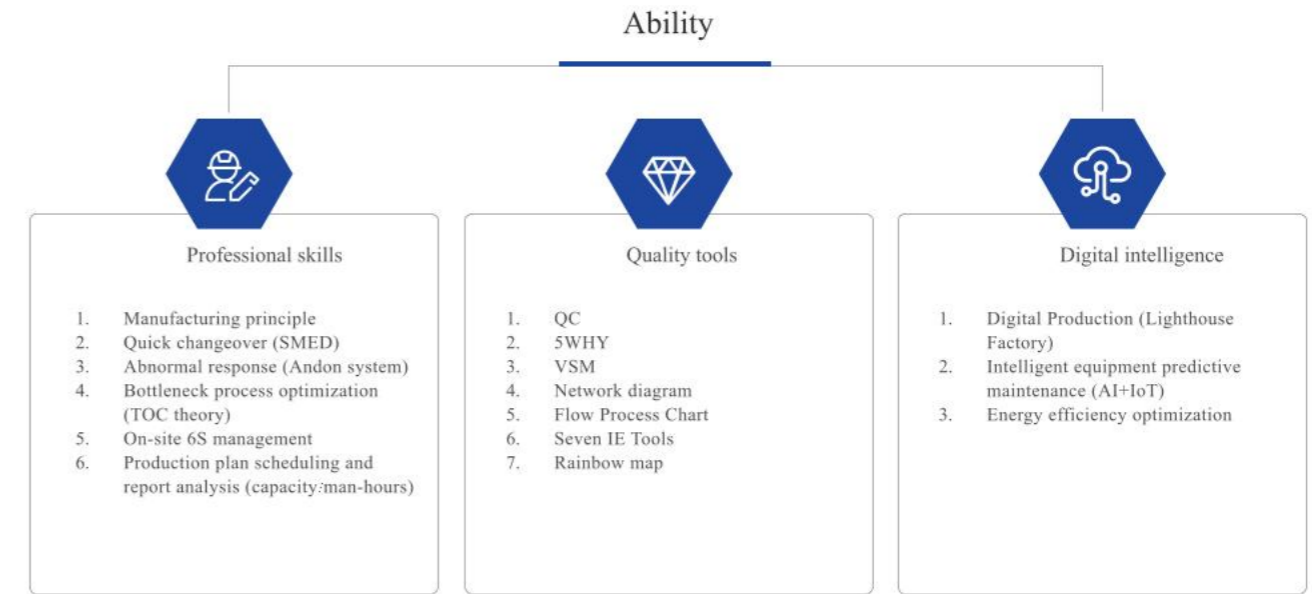
# Tongwei's Skill Matrix for Quality Excellence

Production Department

Ability		KPI							
		Grid breakage	False mark	Dirt	Paste leakage	Stencil life	Paste weight	OEE	Capacity
Professional skills	Production Principle	●	●	●	●	●	●	●	●
	Quick changeover (SMED)	●	●	●	●	●	●	●	●
	Abnormal response mechanism (Andon System)	●	●	●	●	●	●	●	●
	Bottleneck process optimization (TOC theory)	●	●	●	●	●	●	●	●
	Site 6S Management	●	●	●	●	●	●	●	●
	Production plan Scheduling and report analysis (Capacity:Man-hours)	●	●	●	●	●	●	●	●
Quality tools	QC	●	●	●	●	●	●	●	●
	5WHY	●	●	●	●	●	●	●	●
	VSM	●	●	●	●	●	●	●	●
	Network diagram	●	●	●	●	●	●	●	●
	Flow Process Chart	●	●	●	●	●	●	●	●
	IE Seven Tools	●	●	●	●	●	●	●	●
	Rainbow map	●	●	●	●	●	●	●	●
Digital intelligence	Digitalized production (Lighthouse Factory)	●	●	●	●	●	●	●	●
	Intelligent equipment Predictive maintenance (AI + IoT)	●	●	●	●	●	●	●	●
	Energy efficiency optimization	●	●	●	●	●	●	●	●

## Production Department

Mainly responsible for implementing production plans, on-site management, personnel and resource allocation, and safe production, as well as conducting basic quality control to ensure delivery efficiency and maximize production capacity.



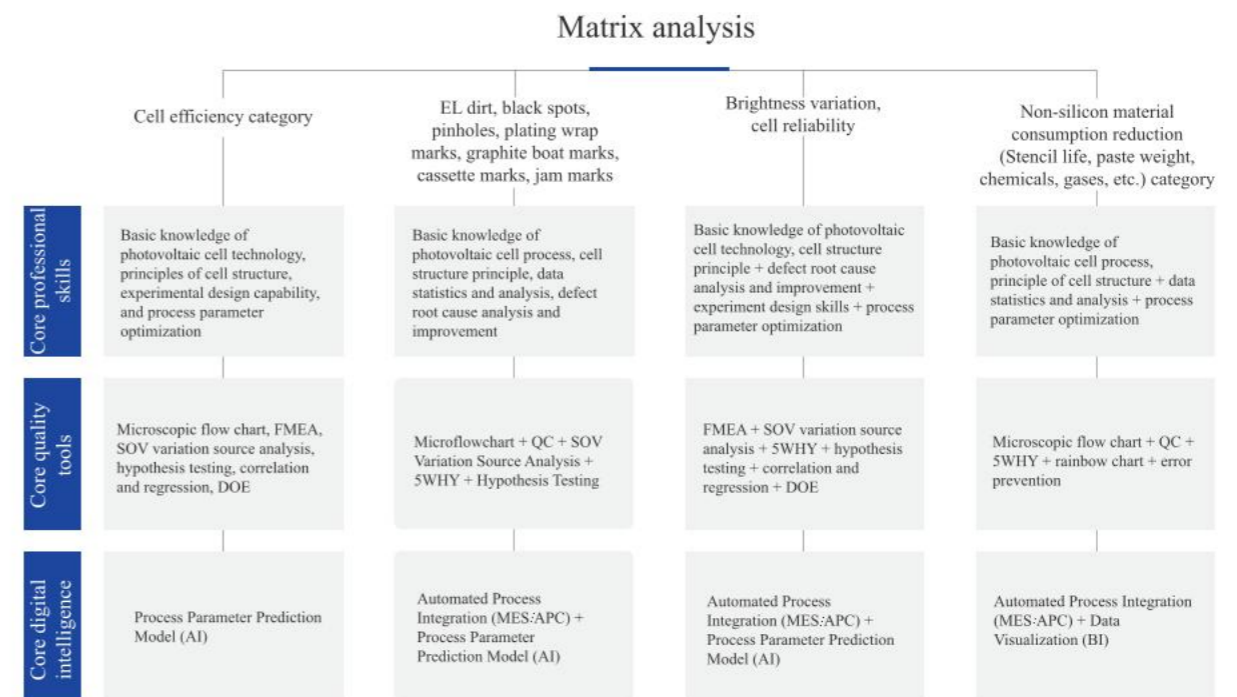
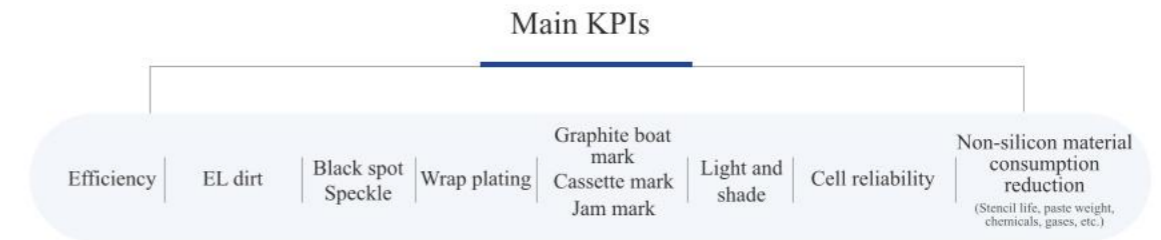
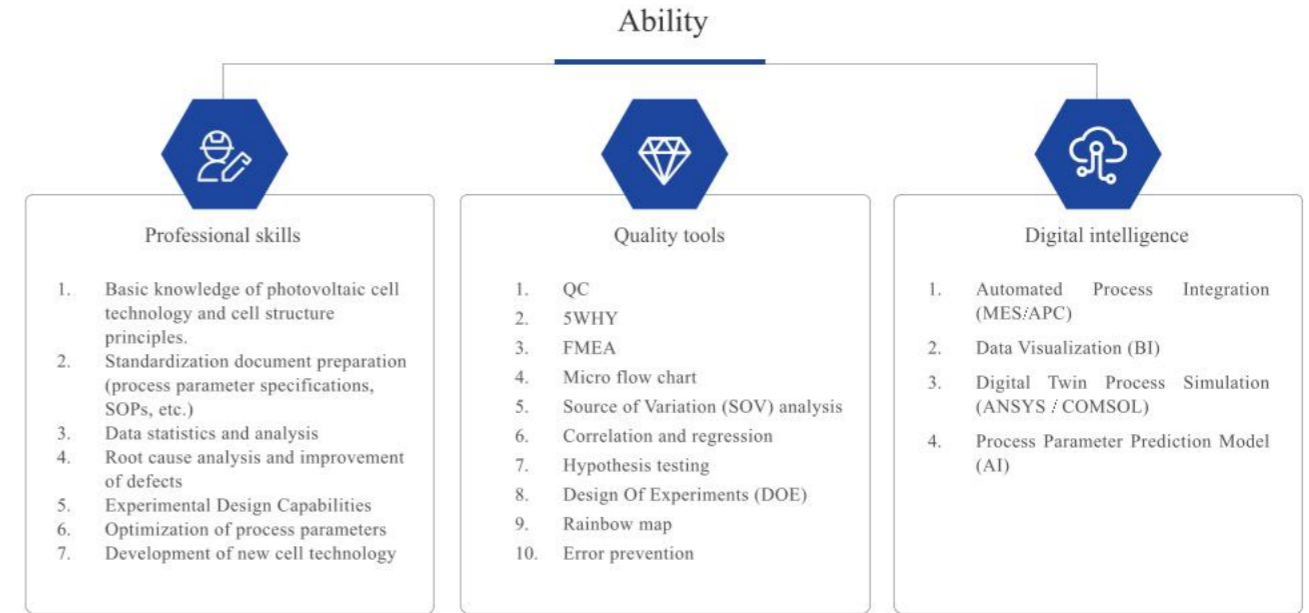
# Tongwei's Skill Matrix for Quality Excellence

Process Department

Ability	KPI	Efficiency	EL dirt	Black spots, pits	Wrap plating	Graphite boat marks, cassette marks, jam marks, etc.	Light and shade	Cell reliability	Non-silicon material consumption reduction (Stencil life, paste weight, chemicals, gases, etc.)
		PV cells	●	●	●	●	●	●	●
Professional skills	Basic process knowledge, cell structure and principles	●	●	●	●	●	●	●	●
	Preparation of standardization documents (Process parameter specifications, SOPs, etc.)	●	●	●	●	●	●	●	●
	Data statistics and analysis	●	●	●	●	●	●	●	●
	Root cause of defect Analysis and improvement	●	●	●	●	●	●	●	●
	Experimental Design Capabilities	●	●	●	●	●	●	●	●
	Optimization of process parameters	●	●	●	●	●	●	●	●
	Development of new cell technology	●	●	●	●	●	●	●	●
Quality tools	QC	●	●	●	●	●	●	●	●
	5WHY	●	●	●	●	●	●	●	●
	FMEA	●	●	●	●	●	●	●	●
	Micro flow chart	●	●	●	●	●	●	●	●
	Source of Variation (SOV) analysis	●	●	●	●	●	●	●	●
	Correlation and regression	●	●	●	●	●	●	●	●
	Hypothesis testing	●	●	●	●	●	●	●	●
	DOE	●	●	●	●	●	●	●	●
	Rainbow map	●	●	●	●	●	●	●	●
	Error prevention	●	●	●	●	●	●	●	●
Digital intelligence	Automated process integration (MES/APC)	●	●	●	●	●	●	●	●
	Data visualization (BI)	●	●	●	●	●	●	●	●
	Digital twin process simulation (ANSYS / COMSOL)	●	●	●	●	●	●	●	●
	Process Parameter Prediction Model (AI)	●	●	●	●	●	●	●	●

Process Department

Mainly responsible for process development and verification, parameter standardization, problem solving, technology upgrading and cost optimization to improve product performance and yield.



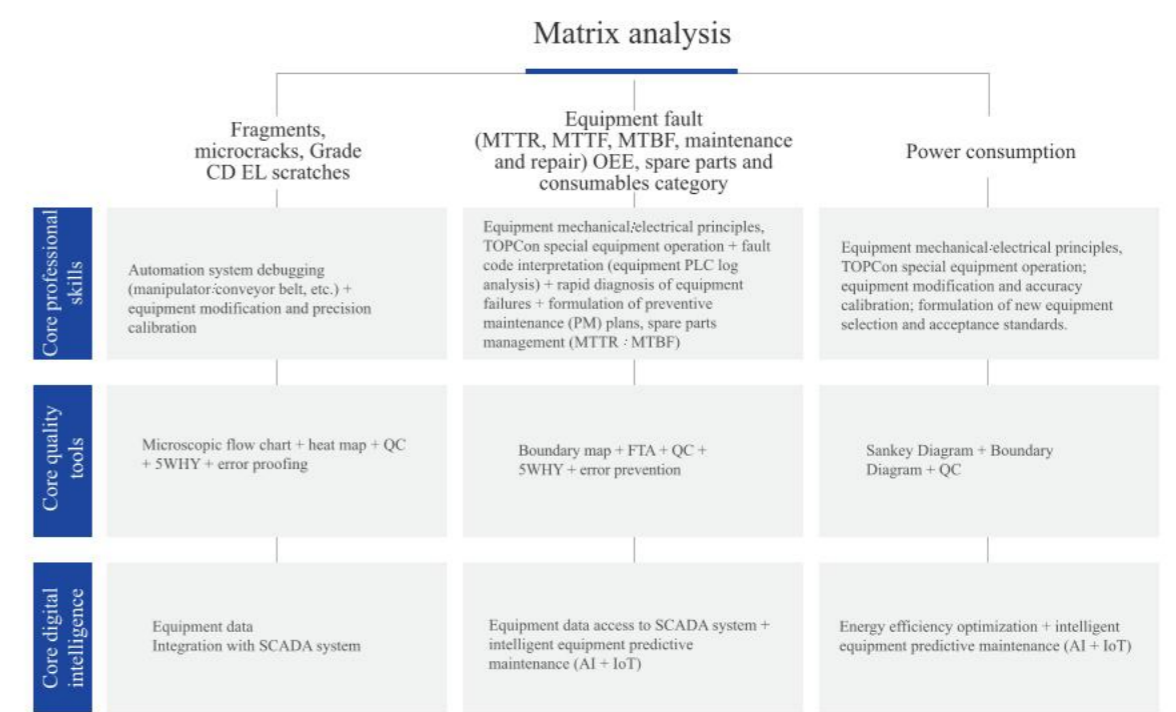
# Tongwei's Skill Matrix for Quality Excellence

Equipment Department

Ability	KPI	Fragment, subfissure	Grade CD rate	EL scratch	Equipment fault (MTTR,MTTF, MTBF, maintenance and repair)	OEE	Spare parts	Power consumption	
Equipment Department	Equipment mechanical/electrical principles, TOPCon special equipment operation	●	●	●	●	●	●	●	
	Commissioning of automation system (Manipulator/conveyor belt, etc.)	●	●	●	●	●	●	●	
	Fault code interpretation (Equipment PLC log analysis)	●	●	●	●	●	●	●	
	Quick diagnosis of equipment failure	●	●	●	●	●	●	●	
	Preventive Maintenance (PM) Planning, Spare Parts Management (MTTR:MTBF)	●	●	●	●	●	●	●	
	Equipment modification and accuracy calibration	●	●	●	●	●	●	●	
	Formulation of new equipment selection and acceptance standards	●	●	●	●	●	●	●	
	QC	●	●	●	●	●	●	●	
Quality Management	5WHY	●	●	●	●	●	●	●	
	Boundary Diagram	●	●	●	●	●	●	●	
	Heat Map	●	●	●	●	●	●	●	
	Error prevention	●	●	●	●	●	●	●	
	FTA	●	●	●	●	●	●	●	
	VSM	●	●	●	●	●	●	●	
	Sankey diagram	●	●	●	●	●	●	●	
	Micro flow chart	●	●	●	●	●	●	●	
	Digital Intelligence	Energy efficiency optimization	●	●	●	●	●	●	●
		Equipment data Integration with SCADA system	●	●	●	●	●	●	●
		Intelligent equipment Predictive maintenance (AI + IoT)	●	●	●	●	●	●	●
		Digital twin	●	●	●	●	●	●	●

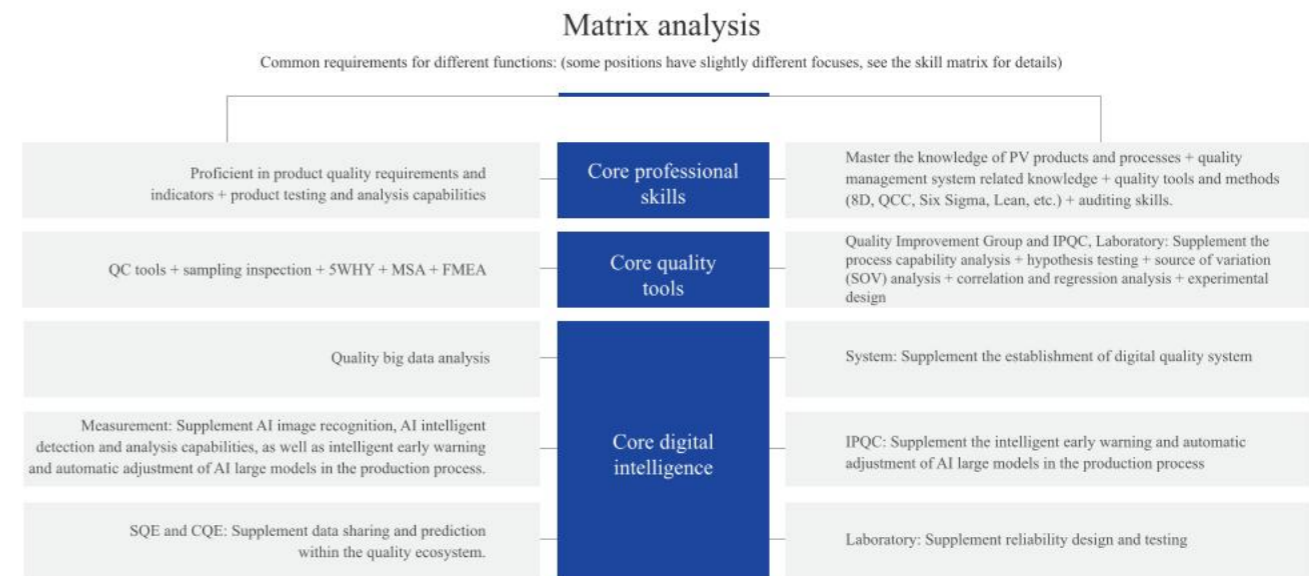
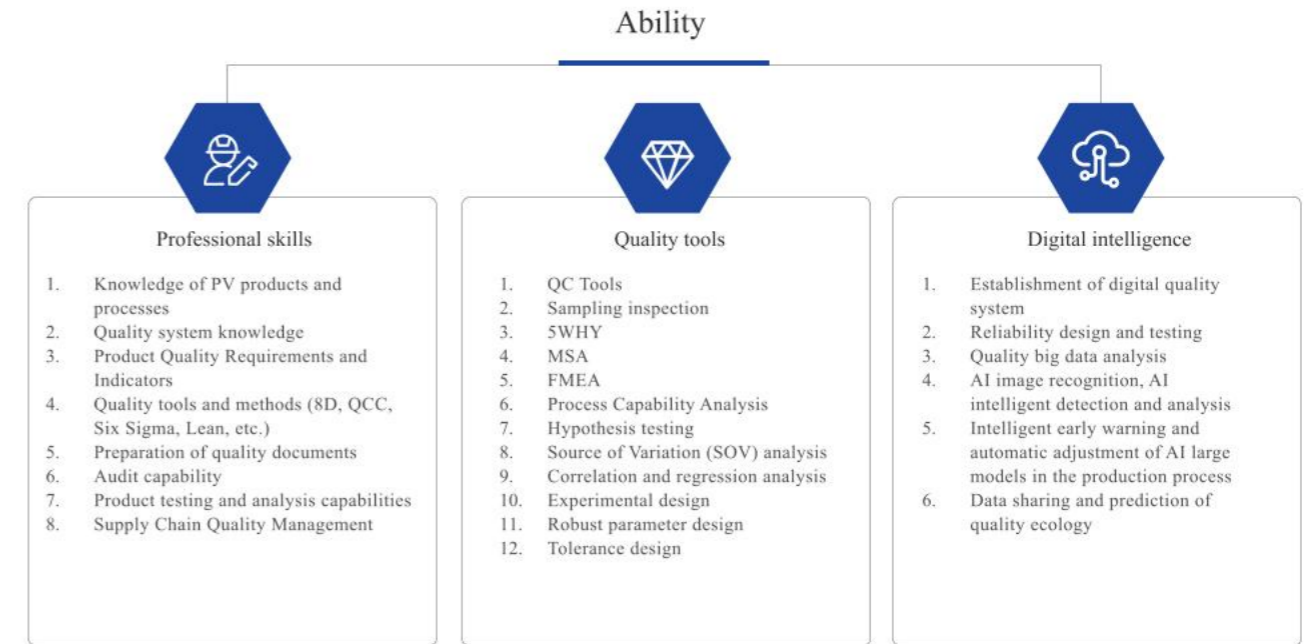
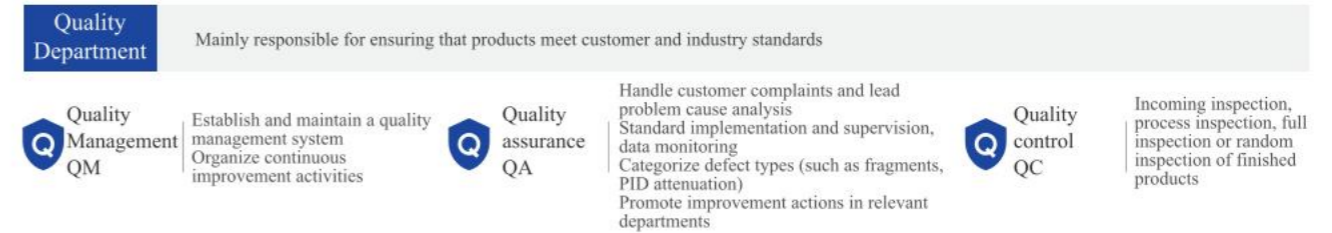
Equipment Department

Mainly responsible for preventive and predictive maintenance and transformation of equipment, spare parts management and automation promotion, as well as energy management to ensure stable operation of equipment and support production capacity and process requirements.



# Tongwei's Skill Matrix for Quality Excellence

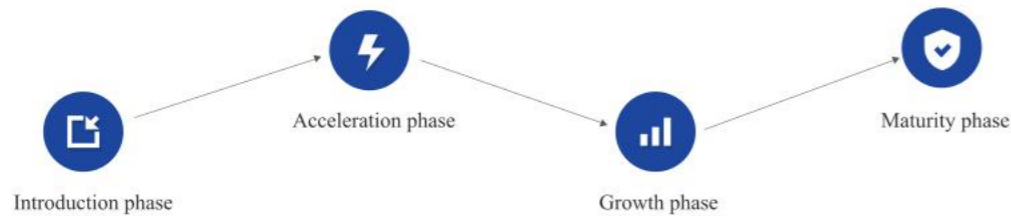
Quality Department		System + QM	Metering	Measurement	SQE	IQC	IPQC	FQC	OQC	CQE	Laboratory
Ability	Knowledge of PV products and processes	●	●	●	●	●	●	●	●	●	●
	Quality system knowledge	●	●	●	●	●	●	●	●	●	●
	Product Quality Requirements and Indicators	●	●	●	●	●	●	●	●	●	●
	Quality Tools and Methods (8D, QCC, Six Sigma, Lean, etc.)	●	●	●	●	●	●	●	●	●	●
	Preparation of quality documents	●	●	●	●	●	●	●	●	●	●
	Audit capability	●	●	●	●	●	●	●	●	●	●
	Product testing and analysis capabilities	●	●	●	●	●	●	●	●	●	●
	Supply Chain Quality Management	●	●	●	●	●	●	●	●	●	●
Quality tools	QC Tools	●	●	●	●	●	●	●	●	●	●
	Sampling inspection	●	●	●	●	●	●	●	●	●	●
	5WHY	●	●	●	●	●	●	●	●	●	●
	MSA	●	●	●	●	●	●	●	●	●	●
	FMEA	●	●	●	●	●	●	●	●	●	●
	Process Capability Analysis	●	●	●	●	●	●	●	●	●	●
	Hypothesis testing	●	●	●	●	●	●	●	●	●	●
	Source of Variation (SOV) analysis	●	●	●	●	●	●	●	●	●	●
	Correlation and regression analysis	●	●	●	●	●	●	●	●	●	●
	Experimental design	●	●	●	●	●	●	●	●	●	●
	Robust parameter design	●	●	●	●	●	●	●	●	●	●
	Tolerance design	●	●	●	●	●	●	●	●	●	●
Digital intelligence	Establishment of digital quality system	●	●	●	●	●	●	●	●	●	●
	Reliability design and testing	●	●	●	●	●	●	●	●	●	●
	Quality big data analysis	●	●	●	●	●	●	●	●	●	●
	AI image recognition AI intelligent detection and analysis	●	●	●	●	●	●	●	●	●	●
	Large model for production process Intelligent early warning and automatic adjustment	●	●	●	●	●	●	●	●	●	●
	Data sharing and prediction of quality ecology	●	●	●	●	●	●	●	●	●	●



3.2

# Total Process Quality Management: "Three Essential Skills" for solving different types of problems

TW Solar has long adhered to the pursuit of excellence in strategy formulation, and tactically advances through four gradual phases: introduction, acceleration, growth, and maturity.



When entering the maturity phase, focus on quality improvement by "sustained accumulation for breakthrough gains".

- Focus on the flexibility of problem analysis and improvement, the applicability of quality tools, and the logic of methodology;
  - Focus on the actual field verification and replicability of the project to maximize benefits;
- Summarize the outstanding cases from previous quality improvement activities, sort out the logic chains and tool chains of solutions, and develop systematic methodologies for different types of problems to enable the replication of similar improvements. Demonstrate the quality improvement methodology for some typical problems as elaborated from four dimensions: "philosophy", "method", "technique", and "instrument".

## Philosophy | Method | Technique | Instrument

"Direction of quality improvement" | "Path to improve quality" | "Techniques to improve quality" | "Tools to improve quality"

### Philosophy Cell efficiency improvement

Improving cell efficiency is the core topic of photovoltaic cells, and there are many ways to improve efficiency.

In summary, there are four main dimensions:

1. Structure and material optimization at the design end
2. Technology optimization and innovation at the process end
3. Process parameter tuning and stabilization at the manufacturing end
4. Collaborative optimization of the supply chain

This example discusses how to improve efficiency from the manufacturing end, while also paying attention to the effects of indicators such as UV reliability and paste weight.

Solution logic:

1. Exploded view of cell structure
2. Corresponding efficiency factors
3. Define the scope of improvement processes and process factors
4. Verify the impact on efficiency

Suggested core tools: exploded view diagram + micro flow chart + SOV analysis + hypothesis testing + DOE

Method	Technique	Instrument	Example
D	Definition and decomposition of Y efficiency		$Y \text{ conversion efficiency} = \frac{\text{Solar cell power}}{\text{Solar cell area} \times \text{irradiance}} = \frac{\text{Open-circuit voltage} \times \text{short-circuit current} \times \text{fill factor}}{\text{Solar cell area} \times \text{irradiance}}$ <p>Note: For solar cell area, the illumination amplitude per unit area is a fixed value.</p>
M	<p>Analyze the preparation structure related to Y efficiency</p> <p>Analyze the main structure affecting Y1 Uoc (open-circuit voltage). Analyze the main structure affecting Y2 Isc (short-circuit current). Analysis of the impact on the main structure of Y3 FF (filling)</p>	Exploded view	
	<p>Identify the relevant manufacturing processes based on the structural parameters that affect efficiency, and prioritize them as the scope of the project.</p>	Flow chart	

<p>A</p>	<p>For each stage of the process By applying process principles, identify efficiency influencing factors (Xs) from a professional perspective</p>	<p>System Diagram</p>	<p>Working procedure</p> <table border="1"> <thead> <tr> <th>Process step</th> <th>Work Elements</th> <th>Failure effect</th> </tr> </thead> <tbody> <tr> <td rowspan="2">Evacuation</td> <td>Pumping speed</td> <td>Too slow pumping speed affects the process time</td> </tr> <tr> <td>Low pressure value</td> <td>The magnitude of the pressure affects the mean free path of molecules, which has a significant impact on the deposition rate and uniformity.</td> </tr> <tr> <td rowspan="2">Leak detection</td> <td>Furnace tube and door Whether there is air leakage</td> <td>Gas leakage leads to reduced gas purity and concentration</td> </tr> <tr> <td>Heating : Heating up</td> <td>Heating-up time and rate</td> <td>Too low temperature affects the phosphorus deposition rate</td> </tr> <tr> <td rowspan="6">Pre-oxidation</td> <td>Ventilation mode</td> <td>The intake pipe is broken or pinholes affect the airflow direction</td> </tr> <tr> <td>Oxidation step time</td> <td>The longer the oxidation step time, the thicker the oxide layer, and the greater the barrier to deposition.</td> </tr> <tr> <td>Temperature of oxidation step</td> <td>The higher the oxidation step temperature, the thicker the oxide layer, and the greater the barrier to deposition.</td> </tr> <tr> <td>Oxidation step flow</td> <td>The greater the oxidation flow rate, the thicker the oxide layer, and the greater the barrier to deposition.</td> </tr> <tr> <td>Oxidation step pressure</td> <td>The higher the pressure, the greater the oxygen density in the tube and the thicker the oxidation layer.</td> </tr> </tbody> </table>	Process step	Work Elements	Failure effect	Evacuation	Pumping speed	Too slow pumping speed affects the process time	Low pressure value	The magnitude of the pressure affects the mean free path of molecules, which has a significant impact on the deposition rate and uniformity.	Leak detection	Furnace tube and door Whether there is air leakage	Gas leakage leads to reduced gas purity and concentration	Heating : Heating up	Heating-up time and rate	Too low temperature affects the phosphorus deposition rate	Pre-oxidation	Ventilation mode	The intake pipe is broken or pinholes affect the airflow direction	Oxidation step time	The longer the oxidation step time, the thicker the oxide layer, and the greater the barrier to deposition.	Temperature of oxidation step	The higher the oxidation step temperature, the thicker the oxide layer, and the greater the barrier to deposition.	Oxidation step flow	The greater the oxidation flow rate, the thicker the oxide layer, and the greater the barrier to deposition.	Oxidation step pressure	The higher the pressure, the greater the oxygen density in the tube and the thicker the oxidation layer.
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	<p>I</p>	<p>Select and identify the main factors Xi</p>	<p>SOV Source of Variation Hypothesis Testing</p>																									
<p>C</p>	<p>Response optimization Find the optimal parameter combination</p>	<p>Regression, DOE etc.</p>	<p>Efficiency vs. Dual &amp; Quad Grid Line Count Contour Plot</p>																									

Reference cases: 2025Q2, Chengdu Company "Efficient Improvement Project for Cell Plant No. 9 (210R)"; 2025 Q2, Tonghe Company "TOPCon Efficiency Improvement in Workshop S2"; 2024 Q2, Jintang Company "Ultimate Cost Reduction and Efficiency Improvement of Public Version 210PERC"; 2023 Q3, Meishan Company "TOPCon SE Efficiency Improvement Project", etc. (Internal document, used with authorization)

### Philosophy Grade CD reduction

Reducing Grade CD problems falls under the category of projects that require continuous improvement. The focus is on being able to refine defect information, convert discrete indicators into continuous information, and thus explore the related process factors behind it. It is recommended to explore defect points through the product defect rate index and correlate product defects with process factors, so as to locate the exact cause of the defect.

Solution logic:  
1. Analyze the location-based defect distribution 2. Sort out potential variables in the process 3. Correlate product defects to process factors 4. Analyze and improve the process factors that have been identified.  
Suggested core tools: heat map + micro flow chart + CE matrix + 5WHY

Method	Technique	Instrument	Example
	<p>Product statistics Location-based defect distribution Identify and screen the key defect locations that need to be improved;</p>	<p>Heat Map Pareto Chart</p>	
<p>P</p>	<p>Carry out microscopic process analysis to identify all process nodes potentially impacting Grade CD cell critical dimensions</p>	<p>Micro flow chart</p>	



D	Correlation: Product location defect * process factor	CE Matrix	<table border="1"> <thead> <tr> <th colspan="3"></th> <th colspan="6">2. Product Location Defects</th> <th></th> </tr> <tr> <th rowspan="2">1. Process Contact Points</th> <th rowspan="2">Working procedure</th> <th rowspan="2">Contact factor at defect location</th> <th rowspan="2">Name of contact point</th> <th>A01</th> <th>B01</th> <th>A10</th> <th>A11</th> <th>A12</th> <th rowspan="2">Total Score</th> </tr> <tr> <th>** %</th> <th>** %</th> <th>** %</th> <th>** %</th> <th>** %</th> </tr> </thead> <tbody> <tr> <td rowspan="8">Double-sided coating</td> <td>X07</td> <td></td> <td>Cassette wafer alignment cylinder</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>3.1%</td> </tr> <tr> <td>X08</td> <td></td> <td>Calibration wheel</td> <td></td> <td></td> <td></td> <td>1</td> <td></td> <td>8.1%</td> </tr> <tr> <td>X09</td> <td></td> <td>Buffer</td> <td>3</td> <td></td> <td></td> <td></td> <td></td> <td>8.5%</td> </tr> <tr> <td>X10</td> <td></td> <td>Variable pit</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>3.1%</td> </tr> <tr> <td>X11</td> <td></td> <td>Belt stop block</td> <td></td> <td></td> <td>1</td> <td>1</td> <td></td> <td>15.0%</td> </tr> <tr> <td>X12</td> <td></td> <td>Dry cassette</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>11.1%</td> </tr> <tr> <td>X13</td> <td></td> <td>Variable pitch pusher cylinder</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>5.4%</td> </tr> <tr> <td>X14</td> <td></td> <td>PE suction cup</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>10.1%</td> </tr> <tr> <td rowspan="3">Printing</td> <td>X15</td> <td></td> <td>Graphite boat jam point</td> <td></td> <td></td> <td>1</td> <td></td> <td></td> <td>56.3%</td> </tr> <tr> <td>X16</td> <td></td> <td>Cassette wafer alignment cylinder</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>9.2%</td> </tr> <tr> <td>X17</td> <td></td> <td>Laser machine table</td> <td></td> <td></td> <td>3</td> <td>3</td> <td></td> <td>37.4%</td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> </tbody> </table> <p>3. Correlation: product location defect * process factor</p>				2. Product Location Defects							1. Process Contact Points	Working procedure	Contact factor at defect location	Name of contact point	A01	B01	A10	A11	A12	Total Score	** %	** %	** %	** %	** %	Double-sided coating	X07		Cassette wafer alignment cylinder						3.1%	X08		Calibration wheel				1		8.1%	X09		Buffer	3					8.5%	X10		Variable pit						3.1%	X11		Belt stop block			1	1		15.0%	X12		Dry cassette						11.1%	X13		Variable pitch pusher cylinder						5.4%	X14		PE suction cup						10.1%	Printing	X15		Graphite boat jam point			1			56.3%	X16		Cassette wafer alignment cylinder						9.2%	X17		Laser machine table			3	3		37.4%										
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C	Analyze the process factors of positioning down to the underlying factors	5WHY	<p>Problem: The synchronous wheel scratches the cell</p> <p>Why: Why does the synchronous wheel transport the cell? Reason: Because of wafer chipping or breakage due to jamming and impact.</p> <p>Why: Why are there wafer jams and breakages due to sticking or collisions? Reason: Because of wafer blockage in the drying tank.</p> <p>Why: Why is there wafer blockage in the drying tank? Reason: Because of unbalanced airflow.</p> <p>Why: Why is the airflow imbalanced? Root cause: Because of mismatch of wind knife height</p> <p>Solution: Adjust the power and direction of the wind knife to enable the stable operation of the silicon wafer.</p>																																																																																																																																								
A	Improve the underlying factors for positioning.	Error prevention, etc.																																																																																																																																									

## Philosophy Production capacity improvement

The essence of production capacity improvement is to enhance OEE. By analyzing the differences between actual and theoretical output, improvement opportunities can be comprehensively identified from three aspects: time availability, performance availability, and pass rate.

Solution logic:  
1. Identify bottleneck processes 2. Analyze and improve time availability 3. Analyze and improve performance availability 4. Analyze and improve pass rate  
Suggested core tools: VSM + OEE + Pareto chart

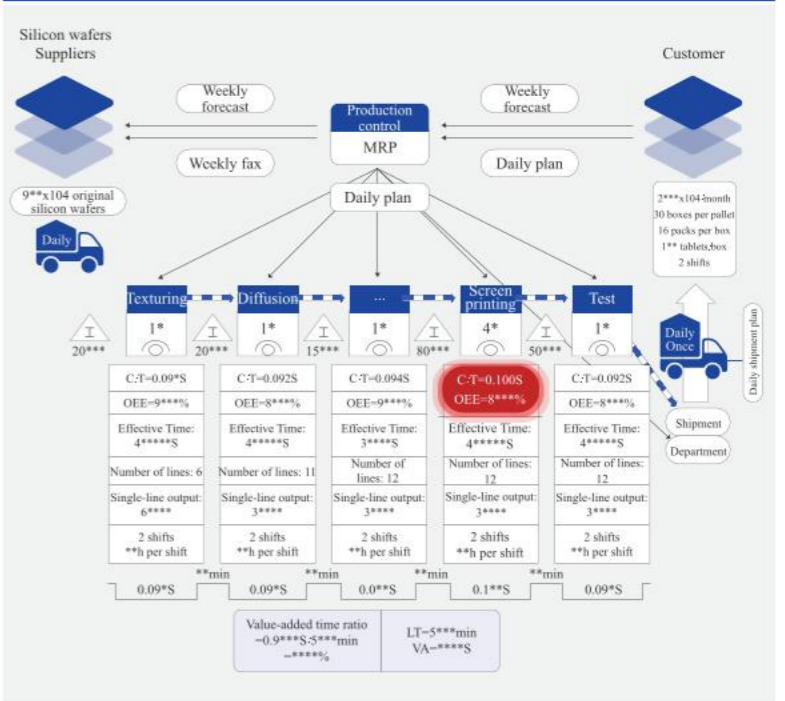
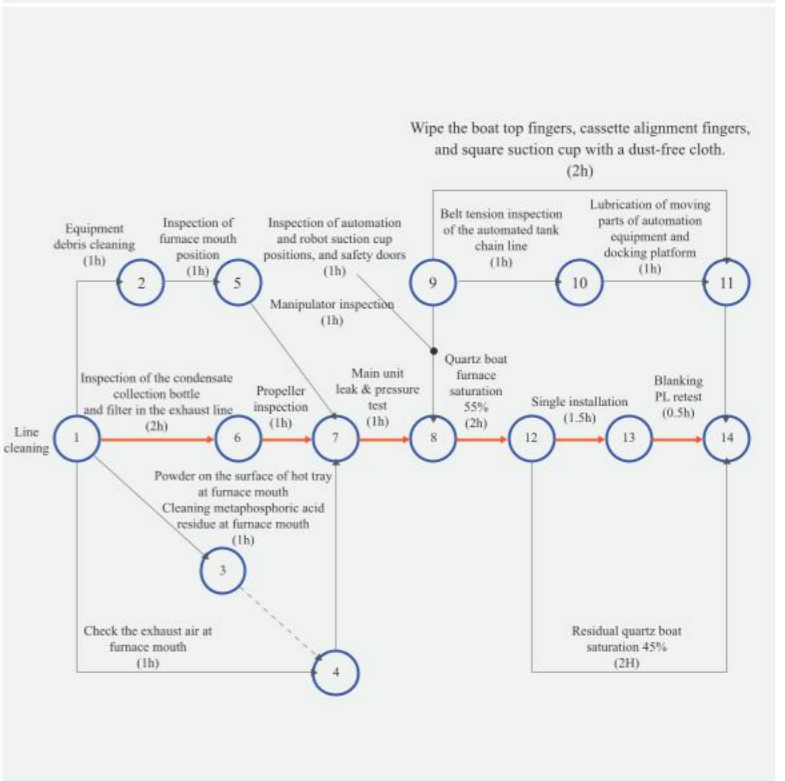
Method	Technique	Instrument	Example
D	Bottleneck process identification via VSM: maximized WIP & prolonged cycle time	VSM	
	OEE= Time availability x Performance availability x First-time pass rate Thus, the project was broken down into 3 small projects	OEE	
M	Y1: Time availability - Identification and improvement of unplanned downtime events - Identification and reduction of planned downtime duration	Pareto Chart	

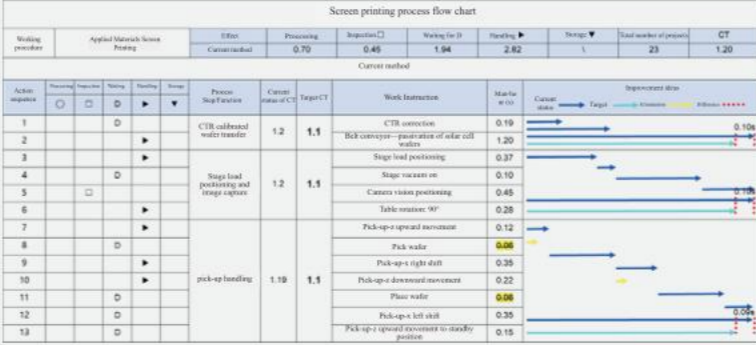
<p>A</p>	<p>Y2: Performance availability -CT speed-up: Decompose the process steps according to the flow chart</p> <p>Analyze the flow chart to study actions and timing, and identify speed-up opportunities.</p> <p>Improved in combination with the ECRS principle</p>	<p>Motion and Time Study ECRS</p>	 <p>Y2 performance availability</p> <ul style="list-style-type: none"> <li>X2-1 Speed loss reduction</li> <li>X2-2 Process CT optimization</li> </ul>
<p>I</p>	<p>Y3: Improvement of first-time pass rate: Identify major defective items for improvement using the Pareto Principle (80:20 rule).</p>	<p>Pareto Chart QC</p>	 <p>Y3 pass rate</p> <ul style="list-style-type: none"> <li>X3-1 Test accuracy</li> <li>X3-2 Reduced fragmentation rate</li> <li>X3-3 Reduced rework rate</li> </ul>
<p>C</p>	<p>Risk assessment of quality and efficiency for relevant factors after process acceleration.</p>	<p>Hypothesis testing DOE etc.</p>	

### Philosophy Takt reduction

Reducing takt time issues is a sub-project of the capacity improvement project and is devoted to shortening takt time and addressing bottleneck operations. This type of project should aim to eliminate non-value-added actions and avoid adjusting process parameters that have a direct impact on product quality or efficiency unless absolutely necessary. While improving the takt time, pay attention to the financial alignment of quality indicators.

Solution logic:  
1. Identify bottleneck processes 2. Identify non-value-added steps 3. Eliminate waste 4. Verify quality impact.  
Suggested core tools: network diagram + flow process analysis + ECRS

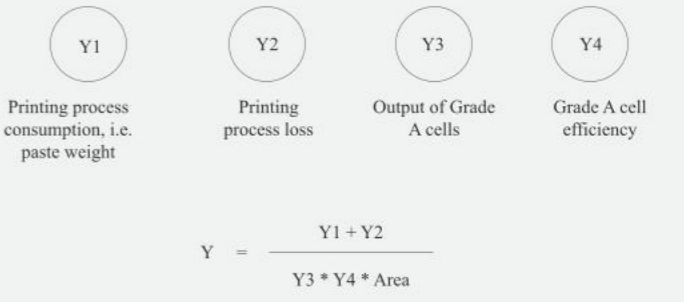
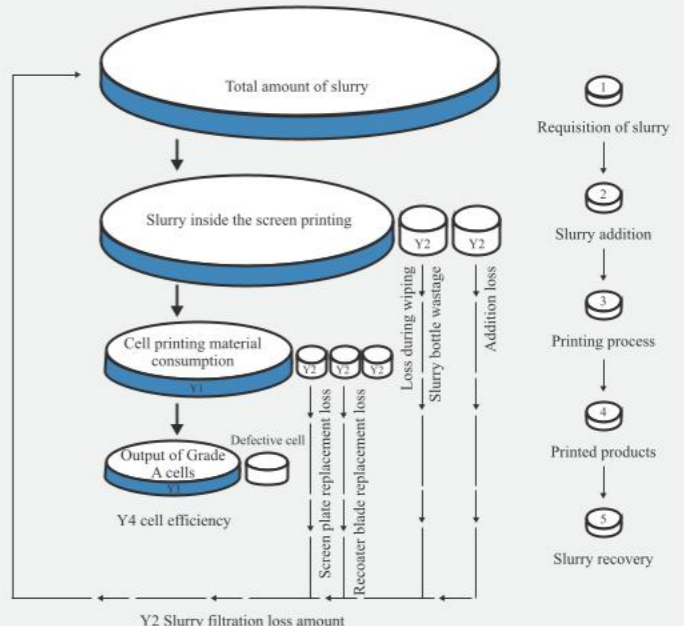
Method	Technique	Instrument	Example																																			
<p>D</p>	<p>Identify bottleneck processes through production line balance analysis</p>	<p>VSM</p>	 <p>Silicon wafers Suppliers</p> <p>Customer</p> <p>Production control MRP</p> <p>Daily plan</p> <p>Texturing, Diffusion, Screen printing, Test</p> <table border="1"> <tr> <td>C:T=0.09*S</td> <td>C:T=0.092S</td> <td>C:T=0.094S</td> <td><b>C:T=0.100S</b></td> <td>C:T=0.092S</td> </tr> <tr> <td>OEE=9***%</td> <td>OEE=8***%</td> <td>OEE=9***%</td> <td><b>OEE=8***%</b></td> <td>OEE=8***%</td> </tr> <tr> <td>Effective Time: 4*****S</td> <td>Effective Time: 4*****S</td> <td>Effective Time: 3*****S</td> <td>Effective Time: 4*****S</td> <td>Effective Time: 4*****S</td> </tr> <tr> <td>Number of lines: 6</td> <td>Number of lines: 11</td> <td>Number of lines: 12</td> <td>Number of lines: 12</td> <td>Number of lines: 12</td> </tr> <tr> <td>Single-line output: 6****</td> <td>Single-line output: 3****</td> <td>Single-line output: 3****</td> <td>Single-line output: 3****</td> <td>Single-line output: 3****</td> </tr> <tr> <td>2 shifts **h per shift</td> <td>2 shifts **h per shift</td> <td>2 shifts **h per shift</td> <td>2 shifts **h per shift</td> <td>2 shifts **h per shift</td> </tr> <tr> <td>0.09*S</td> <td>0.09*S</td> <td>0.09*S</td> <td>0.1*S</td> <td>0.09*S</td> </tr> </table> <p>Value-added time ratio -0.9***S:5***min -****%</p> <p>LT=5***min VA=****S</p>	C:T=0.09*S	C:T=0.092S	C:T=0.094S	<b>C:T=0.100S</b>	C:T=0.092S	OEE=9***%	OEE=8***%	OEE=9***%	<b>OEE=8***%</b>	OEE=8***%	Effective Time: 4*****S	Effective Time: 4*****S	Effective Time: 3*****S	Effective Time: 4*****S	Effective Time: 4*****S	Number of lines: 6	Number of lines: 11	Number of lines: 12	Number of lines: 12	Number of lines: 12	Single-line output: 6****	Single-line output: 3****	Single-line output: 3****	Single-line output: 3****	Single-line output: 3****	2 shifts **h per shift	2 shifts **h per shift	2 shifts **h per shift	2 shifts **h per shift	2 shifts **h per shift	0.09*S	0.09*S	0.09*S	0.1*S	0.09*S
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<p>M</p>	<p>Identify the critical path and non-value-added links of bottleneck processes</p>	<p>Network diagram</p>	 <p>Line cleaning</p> <p>Equipment debris cleaning (1h)</p> <p>Inspection of furnace mouth position (1h)</p> <p>Inspection of automation and robot suction cup positions, and safety doors (1h)</p> <p>Manipulator inspection (1h)</p> <p>Inspection of the condensate collection bottle and filter in the exhaust line (2h)</p> <p>Propeller inspection (1h)</p> <p>Main unit leak &amp; pressure test (1h)</p> <p>Quartz boat furnace saturation 55% (2h)</p> <p>Single installation (1.5h)</p> <p>Blanking PL retest (0.5h)</p> <p>Wipe the boat top fingers, cassette alignment fingers, and square suction cup with a dust-free cloth. (2h)</p> <p>Lubrication of moving parts of automation equipment and docking platform (1h)</p> <p>Check the exhaust air at furnace mouth (1h)</p> <p>Powder on the surface of hot tray at furnace mouth Cleaning metaphosphoric acid residue at furnace mouth (1h)</p> <p>Residual quartz boat saturation 45% (2h)</p>																																			

A	<p>Identify improvement opportunities through Time and Motion Study</p> <p>For action type (Value-added vs. non-value-added)</p> <p>For takt time (Actual takt time vs. target takt time)</p>	Flow process analysis																																																																																					
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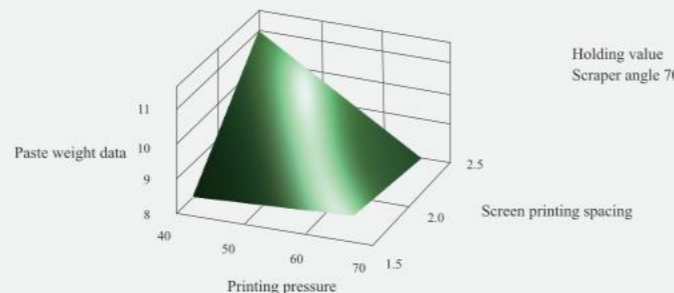
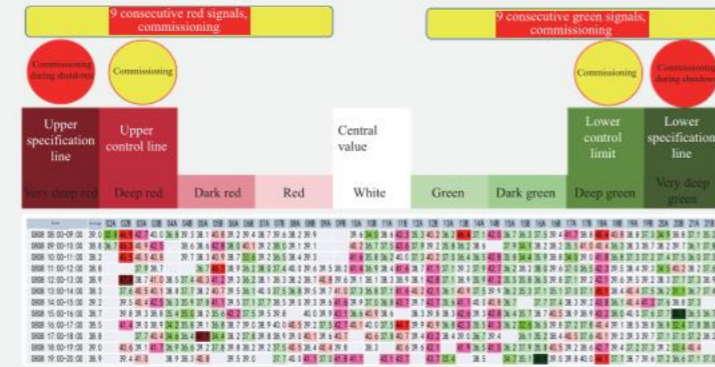
### Philosophy Reducing the specific consumption of silver paste

Reducing the unit consumption of silver paste is a core issue for cell cost reduction and efficiency improvement. The unit consumption of silver paste is not simply a concept of paste weight usage, but a comprehensive index of cost-performance ratio. That is, it is necessary not only to reduce the consumption of silver paste, but also to ensure the efficiency and quality of the cell.

Solution logic:  
1. Define the unit consumption of silver paste 2. Identify the detailed flow direction of slurry consumption 3. Loss process (waste): eliminate and reduce 4. Reduce and monitor the paste weight in the consumption process.  
Suggested core tools: micro flow chart + QC + DOE + SPC

D	<p>Define Y silver paste specific consumption to quantify types of silver paste loss</p> <p>Decompose into four key indicators y1-y4 and set improvement goals for each category</p>	Trend chart	
M	<p>Process micro-analysis Identify the detailed flow path of slurry Establish a loss flow model</p> <p>Analyze and improve the process waste in the Y2 printing stage, which has a minimization target. This includes losses from paste replenishment, paste bottle residue, stencil wiping, stencil replacement, and squeegee blade replacement</p>	Panoramic view of Silver Paste Flow          QC	

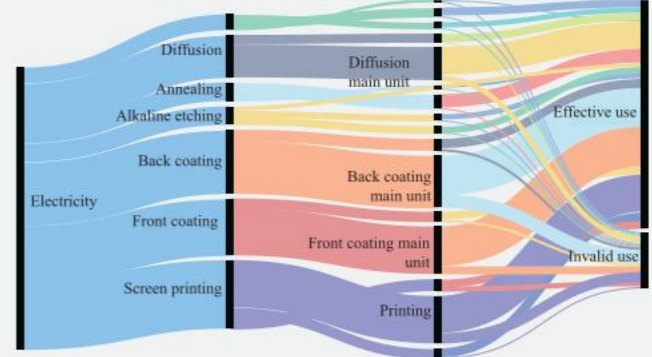
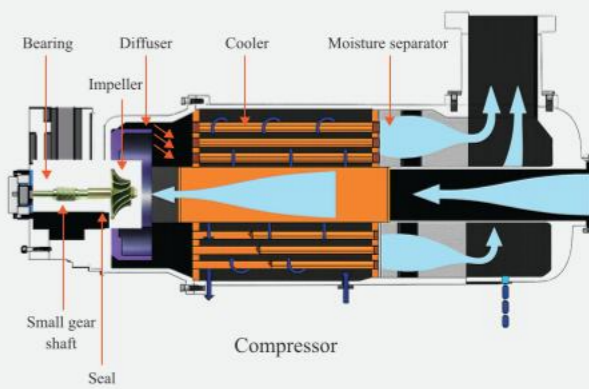
Reference cases: 2023Q3, Chengdu Company "S2 Screen Printing Process Production Breakthrough", 2023Q4, Chengdu Company "S6 Coating Process Capacity Enhancement", 2023Q3, Hefei Company "S1 Workshop PERC Product Bottleneck Process Capacity Improvement", 2024Q2, Chengdu Company "Reducing S6 Equipment Maintenance Time", etc. (Internal document, used with authorization)

A	Conduct process system analysis on paste weight (lower-target characteristic) of Y1 screen printing to identify critical control parameters, then execute process optimization	SOV Source of Variation, DOE, etc.	<p>Surface plot of paste weight data with screen spacing and printing pressure</p> 
I	Implement process system analysis on Y3 Grade A rate and Y4 cell efficiency (higher-target characteristics) to drive performance improvement	Pareto Chart Micro flow chart, DOE, etc.	
C	Paste weight monitoring and early warning	Rainbow map SPC rules Digital early warning	

### Philosophy Power consumption reduction

Reducing power consumption projects aim to lower costs, improve efficiency, and contribute to carbon peaking and carbon neutrality. Such projects should avoid fragmented, opportunistic improvements. Instead, a systematic approach to energy-saving technology and principles must be adopted. This ensures scalability across various industries, scenarios, and processes, while preventing adverse impacts on quality, safety, and cost. The introduction of digital energy management and forecasting systems is also a future direction for reducing energy consumption.

**Solution logic:**  
 1. Identify power-consuming systems and units 2. Summarize energy-saving technologies 3. Propose energy-saving solutions 4. Evaluate and select executable energy-saving solutions from multiple dimensions  
 Suggested core tools: Sankey diagram + exploded view diagram + matrix diagram

Method	Technique	Instrument	Example
D	First, rank the power consumption of energy-consuming systems, then identify the main targets for the energy-saving project. Pay attention to whether the indicators for the objects to be improved have periodic characteristics.	Pareto Chart Sankey diagram	
M	Conduct inter-group difference analysis to identify abnormal consumption points and implement quick-win improvement actions.  Deconstruct major energy-consuming equipment down to individual energy-consuming units	Stratification method  Exploded view Boundary Diagram	 <p>Note: The compressor image is sourced from the Internet</p>



Note: All data in the project cases of this unit are desensitized.

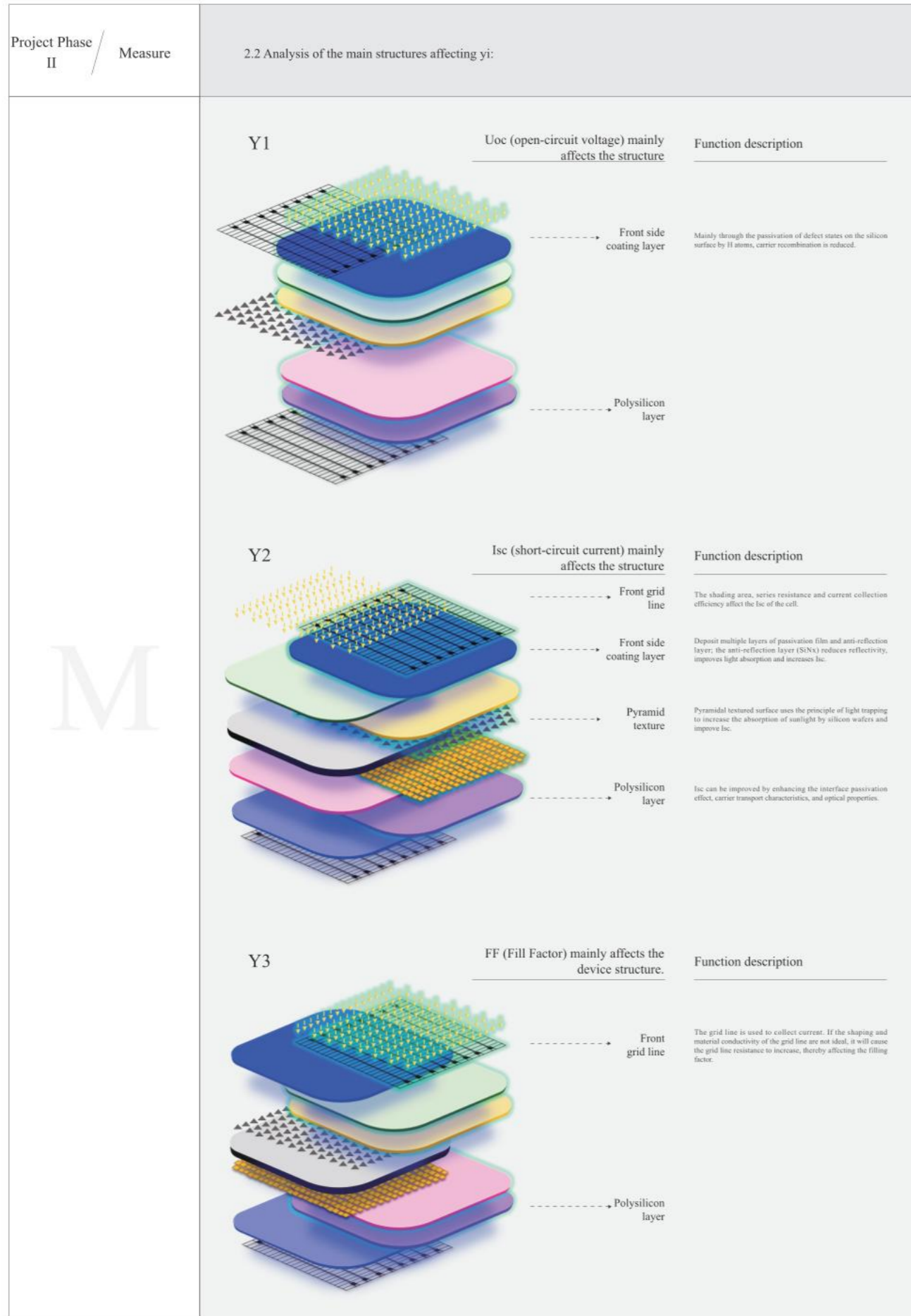


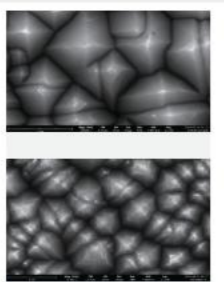
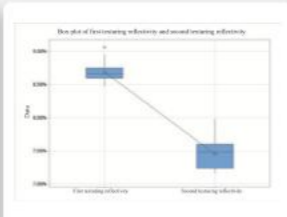
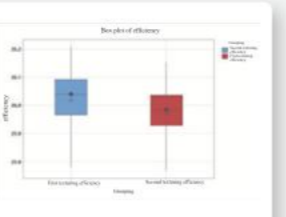
## Quality Practices Case Presentation

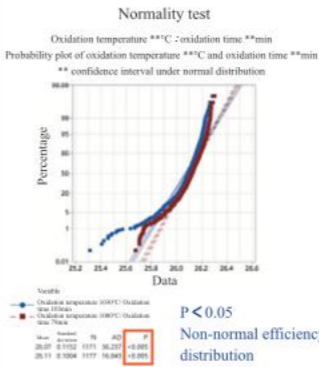
Project Case 1:  
Cell efficiency improvement

Project Topic  
"Plant A TOPCon Cell Efficiency Improvement Project"

<p>Project Phase I / Define</p>	<p>1.1 Background: The efficiency of photovoltaic cells equals profitability; improving efficiency is crucial to enhancing market competitiveness. The theoretical efficiency of bifacial TOPCon cells reaches 28.7%. Leading enterprises are accelerating process upgrades, and breakthroughs are still needed for mass production of new technologies. Improving the efficiency at the manufacturing end of existing production lines remains key. In the four dimensions of cell efficiency improvement, this case demonstrates the efficiency improvement logic and tool application at the manufacturing end.</p>
<p>Project Phase II / Measure</p>	<p>1.2 Current situation and goal setting: Definition and breakdown of Y</p> $Y \text{ Conversion efficiency} = \frac{\text{Solar cell power}}{\text{Cell area} \times \text{irradiance}} = \frac{\text{Open circuit voltage} \times \text{short circuit current} \times \text{fill factor}}{\text{Cell area} \times \text{irradiance}}$ <p>Breakdown of Y Eta efficiency: y1 Voc open-circuit voltage, y2 Isc short-circuit current, y3 FF fill factor</p> <p>Note: For the 210R cell (area 0.038184 m<sup>2</sup>), the irradiance per unit area is set at a fixed value of 1000 W/m<sup>2</sup>.</p>
<p>Project Phase III / Measure</p>	<p>2.1 Measurement system analysis: Conduct MSA analysis on IV tests, reflectivity measurement instruments, EL tests, AOI tests, etc. involved in the analysis process to ensure that measurement errors are within the acceptable range.</p> <p>2.2 Analysis of the preparation structure for Y efficiency: Quality tool: exploded view diagram</p>



Project Phase II / Measure	2.5 Screening of preparation structure efficiency factors: identify the important influencing factors Xi.																																																																																									
M	<p>Quality Tool: CE Matrix</p> <table border="1"> <thead> <tr> <th colspan="2">Rating of importance</th> <th colspan="3">Scoring criteria: 0 (no impact) 1 (weak impact) 3 (medium impact) 9 (high impact)</th> <th rowspan="2">Score</th> </tr> <tr> <th>Fabrication structures affecting electrical performance</th> <th>Impact factors</th> <th>VOC</th> <th>ISC</th> <th>FF</th> </tr> </thead> <tbody> <tr> <td rowspan="6">Pyramid texture</td> <td>X26 Texturing additive category</td> <td>9</td> <td>9</td> <td>3</td> <td>147</td> </tr> <tr> <td>X27 Texturing temperature</td> <td>1</td> <td>3</td> <td>1</td> <td>35</td> </tr> <tr> <td>X28 Texturing time</td> <td>3</td> <td>3</td> <td>3</td> <td>63</td> </tr> <tr> <td>X29 Texturing cycle bubbling process</td> <td>0</td> <td>1</td> <td>0</td> <td>7</td> </tr> <tr> <td>X30 NaOH concentration in texturing</td> <td>3</td> <td>3</td> <td>3</td> <td>63</td> </tr> <tr> <td>X31 Wafer surface condition</td> <td>0</td> <td>1</td> <td>0</td> <td>7</td> </tr> <tr> <td rowspan="5">Alkali polishing</td> <td>X32 Alkali polishing additive category</td> <td>1</td> <td>3</td> <td>1</td> <td>35</td> </tr> <tr> <td>X33 Alkali polishing time</td> <td>1</td> <td>3</td> <td>1</td> <td>35</td> </tr> <tr> <td>X34 Alkali polishing temperature</td> <td>1</td> <td>3</td> <td>1</td> <td>35</td> </tr> <tr> <td>X35 Alkali polishing circulating bubbling</td> <td>0</td> <td>1</td> <td>0</td> <td>7</td> </tr> <tr> <td>X36 Concentration of alkali polishing NaOH</td> <td>1</td> <td>3</td> <td>1</td> <td>35</td> </tr> <tr> <td rowspan="4">Front grid line</td> <td>X37 Four-track stencil line width</td> <td>3</td> <td>9</td> <td>9</td> <td>147</td> </tr> <tr> <td>X38 Four-track stencil membrane thickness</td> <td>1</td> <td>3</td> <td>3</td> <td>49</td> </tr> <tr> <td>X39 Four-track stencil line diameter</td> <td>3</td> <td>3</td> <td>9</td> <td>105</td> </tr> <tr> <td>X40 Scraper angle</td> <td>0</td> <td>1</td> <td>1</td> <td>14</td> </tr> </tbody> </table> <p>Note: Set a four-level rating standard of "0 (no impact), 1 (weak impact), 3 (medium impact), and 9 (high impact)". Professionals use historical experimental data to determine the impact of each factor on VOC, ISC, and FF, and assign a score accordingly.</p>	Rating of importance		Scoring criteria: 0 (no impact) 1 (weak impact) 3 (medium impact) 9 (high impact)			Score	Fabrication structures affecting electrical performance	Impact factors	VOC	ISC	FF	Pyramid texture	X26 Texturing additive category	9	9	3	147	X27 Texturing temperature	1	3	1	35	X28 Texturing time	3	3	3	63	X29 Texturing cycle bubbling process	0	1	0	7	X30 NaOH concentration in texturing	3	3	3	63	X31 Wafer surface condition	0	1	0	7	Alkali polishing	X32 Alkali polishing additive category	1	3	1	35	X33 Alkali polishing time	1	3	1	35	X34 Alkali polishing temperature	1	3	1	35	X35 Alkali polishing circulating bubbling	0	1	0	7	X36 Concentration of alkali polishing NaOH	1	3	1	35	Front grid line	X37 Four-track stencil line width	3	9	9	147	X38 Four-track stencil membrane thickness	1	3	3	49	X39 Four-track stencil line diameter	3	3	9	105	X40 Scraper angle	0	1	1	14
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<p>2.6 Improvement of categorized influencing factors: Evaluate the potential for improvement and improvement cycle, and classify the influencing factor Xi into quick-win improvement and systematic improvement.</p> <p>2.7 Execution of quick-win improvement category Xi:</p> <p>Example: Evaluate the improvement effect from three aspects: suede effect before and after improvement, reflectivity, and efficiency.</p> <div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> <p>Suede contrast</p>  <p>Distribution-Optimized Texturing</p> <p>Note: Image sourced from the internet.</p> </div> <div style="text-align: center;"> <p>Reflectivity comparison</p>  <p>Testing Null hypothesis <math>H_0: \mu_1 - \mu_2 = 0</math> Alternative hypothesis <math>H_1: \mu_1 - \mu_2 &gt; 0</math> T value: 26.48, P value: 49 0.000 Conclusion: P value &lt; 0.05, the null hypothesis is rejected, and the secondary velvet reflectivity is significantly reduced.</p> </div> <div style="text-align: center;"> <p>Efficiency comparison</p>  <p>Testing Null hypothesis <math>H_0: \mu_1 - \mu_2 = 0</math> Alternative hypothesis <math>H_1: \mu_1 - \mu_2 &lt; 0</math> W value: 1742300.00, P value: 0.000 Conclusion: P value &lt; 0.05, the null hypothesis is rejected, and the secondary velvet efficiency is significantly improved.</p> </div> </div> <p>Conclusion: After the introduction of the distribution-optimized texturing process, the efficiency has been significantly improved compared to before, with an average increase of about **%, reaching around 26.**%.</p>																																																																																										

Project Phase III / Analysis	3 System analysis: Verify the significance of the systemic impact factor Xi on efficiency and determine the root cause.																																																																							
A	<p>Quality tools: hypothesis testing, Source of Variation (SOV) analysis</p> <p>Verification principle: Poly time mainly affects the thickness of amorphous silicon. By adjusting the thickness of amorphous silicon, verify if contact resistance and field passivation ability are improved to achieve efficiency enhancement.</p> <table border="1"> <thead> <tr> <th>Process Parameter Range</th> <th>Control group (low level)</th> <th>Experimental Group (High-level)</th> </tr> </thead> <tbody> <tr> <td>3**_5**_s</td> <td>3**_s</td> <td>4**_s</td> </tr> </tbody> </table> <div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> <p>Normality test</p>  <p>P &lt; 0.05 Non-normal efficiency distribution</p> </div> <div style="text-align: center;"> <p>Box Plot</p>  <p>Poly layer process time **</p> </div> <div style="text-align: center;"> <p>Mann - Whitney</p> <table border="1"> <thead> <tr> <th>Sample</th> <th>N</th> <th>Median</th> </tr> </thead> <tbody> <tr> <td>Poly layer process time **</td> <td>**</td> <td>**</td> </tr> <tr> <td>Poly layer process time **</td> <td>**</td> <td>**</td> </tr> </tbody> </table> <p>Descriptive statistics Difference, Confidence interval for difference, Obtained confidence level -0.0172045 (-0.0245048, -0.0099043) 95.00%</p> <p>Inspection Null hypothesis <math>H_0: \mu_1 - \mu_2 = 0</math> Alternative hypothesis <math>H_1: \mu_1 - \mu_2 \neq 0</math> W value: 1362513.00, P value: 0.000 Poly layer process time Significant impact on efficiency</p> </div> </div> <p>Conclusion: The Poly layer process time is a significant factor, and reducing the Poly layer process time can help improve efficiency.</p>	Process Parameter Range	Control group (low level)	Experimental Group (High-level)	3**_5**_s	3**_s	4**_s	Sample	N	Median	Poly layer process time **	**	**	Poly layer process time **	**	**																																																								
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<p>4.1 Planning improvement measures: Formulate appropriate improvement plans based on the data types of variable Xi and response Y.</p> <p>Example:</p> <table border="1"> <thead> <tr> <th>S/N</th> <th>Efficient preparation Structure</th> <th>X</th> <th>Data Type</th> <th>Y</th> <th>Data Type</th> <th>Improvement plan</th> <th>Responsible Person</th> <th>Planned completion Time</th> </tr> </thead> <tbody> <tr> <td>1</td> <td rowspan="2">PN junction</td> <td>X4 Oxidation Temperature</td> <td>Measurement Type</td> <td>Efficiency</td> <td>Measurement Type</td> <td rowspan="2">Research on low-temperature oxidation process Regression analysis to find the optimal parameter combination</td> <td rowspan="2">Xu ** Yang *</td> <td rowspan="2">202*:4:2*</td> </tr> <tr> <td>2</td> <td>X5 Oxidation time</td> <td>Measurement Type</td> <td>Efficiency</td> <td>Measurement Type</td> </tr> <tr> <td>3</td> <td rowspan="4">Front grid line</td> <td>X37 line width</td> <td>Count type</td> <td>Efficiency</td> <td>Measurement Type</td> <td rowspan="4">Orthogonal experiment</td> <td rowspan="4">Xu ** Yao *</td> <td rowspan="4">202*:5:1*</td> </tr> <tr> <td>4</td> <td>X38 film thickness</td> <td>Count type</td> <td>Efficiency</td> <td>Measurement Type</td> </tr> <tr> <td>5</td> <td>X39 wire diameter</td> <td>Count type</td> <td>Efficiency</td> <td>Measurement Type</td> </tr> <tr> <td>6</td> <td>X9 Poly layer process time</td> <td>Measurement Type</td> <td>Efficiency</td> <td>Measurement Type</td> </tr> <tr> <td>7</td> <td rowspan="4">Tunnel oxide layer (Polysilicon structure)</td> <td>X10 Poly layer phosphine flow</td> <td>Measurement Type</td> <td>Efficiency</td> <td>Measurement Type</td> <td rowspan="4">Design Of Experiments (DOE) Optimization to find the optimal parameter combination</td> <td rowspan="4">Xu ** Zou **</td> <td rowspan="4">202*:5:2*</td> </tr> <tr> <td>8</td> <td>X11 Poly layer silane flow</td> <td>Measurement Type</td> <td>Efficiency</td> <td>Measurement Type</td> </tr> <tr> <td>9</td> <td>X12 Hydrogen flow rate of Poly layer</td> <td>Measurement Type</td> <td>Efficiency</td> <td>Measurement Type</td> </tr> <tr> <td>10</td> <td>X13 Poly layer power</td> <td>Measurement Type</td> <td>Efficiency</td> <td>Measurement Type</td> </tr> </tbody> </table>		S/N	Efficient preparation Structure	X	Data Type	Y	Data Type	Improvement plan	Responsible Person	Planned completion Time	1	PN junction	X4 Oxidation Temperature	Measurement Type	Efficiency	Measurement Type	Research on low-temperature oxidation process Regression analysis to find the optimal parameter combination	Xu ** Yang *	202*:4:2*	2	X5 Oxidation time	Measurement Type	Efficiency	Measurement Type	3	Front grid line	X37 line width	Count type	Efficiency	Measurement Type	Orthogonal experiment	Xu ** Yao *	202*:5:1*	4	X38 film thickness	Count type	Efficiency	Measurement Type	5	X39 wire diameter	Count type	Efficiency	Measurement Type	6	X9 Poly layer process time	Measurement Type	Efficiency	Measurement Type	7	Tunnel oxide layer (Polysilicon structure)	X10 Poly layer phosphine flow	Measurement Type	Efficiency	Measurement Type	Design Of Experiments (DOE) Optimization to find the optimal parameter combination	Xu ** Zou **	202*:5:2*	8	X11 Poly layer silane flow	Measurement Type	Efficiency	Measurement Type	9	X12 Hydrogen flow rate of Poly layer	Measurement Type	Efficiency	Measurement Type	10	X13 Poly layer power	Measurement Type	Efficiency	Measurement Type
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Note: All data in the project cases of this unit are desensitized.

**Project Phase IV / Improve**

4.2 Implementation of improvement measures: Take a comprehensive approach to optimizing efficiency by considering the combined arrangement of multiple variables.

Quality tools: regression analysis, DOE (orthogonal experiment design), etc.  
Example:

Contour Plot of Efficiency-I, Poly Layer Hydrogen Flow Rate, and Poly Layer Silane Flow

Hydrogen flow rate of Poly layer

Poly layer silane flow

Poly layer phosphine flow

Efficiency-I

Holding value

- Poly layer process time
- Poly layer phosphine flow
- Poly layer power

**Project Phase V / Control**

5.1 Effect confirmation: Track project indicators to see if the goals have been achieved.

26.\*\*\*% Reached at Stage M

26.\*\*\*% Completion of Phase A

26.\*\*\*% Stage I reached

Improvement plan

- Secondary texturing process, increase by 0.05%
- Optimization of texturing process parameters, increase by 0.05%
- Boron diffusion under low oxygen ↑ 0.08%
- Annealing temperature and time optimization ↑ 0.07%
- Sintering temperature optimization ↑ 0.06%
- DOE test improvement ↑ 0.03%
- Front screen line width+film thickness+ wire diameter combination optimization ↑ 0.02%
- Boron diffusion low-oxygen optimization ↑ 0.02%

March 2025 — Beginning of April 2025 April 2025 – Early May 2025 2025 / 5 — 2025 / 6

5.2 Standardization of measures: institutionalizing improvement actions and accumulating best practices.  
5.3 Financial benefit calculation: Efficiency improvement of this project by 0.33%, with an estimated annual gain of 35 million yuan.

## Quality Practices Case Presentation

**Project Case 2:**  
Grade CD reduction

**Project Topic**  
Improvement of Grade CD Notch Defects in 210 Product

**Project Phase I / Plan**

1. Clarify the problem

1.1 Background: The quality of solar cells is fundamental to survival, and reducing the degradation rate of solar cells can directly increase revenue. Among them, Grade CD notch defects account for more than 80%, so this project mainly focuses on improving the Grade CD notch defects.

1.2 Clarify CTQ: Grade CD notch category judgment criteria

Category	Defect type	Inspection Standard
Grade C notch	Grade C subfissure	Determined as microcrack by EL.
	Grade C notch	Within the range of less than three fine fingers.
Grade D notch	Grade D notch	The notch size is greater than three fine fingers and less than three main fingers, and is classified as Grade D.

Grade C subfissure

Grade C notch

Grade D notch

1.3 Project Status Vs. Target: 0.3% Vs. 0.1%

2. Cause Analysis

2.1 Identify the formation mechanism: The main principle behind notch formation at the Grade CD is: mechanical contact and collision, resulting in uneven force on the cells and thereby causing damage;

2.2 Define project scope: Texturing and alkali polishing are tank-type equipment, which have little impact on the Grade CD at the finished product end; diffusion and retreat, as well as subsequent processes, are the main sources causing notches at the Grade CD.

Start → Texturing → Diffusion → SE laser

PECVD ← Back Passivation ← Annealing ← Alkaline etching

Backside laser → Screen mesh sintering → Sorting and inspection → End

**Project Phase I / Plan**

2.3 Identify contact points: Based on the generation mechanism, a solar cell model is created to simulate production, allowing each affected process to be analyzed and the corresponding contact points and mechanisms to be identified.

Quality tool: Micro Flowchart

Start → Loading (Silicon wafers are loaded from the cassette) → Pusher (Align wafers in cassette with cylinder) → Correction (Alignment on the track) → Alignment (Cylinder alignment, Variable pitch internal silicon wafer) → Transmission (Variable camber lifting) → Blocking (Join location, Blocked by stop block) → Buffer (The silicon wafer enters the variable pitch zone, Untimely feeding, Buffer rise) → Take wafer (Mechanical arm grabs silicon wafer) → Insert wafer (Put the silicon wafer in a graphite boat) → End

Example: Through the PECVD process, the micro-flow chart identifies 9 factors that affect the CD-level notches. The rest of the processes are carried out in turn.

Quality tool: Heat Map

Example: 9-factor point diagram of PECVD process. The rest of the processes are carried out in turn.

2.4 Summary of contact factors (Xs) for each process: A total of 31 contact factors affecting CD grade have been identified.

**Project Phase I / Plan**

2.5 Cell defect location: Convert discrete indicators (defect rate) into continuity indicators (defect points). The 210 cells are divided into 21 defect locations on each side at a spacing of 1 cm, and data is collected for Grade CD notched cells according to the defect locations.

Quality tool: Heat Map

Heat Map of Defect Locations (2.15N - 2.17N)

Pareto Chart of Defect Locations

2.6 Association and ranking: product defect locations Vs. process elements: Associate the frequently occurring notch-type defect locations on the cells with the identified process contact points and mechanisms. Based on the CE matrix scores, process contact elements Xi with higher defect weights are prioritized for further analysis.

Quality tool: Matrix Graph

Working procedure	Contact factor at defect location	Name of contact point	Defect locations																	总分
			A01	B01	A10	A11	A02	B02	A06	B04	A19	A04	A09	A18	D20	A12	A13	A17		
Diffusion - annealing	X01	Cassette top teeth	49%	3.9%	3.8%	3.7%	3.1%	3.1%	3.0%	3.0%	2.7%	2.6%	2.5%	2.5%	2.4%	2.3%	2.3%	1	13.4%	
	X02	Cassette shaping			1						1	1	3	1				1	11.6%	
	X03	Suction cup							1	1		1		1				1	13.7%	
	X04	Boat top tooth							3									1	11.6%	
	X05	Boat shaping			1	1										1	1		12.5%	
Double-sided coating	X06	Quartz boat		1							1			3					14.4%	
	X07	Cassette wafer alignment cylinder								1									3.1%	
	X08	Calibration wheel									1		1					1	8.1%	
	X09	Buffer							1	1								1	8.5%	
	X10	Variable pitch								1									3.1%	
	X11	Belt stop block			1	1							1			1		1	15.0%	
	X12	Dry cassette								1	1		1					1	11.1%	
	X13	Variable pitch pusher cylinder								1									5.4%	
	X14	PE suction cup									1							3	10.1%	
	X15	Graphite boat jam point			1					1	3	1	3	3	3		3	3	56.3%	
Printing	X16	Cassette wafer alignment cylinder							3										9.2%	
	X17	Laser machine table			3	3											3	3	37.4%	
	X18	Calibration wheel								1	1		1						8.8%	
	X19	Suction cup			1	1				1					1				13.3%	
	X20	Buffer			1	1										1	1		12.5%	
	X21	Turnover mechanism											3				3		14.7%	
	X22	Sintering furnace belt	1	1						1	1		1	1		1	3	1	32.1%	
Sorting FQC	X23	Electric injection material box				3	3	3	3	3	3	3	3	3	3		3	3	76.1%	
	X24	Returning of material box			3					3							3	3	42.6%	
	X25	Suction cup																	0.0%	
	X26	Calibration wheel										1	1			1	1	1	12.4%	
	X27	EL material box																	0.0%	
	X28	Sorting material box	3	3			1	1								1			35.6%	
	X29	Collection box	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	49.3%	
	X30	Visual inspection table	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	49.3%	
	X31	Release table	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	49.3%	

Classification: Classify according to the factors that cause Grade CD notch defects:  
 -Process breakage: Grade CD defects occurring in the production line before FQC is defined as process breakage;  
 -Inspection breakage: Grade CD defects caused by human factors in FQC is defined as inspection breakage.

**Project Phase I / Plan**

2.7 Confirm the root cause: Use the 5WHY analysis method to identify the root cause, and use tools such as hypothesis testing to confirm whether it is a significant factor.

Quality tool: 5WHY+hypothesis testing

Primary Cause	Secondary Cause	Tertiary Cause	Judgment Basis	Determination of Key Causes/Conclusion	
X22: Sintering furnace belt	X22-1 The furnace belt speed does not match the feeding and discharging speed	X22-1-1 Poor commissioning and matching	The furnace belt speed is consistent with the feeding and discharging speed	Analysis through hypothesis testing	/
	X22-2 Abnormal connection level of furnace belt	X22-2-1 Defects during line commissioning	The furnace belt and the connecting belt are kept relatively horizontal	All on-site inspections confirmed that no such problems were found	Not a key cause
	X22-3 Deviation of furnace belt	X22-3-1 Problems with furnace belt tension	Maintenance Procedures for A2 Sintering Furnace (Maxwell) Equipment	After on-site inspection, it was confirmed that such problems exist	Key cause
	X22-4 Unstable operation of furnace belt	X22-4-1 Quartz rod wear, bearing jamming and chain skipping, etc.	Maintenance Procedures for A2 Sintering Furnace (Maxwell) Equipment	Under normal circumstances, the quartz rod is in a state of friction and wear	Key cause

Before adjustment			After adjustment		
Total number	Grade CD	Proportion	Total number	Grade CD	Proportion
19800	38	0.191%	22000	27	0.123%

- ◀ Preliminary cause analysis for X22-1-1: The speed of entering and leaving the sintering furnace belt does not match
- ◀ Action: On February 20, the speed parameters for both entry into and exit from the sintering furnace were adjusted to ensure alignment, preventing any slippage of the cells on the furnace belt.
- ◀ Data collection: Verification is conducted by tracking the Grade CD ratio both before and after the adjustment.

Double ratio test and confidence interval

Method	Descriptive statistics	Estimated value of the difference	Inspection	Method	Z value	P value
$P_1$ : Sample 1 - Ratio of events	Sample: N Events Sample P	Difference: 95% lower level of difference	Null hypothesis: $H_0: p_1 - p_2 = 0$	Normal approximation: Fisher's Exact Test	1.79	0.037
$P_2$ : Sample 2 - Ratio of events	Sample 1: 19800 38 0.001919	0.0006919 0.000050	Alternative hypothesis: $H_1: p_1 - p_2 > 0$			0.048
Difference: $(p_1 - p_2)$	Sample 2: 22000 27 0.001227	CI based on normal approximation	The test based on normal approximation employs the continuity ratio estimate (0.00015502).			

Conclusion: As the P value is less than 0.05, the original hypothesis is rejected, confirming the effectiveness of the improvement. The furnace entry/exit speed parameters of X22-1-1 constitute key causes.

Example: Analysis of the specific cause Xi; subsequent Xis are analyzed in sequence.

3. Formulate countermeasures: Develop improvement actions in accordance with the identified significant factors.

Count the contact points through on-site inspection  
Sort out 31 mechanical contact points

Through heat map analysis, determine the top 50% of notch locations and identify 16 key locations

Through matrix analysis, determine the top 70% of points and 9 key points

Through root cause analysis, identify 23 underlying factors, 3 quick wins and 20 suspicious factors

Identify 11 key causes by gradually screening 20 factors.

**Project Phase II / Do**

4. Implementation of measures: Find the best improvement measures and verify their effectiveness.

Reason: Short vacuum breaking delay

Improvement measures: The parameter is adjusted from  $1^{**}\pm 10\text{ms}$  to  $2^{**}\pm 10\text{ms}$

Before improvement: Cell placement by suction cup carries the risk of chip lift

After improvement: Improved stability in cell placement by suction cup

▲ Pre-change cell placement delay:  $1^{**}\pm 10\text{ms}$

▲ Pose-change cell placement delay:  $2^{**}\pm 10\text{ms}$

Example: Improvement of cause Xi. The rest Xis are carried out in turn.

**Project Phase III / Check**

5. Target confirmation: Through the above improvements, the current Grade CD ratio has dropped to 0.08% and is still declining. 5.1 Improvement confirmation: Confirm the important defect locations that affect Grade CD notch defects after improvement. The damaged locations that previously accounted for a high proportion are basically ranked outside the top 60%, preparing for further improvement.





Quality tool: Heat Map

Top 10%
  Top 20%
  Top 30%
  Top 40%
  Top 50%

60.00%

5.2 Recognition of income: After financial accounting, according to the current decline ratio, minus the improvement expenditure cost, the annual income is about RMB 6 million+.

Note: All data in the project cases of this unit are desensitized.

Project Phase IV / Action	6.1 Standardization: Solidify the measures to improve the process. Some Xi examples are as follows:				
A	Primary Cause	X15: Graphite boat jam point	X17: Laser machine table	X22: Sintering furnace belt	
	Secondary Cause	X15-1 Replacement of new points Improve piece falling and warping	X17-1 Laser stage vibration	X22-3 Deviation of furnace belt	Intelligent management, early warning system; consolidate current processes and avoid fluctuations
	Tertiary Cause	X15-1-1 The old clamping point is prone to warping, fragments, etc.	X17-1-1 Unreasonable setting of rigidity parameters for stage rotating motor	X22-3-1 Problems with furnace belt tension	X22-4-1 Quartz rod wear, bearing jamming and chain skipping, etc.
	Relevant measures	Replacement of new points	Optimize the rigidity parameters of the laser stage and perform a full-line inspection to verify whether such issues exist.	During maintenance, check and confirm the deviation and add it to the maintenance list	Daily spot check items for the operation status of sintering furnace belt are added, so that problems can be found and troubleshooted in time
	Relevant supporting evidence				
	Responsible Person	Chen *	Chen *	Wang **	Wang **
Completion Date	Mar. 26	Mar. 11	Mar. 23	Mar. 23	
<p>6.2 Summary: Summary and Outlook</p> <ul style="list-style-type: none"> <li>Convert discrete indicators (defect rate) into continuous ones (defect points), so as to obtain more information, locate the process elements corresponding to the problem, and clearly point out the cause of the problem.</li> <li>Use basic quality tools and data analysis to systematically extract discrete problem information. To address scratch and debris problems, a concise, efficient, and replicable logic chain and tool chain is established.</li> </ul>					

## Quality Practices Case Presentation

Project Case 3: Power consumption reduction

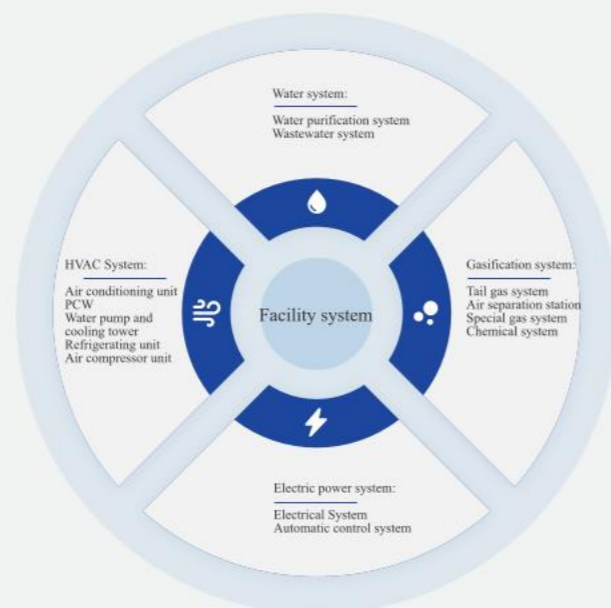
Project Topic  
Power Consumption Reduction Project of Plant A

Project Phase I / Define	<p>1.1 Background: The competition in the photovoltaic industry is becoming increasingly fierce. In response to the national green development strategy, the company has set a carbon footprint target between 2022 and 2025, and simultaneously established a special project for consumption reduction.</p> <p>1.2 Current Status and Objective Setting: The comprehensive power consumption is divided into Y1: unit power consumption of equipment at the workshop end and Y2: average daily power consumption at the facility end.</p>																							
D																								
	<p>1.2.1 Current Status and Objective Setting: Y1: Unit power consumption of equipment at the workshop end (production-end indicators are related to output and do not have periodic characteristics). Current Status Vs. Objectives: Current situation 24,800 kWh/MW Vs. Basic target: 24,500 kWh/MW Vs. Challenge target: 24,000 kWh/MW. Locked project scope: Y1 workshop end: wire mesh, front film, back film, diffusion, texturing, annealing, oxidation, alkali polishing, graphite boat oven.</p>																							
	<p>Quality tool: Pareto Chart</p> <p>Distribution of Daily Average Power Consumption for Each Process in Workshop</p>  <table border="1"> <caption>Distribution of Daily Average Power Consumption for Each Process in Workshop</caption> <thead> <tr> <th>Process</th> <th>Cumulative Percentage</th> </tr> </thead> <tbody> <tr><td>Mesh</td><td>36.5%</td></tr> <tr><td>Positive film</td><td>51.1%</td></tr> <tr><td>Backing film</td><td>64.9%</td></tr> <tr><td>Diffusion</td><td>75.7%</td></tr> <tr><td>Texturing</td><td>82.1%</td></tr> <tr><td>Annealing</td><td>88.1%</td></tr> <tr><td>Oxidizing</td><td>92.9%</td></tr> <tr><td>Alkaline etching</td><td>95.9%</td></tr> <tr><td>Graphite boat oven</td><td>97.4%</td></tr> <tr><td>Micro-conductive</td><td>98.7%</td></tr> <tr><td>SE</td><td>100.0%</td></tr> </tbody> </table>	Process	Cumulative Percentage	Mesh	36.5%	Positive film	51.1%	Backing film	64.9%	Diffusion	75.7%	Texturing	82.1%	Annealing	88.1%	Oxidizing	92.9%	Alkaline etching	95.9%	Graphite boat oven	97.4%	Micro-conductive	98.7%	SE
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SE	100.0%																							

Project Phase I / Define

1.2.2 Current status and objective setting: Y2: Unit power consumption of equipment at the facility end

Defined project scope: Y2: 4 major systems and 11 modules at the facility end.



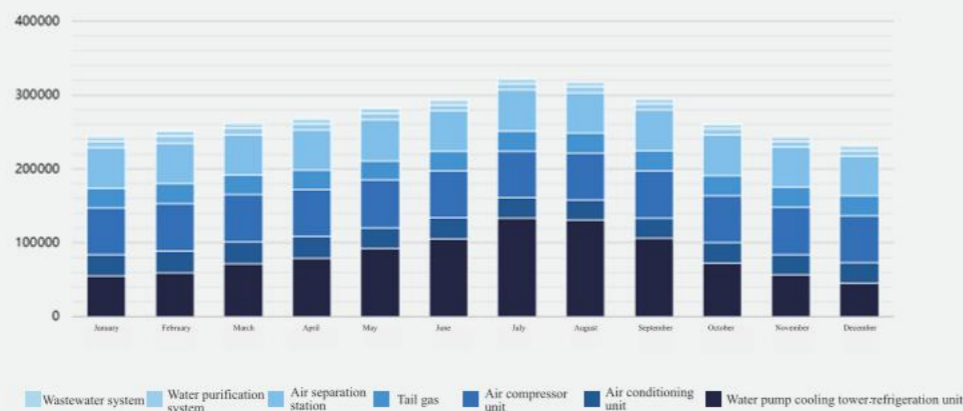
Current Status Vs. Objectives: Facility end indicators, some modules have periodic characteristics and need to be identified.

Quality tool: Stacked Bar Chart

Facility end system split: Y21 non-seasonally affected systems and Y22 seasonally affected systems;

- Y21 Non-seasonally affected system:** Wastewater system, pure water system, air separation station, tail gas, air compressor unit, air conditioning unit;
- Y22 Seasonally affected systems:** Water pump cooling tower:refrigeration unit;

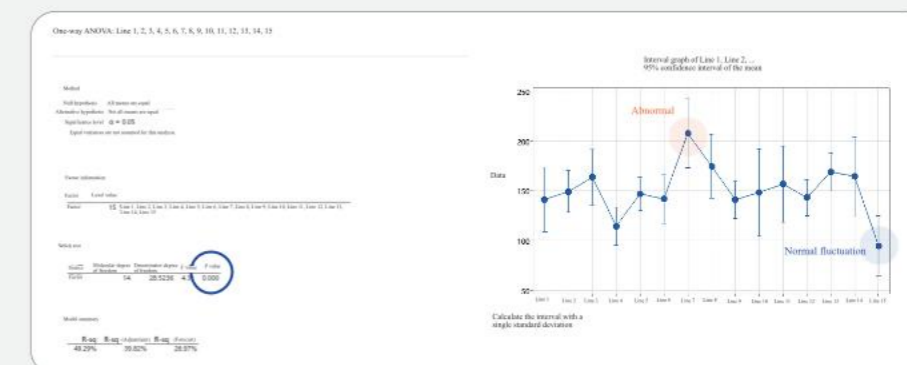
Note: The chilled water of the air-conditioning unit is supplied by the refrigeration unit, and its seasonally affected part is shared by the refrigeration unit. Therefore, the air-conditioning unit is not classified to the seasonally affected module.



- Y21 Average daily power consumption at the facility end - Non-seasonally affected system:** Current Status Vs. Objectives: Current status 190,000 kWh/day Vs. Basic objective: 170,000 kWh/day; Challenging objective: 160,000 kWh/day.
- Y22 Average daily power consumption at the facility end-Seasonally affected systems:** The target is set based on year-on-year benchmarks or historical performance under comparable operating conditions.

Project Phase II / Measure

2.1 Measurement System Analysis: 1. Verify the number of meters and the distribution of measurement points to ensure the granularity of subsequent data. 2. Confirm the consistency between meter readings and actual measurements. 3. Evaluate and analyze the deviation between the main meter and the sum of sub-meters, ensuring that deviations remain within a controllable range. 2.2 Analysis of differences between lines: Identify abnormal consumption points and implement quick-win improvements.



Conclusion: For the alkali polishing – water heater: the data from Line 7 is significantly higher than expected, due to the overflow signal being reversely connected to the tank preparation signal; corrective action is required. The data from Line 15 is significantly lower. Line 15 is a new machine, and its heating efficiency is better than the older lines, resulting in lower electricity consumption, which falls within normal fluctuation.

Quick-win Improvement:

Working procedure	Issue point	Cause analysis	Improvement plan	Responsible Person	Completion date
Alkaline etching	The overflow signal of the water heater line 7 is reversely connected with the tank preparation signal	The overflow signal of the water heater is reversely connected to the tank preparation signal	Swap the overflow signal with the tank preparation signal	Rao **	2024/3/**



Example: Alkali polishing-difference analysis and quick win improvement is carried out for water heater power consumption components, the remaining processes are carried out in turn.

**Project Phase II / Measure**  
 2.3 Electric energy utilization analysis: Electric energy utilization can be analyzed and categorized into useful and non-useful applications.

Quality tool: Sankey Diagram

**Project Phase III / Analysis**  
 3.1 Identify power consumption units: For the main power consumption equipment, carry out structural explosion and gradually split them to specific power consumption units as improvement factors.

Quality tool: exploded view diagram

Note: The image of the air conditioner compressor is sourced from the Internet.

No.	Component name	Function	Power consumption unit or not	Power consumption level
	Primary- and medium-efficiency filter	Filtration of fresh air dust	Yes	◇
2	Cold tray	Refrigeration and dehumidification	No	
3	Integrated coil	Cooling (dehumidification) in summer and heating in winter	No	
4	Hot tray	Heating	No	
5	Motor	Driving fan	Yes	○
6	Fan	Provide positive pressure in the workshop	Yes	◇
7	Punching air diffusing board	Ensure the air supply temperature, humidity and dew point	No	
8	High-efficiency filter screen	Filter hydrogen sulfide gas in the external air	No	
9	FFU	Provide circulating air volume	Yes	◇
10	DCC	Cooling	Yes	◇

**Project Phase III / Analysis**  
 3.2 Power-saving technology: Find and summarize power-saving technologies

Quality tool: layering

Energy-saving technology classification:

Level I	Reduce the number of power-consuming machines	Electric energy conversion Recycling	Electric energy conversion Consumption saving	Process flow energy saving	Replace with low power-consuming equipment	Reduce unit energy consumption	Energy storage					
Level II	Shut down unnecessary machines	Circulating heating	Cooling fan	Heat recovery	Reduce heat loss	Reduce cold dispersion	Improve conversion efficiency	Optimize the process flow	Reduce heat requirements	Replace high-energy-consuming equipment	Increase capacity	Energy storage

**3.3 Identify energy-saving schemes: Develop energy-saving schemes for power-consuming units by integrating various power-saving technologies.**

Quality tool: Matrix Graph

Level I (overall)	Level II (process)	Level III (equipment)	Level III (power consumption unit)	Energy-saving technology										Energy-saving solution		
				Reduce the number of power-consuming machines	Electric energy conversion Recycling	Electric energy conversion Consumption saving	Process flow energy saving	Replace with low power-consuming equipment	Reduce unit energy consumption	Energy storage						
F a c i l i t y e n d v 2 - 1	H V A C	Cooling system Refrigerating unit	X111-1	×	×	×	×	×	×	√	×	×	×	×	Increase the adjustment range of chilled water outlet temperature	
			X111-2	×	×	×	×	×	√	×	×	×	×	×	Clean the condenser of ice maker	
			X111-3	×	×	×	×	×	×	√	×	×	×	×	×	Reduce the return temperature of cooling water
		Cooling system water pump	X112	Motor	×	×	×	×	×	×	√	×	×	×	×	Reduce the pressure difference between supply and return water
			Cooling system Cooling tower	X113	Fan motor	×	×	×	×	×	×	√	×	×	×	×
		Air compression system Air compressor unit		X114-1	High-voltage motor	×	×	×	×	×	×	√	×	×	×	×
	X114-2		High-voltage motor	×	×	×	×	×	×	√	×	×	×	×	×	Reduce the air supply pressure
	Air conditioning and ventilation system	Air compression system Dryer	X115-1	Heater	×	×	×	×	×	×	√	×	×	×	×	Reduce heating time
			X115-2	Heater	√	×	×	×	×	×	√	×	×	×	×	Reduce the number of dryers turned on
		Air conditioning and ventilation system	X116	Motor	×	×	×	×	×	×	√	×	×	×	×	Reduce the frequency of fan motor

Project Phase III / Analysis

### 3.4 Screen feasible energy-saving schemes: Evaluate and screen the consumption reduction plan from multiple dimensions, such as energy consumption benefits, capital investment, transformation time, equipment failure rate, process quality, etc.

Quality tool: Matrix Graph

Energy-saving benefits

No profit High returns

Improvement cost

No cost High cost

Transformation cycle

No modification cycle Long cycle

Equipment failure rate

No fault High failure rate

Safety risk

No risk High risk

Quality risk

No risk High risk

Rating of importance										1151	-274	-186	-1239	-4934	-2215	Total Score
S/N	Working procedure	Equipment	Xs	Energy-saving technology	Energy-saving benefits	Improvement cost	Transformation cycle	Equipment failure rate	Safety risk	Quality risk						
X90	Mesh	Feeder	Replace the low-power stepping motor	Replace high energy-consuming equipment	1	3	3	0	0	0	-229					
X91	Mesh	Laser machine	Optimize the marking path Marking speed-up	Increase capacity	1	0	0	0	0	0	1151					
X93	Mesh	Printing machine	Replace the low-power stepping motor	Replace high energy-consuming equipment	1	3	3	0	0	0	-229					
X94	Mesh	Printing machine	Two sides share a chiller	Shut down unnecessary machines	9	0	1	1	0	0	8934					
X95	Mesh	Oven	Insulation materials are installed at the outlet of oven and sintering furnace	Reduce heat loss	3	0	0	0	0	0	3453					
X96-1	Mesh	Oven	Replacement of low-power furnace belt motor	Replace high energy-consuming equipment	1	3	3	1	0	0	-1468					
X96-2	Mesh	Oven	Frequency conversion of heating equipment	Reduce heat loss	9	3	3	0	0	0	8979					
X97-1	Mesh	Sintering Furnace	Combustion tower cooling	Reduce heat requirements	9	0	0	0	1	0	5425					
X97-2	Mesh	Sintering Furnace	Heat recovery of sintering furnace	Heat recovery	9	9	3	0	0	0	7335					
X98	Mesh	Sintering Furnace	Replace the section heating lamp tube	Replace high energy-consuming equipment	9	1	1	0	0	0	9899					

Project Phase IV / Improve

### 4.1 Implementation of improvement plan: implementation and risk assessment of feasible energy-saving plans

Example: Execute Xi: Improvement to reduce overflow temperature (texturing)

Improvement direction:

Level I energy saving-energy saving from process flow; Level II energy saving-optimization of process flow					
Process/System	Texturing	Power consumption unit	Heater	Responsible person & completion time	Chen **;Zeng* 2024;3;**

Mechanism description:  
The cleaning water heater is mainly heated by a heater. Reducing the overflow temperature of the water heater can reduce electricity consumption.

Before improvement

Overflow temperature 7°C

After improvement

Overflow temperature 6°C

Effect confirmation

Project Topic  
Power Consumption Reduction Project of Plant A

Risk assessment:  
Reducing the overflow temperature of the water heater may cause the patch to carry more liquid.

### 4.2 Evaluation and verification of other impacts: Evaluate and verify whether the plan has any negative impact on product quality, and determine the lower limit for energy reduction.

Example: Execute Xi: Reduce the risk threshold of overflow temperature (texturing)

No.	Overflow temperature	Line verified	Date of verification	Validation quantity	Liquid adhesion defect of patch	Power consumption	Verification conclusion	Analysis tool
1	75	1#	2024/3/20	88654	8	851	OK	Regression analysis Chi-square test Double P
2	70	1#	2024/3/21	92235	12	782	OK	
3	65	1#	2024/3/22	89625	14	672	OK	
4	60	1#	2024/3/23	91245	16	511	OK	
5	55	1#	2024/3/24	88654	45	470	NG	

Line Number	Number of patches	Number of defects	Power consumption
75	88654	8	851
70	92235	12	782
65	89625	14	672
60	91245	16	511
55	88654	45	470

▲ Regression analysis shows that the higher the temperature, the higher the power consumption

▲ P < 0.05  
It shows that different temperatures have a significant impact on liquid adhesion defects on the patches.

▲ P < 0.05  
It indicates that at an overflow temperature of 55°C, the number of patch defects with liquid adhesion significantly increased.



3.3

## Full-scope quality management: Ecosystem Quality from Customer Journey Map to Supply Chain Collaboration

### Customer Requirements Closed-Loop Management System Based on QFD and APQP Integration

In terms of the core performance dimension of photovoltaic products, we take the cutting-edge industry standards as the benchmark, deeply adapt to the differentiated needs of customers, and provide high-quality products with both long-term stability and scenario adaptability. Focusing on key performance indicators such as CTM, power, and bifacial rate, we have established a full-process system of "Customer Voice Mining - Demand Transformation - Experience Optimization." Leveraging integrated end-to-end toolchains and data-driven analytics, this system enables refined customer profiling, standardized demand management, dynamic production control, and full lifecycle experience enhancement. Ultimately, it forms an enhanced closed-loop of "Demand - Design - Delivery - Feedback", ensuring precise alignment of performance with application scenarios and creating stable long-term value for customers. By building a customer journey map, the linkage application of QFD demand matrix and APQP stage review, the real-time monitoring system embedded in user sentiment indicators, and the feedback of after-sales service data to product design innovation mechanism can achieve comprehensive optimization of product defect rate reduction, iteration cycle shortening and customer satisfaction improvement.

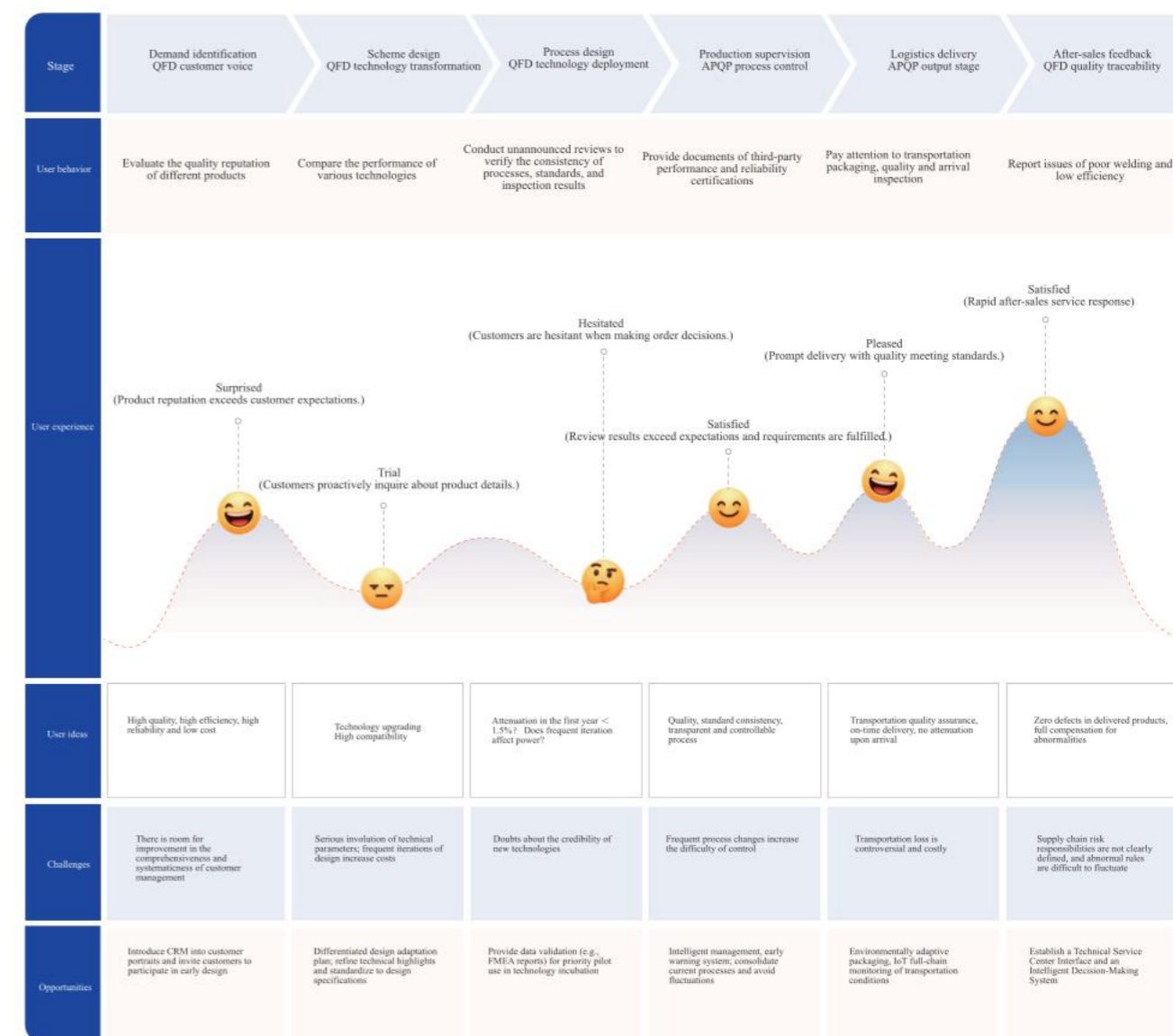


Figure 3.1 Example of TW Solar Customer Journey Map

### 01 Stage I: Analysis of Customer Demand

Note: All data in the project cases of this unit are desensitized.

- Collect customer needs: such as power, reliability, cost, etc., and clarify the core and potential needs of customers
- Analyze market demand and competitors
- Prioritize customer needs
- Establish a matrix of customer needs and technical characteristics
- Identify technical characteristics: According to customer needs, identify the technical characteristics that affect product quality (such as conversion efficiency, anti-PID performance, welding strength, etc.)
- Determine the target value of technical characteristics: Set a target value for each technical characteristic (such as conversion efficiency  $\geq 26.5\%$ ) and clarify the direction of improvement

### 02 Stage II: Technical Characteristics Expansion

- Convert customer needs into cell design characteristics: (such as cell efficiency, thickness, anti-PID performance, etc.)
- Determine the importance of design parameters
- Identify key design parameters and evaluate their technical feasibility
- Establish a relationship matrix between design parameters and component characteristics
- Optimize design schemes through simulation and experiments
- Determine the target values of component characteristics, set target values for each component property (such as grid line width  $\leq 25\mu\text{m}$ ), and clarify the direction of improvement

### 03 Stage III: Process Optimization and Process Control

- Convert design characteristics into production process parameter requirements: Based on the design characteristics, determine the production process parameters (such as diffusion temperature, coating thickness, annealing time, etc.) to ensure that the process parameters can achieve the design characteristics
- Develop process flow charts and key process parameters
- Optimize production process: Ensure that process parameters are within the optimal range (such as diffusion temperature, coating thickness, annealing time, etc.) to improve product quality and consistency
- Develop a process control plan: clarify the monitoring methods and control limits of key process parameters, monitor key process parameters, and ensure the stability and consistency of the production process
- Establish a relationship matrix between process parameters and production operations
- Determine the target values of production operation parameters: such as controlling the coating temperature at  $490\pm 15^\circ\text{C}$ , and clarify the direction of improvement

### 04 Stage IV: Quality Control and Continuous Improvement

- Convert production operating parameters into production control parameters
- Establish a relationship matrix between production control parameters and quality control points
- Determine the target value of quality control points
- Develop a quality control plan to clarify the quality control points and detection methods
- Implement production control to detect and solve quality problems in a timely manner
- Analyze customer feedback and production data to develop constant improvement measures

## A cross-functional centralized management model that integrates order processing, plan decomposition, production process control, and customer delivery.

TW Solar is committed to establishing cross-departmental and intra-departmental data management mechanisms. Starting from a customer requirement closed-loop management system coordinated by QFD and APQP, it introduces a full production process management model covering order-to-delivery operations. By integrating data from ERP, MES, SRM, WMS, full-line monitoring centers, BI systems, and combining IT and OT integration, the company automates business processes across all stages and implements end-to-end management of quality data collection, administration, processing, analysis, and application. This builds a cross-departmental and intra-departmental data management mechanism, facilitating efficient exchange and sharing of quality data across business activities.

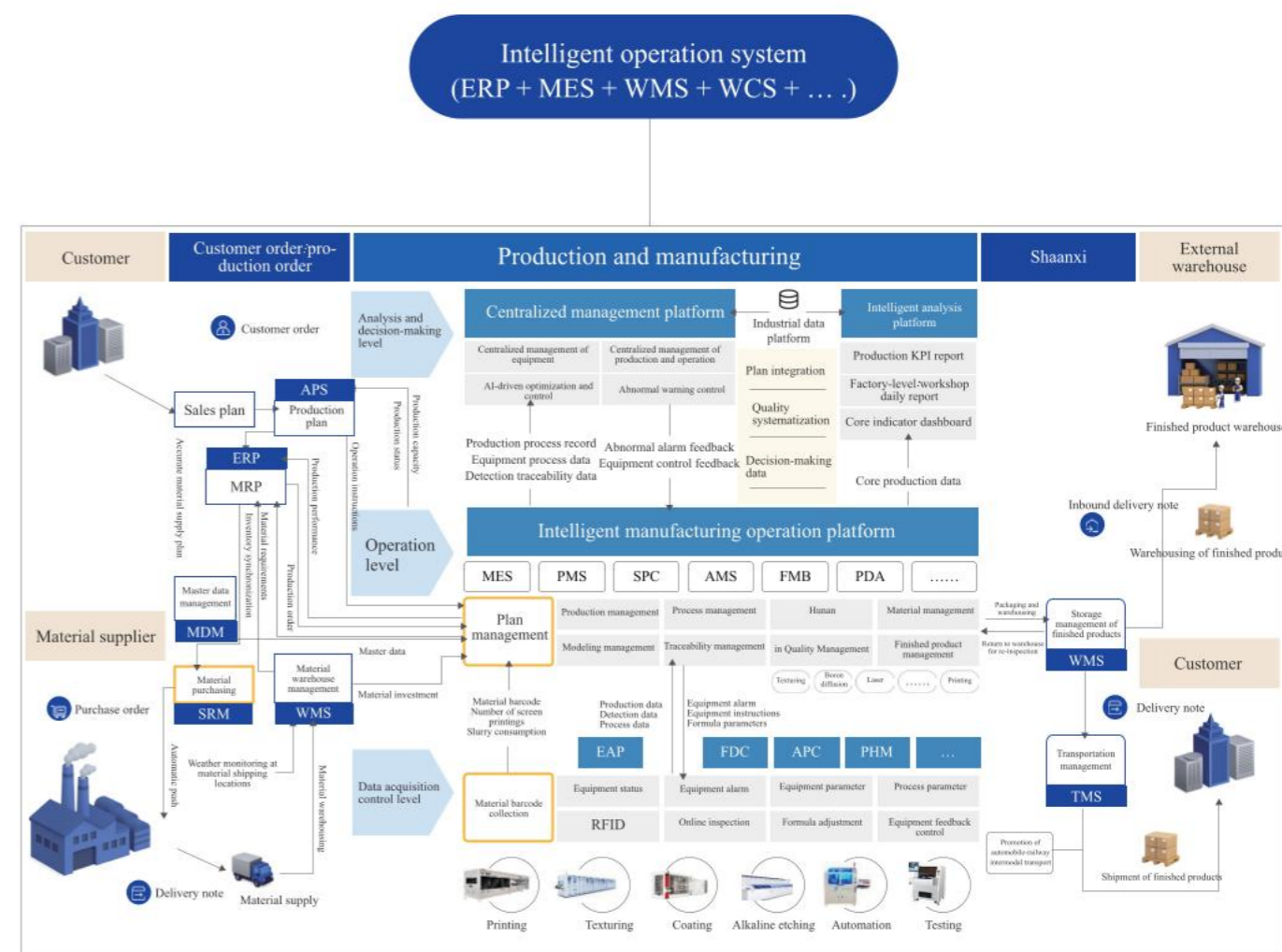


Figure 3.2 TW Solar Intelligent Platform

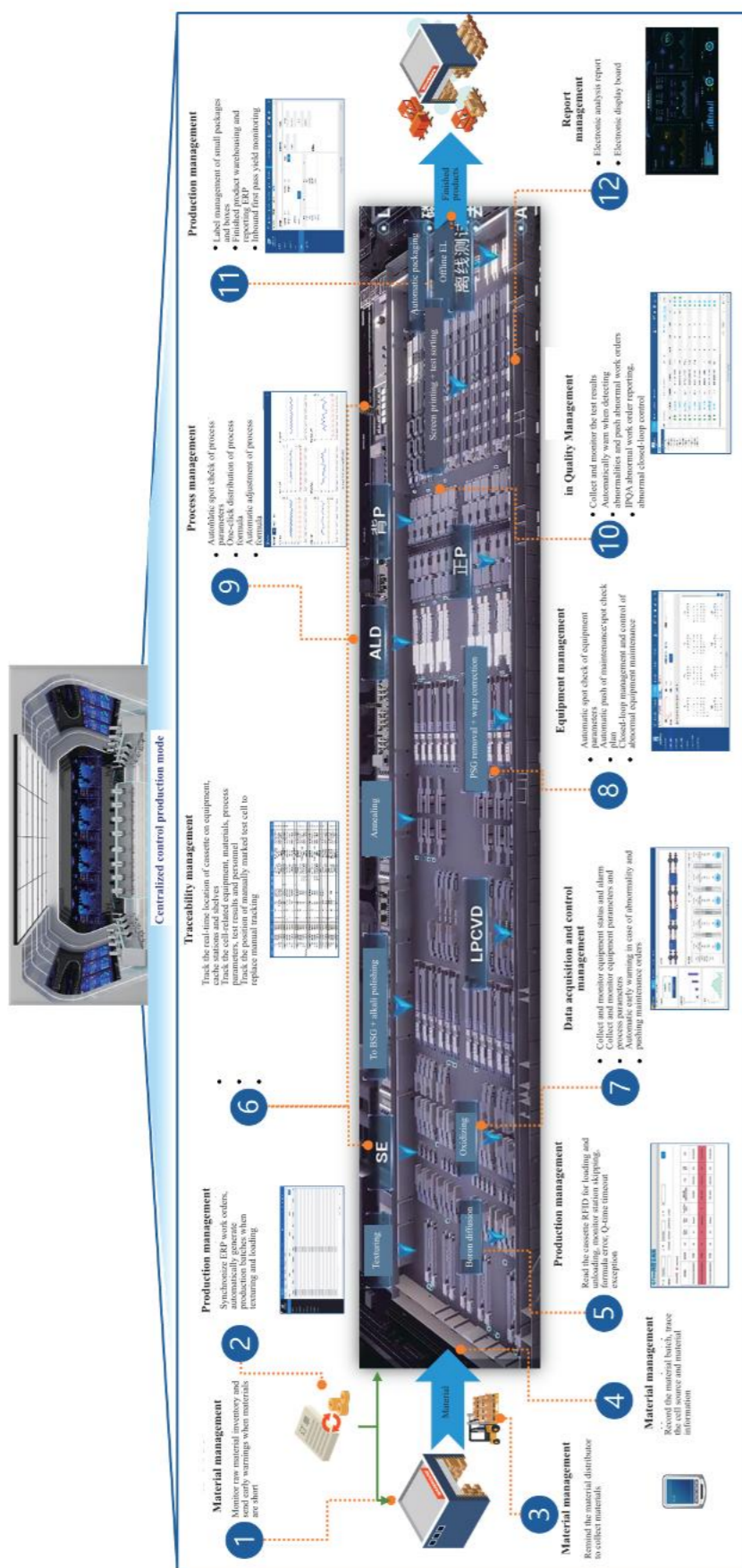
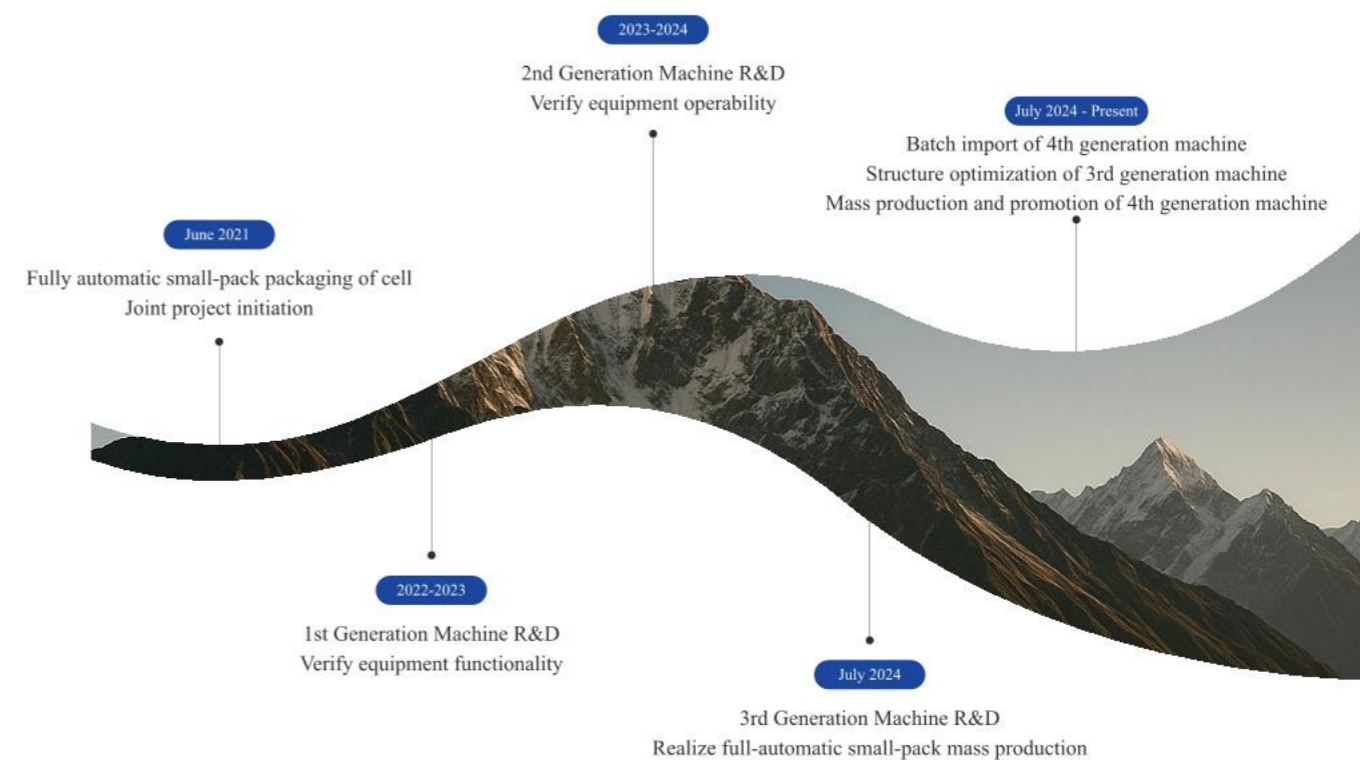


Figure 3.3 TW Solar MES Intelligent Manufacturing System

## Supply Chain Collaboration

We have a deep and close cooperative relationship with our supply chain partners to jointly promote the optimization of supply chain collaboration models and processes. Enhance the company's core competitiveness through supply chain resilience and sustainability, aiming to achieve cost optimization, quality improvement, and technological innovation across the value chain, such as: Study on module power and cell QE curve studies is translated into optimizations of cell materials, structure, and processes. Collaborative innovation with equipment suppliers drives improvements such as the development of small packaging equipment, aluminum boat modifications, furnace upgrades, graphite boat weight reduction, and the establishment of a vendor-managed inventory (VMI) system. To enhance the core competitiveness of the supply chain, reduce production anomalies and equipment failures, achieve annual revenue of more than RMB 10 million, achieve a win-win situation, and ultimately promote the efficient development of the entire solar industry chain, allowing the company to maintain its competitive advantage in the dynamic changes of the industry.

**Example 1:**  
Joint development of fully automatic small-pack packaging machine for cells



In collaboration with industry suppliers, we have spent four years in continuous effort to successfully overcome technical bottlenecks and develop a globally leading fully automatic small-pack packaging machine for solar cells. Through four generations of technological iteration, we have deeply integrated multiple technologies, including mechanical design, intelligent control, and vision inspection, overcoming core challenges such as high-precision positioning, high-speed dynamic packaging, and multi-stage coordinated control. The fully automatic packaging capacity of a single machine per shift has exceeded 500,000 cells, pioneering a new era of fully intelligent production covering cell alignment, inspection, labeling, and packaging, and ultimately achieving a leap in equipment performance.

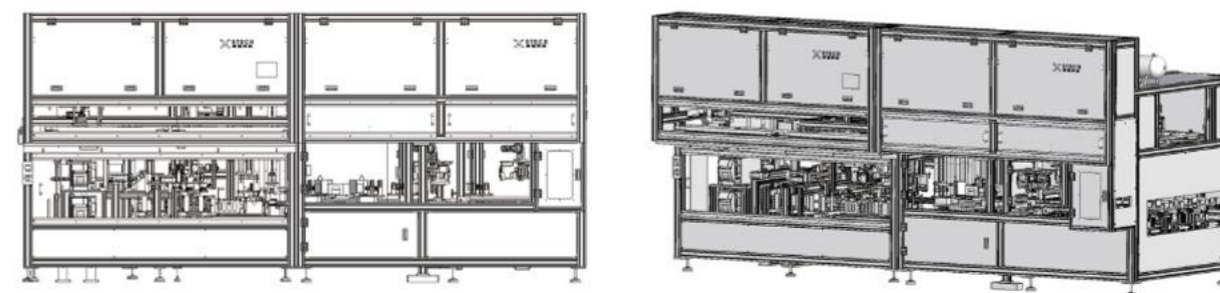


Figure 3.4: Fully Automatic Small-pack Packaging Machine Co-developed by TW Solar and Equipment Suppliers

At TW Solar, we are developing and implementing data-driven quality control and decision models to enhance the responsiveness and timeliness of quality management, resulting in more effective prevention and improvement measures. Leveraging big data for comprehensive quality analysis, control, and improvement across processes, life cycles, and value chains, we advance data-model-driven collaboration throughout the industrial and supply chains. This approach fully utilizes the value of quality data, enabling timely identification of risks and opportunities.

Example 2:  
Aluminum boat base modification

TW Solar, in conjunction with the fixture supplier, designs and transforms the structure of the aluminum boat bottom teeth. The U-shaped bottom teeth of aluminum boat are changed to V-shaped bottom teeth, effectively reducing the occurrence of Al<sub>2</sub>O<sub>3</sub> plating.



Figure 3.5 Improvement in Cell Plating by TW Solar and Partner Suppliers

Example 3:  
Modification of furnace body (insulating block)

TW Solar, in conjunction with equipment suppliers, designs the furnace body ceramic block structure and transforms the distribution of ceramic barrier blocks in the annealing furnace body to reduce the spacing between support points, optimize the furnace wire layout and support structure, reduce thermal stress concentration, extend the service life of spare parts, and reduce the loss by 85% after phase change N:L1.

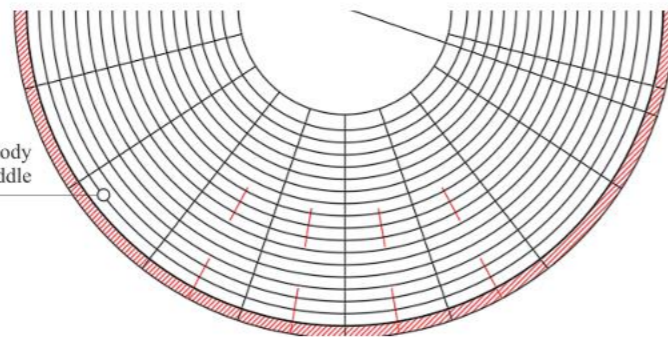


Figure 3.6: Spare Parts Cost Reduction Improvements with TW Solar and Partner Suppliers

Example 4:  
Graphite boat weight reduction

TW Solar, in conjunction with equipment suppliers, reduces the weight of the graphite boat by 7.4kg and reduces motor power consumption by modifying the outer diameter of the ceramic tube of the graphite boat. In addition, the graphite boat mainly plays the role of carrying silicon wafers. The key dimensions of the carrier (tooth spacing, cassette height, cassette width) are unchanged and will not affect the quality.

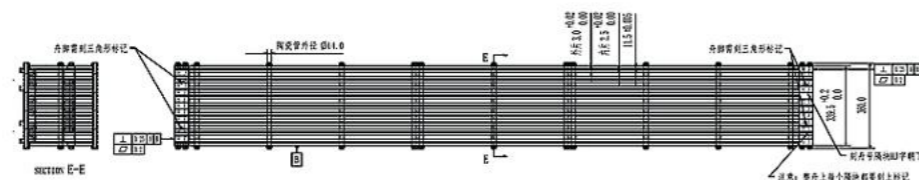


Figure 3.7: TW Solar and Suppliers Collaborate on Motor Energy Consumption Reduction

# Chapter IV

## Part

### Future Trends and Initiatives of PV Quality



4.1

# Digital quality: Intelligence and Wisdom

## Digitalized Production Workshop in an Industry 4.0 Smart Industrial Park



200+ Intelligent manufacturing lines

3000+ Intelligent transport robots



Industry 4.0 High-efficiency automated cell production line

Leading the world 5G Application Base in Photovoltaic Industry



5G proprietary frequency band Stability up to 99.999%

We are committed to building a “digital operation and control capability for solar modules”, aiming to enhance data governance while controlling costs. This involves managing product quality through capabilities such as production process control, big data analytics, refined cost management, and end-to-end product quality control.

## "1+1+3+3" Strategy for Overall Architecture of Digital Intelligent Plant

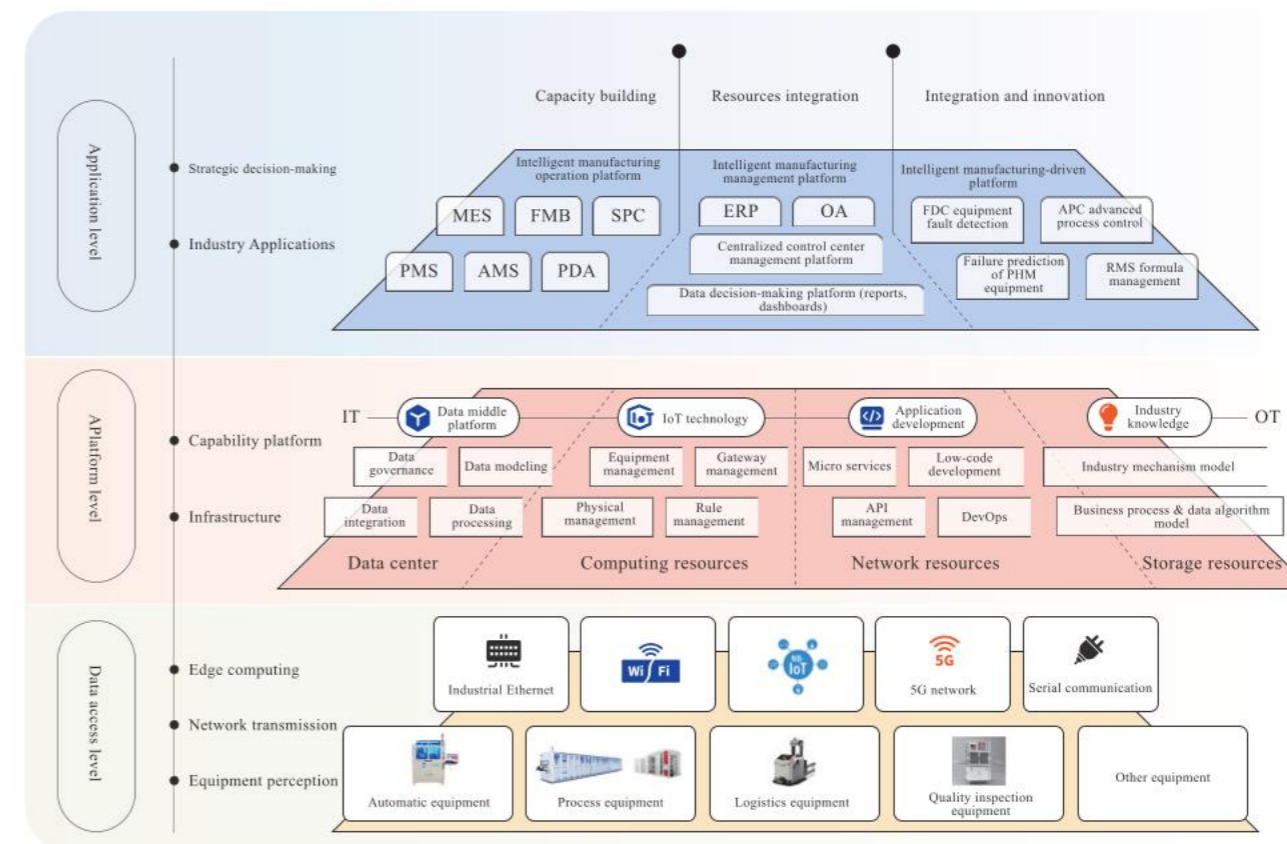


Figure 4.1 Overall Architecture of TW Solar's Digital Intelligent Plant

### "1" basic platform

Develop an industrial Internet foundational platform encompassing infrastructure, data middle platform, IoT technologies, application development, and integrated industry expertise. This platform aims to achieve three key objectives: enhancing informatization, building core capabilities, and enabling collaborative integration, thereby supporting efficient development, operation, and maintenance of industrial applications.

### "1" access system

Through the digital transformation of EAP systems and equipment, unify equipment access standards and specifications to achieve data collection and cell-level traceability; build an industrial control network to achieve rapid access and interconnection of automation equipment, process equipment, testing equipment and other equipment.

### "3" Improvement Stages

The entire digital transformation process involves three progressive stages: capability building, resource integration, and integrated innovation accompanied by organizational optimization and transformation within the enterprise.

### "3" intelligent manufacturing application platforms

Starting from the enhancement of fundamental digital capabilities and based on an Industrial Internet platform, the integration of existing systems with the development of new industrial applications forms three major application domains: intelligent manufacturing operations, management, and drive. This framework drives the enterprise's transformation and upgrading toward smart manufacturing.

# Digital Use Case Panorama

Cost Reduction	Efficiency Increase	Quality control	Equipment	Supply Chain
<ul style="list-style-type: none"> <li>Full-process multi-objective intelligent production scheduling based on operations research model</li> <li>Flexible rework processing based on AOI image recognition and AGV linkage</li> <li>Automatic closed-loop optimization of tubular equipment</li> <li>Automatic spot check system for workshop mechanical meters</li> <li>Automatic handling system of graphite boat</li> <li>Automatic handling system of quartz boat</li> <li>Automatic unpacking machine</li> <li>Automatic receiving machine of FQC finished product</li> <li>Automatic control system for the tail exhaust of coating vacuum pumps</li> <li>Self-made table paper</li> <li>Automatic detection and control system for hydrogen content of cleaning equipment</li> </ul>	<ul style="list-style-type: none"> <li>End-to-end cell efficiency optimization driven by billion-level big data models</li> <li>Closed-loop efficiency control based on intelligent analysis</li> <li>Deep learning model for optimizing the use of high-value materials</li> <li>Intelligent management for high-value consumables life prediction</li> <li>Wafer-level traceability of solar cells based on data acquisition</li> <li>Digital monitoring and automation implementation of key processes</li> <li>Intelligent spot check of process parameters</li> <li>Sheet resistance model prediction</li> <li>SMBB test modification project</li> </ul>	<ul style="list-style-type: none"> <li>Intelligent detection of coating thickness based on CNN/DNN and optimization control empowered by big data</li> <li>Closed-loop management of quality issues based on wafer-level tracking</li> <li>Monitoring system based on the quality of incoming materials throughout the process</li> <li>High-order process abnormality diagnosis</li> <li>Comprehensive full-process image diagnosis</li> <li>Big data EL intelligent segmentation</li> <li>Intelligent EL re-assessment</li> <li>Automatic inspection of screen</li> <li>Automatic test and analysis of sheet resistance</li> <li>Automatic test and analysis of weight loss</li> </ul>	<ul style="list-style-type: none"> <li>Digital energy management system based on advanced analytics</li> <li>Equipment OEE management based on GenAI expert system</li> <li>Diagnosis based on active alarm of equipment</li> <li>Equipment health assessment and predictive maintenance recommendations</li> <li>Alarm notification via smart wristband</li> <li>Electronic workflow work order</li> </ul>	<ul style="list-style-type: none"> <li>Intelligent assembly of cell products</li> <li>Material transfer between processes via IGV trolley</li> <li>Outdoor 5G unmanned forklift</li> <li>Smart park management</li> <li>Intelligent warehouse management</li> <li>Smart financial management</li> <li>Digital ERP4.0</li> </ul>
			Factory safety and environmental protection	Smart office
			<ul style="list-style-type: none"> <li>Intelligent facility operation and maintenance system</li> <li>EHS safety platform</li> <li>Timely push of alarm information</li> <li>Energy management system</li> <li>Water balance system</li> <li>Efficiency improvement of refrigeration system</li> <li>Consumables consignment management system</li> </ul>	<ul style="list-style-type: none"> <li>PV cloud disk</li> <li>Photovoltaic learning center</li> <li>TW Solar</li> <li>Creative Center</li> <li>FBC Process Center</li> </ul>

Leveraging outstanding practices in intelligent manufacturing and exceptional corporate management, we are building an Industry 4.0 digital smart plant, establishing a data-driven, intelligent operation framework known as "Digital TW" and "Smart TW".



Figure 4.2 Intelligent Manufacturing System Diagram of TW Solar Lighthouse Factory

## Case 1: Single cell traceability management system

Traditional cell traceability is carried out by batch and cassette, but the data granularity is too coarse to accurately locate. Abnormality analysis and investigation require manual backtracking, which is time-consuming and prevents rapid root cause analysis. TW Solar has developed a single cell traceability management system. Through real-time interaction between EAP and equipment, MES generates a virtual ID for each cell according to the rules, records the position changes of the physical cell and the virtual ID, and forms the production history of each cell.

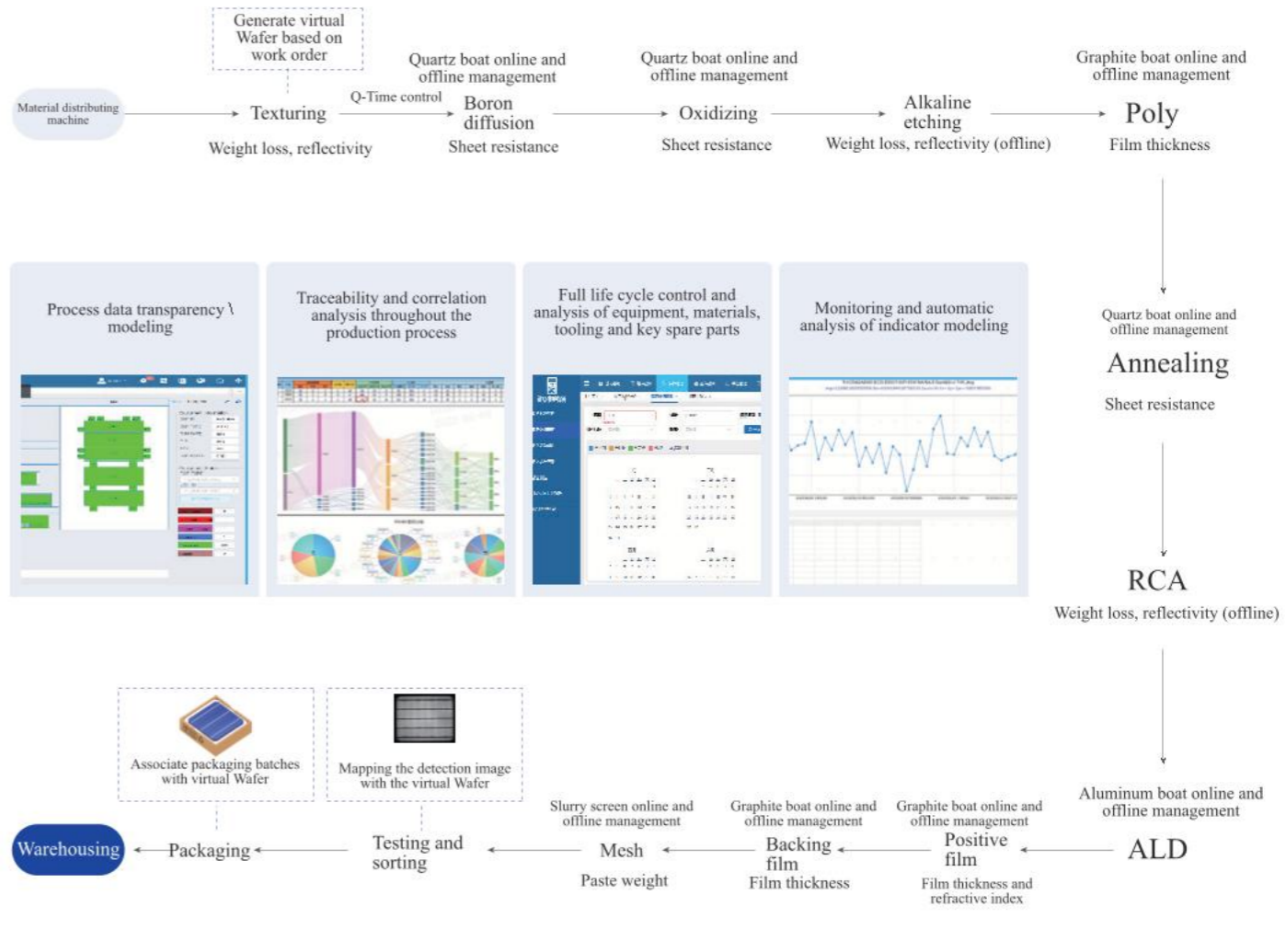


Figure 4.3 TW Solar Single Cell Traceability Management System

Achieve cell-level traceability for batteries, enabling identification of specific furnace tubes and boats, with full integration of all production data prior to in-house testing and sorting:

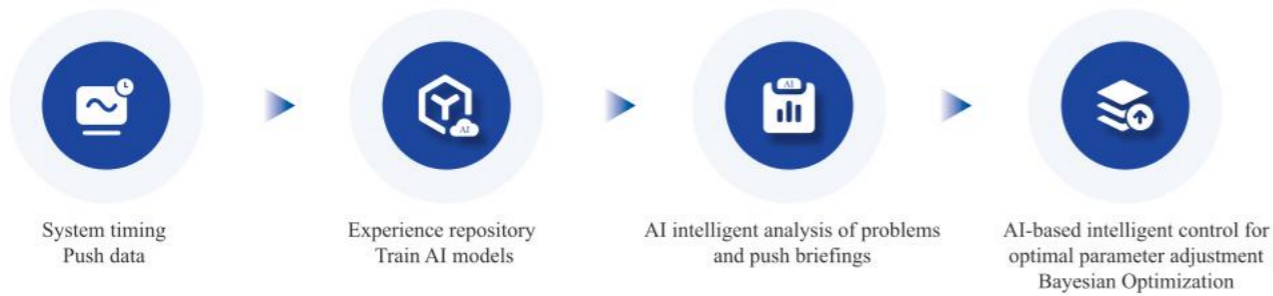
1. By implementing a single-cell traceability system on-site, abnormal cell positions can be quickly located, with an average root cause identification time of less than 30 seconds. This significantly improves the accuracy of defect tracking and enables timely detection and handling of anomalies, effectively reducing the continued output of defective products during the fault-location period.
2. The system continuously collects big data related to "product characteristics-process characteristics", providing high-quality data support for model building and AI training, driving the continuous optimization of process and production models, and helping enterprises reduce costs and increase efficiency.

**Case 2:**  
AI quality inspection and early warning

Manual quality inspections on traditional production lines present the following challenges:

- Abnormalities are prone to missed processing,
- Unable to monitor alarms in real time,
- No closed-loop feedback measures,
- Abnormal data feedback information is discrete and difficult to statistically analyze
- Personnel turnover leads to experience gaps and make it difficult to effectively solve problems.

Improvement direction: shift from traditional improvement concepts to the underlying logic of "AI-driven preventive quality control".



1. Based on the test machine detection data, establish early warning rules, push early warning information to the mobile terminal through the MES system, turn sampling inspection into comprehensive monitoring, improve the timeliness of abnormal discovery and feedback, and support real-time monitoring alarm. Abnormalities are included in the closed-loop feedback process, and ledgers are automatically generated and saved, connecting the experience repository, AI model, and production equipment into a complete closed-loop system.

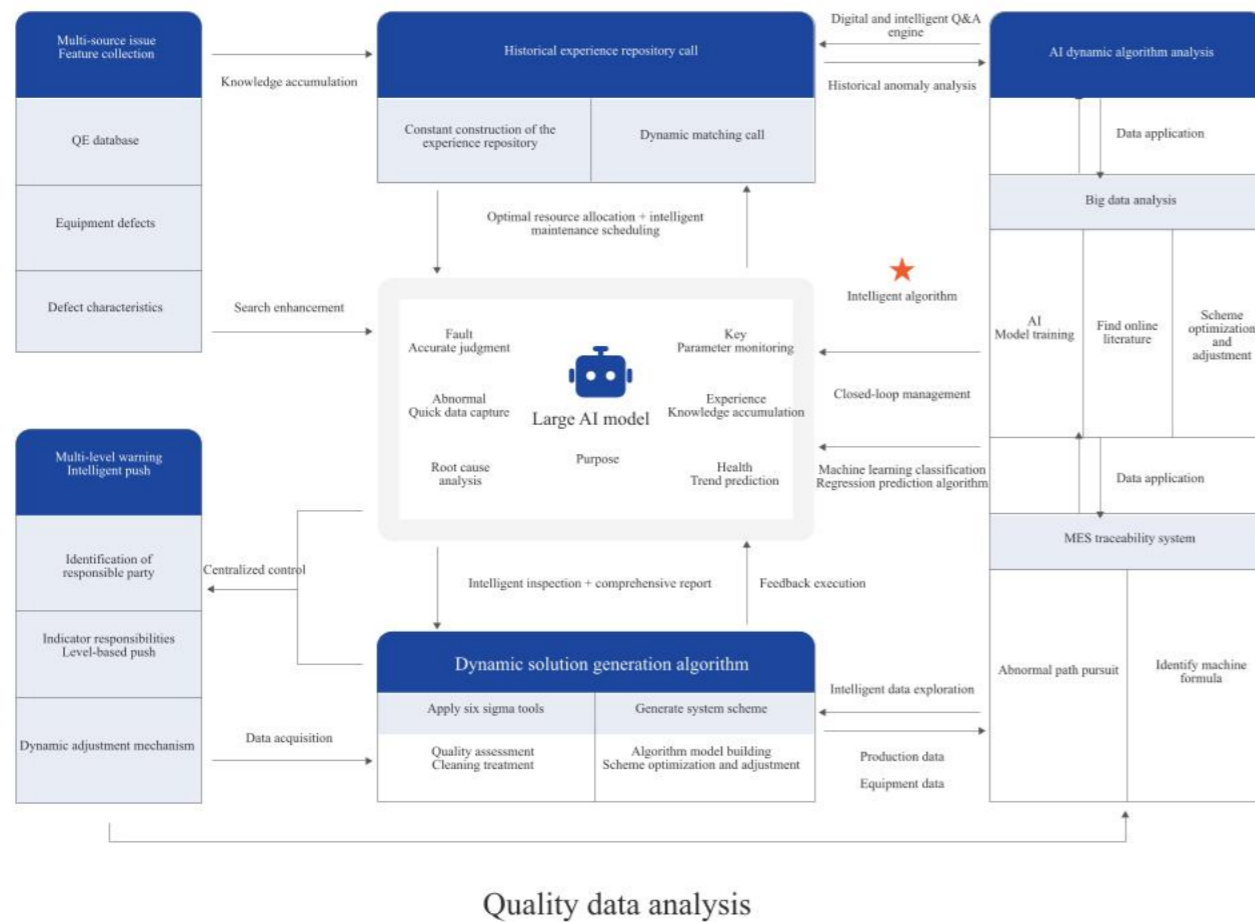


Figure 4.4 TW Solar Intelligent AI Connection Index Analysis and Push System

2. Establish an engineer experience repository, deploy local AI, and intensively refine training models. By realizing full-process intelligence for "data collection-analysis-execution-feedback", we harness AI for data analysis, prediction, and automation to overcome the limitations faced by employees in managing complex systems. Ultimately, this leads to sustained improvement in A-level rates and a flexible upgrade to the production system.

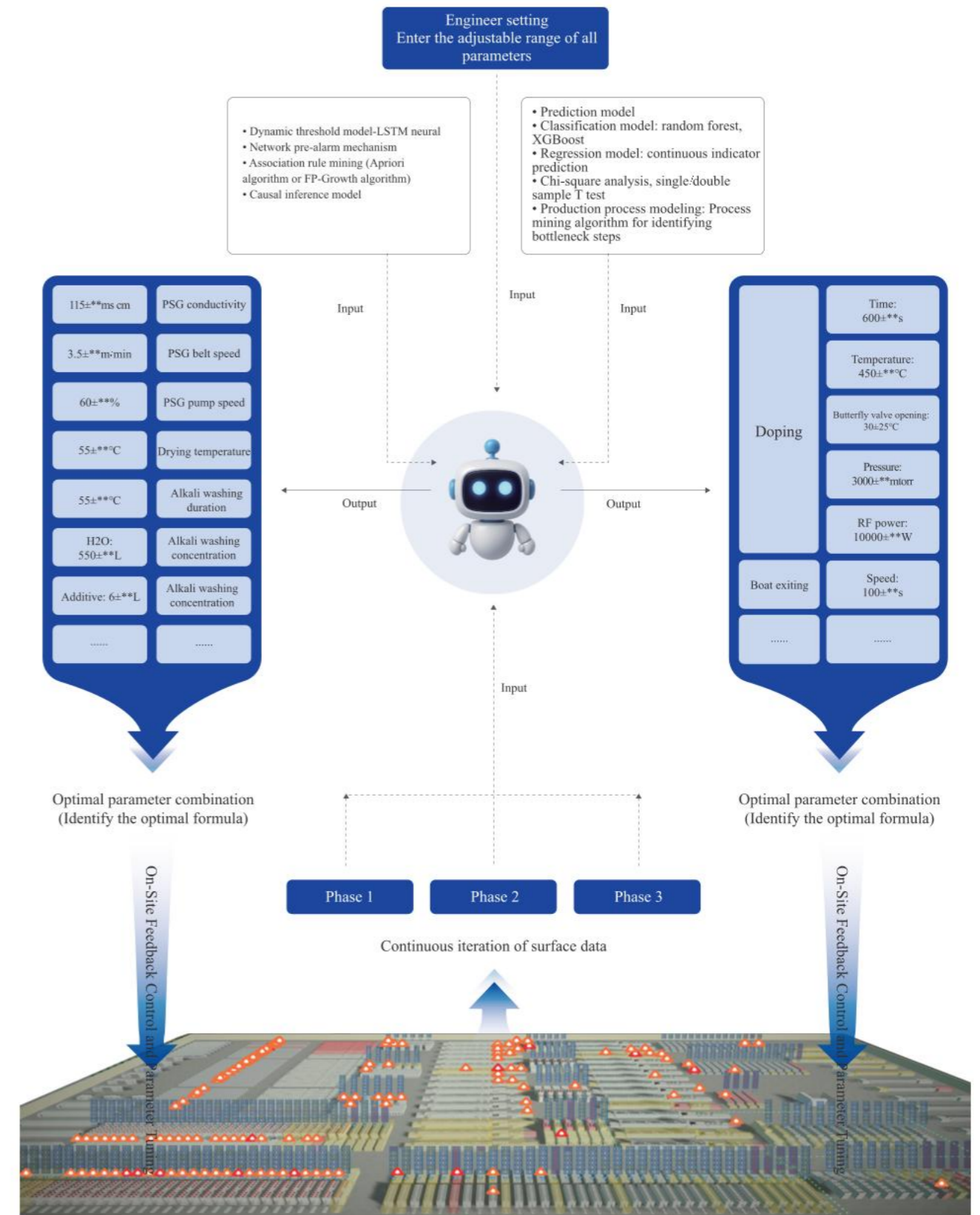
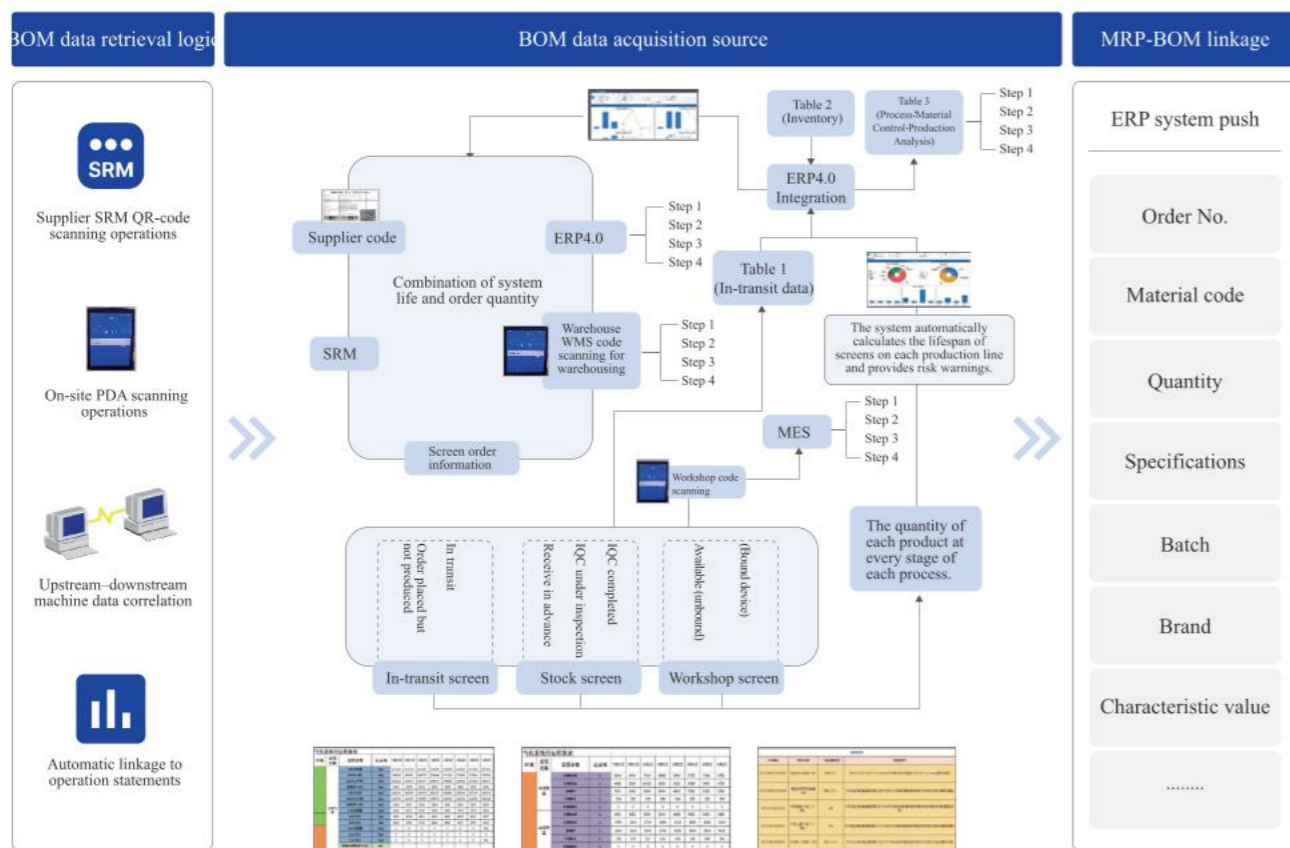
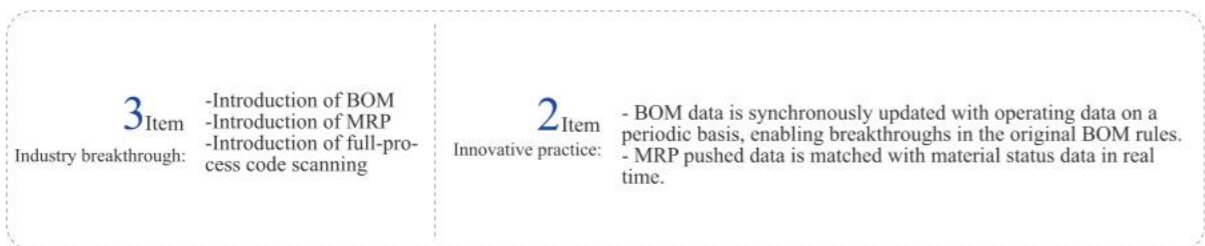


Figure 4.5 TW Solar Intelligent AI Reverse Control System

Case 3:  
MRP and BOM linkage

TW Solar pioneered a full-material control BOM in the solar cell industry, integrating BOM data with APS to automatically generate MRP material requirements, supporting full lifecycle data tracking and precise material management.



4.6 TW Solar MRP-BOM Linkage System

**BOM data 1:** Silicon wafers, screens, and pastes are all put online by scanning the code throughout the process to achieve full-process data tracking and 100% data perspective.

**BOM data 2:** Chemical reagents, additives, gases, and packaging materials use operational data with automatic data retrieval and linkage.

Through BOM data, APS production scheduling automatically matches and generates MRP material demand information push-down.

4.2

# Innovation drives the future

TW has always adhered to the development based on technology and driven by innovation. TW has established the industry's most advanced and comprehensive R&D platform, strategically focusing on mainstream technologies including TOPCon, HJT, XBC, and perovskite/crystalline silicon tandem cells and modules, thereby driving technological progress within the sector. Powered by the continuous infusion of robust R&D capabilities from TW's Global Innovation and R&D Center, TW is deepening its commitment to photovoltaic technology innovation, advancing steadily and making meaningful contributions to sustainable development both in China and worldwide<sup>[7]</sup>.

**通威 THC+THL**  
Tongwei HJT+THL

行业HJT电池及组件标杆  
完美的双面电池，适合高温双面发电

研发最高批次效率 **26.2%**  
Highest cell efficiency in R&D line: 26.2%

**通威 TNC**  
Tongwei TOPCon

通威自研PE-poly技术路线  
具有性价比优势，全场景应用

量产电池效率 **26.33%**  
Mass production cell efficiency of 26.33%

**通威 TBC**  
Tongwei BC

行业最先进水平行列  
最高效率，最佳单面应用

量产电池效率 **26.8%**  
Mass production cell efficiency of 26.8%

**钙钛矿硅叠层技术**  
Perovskite-silicon Tandem Technology

超越晶硅单结电池29.56%效率极限  
下一代电池技术研究热点

实验室电池效率 **34.78%**  
Laboratory Cell Efficiency: 34.78%

4.3

# Quality Initiatives in the Photovoltaic Industry

At present, with the expansion of market scale and the reconstruction of regional pattern, the global photovoltaic industry is undergoing structural changes. The rapid development of China's photovoltaic industry has achieved absolute advantages in all links and dominated the world. At the same time, it is also facing the dual pressures of overcapacity and technological iteration.

In the rapid development of the photovoltaic industry, there remain many areas that call for greater industry consensus and standardization, such as the definition of uniformity indicators, process SPC control strategies, FMEA rating standards, and supply chain traceability management. We look forward to working with our peers across the industry to explore more practical applications of continuous improvement and lean management in the transformation and upgrading of manufacturing.

With value creation as its core, TW Solar supports the integration of industrial chains and resource optimization, and works with industry partners to jointly promote the high-quality development of the photovoltaic industry.

## Distribution Map of Various Industrial Chains in PV Industry-Silicon Materials

### Inner Mongolia

Inner Mongolia Jingyuntong New Materials Technology Co., Ltd.  
Baotou JA Solar Technology Co., Ltd.  
Hongyuan New Materials (Baotou) Co., Ltd.  
Inner Mongolia Tongwei High-Purity Silicon Co., Ltd.  
Inner Mongolia Ordos High-Tech Silicon Materials Co., Ltd.  
Inner Mongolia Xinyuan Silicon Material Technology Co., Ltd.  
Inner Mongolia Daquan New Energy Co., Ltd.  
Inner Mongolia Xinte Silicon Material Co., Ltd.  
Inner Mongolia Zhonghuan Crystal Material Co., Ltd.

### Qinghai

Asia Silicon (Qinghai) Co., Ltd.  
Qinghai Lihao Qingneng Co., Ltd.  
Qinghai Asia Silicon Semiconductor Co., Ltd.  
Qinghai Asia Silicon Material Co., Ltd.

### Sichuan

Sichuan Jinko Energy Co., Ltd.  
Leshan Jingyuntong Semiconductor Material Co., Ltd.  
Sichuan Yongxiang New Energy Co., Ltd.  
Sichuan Yongxiang Polysilicon Co., Ltd.

### Yunnan

Qujing LONGi Silicon Materials Co., Ltd.  
Qujing JA Solar Technology Co., Ltd.  
Lijiang LONGi Silicon Materials Co., Ltd.  
Yunnan Tongwei High Purity Crystalline Silicon Co., Ltd.



## Distribution Map of Various Industrial Chains in PV Industry-Silver Paste

### Shaanxi

Xi'an Chuanglian Photovoltaic New Material Co., Ltd.

### Hunan

Hunan LEED Electronic Ink Co., Ltd.

### Henan

Henan Haofeng Aluminum Industry Technology Development Co., Ltd.

### Sichuan

Sichuan DKEM Electronic Materials Co., Ltd.



Source: Yinchuang Think Tank and TW Solar's partner supplier

## Distribution Map of Various Industrial Chains in PV Industry-Silicon Wafer

### Xinjiang

Xinjiang Daqo New Energy Co., Ltd.  
East Hope Group Co., Ltd.  
Xinte Energy Co., Ltd.

### Shanxi

Shanxi Lu'an Solar Energy Technology Co., Ltd.

### Shaanxi

Xi'an LONGi Silicon Technology Co., Ltd.  
Shaanxi Non-ferrous Photovoltaic Technology Co., Ltd.  
LONGi Green Energy Technology Co., Ltd.

### Qinghai

Asia Silicon (Qinghai) Co., Ltd.

### Sichuan

Sichuan Yongxiang Co., Ltd.  
GCL Group Holdings Limited  
Tonghe New Energy (Jintang) Co., Ltd.  
Leshan Jingyuntong New Materials Technology Co., Ltd.  
Leshan Jingyuntong Silicon Wafer Co., Ltd.  
Sichuan Xingdefei New Energy Co., Ltd.  
Sichuan Yongxiang PV Technology Co., Ltd.  
Sichuan Gokin Solar Technology Co., Ltd.  
Zhongwei New Energy (Chengdu) Co., Ltd.

### Henan

China Silicon Corporation Ltd.  
Henan Hengxing Technology Co., Ltd.

### Hebei

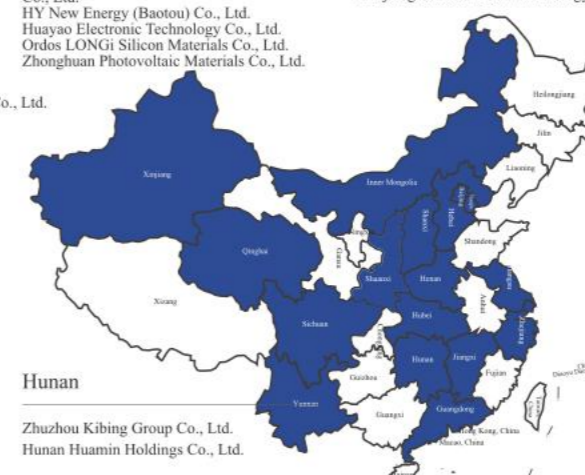
Yingli Green Energy Holdings Limited  
JA Solar Technology Co., Ltd.

### Inner Mongolia

Inner Mongolia Dongli Photovoltaic Electronics Co., Ltd.  
Ordos JA Solar, Inner Mongolia HY Solar, Baotou Meike  
Inner Mongolia Haoan, CSI Solar and Shansheng New Energy  
Lijiang Silicon New Materials (Inner Mongolia) Co., Ltd.  
Inner Mongolia Tongwei Silicon Co., Ltd.  
Hengli Silicon New Materials (Inner Mongolia) Co., Ltd.  
HY New Energy (Baotou) Co., Ltd.  
Huayao Electronic Technology Co., Ltd.  
Ordos LONGi Silicon Materials Co., Ltd.  
Zhonghuan Photovoltaic Materials Co., Ltd.

### Zhejiang

Ningbo Siyuanda New Energy Co., Ltd.  
EGING PV Technology Co., LTD.  
Cixi Hongyu Electric Co., Ltd.  
Quzhou Dongyu Quartz Products Co., Ltd.  
Zhejiang Dongshuo New Energy Co., Ltd.  
Zhejiang Xisheng Electronics Co., Ltd.  
Zhejiang Sunflower Juhui New Energy Technology Co., Ltd.  
Zhejiang Sunoren Solar Technology Co., Ltd.



### Hunan

Zhuzhou Kibing Group Co., Ltd.  
Hunan Huamin Holdings Co., Ltd.

### Yunnan

Chuxiong LONGi Silicon Materials Co., Ltd.  
JinkoSolar (Chuxiong) Co., Ltd.  
Chuxiong Yuze Supply Chain Co., Ltd.  
Yunnan Yuze New Energy Co., Ltd.

### Tianjin

TCL Zhonghuan New Energy Technology Co., Ltd.  
Tianjin Trillion Yi Jing Ding Technology Co., Ltd.  
Tianjin Zhonghuan Photovoltaic Solar Co., Ltd.  
Tianjin Huanou International Silicon Materials Co., Ltd.

### Hubei

Yichang CSG Polysilicon Co. Ltd.

### Beijing

Beijing Jingyuntong Technology Co., Ltd.  
CETC Electronic Equipment Group Co., Ltd.  
Jinzhou Youhua Silicon Materials Co., Ltd.

## Distribution Map of Various Industrial Chains in PV Industry-Photovoltaic Cell

### Xinjiang

Daqo New Energy Co., Ltd.

### Shaanxi

LONGi Green Energy Technology Co., Ltd.

### Guangdong

Aiko Technology Co., Ltd.  
Tuori New Energy Technology Co., Ltd.  
Guangwei Energy Technology Co., Ltd.  
Toupu New Energy Co., Ltd.  
Guofu Photovoltaic Technology Co., Ltd.  
Lixin Group Co., Ltd.

### Shandong

Runsol New Energy Technology Co., Ltd.  
Limu Photovoltaic Hi-Tech Co. Ltd.  
Ronma Solar Technology Co., Ltd.  
Angli Tiansheng Photovoltaic Technology Co., Ltd.

### Sichuan

TW Solar Co., Ltd.  
Sichuan Yingfa Ruineng Technology Co., Ltd.  
SunSync Photovoltaic Technology (Yibin) Co., Ltd.  
Hengdian Group DMEGC Co., Ltd.

### Ningxia

Ningxia LONGi Green Energy New Energy Co., Ltd.

### Guangxi

Guangxi Skyworth New Energy Technology Co., Ltd.

### Yunnan

Yunnan Huasheng New Energy Technology Co., Ltd.

### Zhejiang

Risen ENERGY Co., Ltd.  
EGING PV Technology Co., LTD.  
Ginlong Technologies Co., Ltd.  
Ulica Solar Co., Ltd.  
CHINT Solar Technology Co., Ltd.  
OSDA Solar Co., Ltd.  
DAS Solar Co., Ltd.

### Fujian

Fujian Gold-Stone Energy Co., Ltd.

### Jiangxi

Shanghai Jinko Green Energy Enterprise Management Co., Ltd.  
Jiangxi Zhanfeng Photovoltaic Technology Co., Ltd.

### Jiangsu

Jiangsu Zhongneng Polysilicon Technology Development Co., Ltd.  
GCL-Poly Energy Holdings Limited (HK3800)  
Canadian Solar Inc. (CSI)  
Winsun New Energy Co. Ltd  
Sino-si advanced material Wuxi Co., Ltd  
Runhai Solar Technology Co., Ltd.  
Jiangsu Huasheng Tianlong Optoelectronic Equipment Co., Ltd.  
Aoli Energy Technology Co., Ltd.  
Nanjing Daqo New Energy Co., Ltd.  
Funeng Technology Jiangsu Co., Ltd.  
Jiangsu Shunfeng Photovoltaic Technology Co., Ltd.  
Jiangsu Zhongrun Solar Technology Development Co., Ltd.  
Lianyungang Feiguan Quartz Products Co., Ltd.  
Suzhou Jingying Optoelectronics Technology Co., Ltd.  
Trendy Group Co., Ltd.  
Yangzhou Weiye Innovation Technology Co., Ltd.  
Zhenjiang Rongde New Energy Technology Co., Ltd.  
Wuxi Rongneng Semiconductor Materials Co., Ltd.  
GCL Technology (Suzhou) Co., Ltd.  
Wuxi Jingyuntong Technology Co., Ltd.  
Hongyuan New Materials (Xuzhou) Co., Ltd.  
Changzhou Huayao Optoelectronic Technology Co., Ltd.

### Guangdong

Shenzhen Lemes Silicon Industry Co., Ltd.  
Shenzhen CSG Photovoltaic Energy Co., Ltd.  
Shenzhen S.C New Energy Equipment Co., Ltd.  
Shenzhen Tuori New Energy Technology Co., Ltd.  
Yiteng New Materials Technology Co., Ltd.  
Guangdong Jinwan Gokin Solar Technology Co., Ltd.  
Gokin Solar Co., Ltd.

### Shanghai

Shanghai Aerospace Automobile Electromechanical Co., Ltd.  
Shanghai Comtesolar Technology Co., Ltd.  
Shanghai Shenhe Thermomagnetic Electronics Co., Ltd. (FTS)

### Jiangxi

Jiangxi LDK Solar Hi-tech Co., Ltd.  
Yichun Yuze New Energy Co., Ltd.  
Shanghai Jinko Green Energy Enterprise Management Co., Ltd.

### Shanxi

Shanxi Lu'an Solar Energy Technology Co., Ltd.

### Tianjin

Tianjin Zhonghuan Semiconductor Co., Ltd.

### Jiangsu

Trina Solar Co., Ltd.  
Zhongli Group Co., Ltd.  
Jolywood (Suzhou) Sunwatt Co., Ltd.  
Jiangsu Runergy Yueda PV Technology Co., Ltd.  
Hua'an Jietai New Energy Technology Co., Ltd.  
Canadian Solar Inc. (CSI)  
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Goodwe Technologies Co., Ltd.  
Almaden Co., Ltd.  
Arctech Solar Holding Co., Ltd.  
Jiangsu Zhongrun Solar Technology Co., Ltd.

### Shanghai

GCL System Integration Technology Co., Ltd.  
Shanghai Jinko Green Energy Enterprise Management Co., Ltd.  
Xwoe Energy Technology Co., Ltd.  
Shanghai Aiko Solar Energy Co., Ltd.

### Hebei

JA Solar Technology Co., Ltd.

Source: Yinchuang Think Tank and TW Solar's partner supplier

## Appendixes

- 【1】 China Photovoltaic Industry Association (CPIA)'China Photovoltaic Industry Development Roadmap(2023-2024)'
- 【2】 Infolink Release: 2024 Full-Year Solar Cell Shipment Rankings, February 17, 2025.  
<https://www.infolink-group.com/energy-article/cn/solar-topic-cell-shipment-ranking-2024-top5-yoy-decline>
- 【3】 Infolink '2030 Photovoltaic and Energy Storage Transition White Paper,'p.30
- 【4】 China Photovoltaic Industry Association (CPIA)'2024-2025 China Photovoltaic Industry Development Roadmap,'p.33
- 【5】 Infolink Release: 2025 First-Half Solar Cell Shipment Rankings, August 8, 2025  
<https://www.infolink-group.com/energy-article/cn/solar-top-ic-infolink-1h25-pv-cell-shipment-ranking-top-five-manufacturers-up-13-yoy>
- 【6】 Infolink '2024 Photovoltaic Technology Supply and Demand Report'
- 【7】 Tongwei Release: 25.28%! Tongwei TNC High-Efficiency Module Efficiency Breaks Record Again! March 21, 2025  
<https://www.tongwei.cn/news/11673.html>
- 【8】 'Tongwei Module White Paper,'p.8
- 【9】 Tongwei TNC2.0 Product White Paper P7

## Interpretation of Abbreviations

PERC	Passivated Emitter and Rear Contact
BC	Back Contact
TOPCon	Tunnel Oxide Passivated Contact
HJT	Heterojunction Technology
TNC	Tongwei N-type passivated Contact Technology
OEE	Overall Equipment Effectiveness
FMEA	Failure Mode and Effects Analysis
SPC	Statistical Process Control
TQM	Total Quality Management
QCC	Quality Control Circles
TPM	Total Productive Maintenance
DOE	Design of Experiment
QFD	Quality Function Deployment
VSM	Value Stream Mapping
CTQ	Critical-To-Quality

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