



EQUIPMENT FOR GW CELL PRODUCTION

...for HJT, TOPCon, POLO,
IBC & Tandem Perovskite

SINGULUS 

SINGULUS TECHNOLOGIES

Ready for GW Production



Innovative Technology for Photovoltaics

SINGULUS TECHNOLOGIES develops innovative systems and technologies for efficient and resource-friendly production processes, taking advantage of its existing core technologies including vacuum thin-film coating, surface engineering, wet-chemical and thermal processes as well as automation and process control. The company offers machines worldwide in the market sectors Photovoltaics, Semiconductor, Medical Technology, Packaging, Glass & Automotive as well as Battery & Hydrogen.

A carbon neutral energy system is one of the biggest challenges in the world. Solar power is at the forefront of being one important pillar for sustainable energy supply. Highly efficient photovoltaic cells will pave the road to this destination. Modern storage and battery technologies will sharply increase the use of environmentally friendly energy.

SINGULUS TECHNOLOGIES production equipment follows the requirements of the latest PV cell processes, high throughput, low material and media consumption, thus enabling to improve cell efficiency, to save energy and raw materials and to reduce manufacturing costs for highly efficient solar cells.

New Cell Concepts

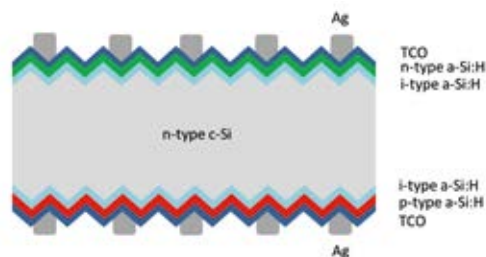
The transfer of new, highly efficient solar cell concepts like HJT, TOPCon, IBC, PERC passivated contacts, and tandem cells successfully into industrial mass production, requires reliable machines covering the following process steps:

- » PVD vacuum thin-film coating (sputtering and evaporation)
- » CVD vacuum thin-film coating (PECVD)
- » Wet chemical processes

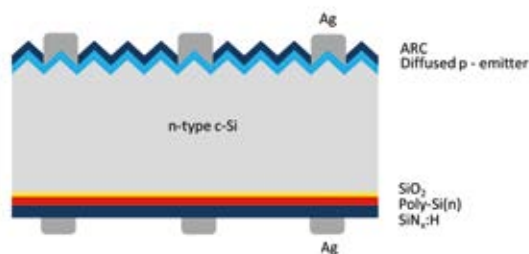
- » Specific thermal processes to achieve optimum layer properties
- » A combination of vacuum, wet chemical, and thermal process technologies for the fabrication of tandem solar cells

The modular tool platforms GENERIS for PVD & PECVD as well as the SILEX platform are continuously improved and adapted to the specific requirements of existing and future crystalline silicon solar cell concepts.

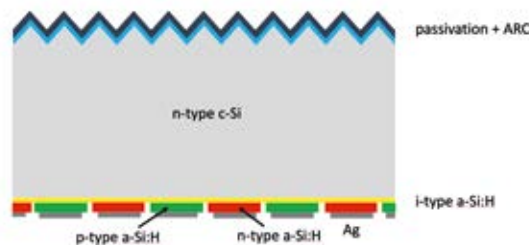
CRYSTALLINE HETEROJUNCTION TECHNOLOGY (HJT/SHJ)



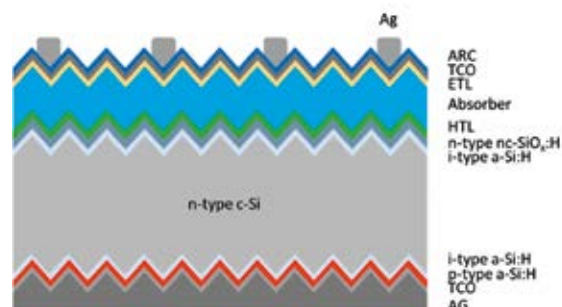
SOLAR CELLS WITH PASSIVATED POLY-SILICON CONTACTS (E.G. TOPCON, POLO)



IBC SOLAR CELLS



TANDEM SOLAR CELLS COMPRISING PEROVSKITE TOP CELL



GENERIS PVD

Inline Sputtering System for High-Performance Solar Cells

GENERIS PVD Sputtering System

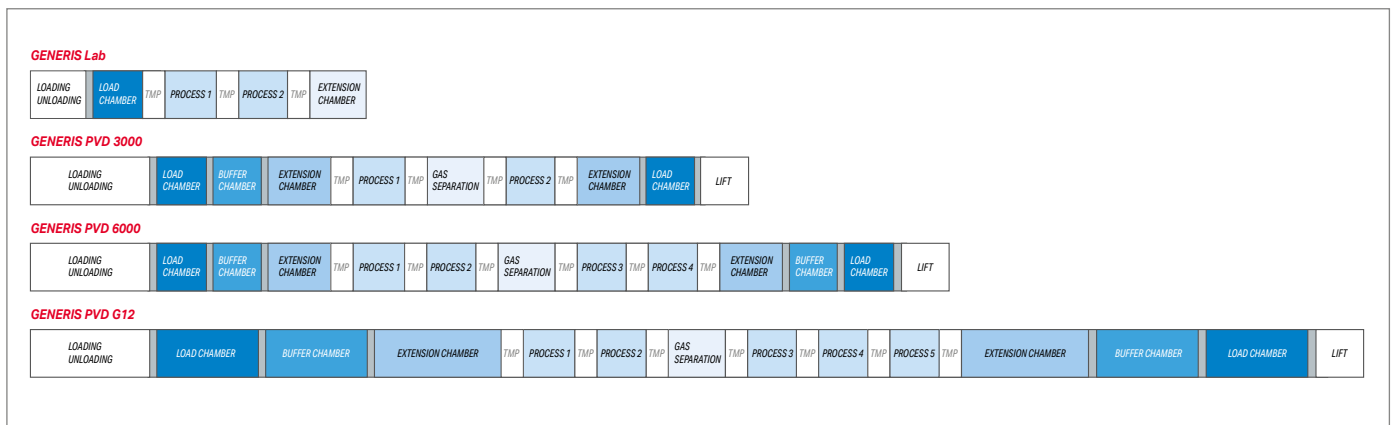
Numerous SINGULUS TECHNOLOGIES vacuum sputtering machines are in operation in the solar industry, where SINGULUS TECHNOLOGIES provides the GENERIS PVD as a high throughput inline sputtering system platform with horizontal substrate transport. The GENERIS PVD ideally meets the key requirements of the heterojunction solar cell technology with respect to sophisticated transparent conductive oxide layers (TCO) such as ITO (Indium Tin Oxide) and AZO (Aluminum doped Zinc Oxide). The solar cells are automatically transported through the process chambers of the GENERIS PVD, following the inline principle, and applying coatings on both sides. The sputtering system safeguards a high level of layer thickness uniformity with high layer reproducibility, high productivity and at the same time very low operating expenses (OPEX).



With the latest system generation GENERIS PVD, SINGULUS TECHNOLOGIES can assure capacities up to 8,000 wafers per hour of G12 HJT cells. There are further savings due to the smaller footprint of the equipment and related smaller building and cleanroom space requirements. The dual-sided processes of the GENERIS PVD



The Modularity of the GENERIS PVD System Allows a High Degree of Flexibility



require less wafer handling resulting in reduced wafer breakage, wafer damage and wafer marks. SINGULUS TECHNOLOGIES takes advantage of in-house engineering of crucial components such as sputtering magnetrons, simulation and optimization of different sputtering processes and processes developed using state-of-the-art sputtering lab equipment at SINGULUS TECHNOLOGIES R&D center. Newly developed processes can be directly industrialized to the GENERIS PVD mass production platform.

TYPICAL PERFORMANCE CHARACTERISTICS

- » Sputtering materials: TCOs and other reactively sputtered layers: ITO, AZO, NiO, TiO₂, SiN and more metallic layers: Ag, Cu, Cr, Mo, Ni and more
- » Applications include anti-reflection layers, barrier layers, electrical contacting or insulating layers
- » Available in different throughput versions of lab, pilot & mass production

- » Wafer size: up to G12 & half cut formats
- » Substrates thickness of down to 60 µm
- » Typical tact time: 40 - 75 s per carrier
- » Parallel processing of substrates (e.g. display, glass, Si wafers) via carrier tray
- » High-speed automatization for carrier tray loading and unloading (single or double side)
- » Top-down and bottom-up sputtering configurable – dual side sputtering without vacuum breakage
- » Full substrate temperature control
- » Low cost of ownership and high uptime
- » Patented features such as fast venting systems and carrier
- » Rotatable cylindrical magnetrons with highest utilization of target material
- » Carrier return system (CRS) underneath
- » Vacuum base pressure: < 1 x 10⁻⁶ mbar



GENERIS PECVD

Inline Plasma Enhanced Chemical Vapor Deposition System for TOPCon, POLO, HJT & PERC Solar Cells

GENERIS PECVD System

SINGULUS TECHNOLOGIES employs inductively coupled plasma (ICP) and capacitively coupled (CCP) sources for inline PECVD coating applications. ICP is a method that offers a high electron and activation density in conjunction with low ion energy, which allows very high deposition rates over a large width and extraordinary layer quality with wide process windows at low substrate damage. Therefore, ICP plasma sources are ideally suitable for high-rate and low-damage mass production of electronic devices like solar cells. CCP is an ideal method for depositing of thin or thick conductive layers, highly doped as needed in the PV cell technology. SINGULUS TECHNOLOGIES has developed new, large-scale linear plasma sources based on ICP and CCP technology. Both technologies are used for processes developed using state-of-the-art PECVD lab equipment at SINGULUS TECHNOLOGIES R&D center.

SINGULUS TECHNOLOGIES has also delivered systems for the deposition of functional layers for the production of gallium arsenide (GaAs) photovoltaic cells. The PECVD coating step is a crucial quality factor for GaAs solar cells that are renowned to achieve very high efficiency in excess of 35 % in multi-junction setup and that are used in space applications for the power generation of satellites.

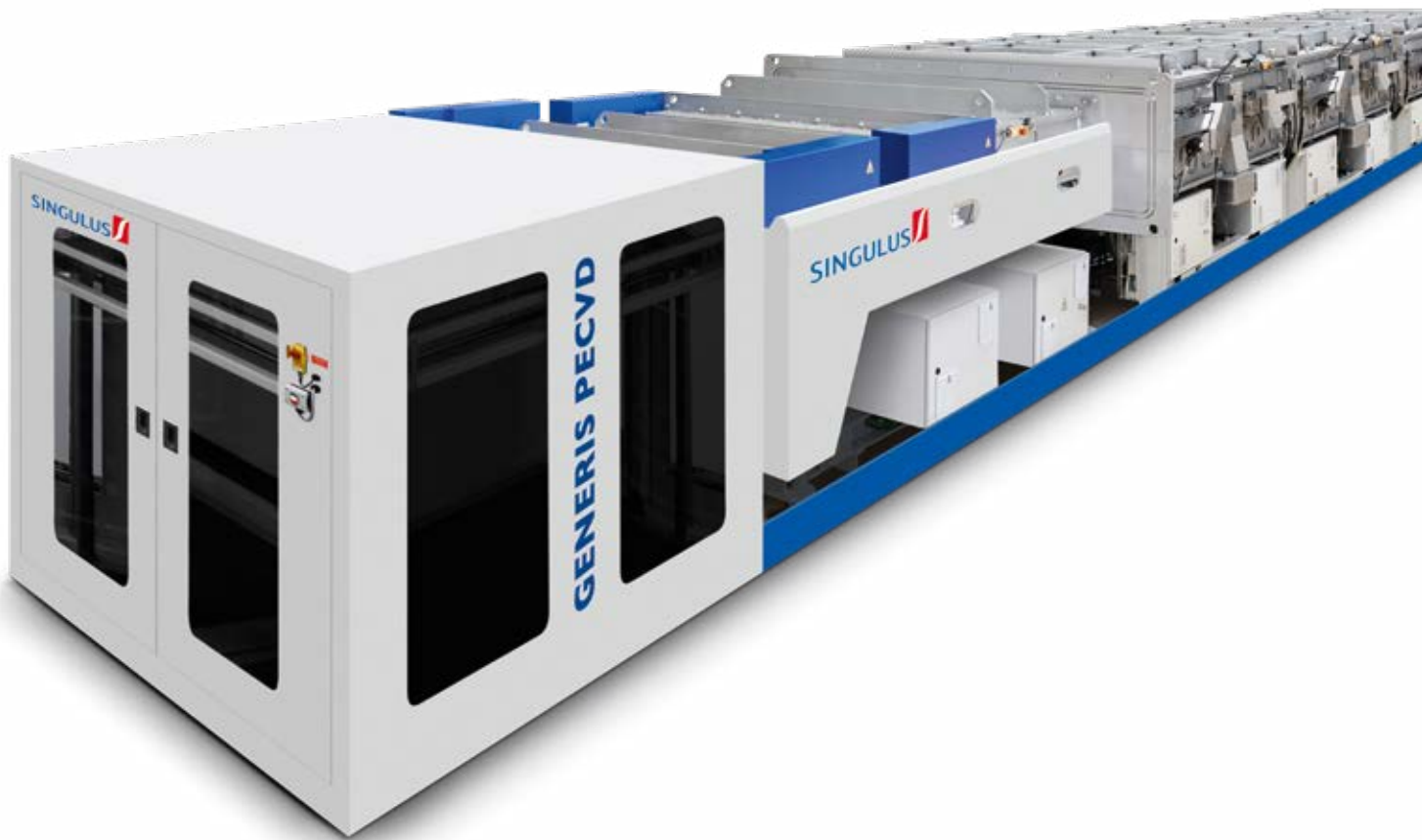
The GENERIS PECVD is a modular horizontal inline tool designed for the special needs in mass production of state-of-the-art crystalline silicon solar cells with highest efficiencies, such as passivated emitter and rear cells (PERC) and cells with passivated contacts (e.g., TOPCon, POLO and HJT). PERC solar cells are coated on both sides with dielectric passivation layers. Rear side passivation is achieved by deposition of a thin

aluminum oxide (AlO_x) layer capped by hydrogen rich silicon nitride (SiN_x:H). On the front side, a layer of SiN_x:H serves as both, passivation, and anti-reflective coating (ARC).

Cells with passivated contacts are coated with conducting amorphous a-Si:H(n,p) or polycrystalline silicon poly-Si:H(n,p) layers single sided in the case of TOPCon or POLO cell structures or both sides in the case of HJT technology. The modular systems are ideally suited for cost effective mass production with high throughput, high uptime, short cleaning interruptions and maximum utilization of raw materials. The substrate temperature is fully controlled during the whole process, which enables optimum layer performance at temperatures from 200 °C to 500 °C for HJT, PERC and TOPCon cells. The thermal properties can be adapted in a wide range for other layer stacks and applications. SINGULUS TECHNOLOGIES carriers allow single side deposition with close to zero wrap-around.

The GENERIS PECVD allows for deposition on both sides of the wafer without vacuum interruption. The application of both processes AlO_x and SiN_x is realized in one common system with a gas separation chamber. Same gas separation chamber enables the deposition of intrinsic and doped amorphous layers without vacuum breakage.

Especially the configuration in which all PECVD layers are deposited in one tool represents a cost attractive, highly productive, and straight forward production solution. High-rate inline deposition of these dielectric or conductive semiconductor structures without wrap-around allows future industrial mass production of more advanced and ultra-high efficient cell architectures like PERC, TOPCon, POLO-BJ HJT and tandem perovskite solar cells.



TYPICAL PERFORMANCE CHARACTERISTICS

- » PECVD materials: a-Si(i,n,p) nc-Si(i,n,p) poly-Si(i,n,p) AlOx, SiNx SiOx and more
- » Typical applications include anti-reflection layers, barrier layers, electrical contacting or insulating layers
- » Available in different versions up to 5,800 wph
- » Wafer size: up to G12 & half cut formats
- » Typical cycle time: 35 - 70 s per carrier
- » Parallel processing of substrates (e.g., display, glass, Si wafers) via carrier tray
- » High-speed automatization for carrier tray loading and unloading (single or double side)
- » Top-down and bottom-up deposition configurable – dual side deposition without vacuum breakage
- » Full substrate temperature control
- » Low cost of ownership and high uptime
- » Coating sequence configurable
- » Highest utilization of precursor material
- » Carrier return system (CRS) underneath of machine



SILEX III

Automated Wet Processing System for Texturing and Cleaning of Solar Cells

SILEX III Batch Wet Processing Equipment

SINGULUS TECHNOLOGIES provides complete automated dry-in/dry-out solutions for wet-chemical treatments of Si-wafers in standard and high-efficiency solar cell lines. The recently introduced modular SILEX III batch system offers a wide range of process options. With respect to highest flexibility in configuration, the SILEX III is characterized by a clear modular design and compact footprint.

The **SILEX III** was specially designed for high production volumes. With this mass production system, which can achieve up to 730 MW annual capacity and more, depending on cell efficiency, all wet chemical applications (batch) at the HJT, TOPCon and PERC cell concepts can be covered. The SILEX III system achieves an output starting up to 14,000 wph (gross), depending on wafer size.

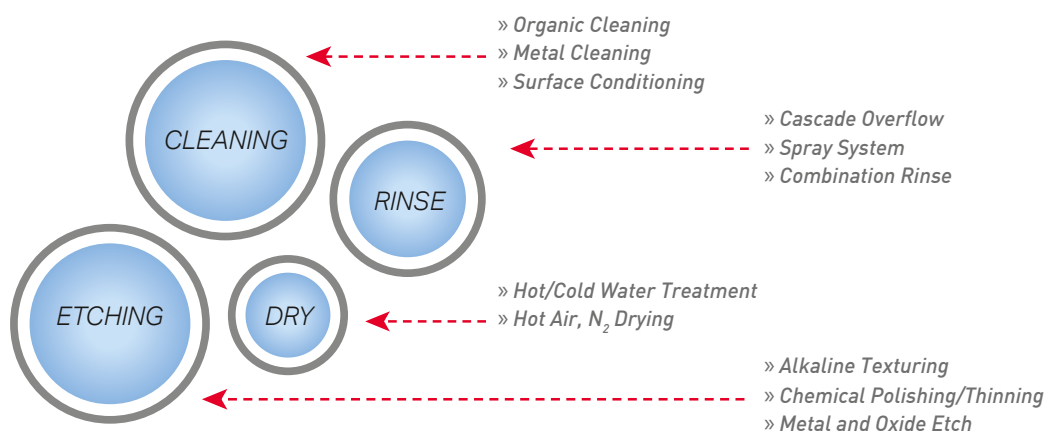
The **SILEX III** combines common etching and cleaning steps of monocrystalline Si with advanced cleaning and conditioning processes.

The heart of the SILEX III is the **alkaline texturing** process improved and adapted to future demands through several years. SINGULUS TECHNOLOGIES guarantees a stable, mass production proven process, which can be used in all common and upcoming cell stacks. Different requirements like pyramid size and shape can be easily adjusted by the use of different additives and process parameters.

Efficient cleaning steps are an indispensable requirement to improve cell efficiencies and reduce operation costs. **Ozone-based cleaning operations**, applied on SILEX III wet bench, combine efficient organic and metal removal with an appropriate surface conditioning under high and stable ozone concentrations due to the self-developed



Common and Advanced Process Applications



SINGOZON system. Due to low chemical costs and consumption, simple process control and high metal removal efficiency, ozonized cleaning baths are the perfect substitute for traditional, expensive multi-step RCA cleanings, known from the solar and semiconductor industry.

The ozone treatment can also be used in combination with HF for **pyramid rounding**, which achieves an optimal surface for passivation in HJT production lines.

Alkaline chemical etch isolation is a PERC and TOPCon relevant process, which can be done, in combination with a prior single side inline HF step, in the SILEX III system. This results in an excellent polished, isolated wafer surface. With this development Singulus offers a HNO₃-free, environmentally friendly option for etch isolation.

The **SILEX III ALTEX** is designed to apply IPA-free texturing processes, offering substantial cost advantages compared to traditional etching systems. This texturing process can be adjusted to the individual requirements of standard and advanced cell technologies.

The **SILEX III CLEAN** is provided to run dedicated cleaning sequences for pre- or post-deposition processes. Depending on cell process flow and requirement the configuration can be designed individually, involving RCA or Ozone based cleanings as well as slight etching steps.

TYPICAL PERFORMANCE CHARACTERISTICS

- » High throughput up to 14,000 wph gross; wafer size: up to G12
- » High throughput for GW scale mass production
- » Short, stable, and adjustable texturing process
- » Low cost of ownership and high uptime
- » Low breakage rate < 0.01 %
- » Ozone-enhanced cleaning & etching
- » Appropriate and effective rinsing and drying
- » Individual, flexible process sequencing
- » Onboard scheduler software for throughput and recipe tuning
- » Onboard performance analyzer software
- » Intelligent water-cascading for optimal rinsing quality by low water consumption
- » Smart integration of different rinsing principles for decreasing of media carry over
- » Ideal feed and bleed balance permits long bath lifetimes



Turn-Key Solutions for HJT and TOPCon Solar Cell

SINGULUS TECHNOLOGIES is the Full Solution Provider for Cell Lines from Design

SINGULUS TECHNOLOGIES Business System

- » Greenfield or existing building integrated turn-key solutions for TOPCon or HJT solar cell lines
- » Full-service provider – one contract, one general contractor
- » Technology analysis for investment decisions
- » Business case creation support (technical due diligence, risk assessment and furthers)
- » Comprehensive engineering services for equipment-, automatization- and overall fab planning, including facility- and utility structure
- » Project Management (technical & administration)
- » Consulting/Support on building related questions (for line integration)

WAFER FEED-IN

Inspection and Loading

Process Step 1

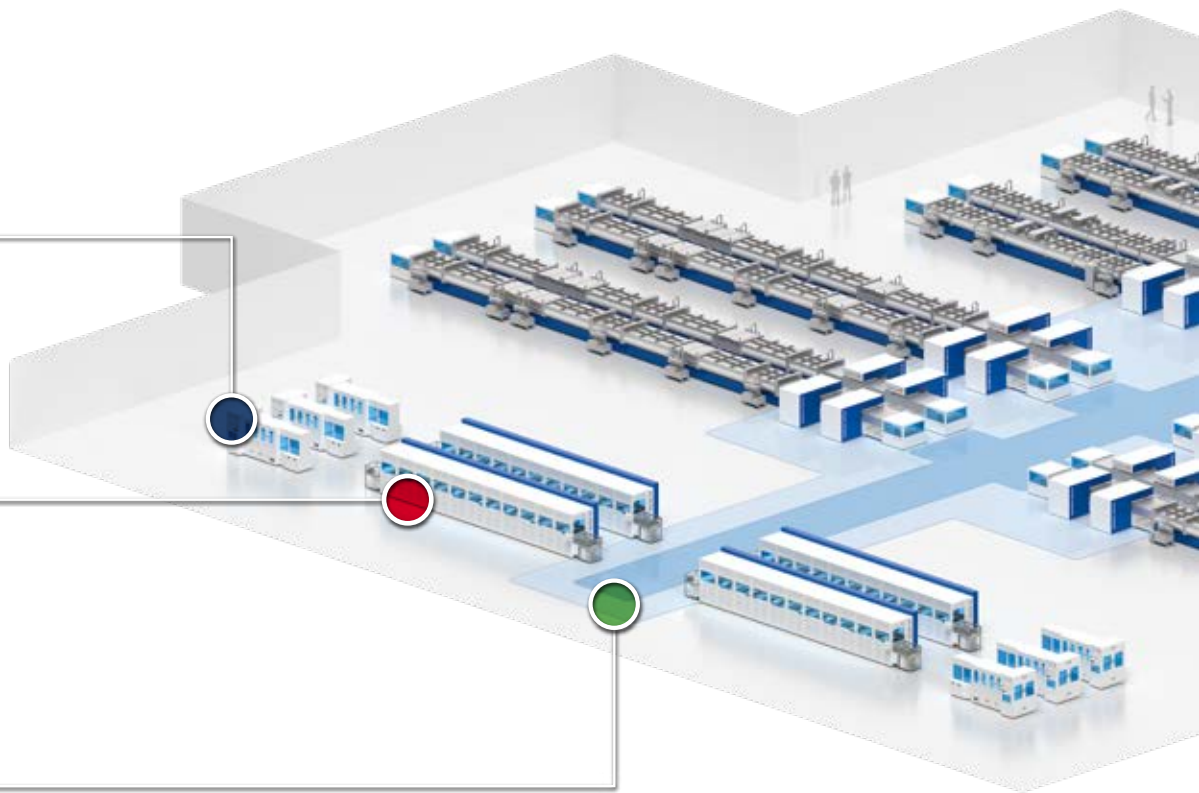
WET CHEMICAL

Cleaning and Texturing

Process Step 2

SINGULUS 

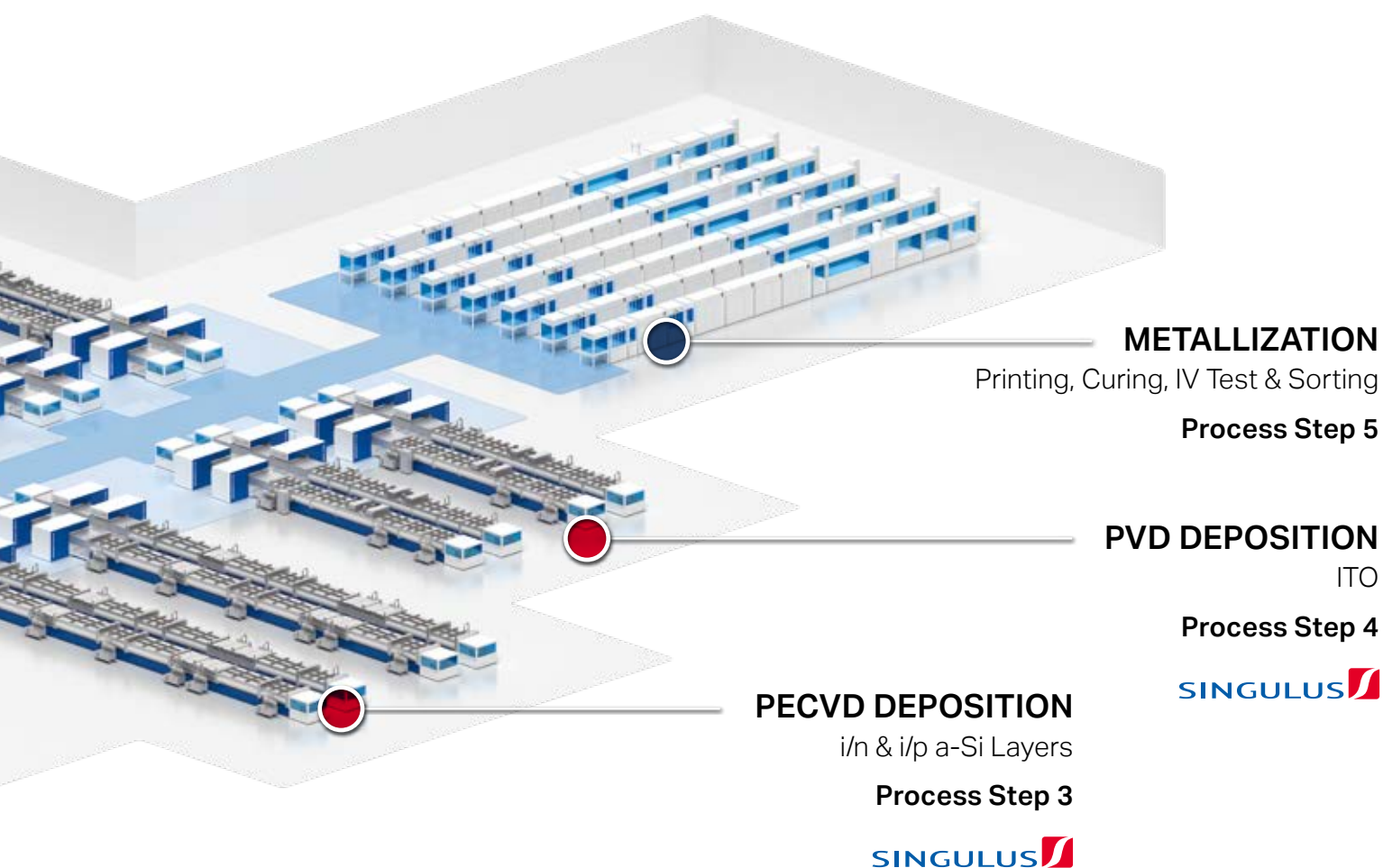
CLEANROOM



Lines

to Mass Production

- » Training of staff
- » Equipment move-in, installation and production line interconnection
- » Supply of state-of-the-art equipment
- » Process transfer line ramp-up and production line hand-over
- » Long-term process services, to provide process- and product technology roadmap for increase of cell efficiency and module power
- » Partnership with tier 1 solar institutes for up-to-date product and process development





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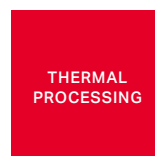
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SINGULUS TECHNOLOGIES - Thin-Film Coating and Surface Treatment

SINGULUS TECHNOLOGIES develops and assembles innovative machines and systems for efficient thin-film coating and surface treatment processes, which are used worldwide in the Photovoltaics, Semiconductor, Medical Technology, Packaging, Glass & Automotive as well as Battery & Hydrogen markets.

The company's core competencies include various processes of coating technology, surface treatment as well as wet-chemical and thermal production processes. SINGULUS TECHNOLOGIES sees sustainability as an opportunity to position itself with innovative products. In the focus are:

- » Environmental awareness
- » Efficient use of resources
- » Avoidance of unnecessary CO₂ pollution

SINGULUS TECHNOLOGIES attaches great importance to responsible and sustainable corporate governance.