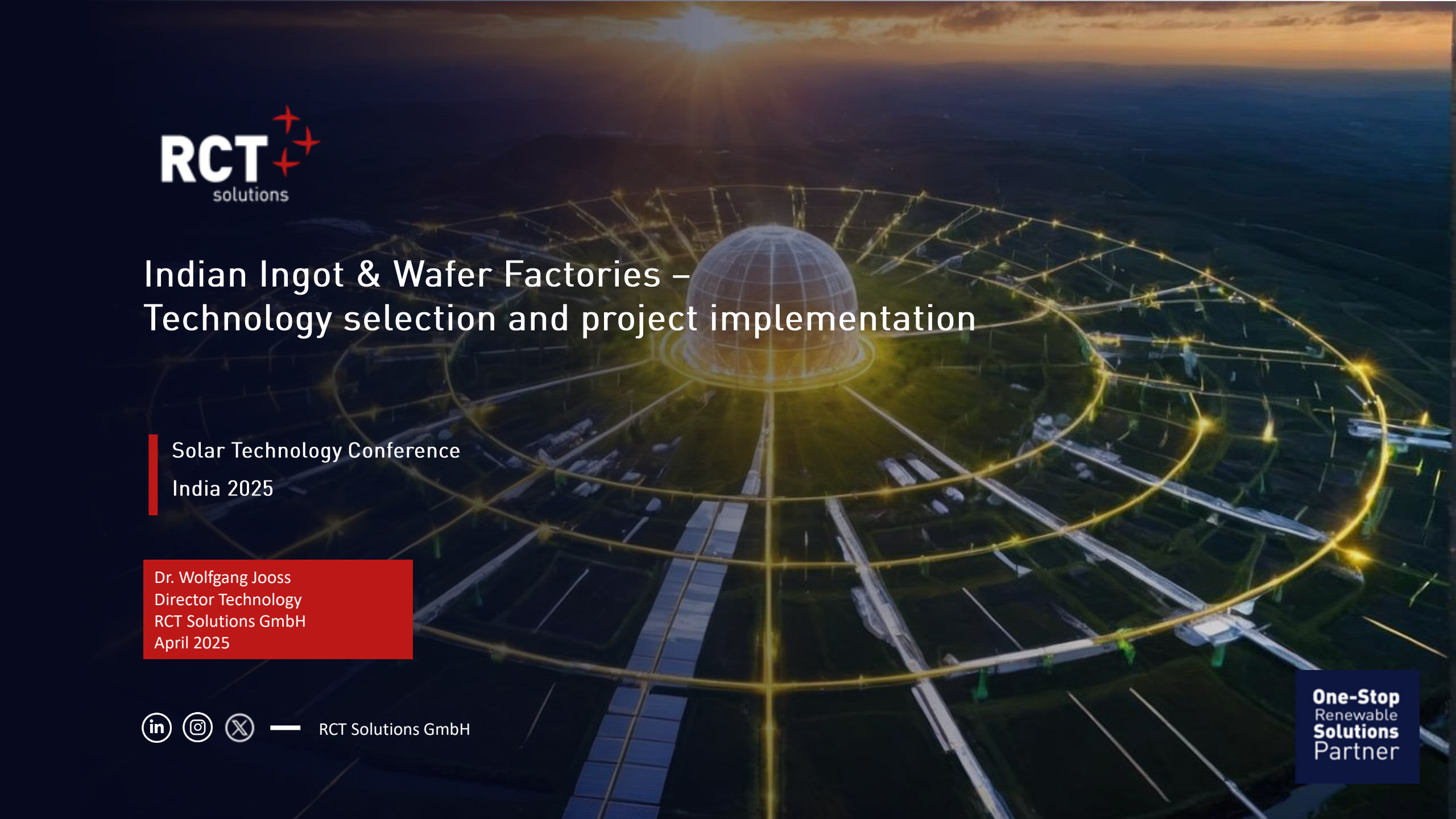


Indian Ingot & Wafer Factories – Technology selection and project implementation

Solar Technology Conference

India 2025

Dr. Wolfgang Jooss
Director Technology
RCT Solutions GmbH
April 2025

One-Stop Renewable Solutions Partner

RCT Group at a glance

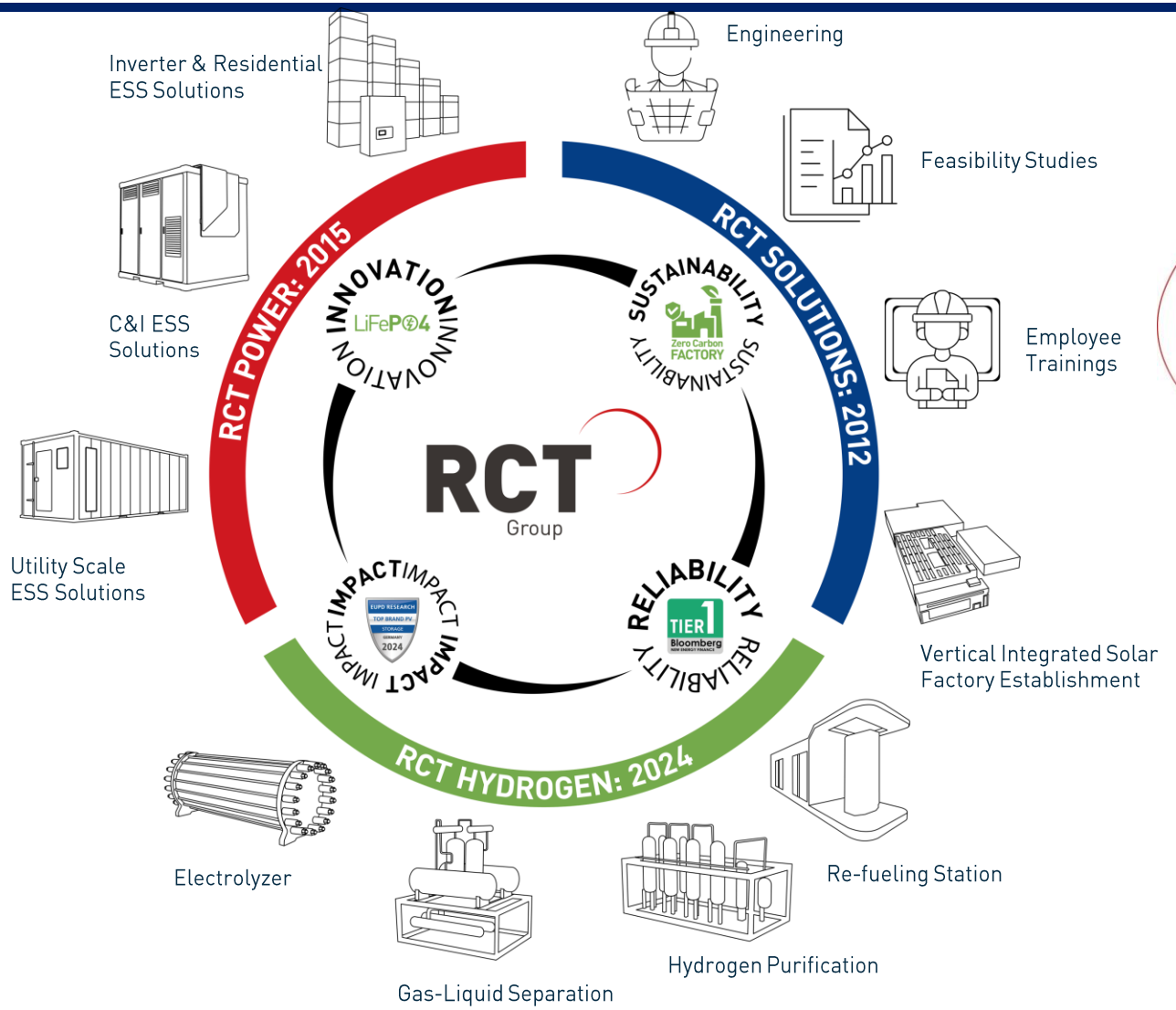
74 GW Integrated Solar Technology Factories establishment in **26** Countries since **2012.**
Local presence in **4** countries.
A key partner of **PV technology investors,** governments & research institutes.

One of its kind PV Turnkey solutions partner to integrated manufacturing projects"

Germany based **Tier 1** Manufacturer of Inverter & Batteries for Residential, C&I and Utility ESS (Energy Storage Systems)

20 GW annual production capacity of **4** factories since **2015**

Green hydrogen equipment manufacturer with **250 MW** capacity factory since **2024.**
A Europe based comprehensive solution partner for hydrogen turnkey projects with **engineering, feasibility, maintenance and training service.**



The Global Top Brand for
Renewable Manufacturing

Headquarter
Germany

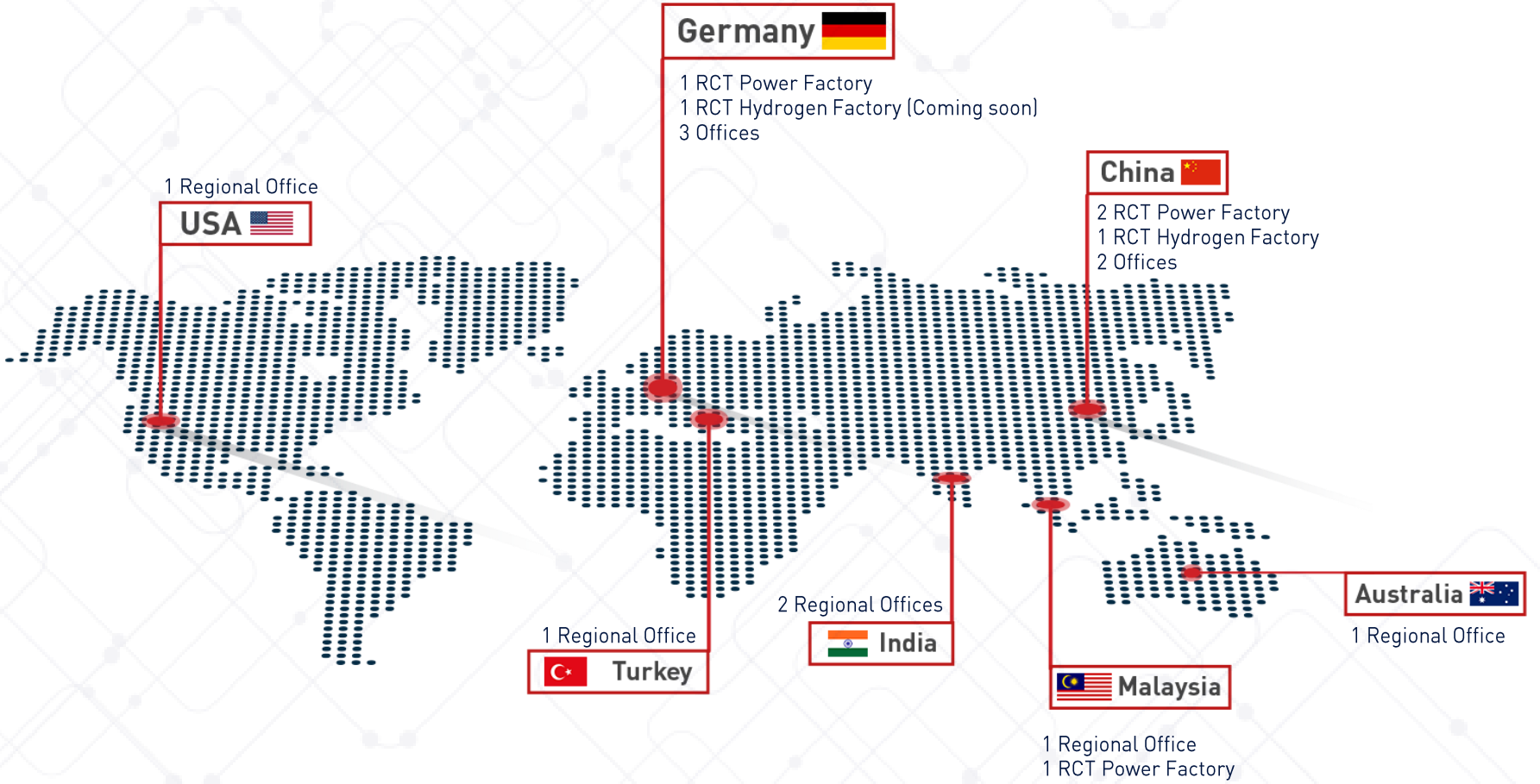
Employees
550+

Manufacturing
Germany, China, Malaysia

Cumulative Shipment
12.5GWh

27 Countries
Active Services

73 GW
Executed PV Engineering



a member of RCT Group

About RCT Group at a glance

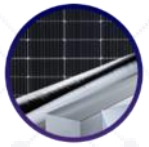
RCT solutions


Owner's & Lender's Engineering


Feasibility Studies


Training Academy


Conceptual & Basic Design


Full Value Chain

2012
Founded, privately owned

26
Countries

World's First
Fully integrated 1.2 GW Factory installation

72 GW
Total global manufacturing capacity served

62
Factories worldwide

76 GW
Ingot & Wafer integration

RCT power

pv magazine SPOTLIGHT 2020

STROM SPEICHER Inspektion 2024


RCT Power Residential Batteries


RCT Power Utility Battery Storages


RCT Power inverters

2015
Founded, privately owned

11.4kWh
Modular concept development

Mass Production
Residential & battery pack for container solutions

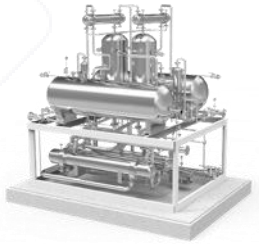
>10GWh
Total shipment

Best Storage
Awarded in Germany

EU&USA Based
Battery production & Operation

SOLAR PRO SUMER AWARD DEUTSCHLAND
>22.000 BEWERTUNGEN
WECHSELRICHTER
KAUFEMPFEHLUNG
EUPD Research
2022/23

RCT hydrogen


Gas Seperation System


Hydrogen Purification System


Re-fueling station


Electrolyser stack

Indian Ingot & Wafer Factories – Technology overview and project implementation

1. **Introduction – Current manufacturing landscape**
2. **Technology Overview**
3. **Project Execution**
4. **Summary**

The PV ecosystem

Local integrated manufacturing along the value chain

Mg-Si

Poly Silicon

Ingot & Wafer

Cell

Module

Equipment

Supply Chain / Materials

Technology / R & D / Institutes

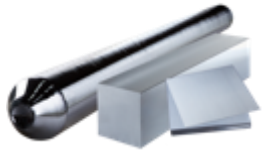
Training / Skills

Distribution of Worldwide PV Production

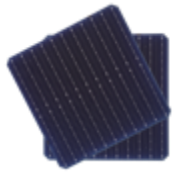
Local Integrated Manufacturing Along the Value Chain

Mg-Si

Poly Si

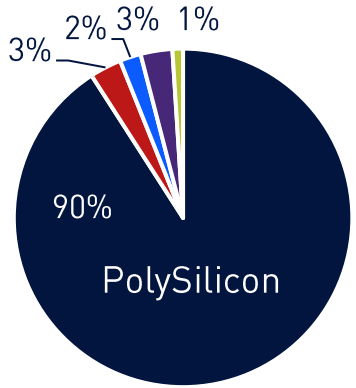


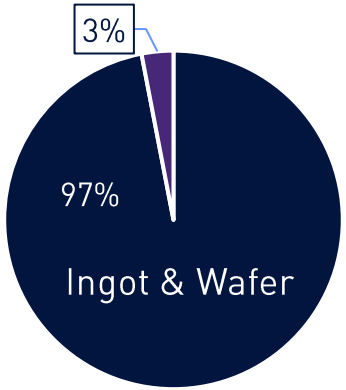
Ingot&Wafer

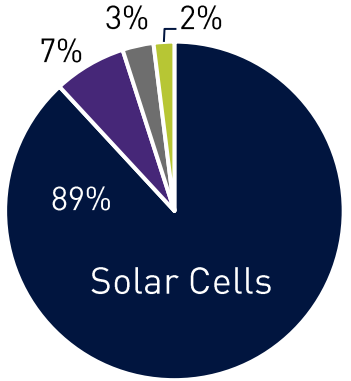


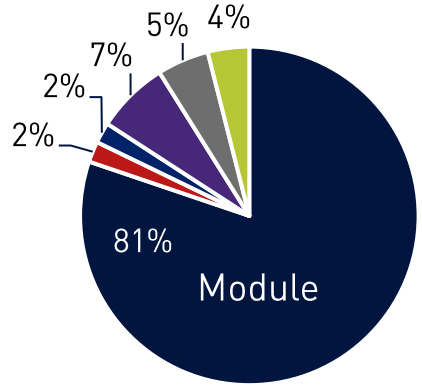
Cell

Modul









China Europa USA SEA India ROW

Current Capacity by Non-Chinese companies is < 2%

Total Chinese capacity Company	Capacity 2023	Capacity 2024	*Of that: outside China* Country	Capacity 2023/24
Zhonghuan	183	*190*		
Longi	170	*180*	Malaysia	4
Jinko	85	120	Vietnam	12
JA Solar	85	100	Vietnam	4
Trina	55	60	Vietnam	6.5
Canadian	21	50	Thailand	5
ET Solar	0	0	Vietnam	5
Shuangliang	90	128	**Total**	**36.5**
Gaojing	80	85		
GCL	58.5	*60*		
Yuze	50	75		
Hongyuan	45	*45*		
Meike	40	*60*		
Gaoce	38	63		
Jingyuntong	20	42		
Tongwei	15	31		
Hongxin	14	*14*		
East Hope	*14*	*14*		
Jingpin	12	*12*		
Qingdian	10	*10*		
Hoshine	5	20		
Total	**1091**	**1359**		

Estimates in *italics*

Non-Chinese companies Company	Country	Capacity 2023/24
NorSun	Norway	1
Kalyon PV	Turkey	2
Adani	India	2
Vsun	Vietnam	4
Hanwha	USA	3.3
Total		**12.3**

Capacities in GW; Source: Bernreuter Research

Top 5 Manufacturer >50% Capacity

中环股份 ZHONGHUAN SEMICONDUCTOR

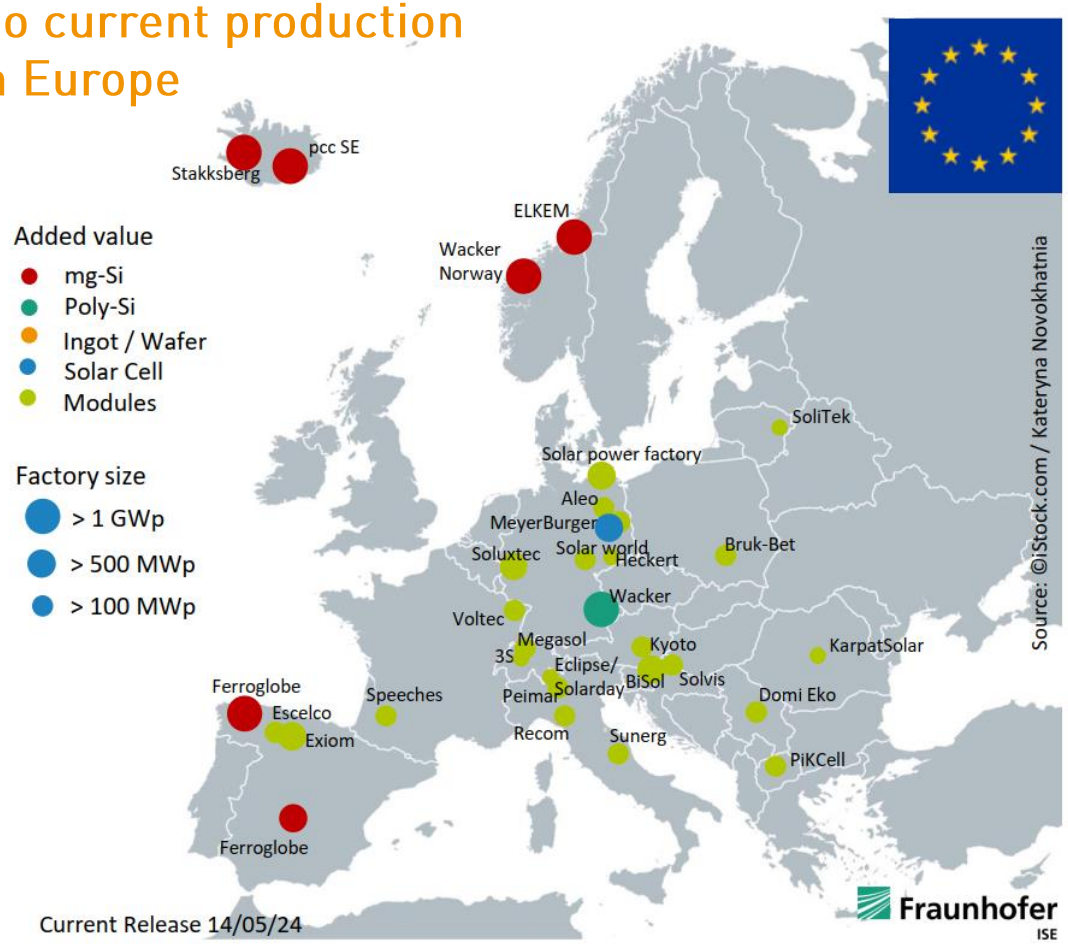
LONGi

JA SOLAR

JinKO Solar

双良 SHUANGLIANG ECO-ENERGY

No current production in Europe



Indian Ingot & Wafer Factories – Technology overview and project implementation

1. Introduction – Current manufacturing landscape
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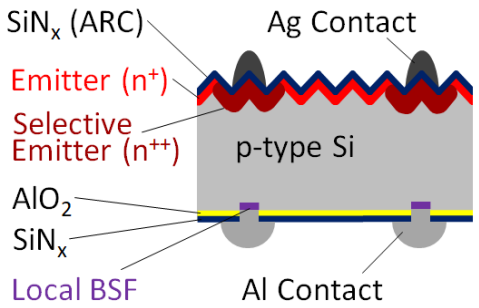
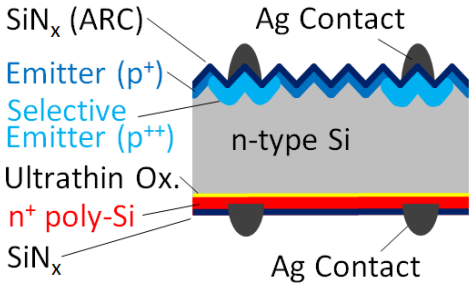
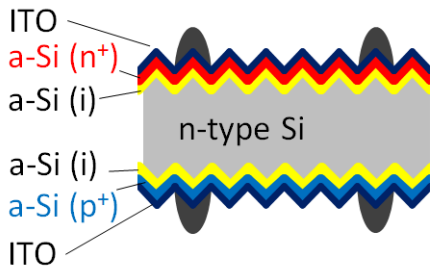
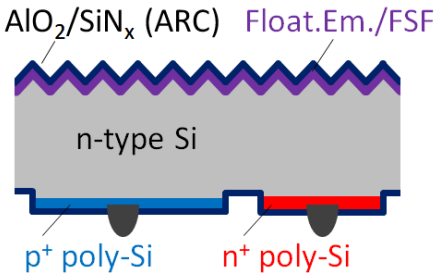
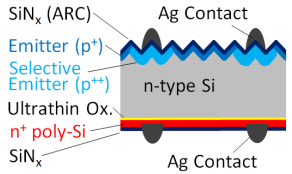
Overview of Current Solar Cell Concepts

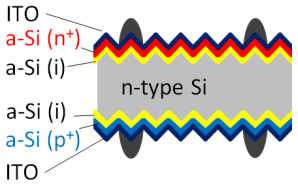
Technology	PERC SE	TOPCon	HJT	TBC
Description	Passivated Emitter and Rear Cell with Selective Emitter	Tunnel Oxide Passivated Contact Solar Cell with LECO	Silicon Hetero Junction Solar Cell Technology	TOPCon Back Contact Solar Cell with partial Cu metallization
Production Capacity	250 GW	500-700+ GW	50 – 70+ GW	(10 - 20 GW, for XBC)
Cell Eff. (Fab-Theoretical)	23.2% → 24.5%*	25.0% → 27.1%*	25.2% → 28.5%*	25.5% → 29.1%**
Cell Structure				

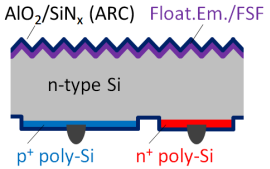
**- Solar Energy Materials & Solar Cells 231 (2021) 111291, **- Solar Energy Materials & Solar Cells 238 (2022) 111560*

Solar cell technology and required wafer KPI‘s

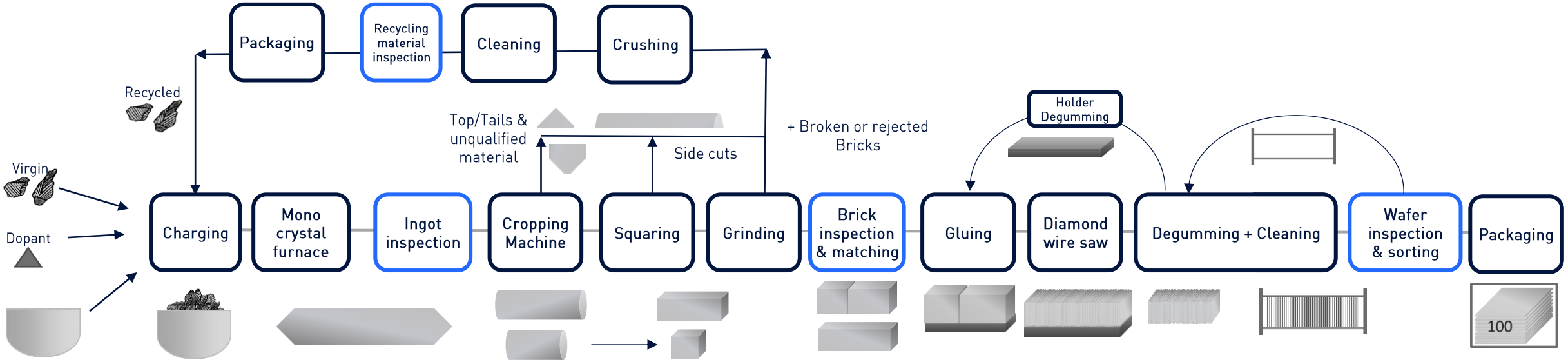
	Characteristics of Technology	Wafer Requirements	Parameter control
TOPCon	Mature technology High-temperature processes > 950°C High-efficiency product	Differentiated size Low Oi as key	Res: 0.6-1.6 → 0.9-1.2 cm Size: G10/G12R/G12 Oi: ≤12 ppma → ≤11 ppma
HJT	Fewer process steps (5-7) High equipment investment High-efficiency product	Thin wafer & half-wafer High MCLT	Thin wafers: Half wafer, ca. 110 and below High MCLT: MCLT avg. ≥ 5000
XBC	More process steps, generally > 15 Higher technical difficulty High-temperature diffusion process Higher cost	High resisitivity High MCLT Low Oi Different sizes	High res: 4-28/2-14 cm MCLT: MCLT avg. ≥ 7000 Oi: ≤12 ppma → ≤10 ppma Size: 210.5/192.5/184







Factory processes and main material flow



Ingot inspection
- Dislocations
- Crystal orientation
- Resistivity
- Diameter
- Interstitial oxygen
- Substitutional carbon
- MCLT
- Dopant and impurity concentration

Brick inspection
- Dislocations
- Crystal orientation
- Resistivity
- Diameter
- Interstitial oxygen
- Substitutional carbon
- MCLT
- Dopant and impurity concentration

Wafer inspection
- Resistivity
- MCLT
- TTV
- Wafer thickness
- Saw mark damage depth
- Bow and warp
- Edge chipping depth and length
- (O_i C_s Fe)

Latest history of wafer sizes used in industry

Golden module size

M10 size (182x182)

G12 size (210x210)

G12 h (half cut)

G12R (210x182)

M10L (191x182)

188R /199R

186R

LONGi [5]

Trinasolar [1]

risen solar technology, HUASUN [4]

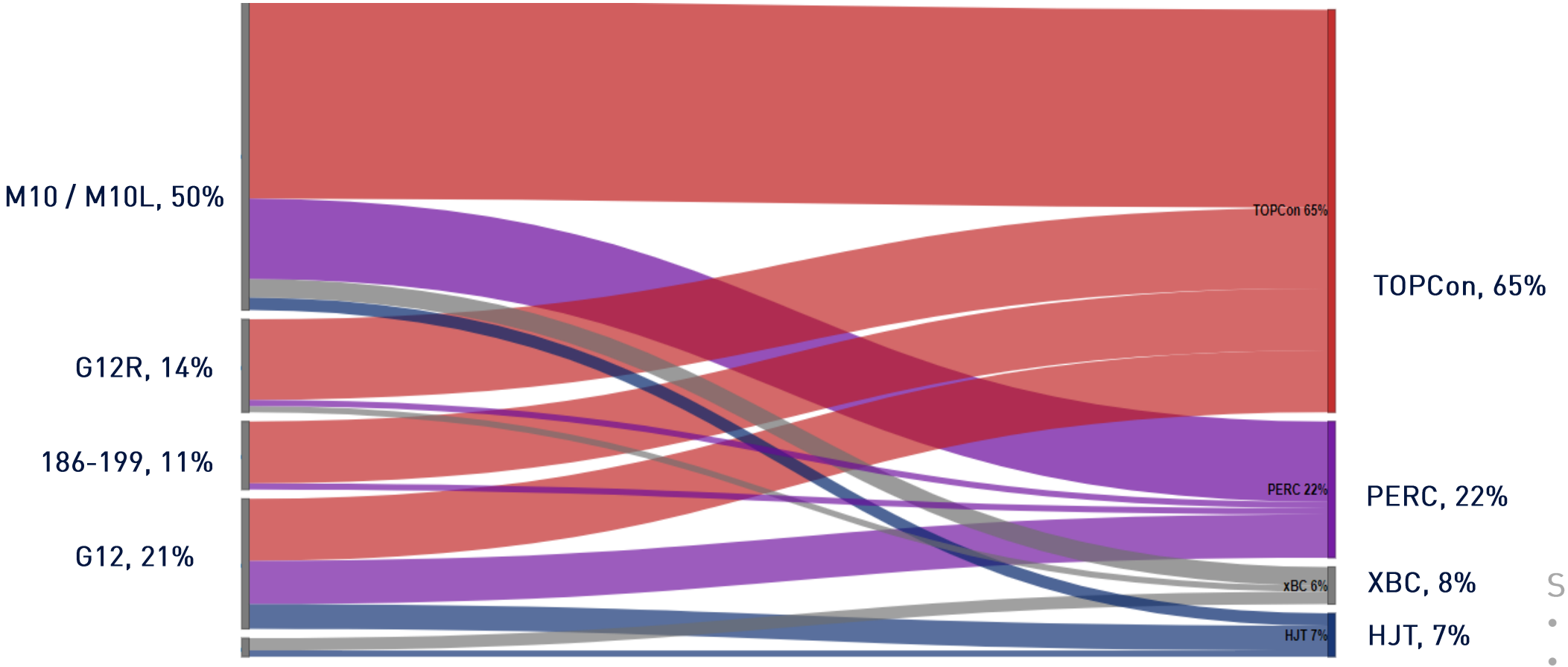
Trinasolar, JinkO Solar [3]

LONGi, CanadianSolar, risen, TW SOLAR, DASOLAR [2]

JA [6]

JinkO Solar

Status of wafer type & size in 2024



TOPCon, 65%

PERC, 22%

XBC, 8%

HJT, 7%

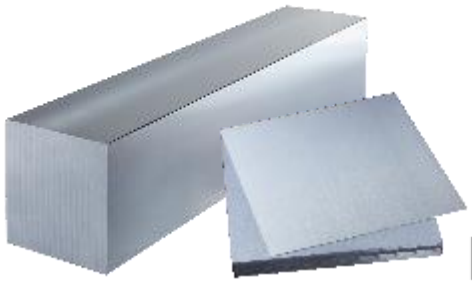
Source:
- Internal tracking
- PV Infolink
- CPIA
- ITRPV

→ Biggest stream is M10/M10L & G12R for TOPCon

Exploring the new wave of wafer/cell sizes

Crystal Diameter

≈252 mm | ≈263 mm | ≈268 mm | ≈272 mm | ≈281mm | ≈302 mm



Full size wafer

M10/ M10L	186R	M11- L	199R	G12R	G12
183 mm x 182 mm	186 mm x 182 mm	191 mm x 182 mm	199 mm x 182 mm	210 mm x 182 mm	210 mm x 210 mm

Half-Cut wafer

M10h				G12Rh	G12h
91 mm x 182 mm				105 mm x 182 mm	105 mm x 210 mm

Hybrid cell cut

188Rh 94 mm x 182 mm

+

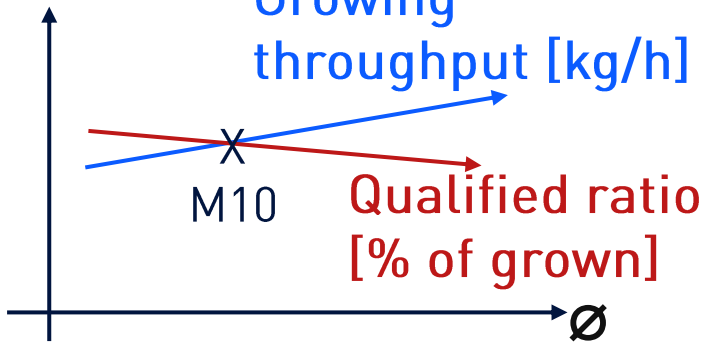
210Rh 105 mm x 182 mm

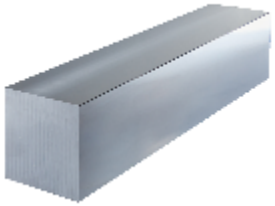
Challenges in the ingot and wafer factory
(for processing different wafer sizes)

M10: 252 mm

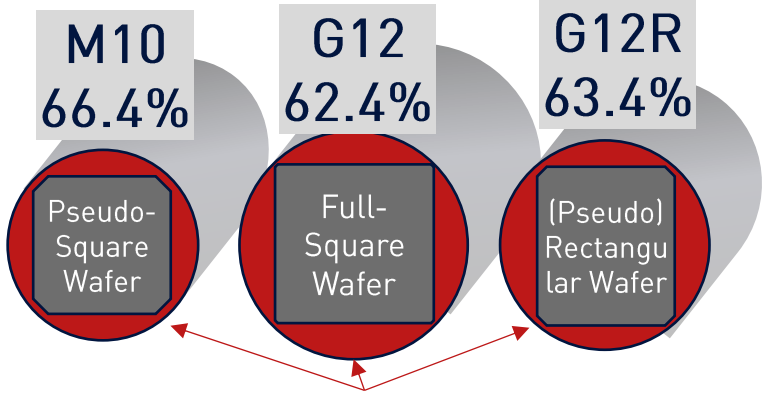
G12: 302 mm

Share of heads/tails increases



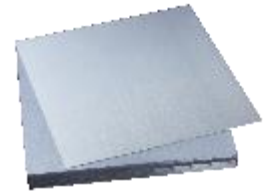


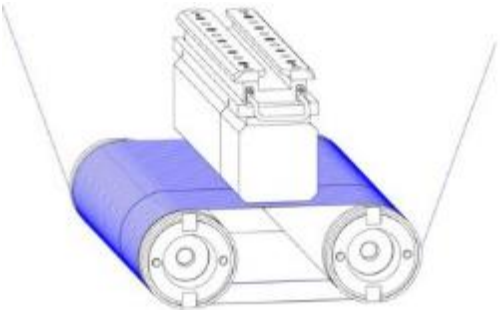
Squaring utilization rate:



Downside of recycling material

1. Energy and material were wasted for growing this part of the ingot
2. During recycling for reuse, losses occur





Slicing:

- Set-up time share to cutting time reduced if brick width increases
- Feed rate increases, with shorter width

Cost analysis of different wafer sizes

Δ COO (incl. shipping)		Module Sizes used by TOP 5 Manufacturers [mm]										
		1134 x 1722	1134 x 1762	1134 x 1800	1134 x 1961	1134 x 2063	1134 x 2094	1134 x 2278	1134 x 2333	1134 x 2382	1134 x 2465	1303 x 2382
Wafer Size	M10L	1.4%					0.3%	0.0%			1.1%	
	186R		1.4%									
	M11L			1.5%						-0.5%		
	188R		1.0%						-0.4%			
	199R					-0.1%		-0.1%				
	G12R		0.9%		0.5%					-1.2%		
	G12											-2.4%
	G12h											-1.5%

Above table shows the **delta in Cost of Ownerships of PV Modules** including shipping cost for **different module sizes** with **different wafer sizes**. The calculation is limited to products available on the market.

1. COO differences shown depend more on module than on wafer size (→ equipment and module design more efficient for larger modules, a known fact)
2. Rectangular wafer reduce the cost especially in larger scale modules, which is the most important market for the producers
3. Only slight improvement for larger or rectangular wafer in smaller sized modules
4. Going for G12 and larger would be beneficial, but the wafers are currently not fitting into the standard glass sizes

Indian Ingot & Wafer Factories – Technology overview and project implementation

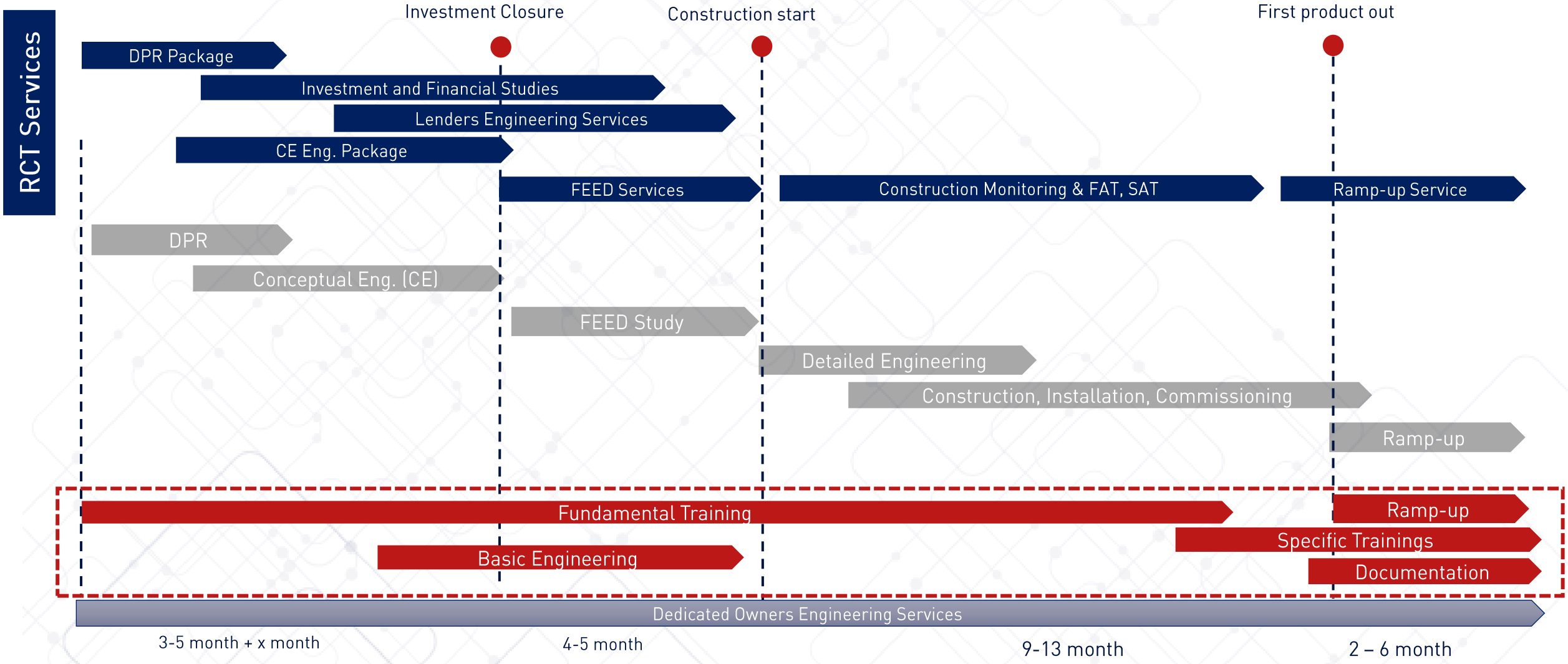
1 **Introduction – Current manufacturing landscape**

2 **Technology Overview**

3 **Project Execution**

4 **Summary**

Typical Project Tasks, Timelines and Milestones



Basic Engineering
Right balance between cost and performance

Time & Speed*

Skipping vendor & equipment selection with real time accurate data

Modular Design**

Equipment selection preparation based on order and sales funnel

Optimum load & multi layer approach

Preventing over-engineering

Extensive Vendor Database

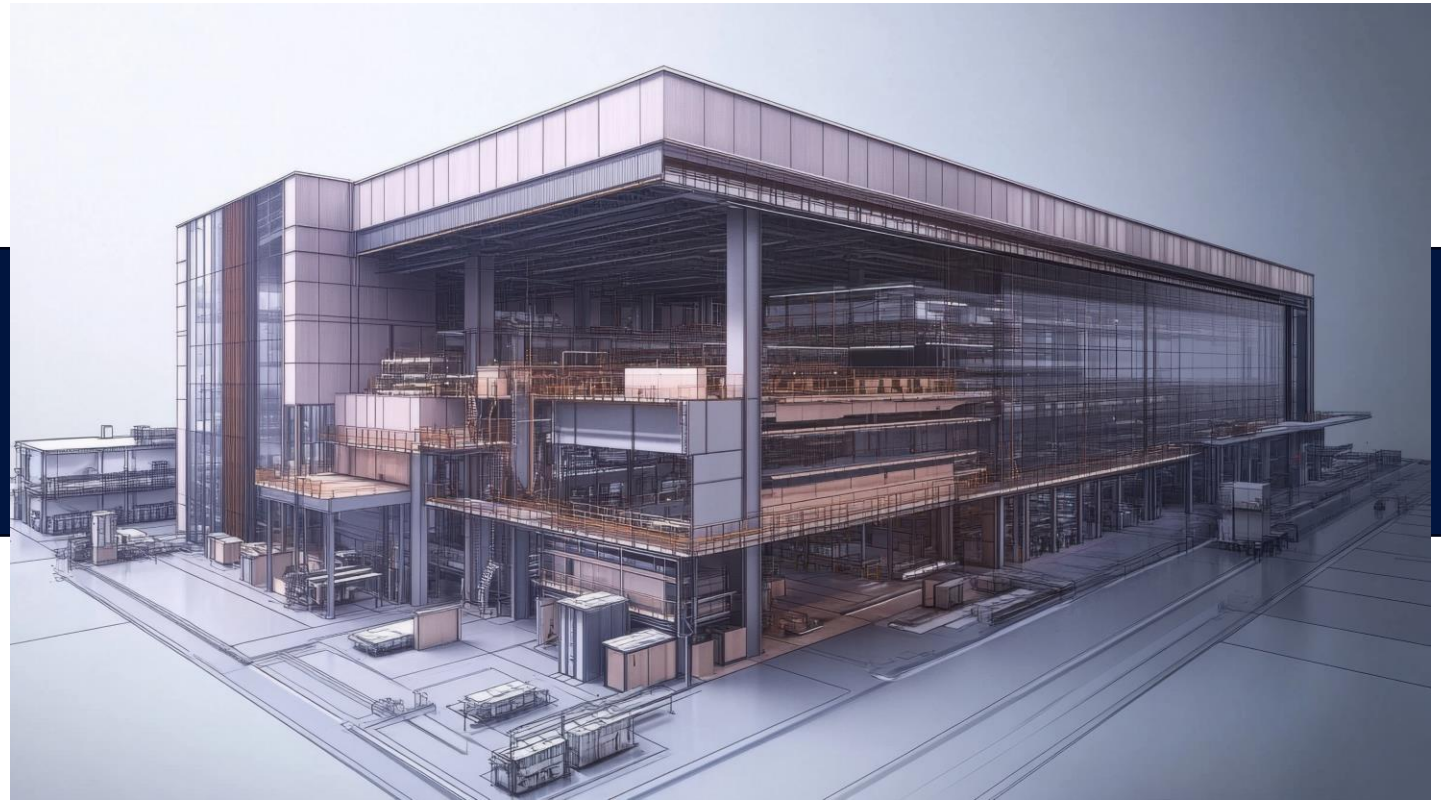
Basic layout & FUM prepared beyond vendor requirements

Production technology

Production & engineering transfered to engineering

Regional know-how

Energy saving & sustainability approach



** Equipment selection has been parallelly made since engineering services negotiate with vendors directly*

** Preventing over purchase of machinery by installing 100 quantity of machine in 20x5 batches.*

PV Trainings

Our approach for top-qualified employees.

- Intense exchange with industry partners during the development of the curriculum
- Training content tested in the field and updated continuously
- Integration of the production lines with experienced trainers for practical training
- Train-the-trainer courses on the use of the equipment
- Practice-oriented training concepts and training books
- Modular structure of the PV Trainings - Production programme
- Innovative blended learning programme
- Professional support and moderation
- A high advanced online platform

We provide trainings for industrial PV manufacturing.

PV Trainings - Production programme are designed for solar professionals: integrated production line staff, engineers and all types of associated partners who ensure the best results in a manufacturing facility.

The trainings are offered for 3 different levels: Beginner, Advanced and Expert. Individual trainings tailored to customers' needs and on-site workshops are also important components.

In a blended learning programme, we offer a combination of online and in-person or virtual training courses.

MODULE I

Fundamentals
Live Online Course / E-learning

MODULE II	MODULE III
Advanced Presence Hands-on / on-site lectures	Specialist Live Online Course / E-learning Interactive online meetings
Advanced Online Live Online Course / E-learning Interactive online meetings	Specialist Training at production line

CERTIFICATE

At the end of the training courses, participants are certified to have acquired the relevant knowledge and skills.

PV TRAININGS -production

Your path to PV production expertise.

Fundamentals of Photovoltaics training program has been established to expand and master extensive skills in growing know-how focusing on full value chain of PV production.

By the end of the training courses, you will have an extensive knowledge of each phases of photovoltaic production starting from preperations to ramp-up.

Duration: 3 months
Learning format: In-Class and Online learning
Programme language: English

Other programs aim to train the best-in-class skilled workforce or solar manufacturing facilities in the global market.

- Module
- Ingot & Wafer
- Cell
- Poly-Si & Mg-Si
- MES
- CAPEX & OPEX
- LCOE & LCA
- Value Chain
- HSE
- Quality
- Architectural PV Applications
- Factory Design & Layout

MODULE I

Fundamentals
Live Online Course / E-learning

MODULE II	MODULE III
Advanced Presence Hands-on / on-site lectures	Specialist Live Online Course / E-learning Interactive online meetings
Advanced Online Live Online Course / E-learning Interactive online meetings	Specialist Training at production line

CERTIFICATE

ISC research for a sunny future

RCT solutions

WIP RENEWABLE ENERGIES

Documentation

Bill of Materials (BOM)

- Component lists
- Material specification

Machine Handbooks

- Operational procedures
- Compliance guidelines

Process Flow Diagrams

- Workflow diagrams
- Process mapping

Standard Operating Procedures (SOPs)

- Operational procedures
- Compliance guidelines

Safety Documentations

- Safety protocols
- Risk assessments

Maintenance & Troubleshooting Manuals

- Routine & Emergency Repairs
- Common Issues & Resolutions

RCT solutions

Documentation Services

Documentation is part of RCT‘s trainings and skills package

Overview of Documentation

RCT Solutions GmbH
Line-Eid-Strasse 1
D-78467 Konstanz, Germany
rct-solutions.com

HANDBOOK

Wafer Manufacturing

GC-GP950L Integrated Silicon Rod Grinding and Polishing Machine Handbook

Book issued: 16.01.2024

Created by: RCT Solutions GmbH

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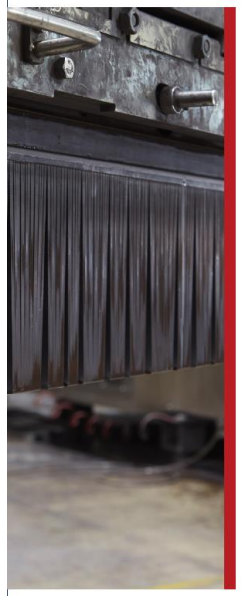


One-stop
Photovoltaic solutions partner

1. Flanged universal ball

The Flanged Universal Ball ensures precise movement and alignment in the machine, reducing friction for efficiency and reliability. Built durably, it enhances longevity.

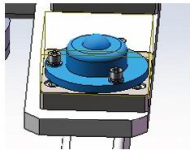


Image 5: Figure of Flanged Universal Ball

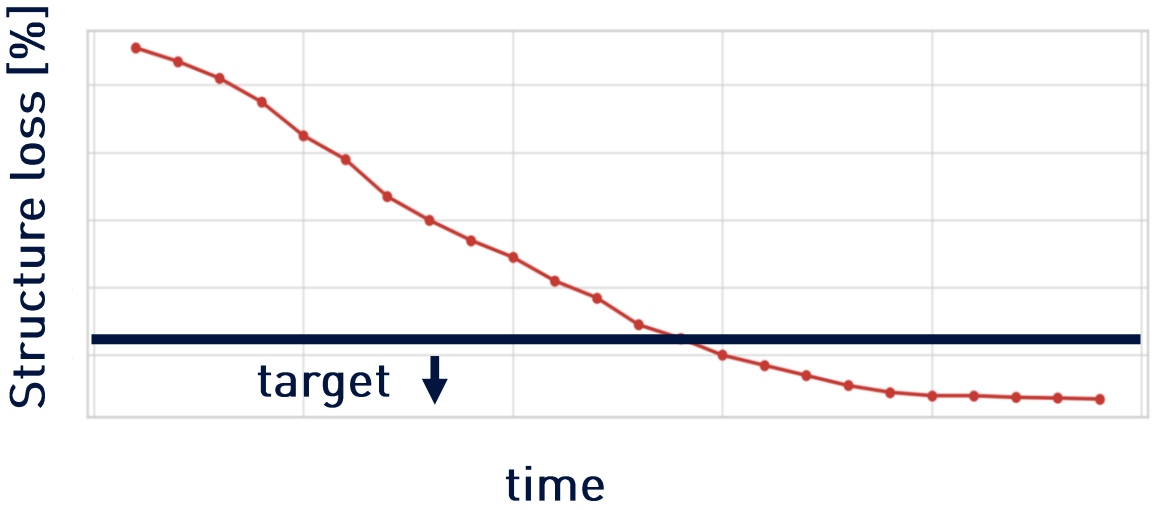
2. Cleaning of degumming tank, buffer tank and soaking tank, and removal of fragments

The process involves cleaning the degumming, buffer, and soaking tanks, eliminating any residues or fragments present. This ensures optimal conditions for subsequent stages in the operation, maintaining efficiency and product quality.

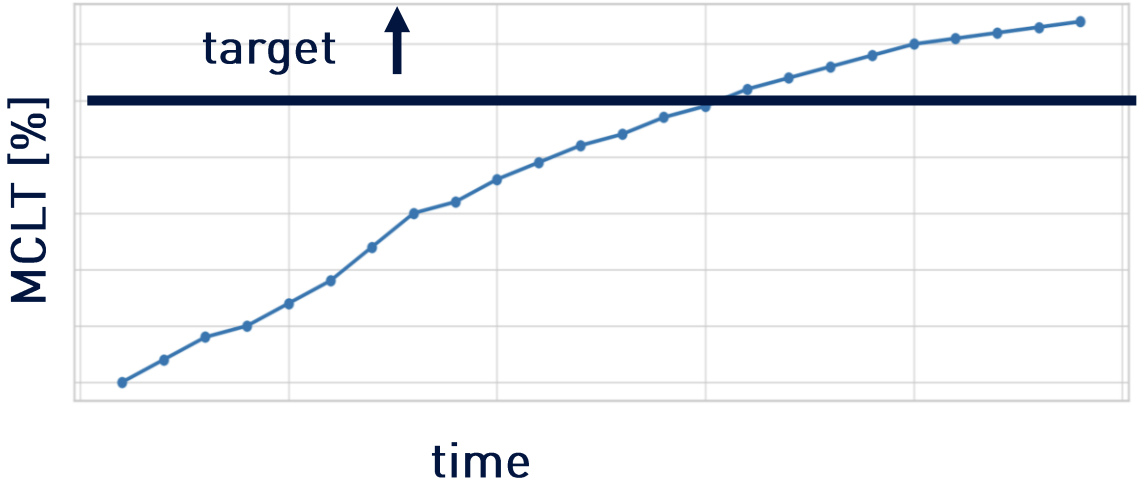
Image 6: Figure of cleaning of degumming tank, buffer tank and soaking tank, and removal of fragments

Ramp-up – Meeting all KPI‘s as fast as possible

Structure loss over time



Minority carrier lifetime



Process and Technology

- Decision for reliable and proven equipment
- Experienced technology team
- Know-how in executing Ingot&Wafer projects

Project Management

- Experienced PM team
- Stringent acceptance procedure of all equipment: from pre-FAT, FAT, SAT up to factory acceptance

Reduced costs, high quality products

Indian Ingot & Wafer Factories – Technology overview and project implementation

1. Introduction – Current manufacturing landscape
2. Technology Overview
3. Project Execution
4. Summary

Summary

Ingot & Wafer technology:

- Slightly different wafer KPI‘s for different solar cell concepts (MCLT, Oi, base doping, surface preparation) as a consequence of their processes (high T) and structure (TBC)
- Continuous improvement of RCZ sufficient to meet target KPI‘S
- Zoo of different wafer sizes emerged, G12R (M10L) currently seen as bet he „winner“

Project execution: Key factors for success

- Technology and equipment selection
- FEED: quality and costs
- Training and Documentation
- Ramp-Up: equipment acceptance procedures and experienced ramp-up team

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Thank you

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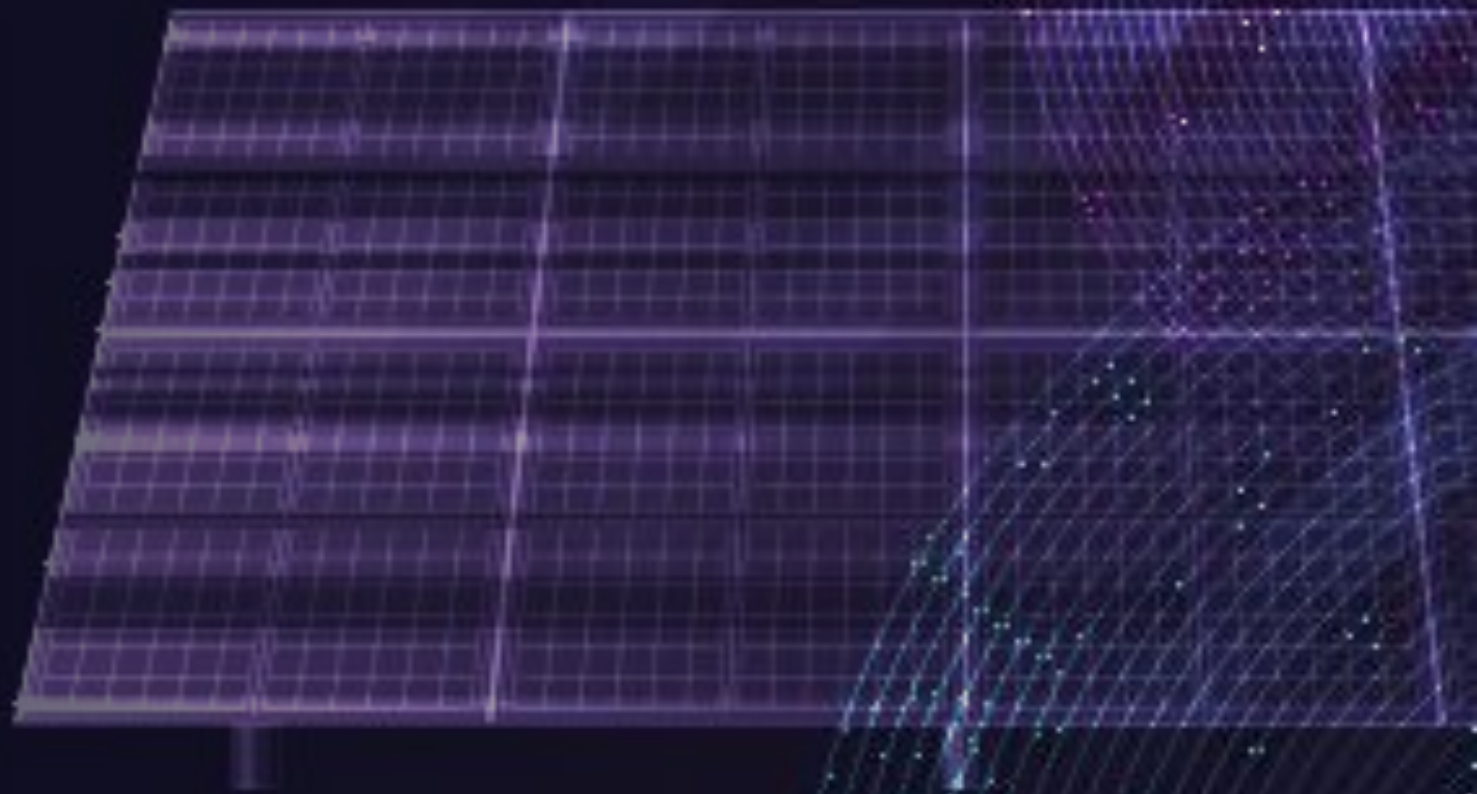
Appendix

Exploring the PV supply chain landscape, this section highlights the details of local manufacturing, offering insights into current market trends and future opportunities for growth.



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