



Comparative Global PV Manufacturing Cost and Sustainable Pricing Assessment: China, Southeast Asia, India, USA, and Europe

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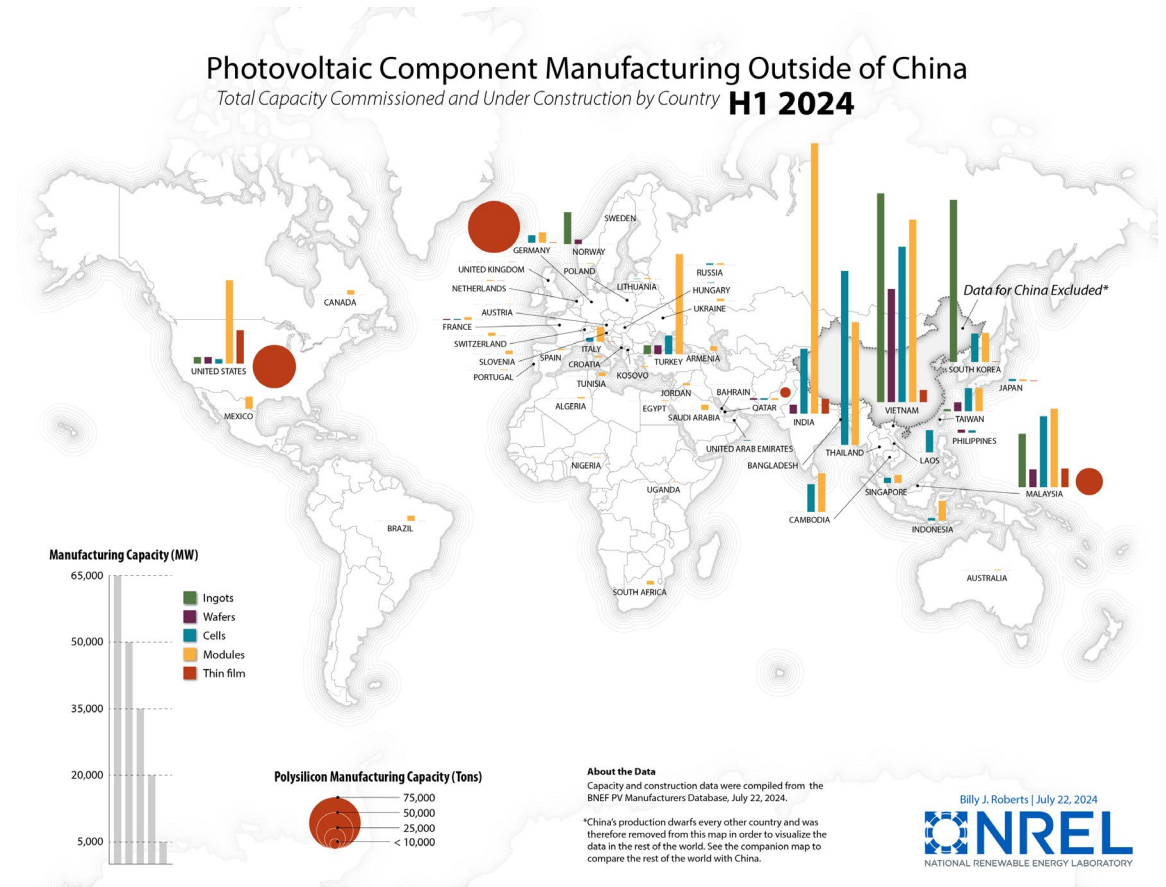
Comparative Global PV Manufacturing Cost and Pricing Assessment

Motivation and Objective

Motivation

- Production locations for PV manufacturing are diversifying globally from dominating China and Southeast Asia
- Incentive programs available e.g. in India, USA, Turkey, and in-sight for Europe
- Question of investors and governments in PV manufacturing:
 - Which are the main cost drivers at each production stage along the PV value chain?
 - What are the cost differences for PV production in different global regions?

NREL, RCT Solutions, and Fraunhofer ISE teamed-up for:
Analyzing production cost differences along the PV value chain for different global PV manufacturing regions

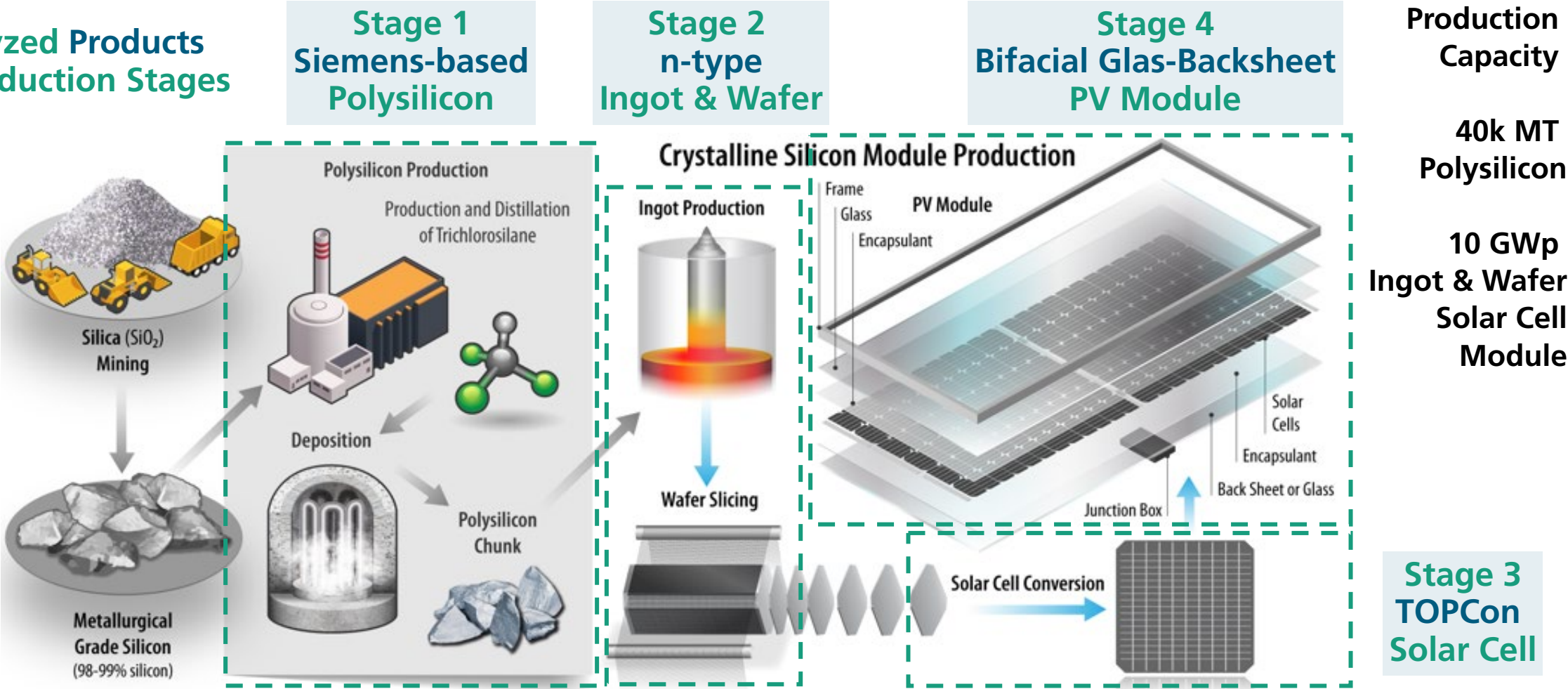


Map by NREL based on capacity data from BNEF.

Comparative Global PV Manufacturing Cost and Pricing Assessment

Analyzed Product and Manufacturing Stages along the PV Value Chain

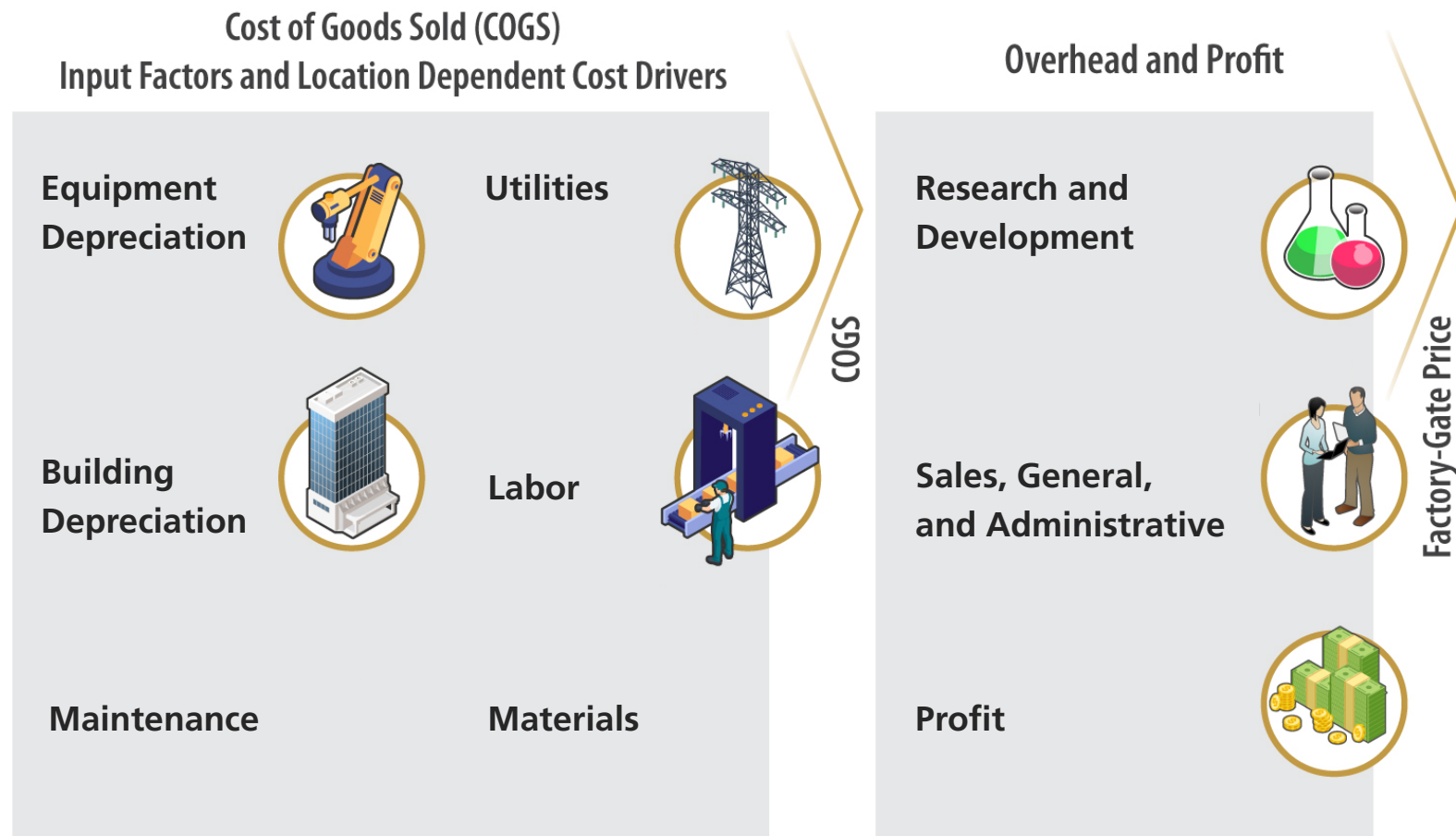
Analyzed Products & Production Stages



Graph: © NREL

Comparative Global PV Manufacturing Cost and Pricing Assessment

Data Input and Methodology for Calculating of Averaged Minimum Sustainable Price (MSP)



Methodology

Aggregated and anonymized data input by NREL, RCT and ISE for each manufacturing stage in joint cost model.

1. Calculation of direct Cost Of Goods Sold (COGS) for greenfield production
2. Inclusion of overhead costs, debt payments and "sustainable" profit*

Partners averaged
Minimum Sustainable Price (MSP)
= COGS + Overhead and Profit
for each production stage
(not including direct subsidies or transport of products!)

Graph: © NREL

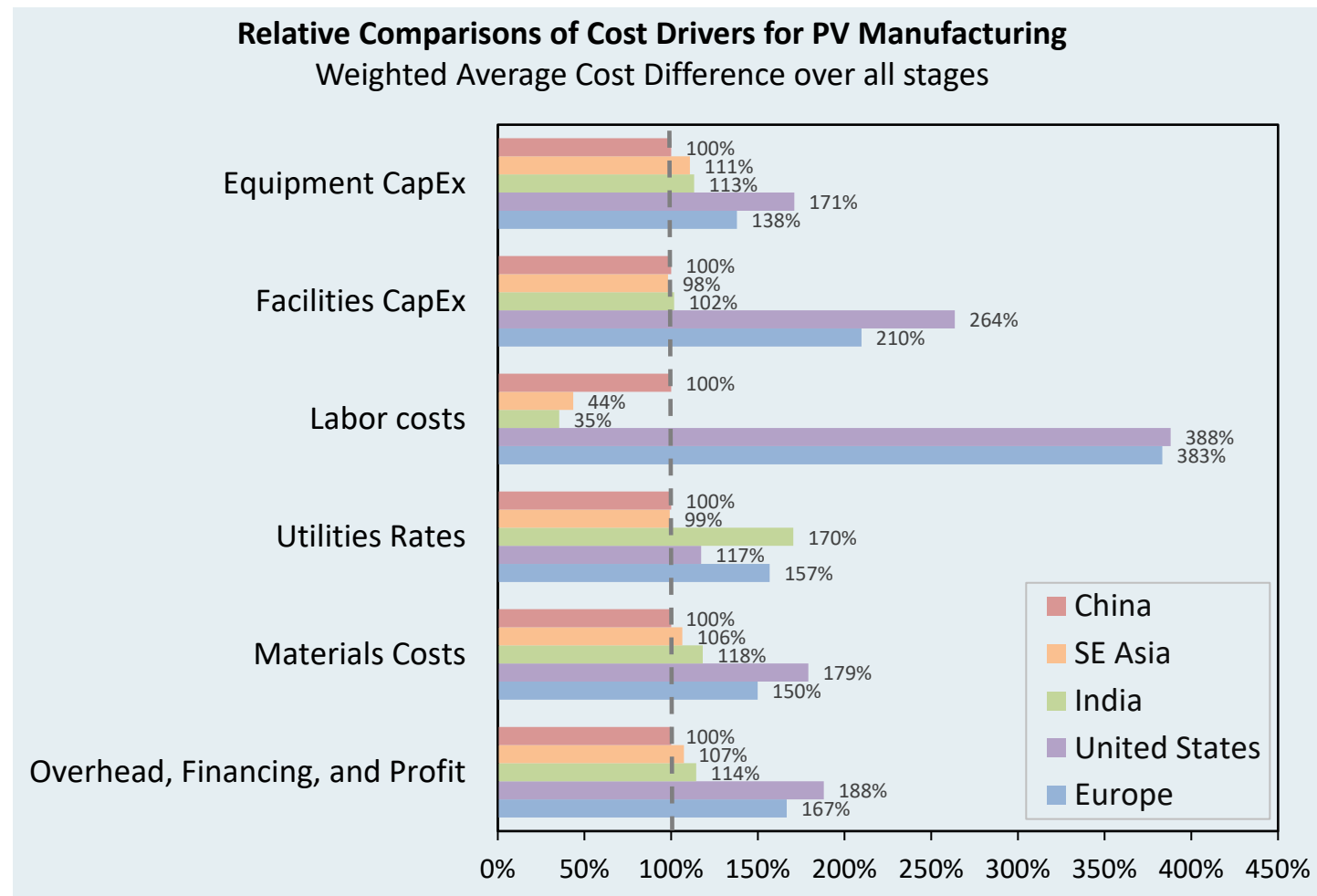
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*Net profit margins of ~5% assumed for each stage and region

NREL/RCT/ISE Averaged Cost Modelling Results

Analysis of "fully-local" PV Manufacturing along the Value Chain in Different Global Regions



Key Cost Drivers in Europe and US in comparison to China

Equipment CAPEX

- 40-70% higher (w/ Western Equipment)

Building and Facility CAPEX

- 2.1-2.6 x higher construction costs

Labor costs

- 3-4 x higher: wages & working hours

Utility (Electricity, Water, ...)

- 20-60% higher

Material Costs:

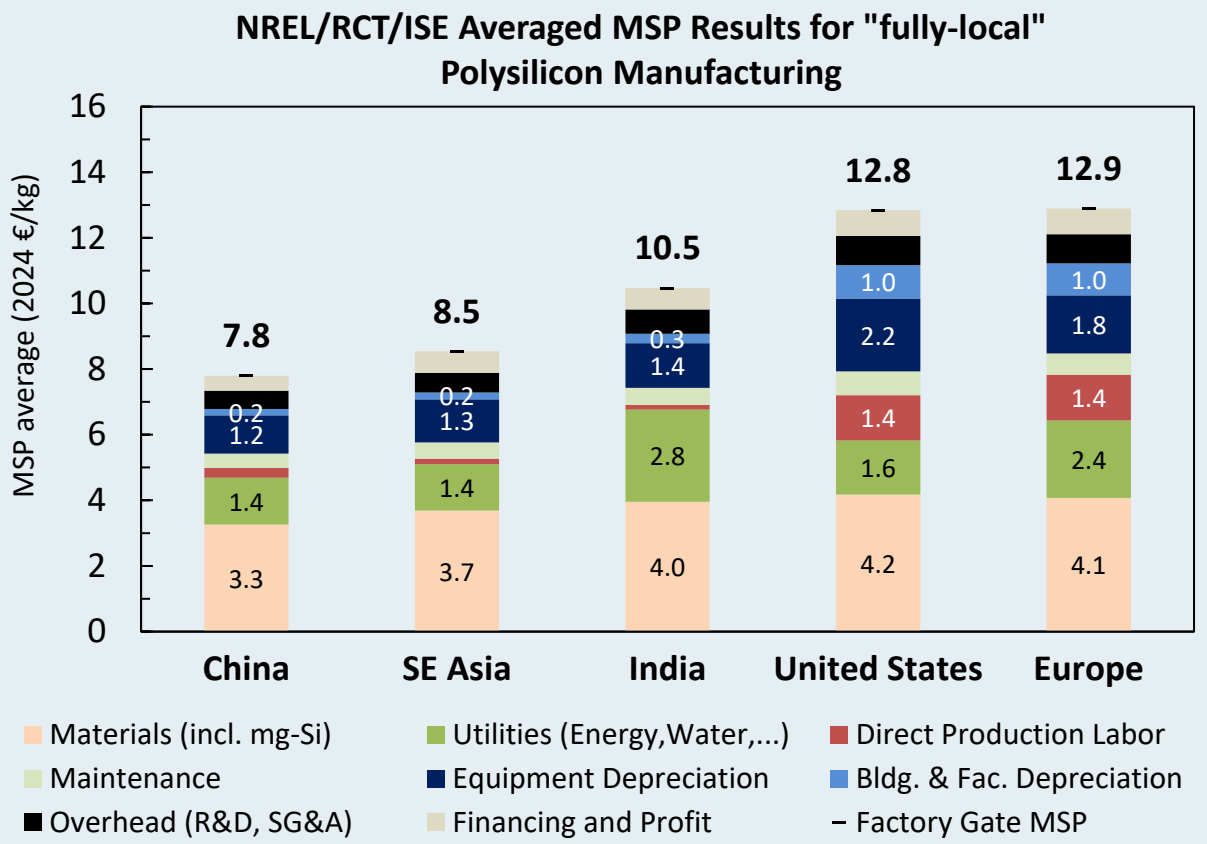
- 50-80% higher (with local BOM)

Overhead, Financing, and Profit

- Same margin adding more to MSP

Polysilicon Production: Siemens Process – n-type Material

Manufacturing Cost Results in €/kg



Impact on "fully-local" in Europe or US manufactured Polysilicon n-type Material MSP

Main cost difference in EU/US to CN:

1. Depreciation 1.4 – 1.9 €/kg
2. Production Labor 1.0 – 1.1 €/kg
3. Materials 0.8 – 0.9 €/kg
4. Utility (Energy, Water, ...) 0.2 – 0.9 €/kg

Low energy price locations in Europe and US assumed!

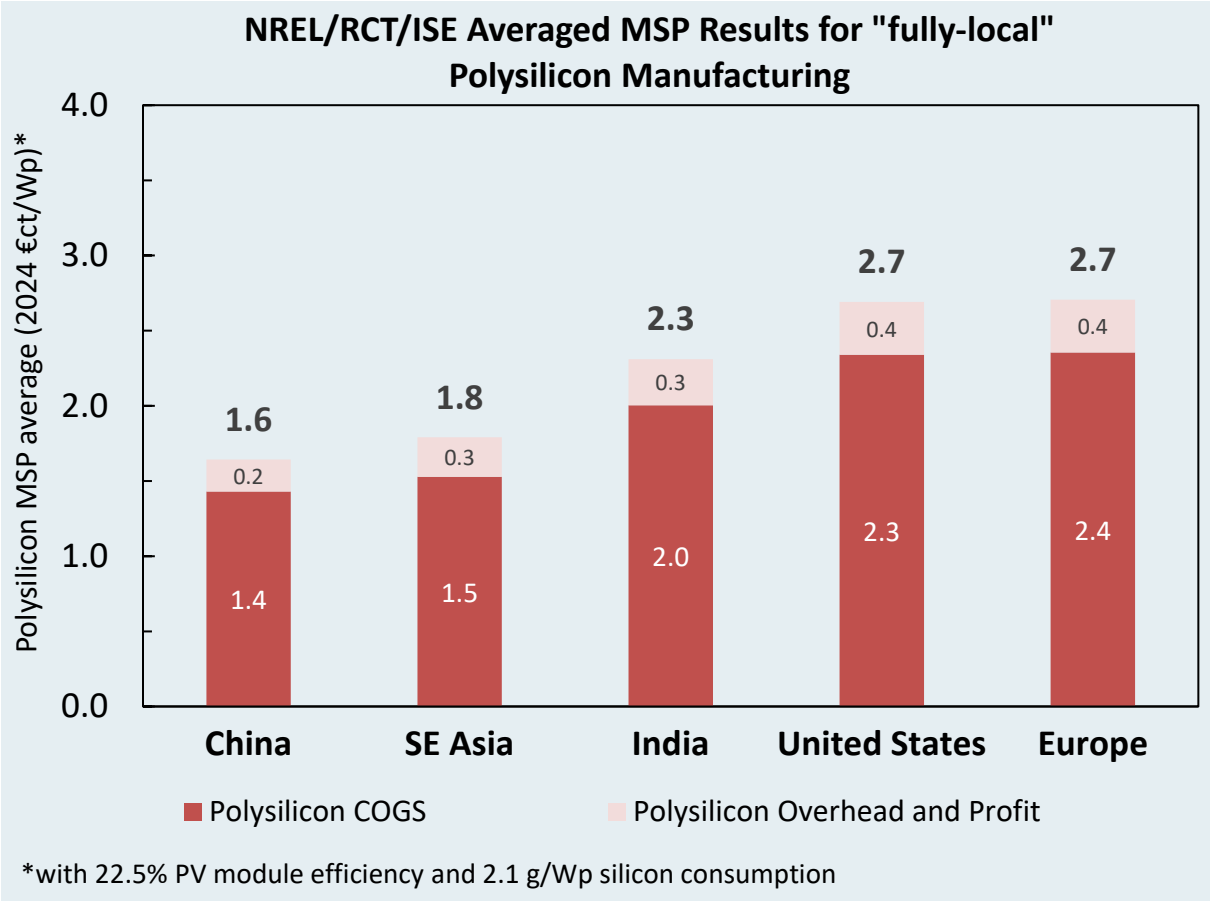
MSP for Polysilicon in Europe and US ~5 €/kg higher.

Current <5 €/kg Poly-Si market prices in China are not sustainable (negative net margins*)!

*In H1/2024 negative net margins for all large Polysilicon manufacturers in China.

Polysilicon Production: Siemens Process – n-type Material

Manufacturing Cost Results in €ct/Wp



Impact on “fully-local” in Europe or US manufactured Polysilicon n-type Material MSP

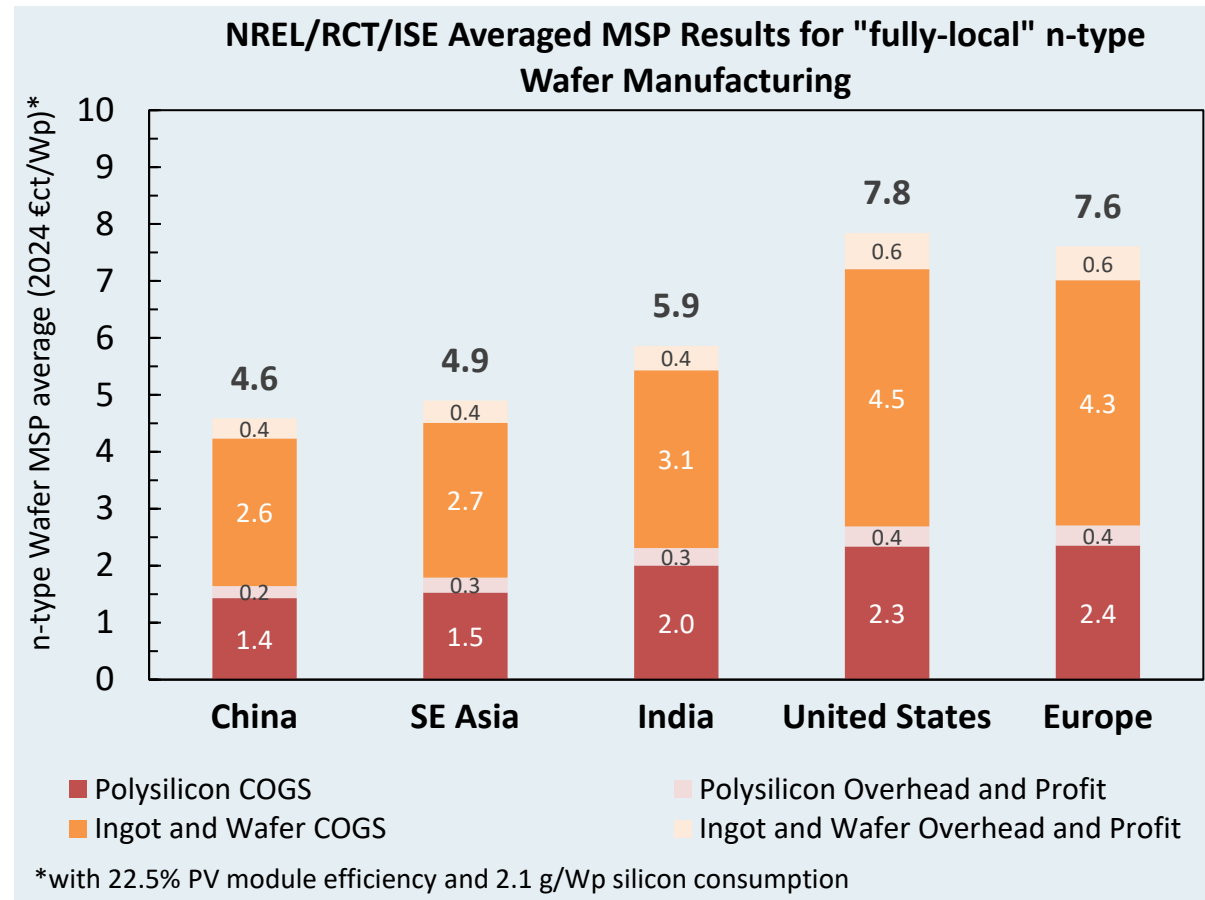
Difference in Europe & US in comparison to China:

Poly-Si MSP difference ~1.1 €ct/Wp

for “fully-local” manufactured n-type Polysilicon.

Ingots and Wafer Production: n-type Wafer

Manufacturing Cost Results in €/Wp



Impact on "fully-local" in Europe or US manufactured n-type Wafer

Difference in Europe & US in comparison to China:

- Polysilicon ~1.1 €/Wp
- Polysilicon-to-Wafer 2.0 - 2.2 €/Wp

Main cost differences for Labor, Materials, and Utility.

Wafer MSP difference 3.0 - 3.3 €/Wp

for "fully-local" manufactured n-type Wafer.

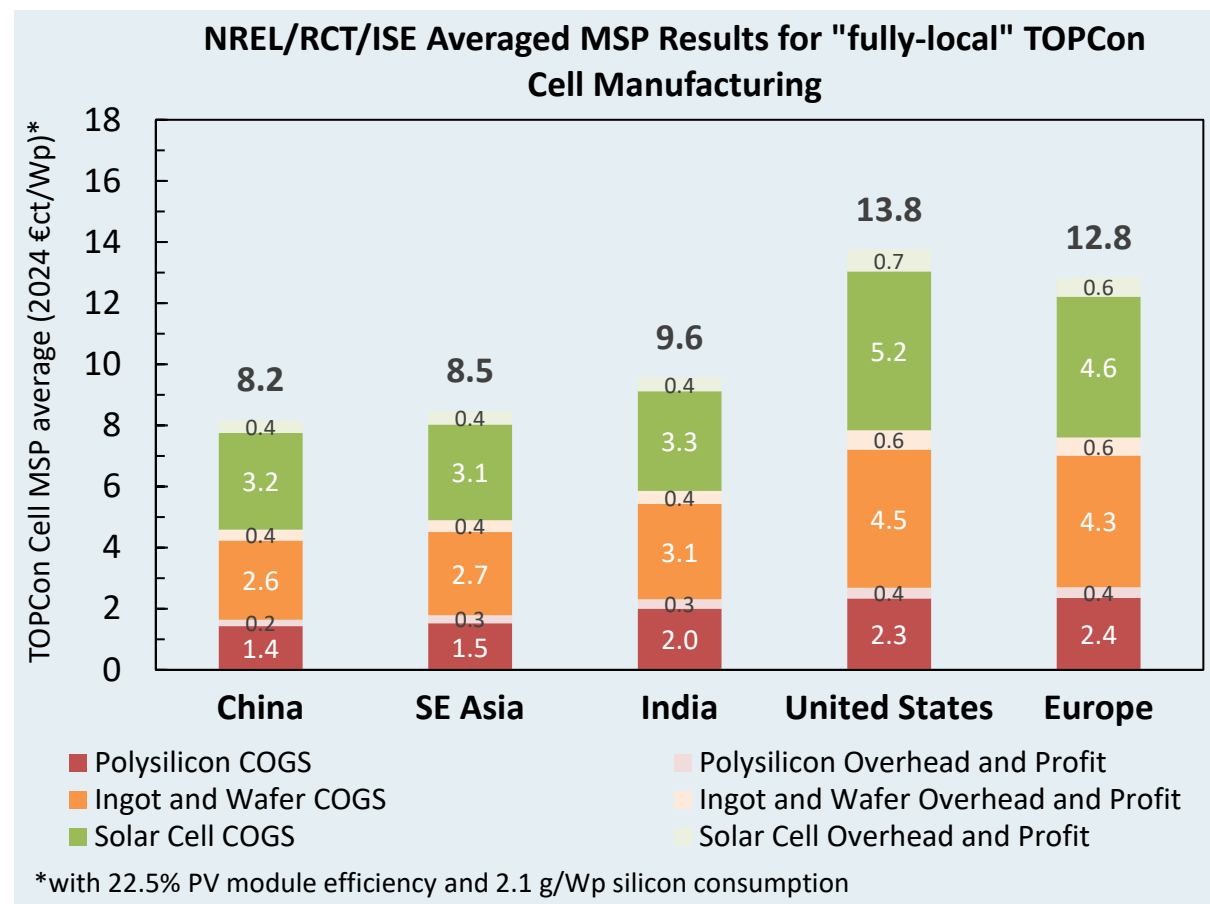
In Southeast Asia similar, in India slightly higher MSP.

Solar Cell Production: TOPCon

Manufacturing Cost Results in €ct/Wp



Cell



Impact on "fully-local" in Europe or US manufactured TOPCon Solar Cell

Difference in Europe & US in comparison to China

- Polysilicon ~1.1 €ct/Wp
- Polysilicon-to-Wafer 2.0 - 2.2 €ct/Wp
- Wafer-to-Cell 1.6 - 2.3 €ct/Wp

Main cost differences for Labor, Materials, Depreciation.

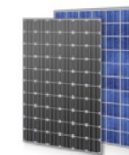
Cell MSP difference 4.7 - 5.6 €ct/Wp

for "fully-local" manufactured TOPCon Solar Cell.

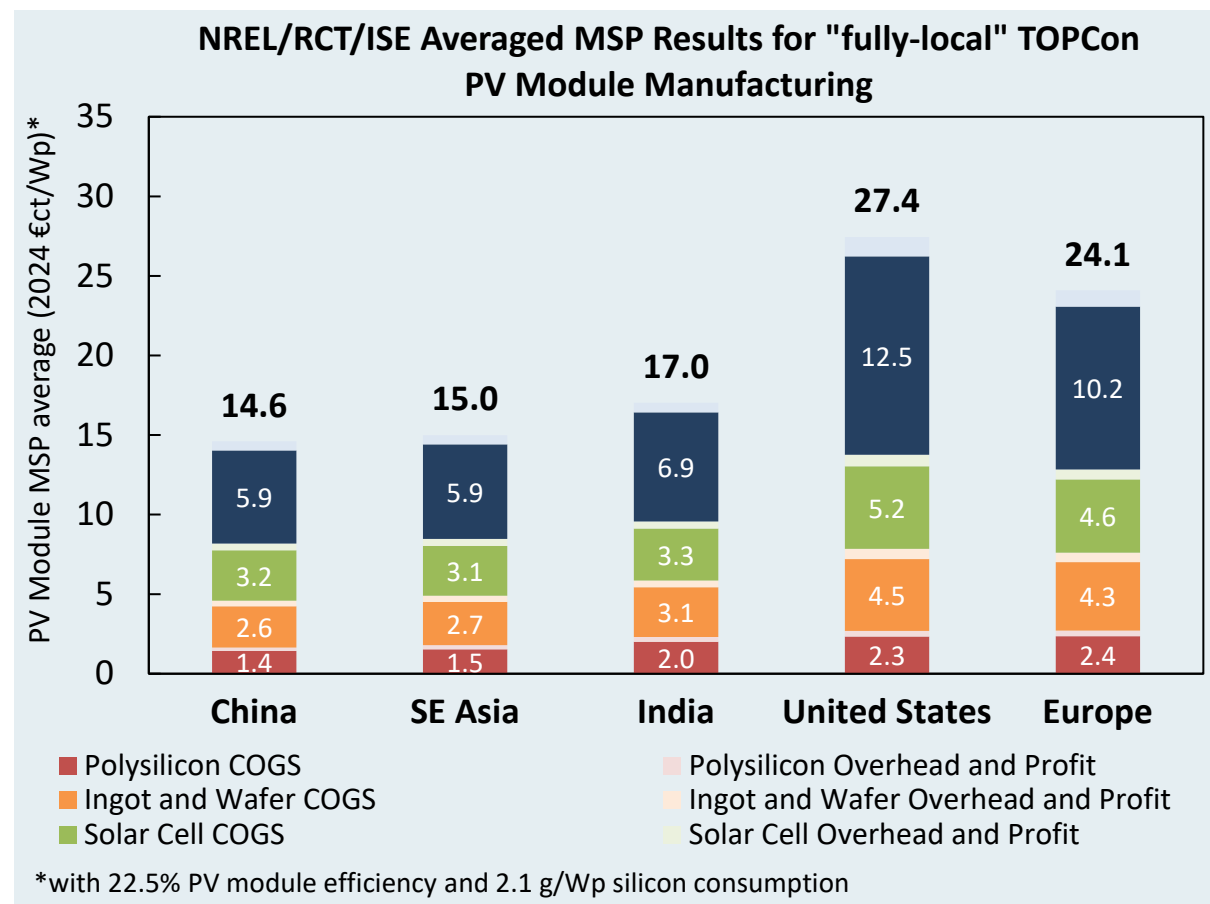
In Southeast Asia similar, in India slightly higher MSP.

NREL/RCT/ISE Averaged Cost Modelling Results

Analysis of "fully-local" PV Manufacturing along the Value Chain in Different Global Regions



Module



Impact on "fully-local" in Europe or US manufactured TOPCon PV Module

Difference in Europe & US in comparison to China

- Polysilicon ~1.1 €ct/Wp
- Polysilicon-to-Wafer 2.0 - 2.2 €ct/Wp
- Wafer-to-Cell 1.6 - 2.3 €ct/Wp
- Cell-to-Module 4.8 - 7.3 €ct/Wp

Main cost differences for Materials and Labor.

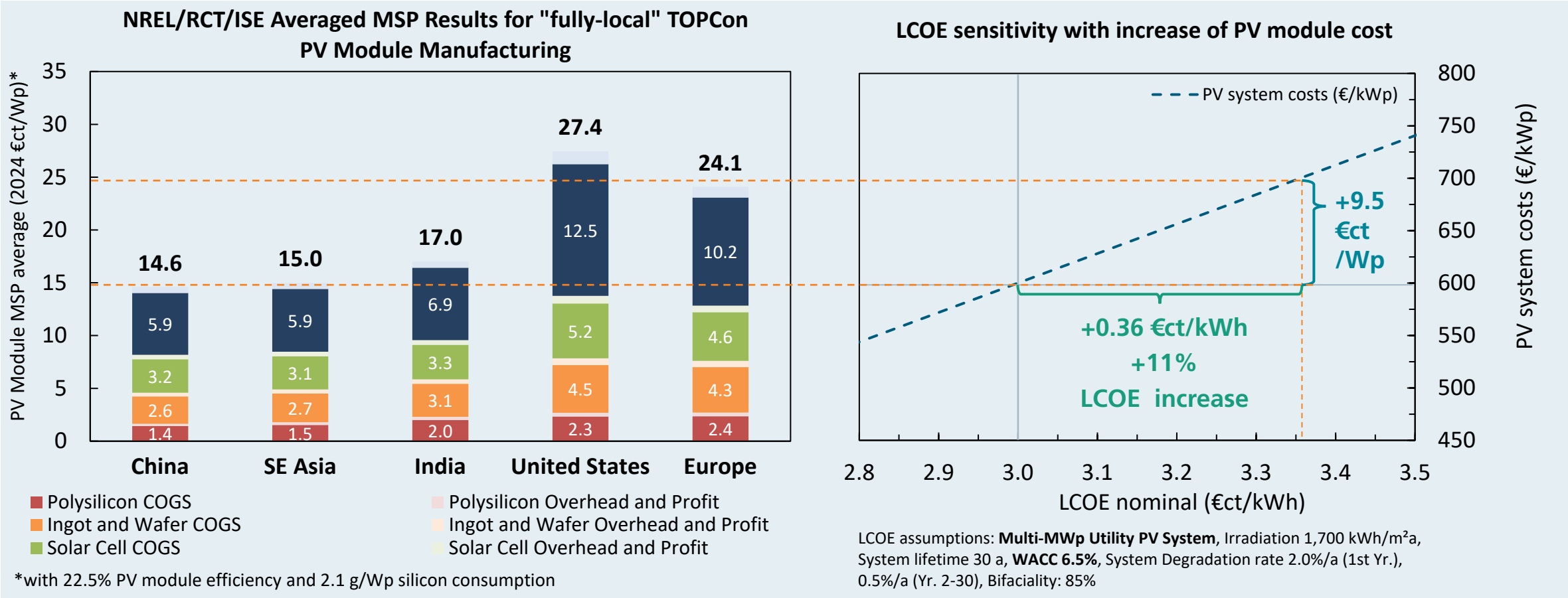
MSP difference 9.5 – 12.8 €ct/Wp

for "fully-local" manufactured TOPCon PV Module.

In Southeast Asia similar, in India slightly higher MSP.

Impact of European Cost Delta on the LCOE

What is the Impact of a “fully-local” manufactured PV Module on Utility Electricity Production?

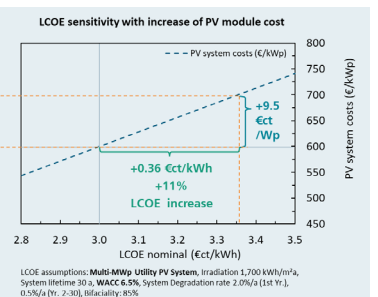
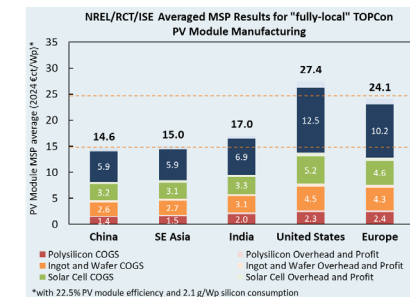
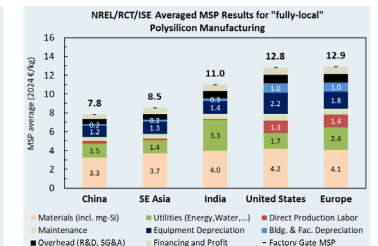
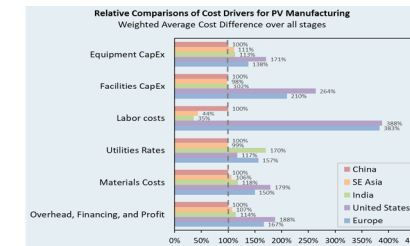
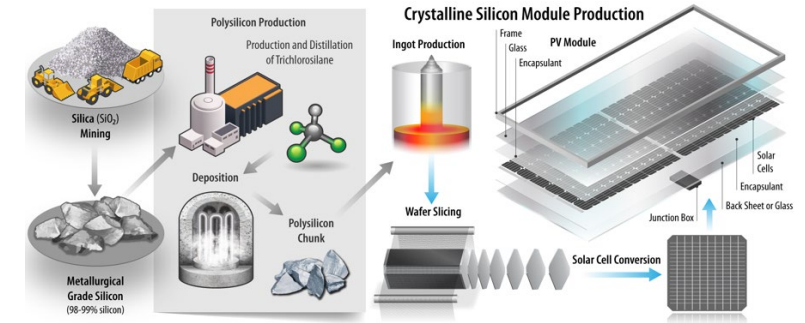


Comparative Global PV Manufacturing Cost and Pricing Assessment

Analysis of “fully-local” PV Manufacturing along the Value Chain in Different Global Regions

Summary and Conclusion

- Comparison of PV module manufacturing costs in global regions with collaboration of cost modelling experts from NREL, RCT & ISE
- Minimum Sustainable Price (MSP) analysis results in 9.5 €/Wp higher MSP for “fully-local” European PV Module production**
- In Europe and US low financing costs, low energy prices and high automation degree (to reduce labor costs) preferable
- Scaling of European materials supply chains could lower material costs
- Impact of “fully-local” European PV module supply chain on Utility-scale LCOE of PV is 0.3 – 0.4 €/ct/kWh**



Thank You for Your Attention!

Contact

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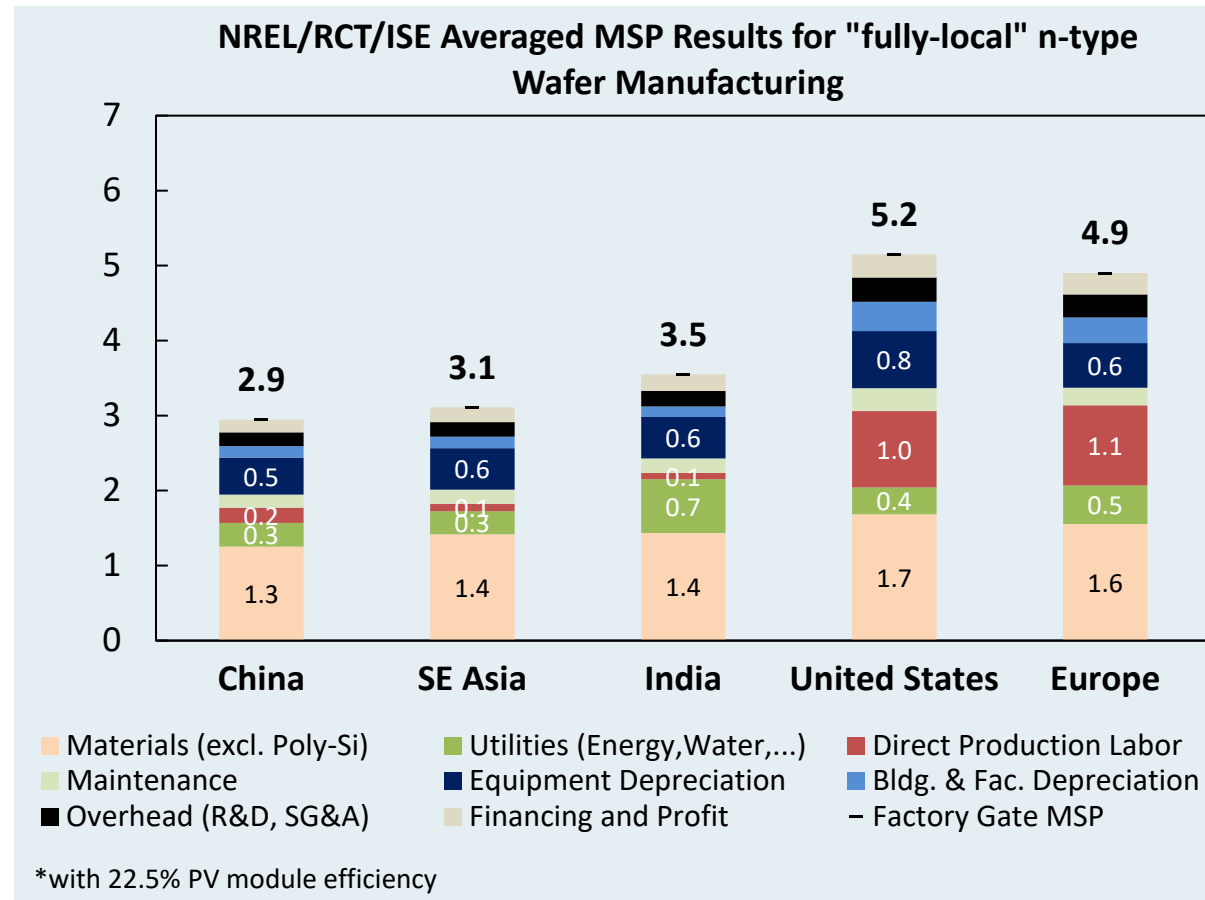


Link to Fraunhofer ISE
contributions of the
41st EU PVSEC:
<https://ise.link/eupvsec2024>
available as of 25.09.2024



Ingot and Wafer Production: n-type Wafer

Polysilicon-to-Wafer Manufacturing Cost Results in €/ct/Wp



Impact on Polysilicon-to-Wafer conversion

Main cost difference in EU/US to CN

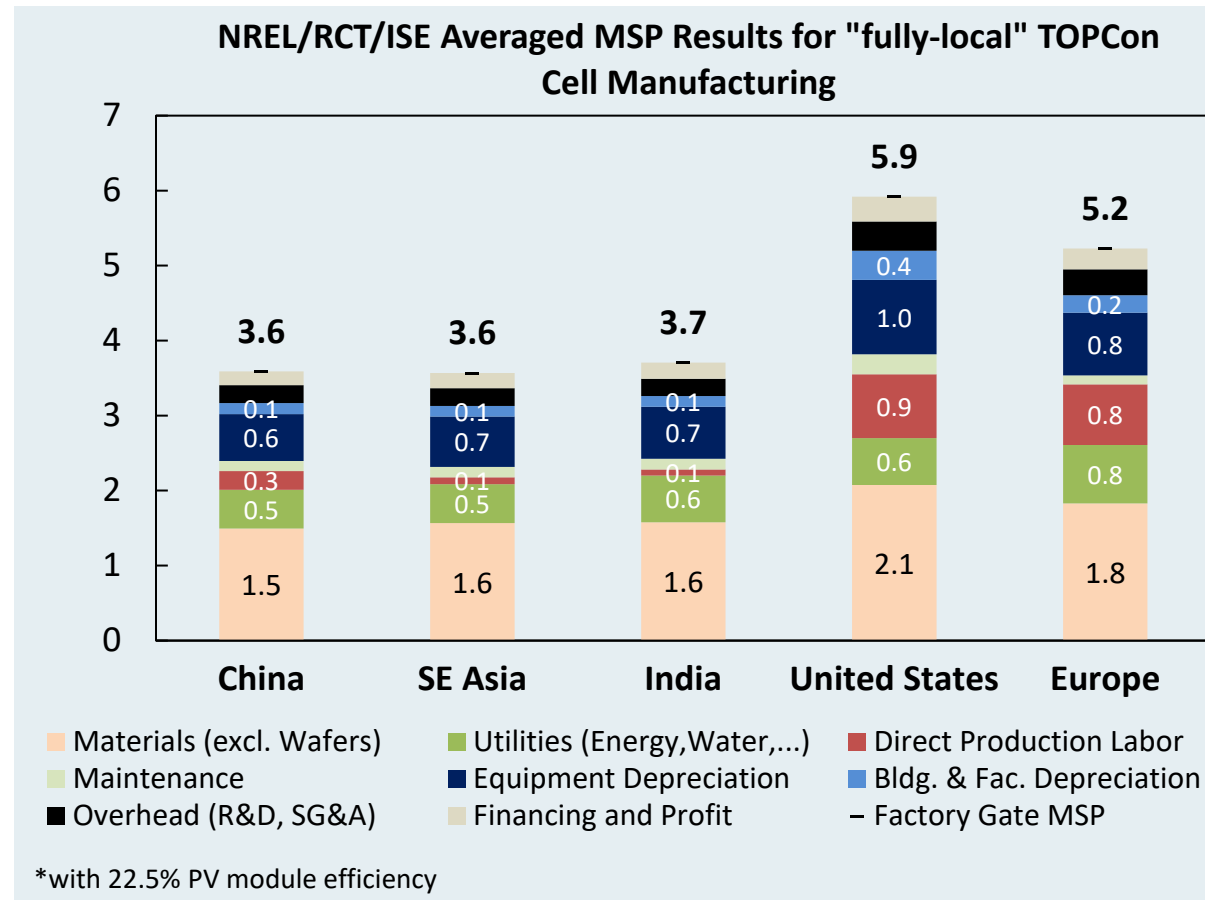
1. Production Labor 0.8 – 0.9 €/ct/Wp
2. Materials (excl. Poly-Si) 0.3 – 0.4 €/ct/Wp
3. Utility (Energy, Water, ...) 0.0 – 0.2 €/ct/Wp

MSP for Polysilicon-to-Wafer conversion in Europe and US 2.0 – 2.2 €/ct/Wp higher

In Southeast Asia and India similar MSP achievable.

Solar Cell Production: TOPCon

Wafer-to-Cell Manufacturing Cost Results in €ct/Wp



Impact on Wafer-to-Cell conversion

■ Main cost difference in EU/US to CN

1. Production Labor 0.5 – 0.6 €ct/Wp
2. Materials 0.3 – 0.6 €ct/Wp
3. Equip., Bldg & Fac. Depreciation 0.3 – 0.6 €ct/Wp

MSP for Wafer-to-Cell conversion in Europe and US 1.6 – 2.3 €ct/Wp higher

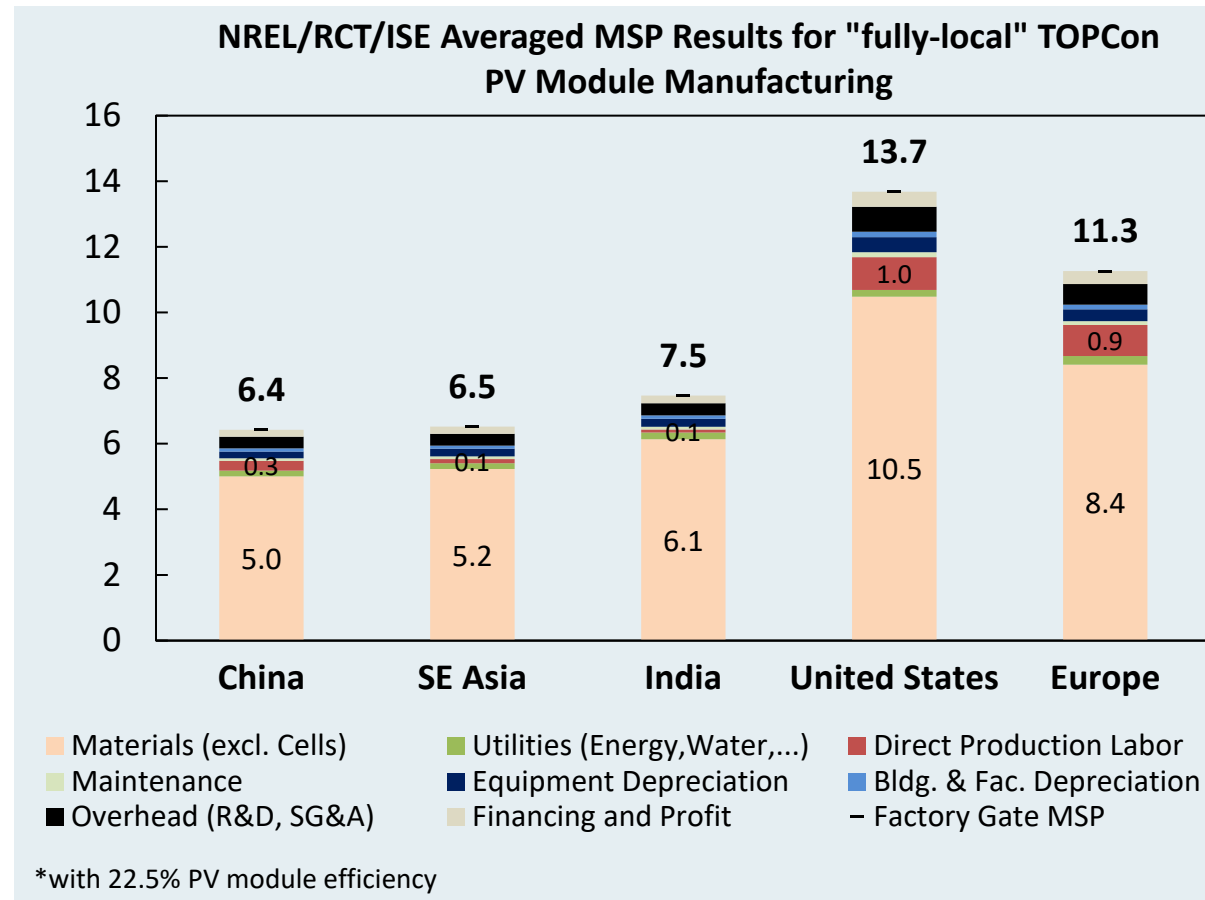
In Southeast Asia and India similar MSP achievable.

PV Module Production

Manufacturing Cost Results



Module



Impact on Cell-to-Module conversion

- Materials costs with significant differences among regions
- Main cost difference in EU/US to CN**
 - Materials 3.4 – 5.5 €ct/Wp
 - Production Labor 0.6 – 0.7 €ct/Wp

MSP for Cell-to-Module conversion in Europe and US 4.8 – 7.3 €ct/Wp higher

In Southeast Asia similar, in India slightly higher MSP.