



International Technology Roadmap for PV (ITRPV)

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Leipzig, Germany
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Agenda

- | | |
|---------------|---|
| 10.00 – 10.10 | Welcome, Anti-Trust Reminder & Introduction |
| 10.10 – 12.30 | Presentation & Discussion of ITRPV |
| 12.30 – 13.15 | Lunch Break |
| 13:15 – 15.30 | Discussion about Cost of ownership elements |
| 15.30 – 16.00 | Summary & Closure |

Antitrust Reminder

- SEMI activities are a coordinated effort among competitors in the PV, semiconductor equipment, FPD, and related industries. *Accordingly, every effort must be made to avoid even the appearance of impropriety.*
- Do **NOT** discuss or participate in topical areas such as:
 - Pricing, purchasing, or marketing of either a company or of a specific products
 - Industry or customer allocation, production, or capacity
 - Matters relating to actual or potential corporate entities that might provide undue bias or influence towards said entity's business and/or their marketplace

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- When possible, any roadmap document should avoid the necessity of using patented technology or copyrighted information.
- All members are responsible to make known any
 - non-confidential patented technology or copyrighted information, or
 - issued patents and published patent applications,which may be required for compliance with the roadmap document being developed.
- Intentionally concealing of any intellectual property, *while knowing it could have an effect on the document under development*
 - Is seen as unprofessional,
 - May render the intellectual property rights unenforceable in the future.



ITRPV 2010 – results and review

Timeline

- 2008: European c-Si cell manufacturers started informal meetings to have technical discussions at COO Level
- 2009/06: start of data collection processes w/ several meetings
- 2009/09: first ITRPV publication at EU PVSEC
- 2010: c-Si cell manufacturers join SEMI and establish a special interest group (CTM – crystalline Technology Manufacturing Group*)
- 2010/03: first edition of ITRPV was published
- 2010/2011: extension along the value chain w/ more int. contributors information exchange w/ institutes, material -, and tool suppliers
- 2011/03: second edition of ITRPV was published
- 2011/06: first meeting with non-European PV manufacturers
- 2011/autumn: follow-up meeting at EU PVSEC
- 26 March 2012: publication of third edition during PV Fab Managers Forum (www.pvgroup.org/pvfmf)

Contributors



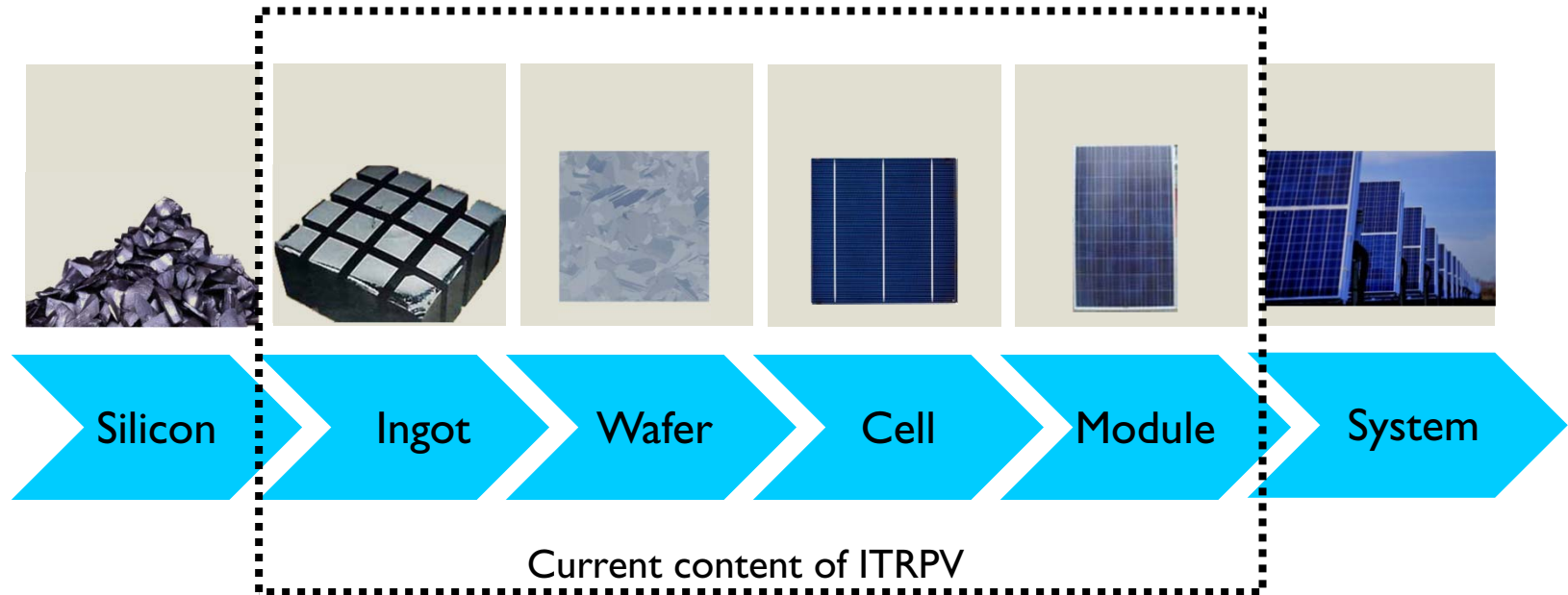
ITRPV Objectives

- Common path towards **sustainable PV market**
- Roadmap for **crystalline silicon PV value chain**
- Basis for cooperation with **customers**
- Guideline for **material+equipment suppliers**
- Targets for **R&D**
- Requirements for **PV Standardization**

ITRPV Methodology

- **Active working group** initiated by CTM Group
- Focusing on **key technology parameters**
- **Anonymous data collection** from participants by SEMI
- **Data processing** (e.g. averaging) by SEMI
- **Workshops** with suppliers and R&D organizations
- **Yearly update** and publication of roadmap

ITRPV Structure

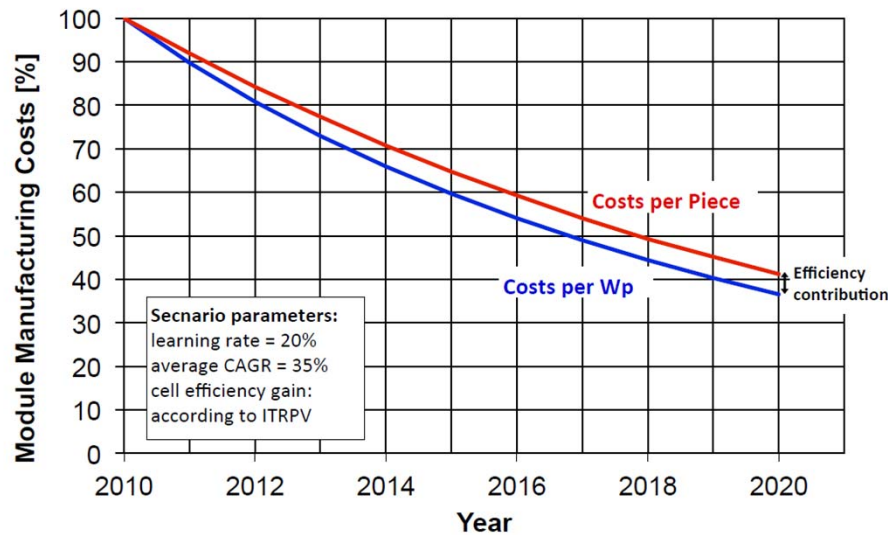


Key Areas:

- Materials
- Processes (Manufacturing, Technology)
- Products

Main Technology Driver

ITRPV addresses cost reduction as main technology driver in PV industry



Key parameters for cost reduction:

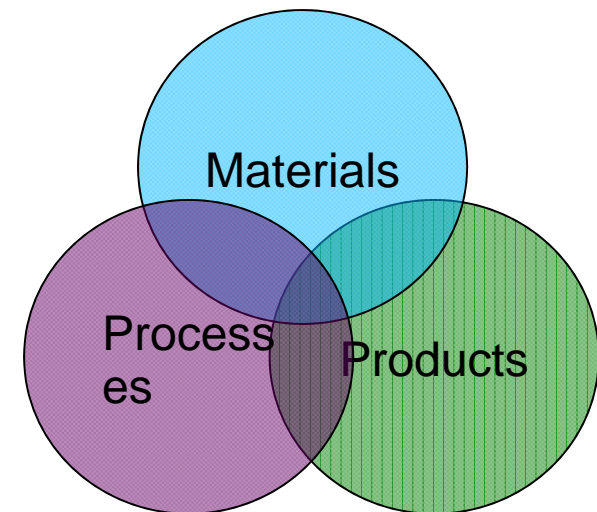
- Annual growth rate
➔ Sustainable market growth
- Learning rate
➔ Progress in technology

Cost reduction is clearly dominated by reduction of manufacturing cost piece. Improvement of efficiency alone is insufficient!

Benefit

ITRPV gives guidance for cost reduction along the value chain
(crystallization & wafering, cell processing and module manufacturing)

- **Material costs**
 - Poly-Si, consumables, wafer thickness, replacement of silver,...
- **Productivity**
 - Equipment throughput, yield, uptime, specific invest, operators per equipment, floor space,...
- **Efficiency**
 - Surface and bulk recombination, finger width, module to cell power ration, n-type Si, rear contact cells,...



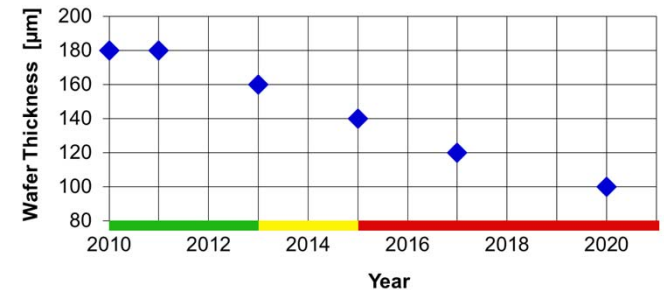
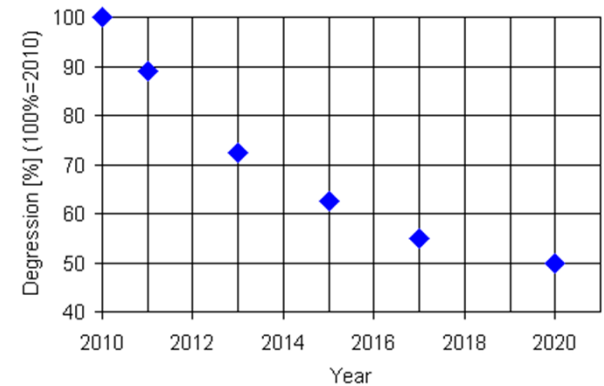


Color coding for selected parameter defines today's maturity

Green	Industrial solution exists, and is being optimized in production.
Yellow	Industrial solution is known but not yet in production
Orange	Interim solution is known, but too expensive or not suitable for production
Red	Industrial solution is not known

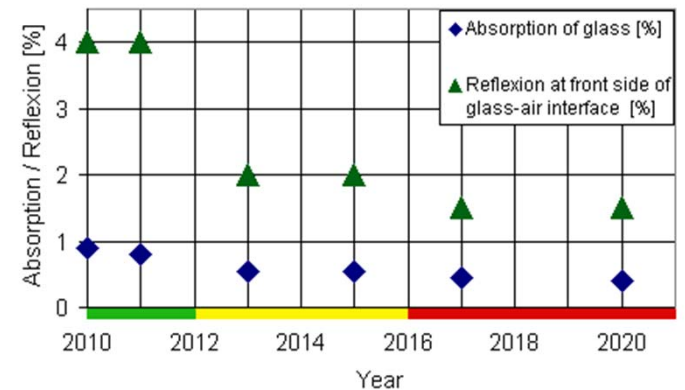
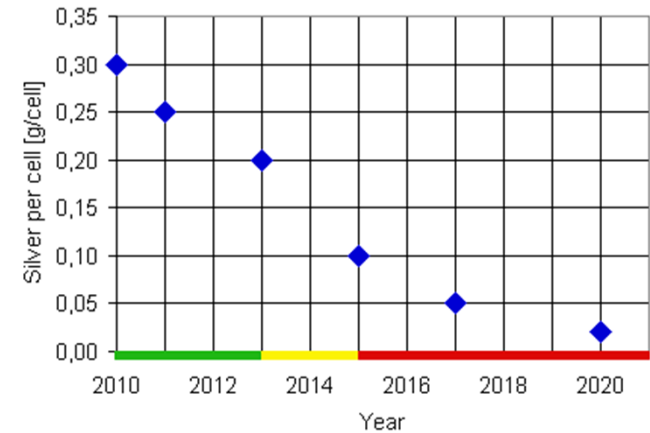
Extracts 2010 edition

- Significant price reductions in Poly Si and consumables is needed
 - 156mm x 156mm remains main stream cell format
 - larger wafers to appear in production earliest 2017
- Reduction in wafer thickness is necessary
 - more efficient use of Poly Si
 - need of innovative handling concepts
 - need new high eta cell concepts
 - need for new interconnect/ encapsulation technologies
 - improved wafer sawing technologies (reduced TTV + Kerf loss)



Extracts 2010 edition

- Reduction of Silver consumption per cell
 - necessary as Silver is most expensive beside
 - high eta lead free pastes needed mid 2012
 - Cu is supposed to replace Silver starting in 2015
- Trend of absorption and reflection of glass
 - reduced front side reflection starting in 2013 by introducing anti-reflection glass
 - reduces cell-to module power loss

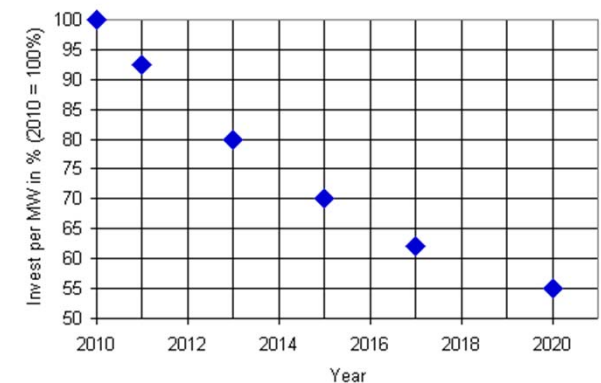
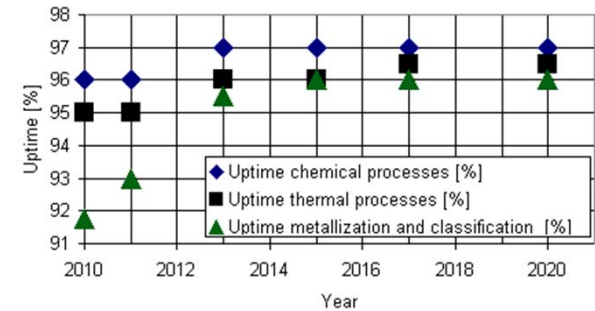


Extracts 2010 edition

- Tool up times need to be improved
 - special efforts are necessary in metallization and testing
- Throughputs of the cell production tools have to increase
 - the gap between front- and back end has to be closed

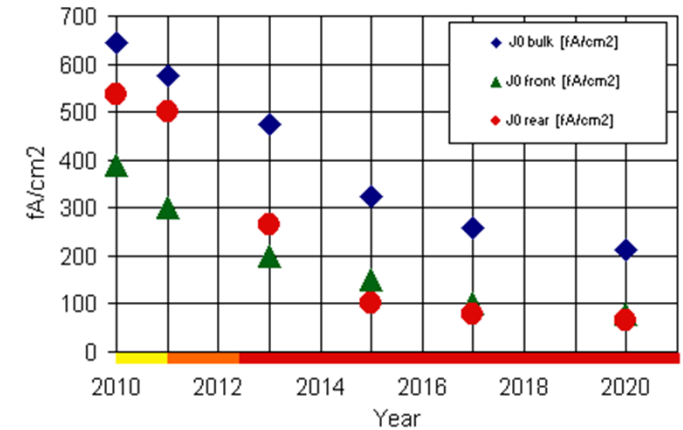
Year	Front end [wafer/h] (chemical + thermal)	Single line back end [wafer/h] (metallization + classification)
2011-2012	3600	3000
2013	5000	3600
2015	6400	5400
2020	7200	7200

- Relative invest for new cell fabs has to be reduced over the next years
 - estimates base on p-type concepts with similar or only slight increased number of processing steps

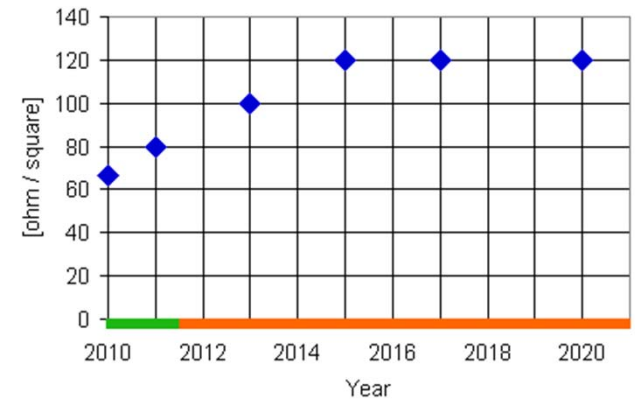


Extracts 2010 edition

- Recombination losses have to be reduced
 - In the crystalline Si bulk material
 - at the front side of the cell
 - at the back side of the cell
- new processes w/ lower CoO and better passivation are needed
- values below 200fA/cm² can not be reached w/ Al BSF



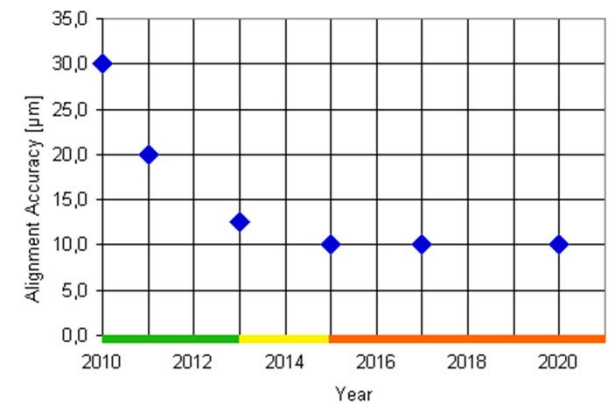
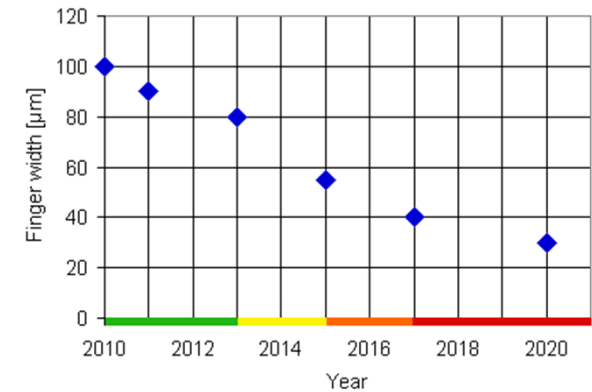
- Increased emitter sheet resistance is needed
 - mandatory for reduced FS recombination currents
 - values for n-doped emitters are shown



Extracts 2010 edition

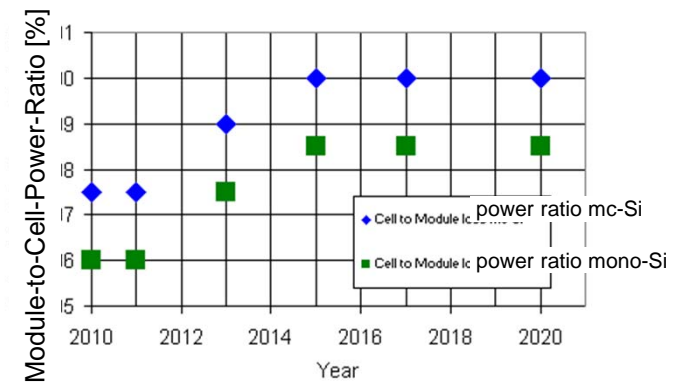
- Finger width of front side print has to be reduced
 - width reduction w/o higher finger resistances
 - economic mass production solutions for $\leq 50\mu\text{m}$ are needed

- Alignment accuracy has to be improved
 - 3 sigma values are indicated
 - necessary for future more complex structures
 - 10 μm accuracy is expected in 2015



Extracts 2010 edition

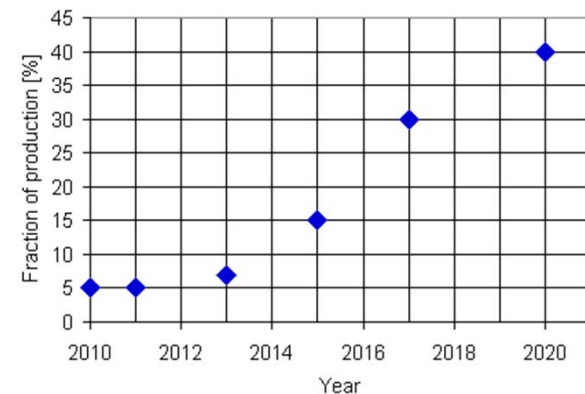
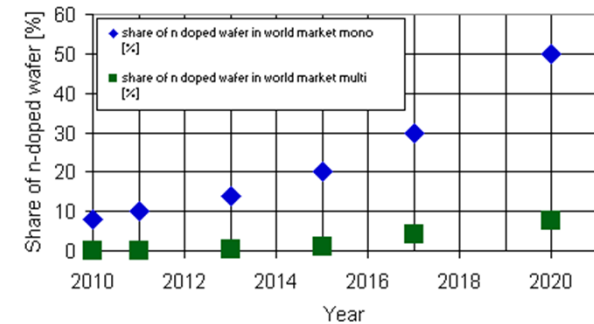
- Improvement of module to cell power ratio is needed
 - improvement in 2013 due to introduction of AR glass
 - further improvements by introduction of new interconnection technologies
 - new encapsulation technologies
 - further improvement by introduction of back contact cells



Extracts 2010 edition

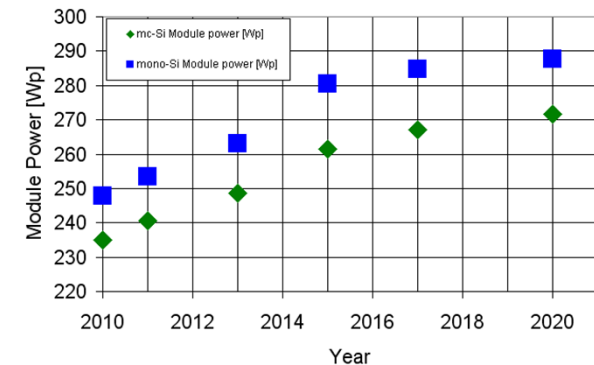
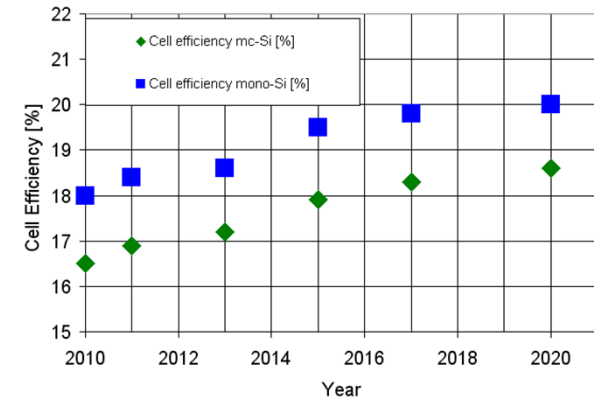
- Expected share of n-type material
 - introduction of n-type cells will advance
 - less share is expected for multi material

- Share of rear side contacted cells
 - share is expected to increase
 - standard double contacted cell will remain mainstream



Extracts 2010 edition

- Average efficiencies of p-type c-Si cells will improve
 - stabilized efficiencies only are considered
 - shown are cells out of a state of the art mass production line
 - gap between mono and multi remains valid
- Trend of output power of 60 cell modules
 - cell efficiency improvement are included
 - improvements of module technology are included
 - trend implies shift to full square Mono starting in 2015



New Parameters

- Trends in wafer sawing (slurry vs. Diamond)
- Throughput values in wafer sawing
- Price degression of wires, slurry and graphite parts
- Share of materials (mc-Si vs. mono-Si vs. mono-cast)
- Share of back contact modules
- Limit of cell thickness in module technology
- Efficiency values for different materials

Preview 2011 edition

Key parameters for LCA PV (c-Si)

Poly-silicon	2011	2013	2015	2017	2020	Unit
metallurgical silicon						kg / kg poly-Si
electricity						kWh / kg poly-Si
electricity hydropower						share in %, total of all 3 process questions has to be 100%
electricity cogeneration						share in %, total of all 3 process questions has to be 100%
electricity country mix						share in %, total of all 3 process questions has to be 100%
natural gas						m ³ / kg poly-Si
Siemens						share in %, total of all 3 process questions has to be 100%
FBR						share in %, total of all 3 process questions has to be 100%
UMG						share in %, total of all 3 process questions has to be 100%
Crystals/ingots	2011	2013	2015	2017	2020	Unit
poly-silicon, virgin						kg / kg crystal or ingot
poly-silicon, recycled						kg / kg crystal or ingot
electricity						kWh / kg crystal or ingot
Wafer	2011	2013	2015	2017	2020	Unit
Crystal or ingot						kg / wafer
silicon carbide, virgin						kg / wafer
silicon carbide, recycled						kg / wafer
polyethylene glycol, virgin						kg / wafer
polyethylene glycol, recycled						kg / wafer
electricity						kWh / wafer
Cells	2011	2013	2015	2017	2020	Unit
						kWh / cell
electricity						
Modules	2011	2013	2015	2017	2020	Unit
frame						kg / meter
thickness glass						mm
thickness EVA						micron
thickness backsheets						micron
glass loss						%
cutting loss EVA						%
cutting loss backsheets						%

- **Whats your feedback to the 2010 edition?**
 - in Crystallization & Wafering
 - in Cell Manufacturing
 - in Module Manufacturing
- **What parameters are missing, what parameters should be included in the 2011 edition?**
- **Any other feedback?**



Cost of Ownership for PV

Motivation

- Standardized CoO-Model for C-Si value chain elements
 - Based on SEMI Standards E35 (CoO calculation), E10 (machine utilization) and E79 (equipment efficiency)
 - Predefined cost categories including yield loss
 - Comprehensive calculations and results to identify all important parameters
- Applicable to single equipments, process steps, production lines and complete fabs

Cost of Ownership Basic Elements

CoO calculation elements are based on different SEMI standards that are globally accepted

- SEMI E35 (calculation),
- SEMI E10 (utilization)
- SEMI E79 (efficiency)

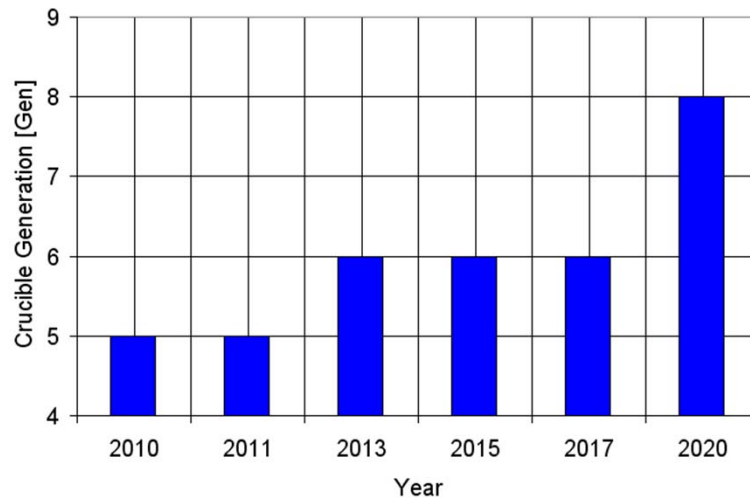
Parameters with direct influence on Cost of Ownership

- Throughput
- Productivity
 - productive time depending from
Up-, Standby-, Engineering-, Down (shed., unshed.) Time,
 - Overall Equipment Efficiency dependend from
availability-, performance-, and Quality Efficency
- Depreciation
- Floor Space
- Materials /Consumables
- Utilities
- Waste Disposal
- Labour
- Cost of yield loss

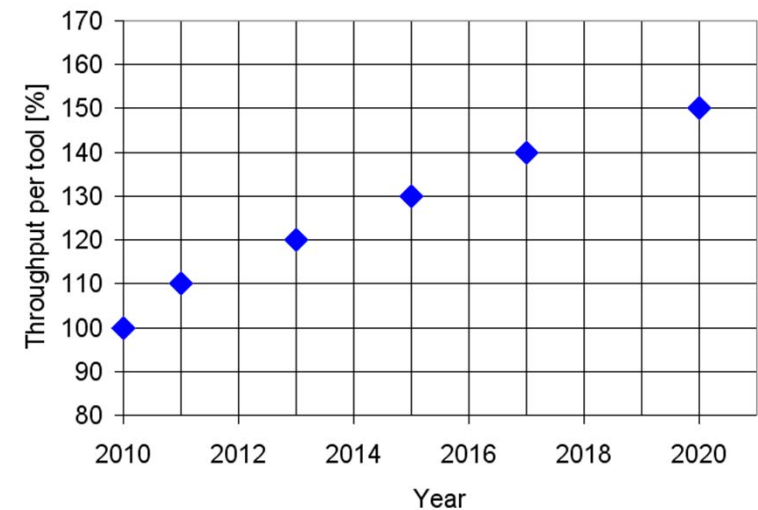
→ Result in a CoO of €/pc or €/Wp

CoO Elements in ITRPV – Processes – Manufacturing

- Using economy of scale requires:
 - high **throughput** approaches
 - in crystallization: a trend to **larger ingots** is predicted

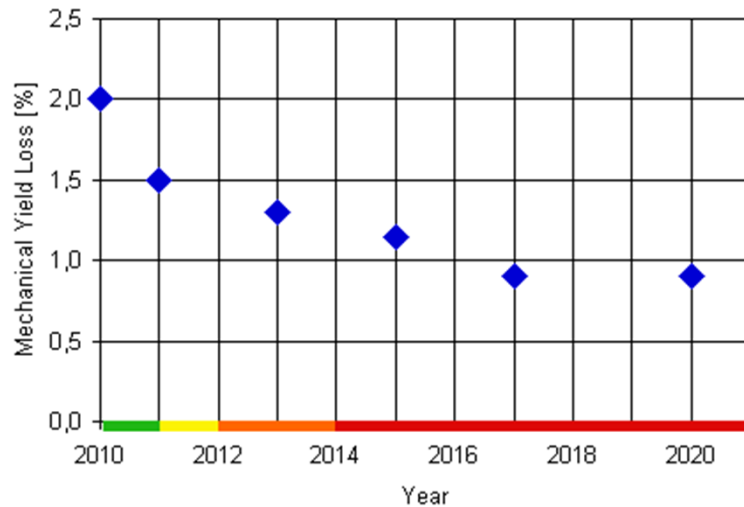


→ in wafering:
continues increase in **throughput** is expected

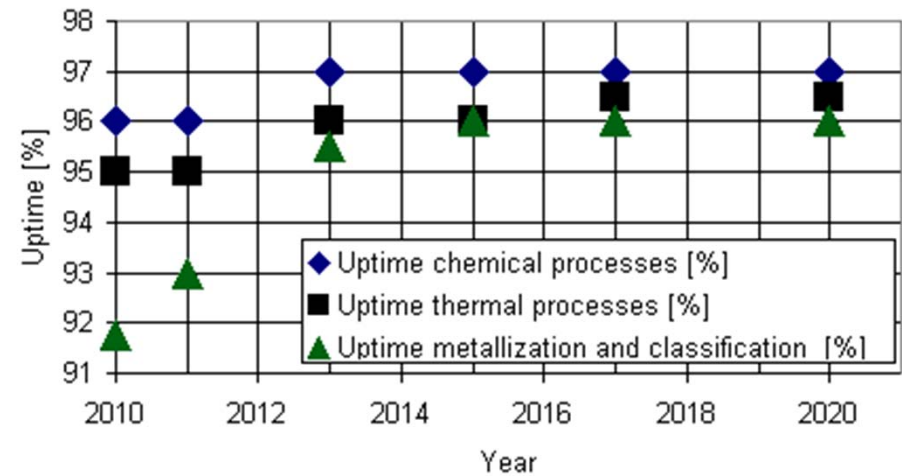


CoO Elements in ITRPV – Processes – Manufacturing

- **Mechanical yield loss** during cell production has to be reduced as well



- **Tool up times** need to be improved
- special efforts are necessary in metallization and testing

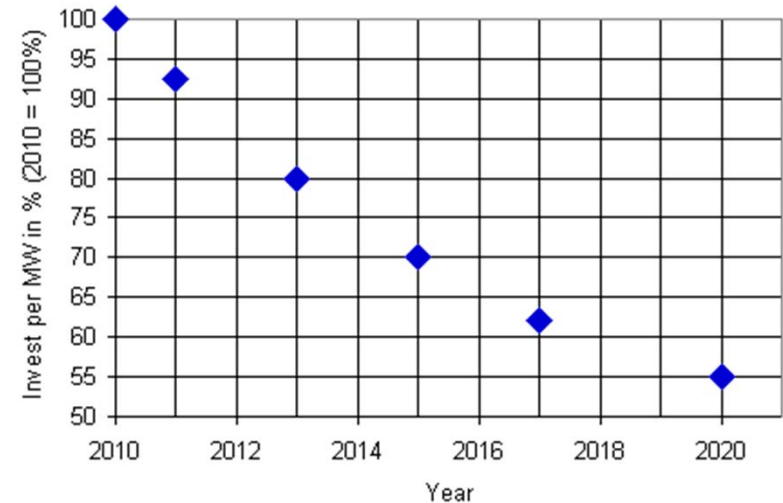


CoO Elements in ITRPV – Processes – Manufacturing

- **Throughputs** of the cell production tools have to increase
- the gap between front- and back end has to be closed

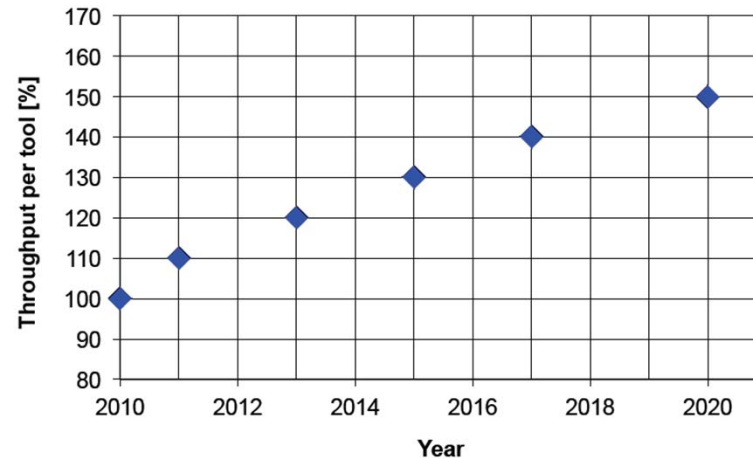
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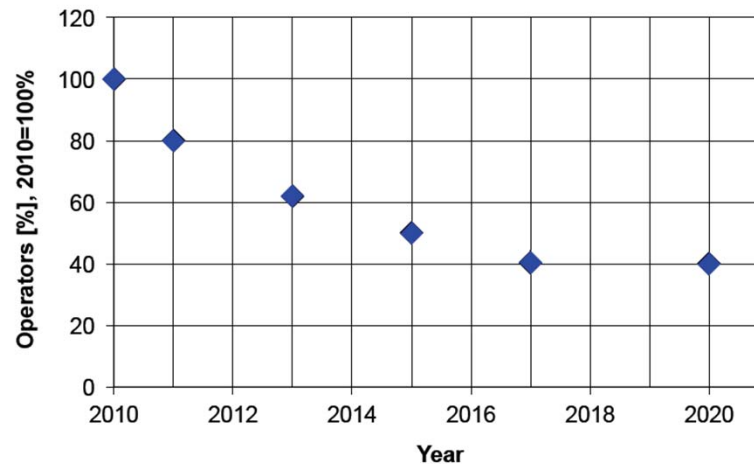


CoO Elements in ITRPV – Processes – Manufacturing

- **Throughput per tool** for wafer sawing and cleaning has to increase by 50% until 2020

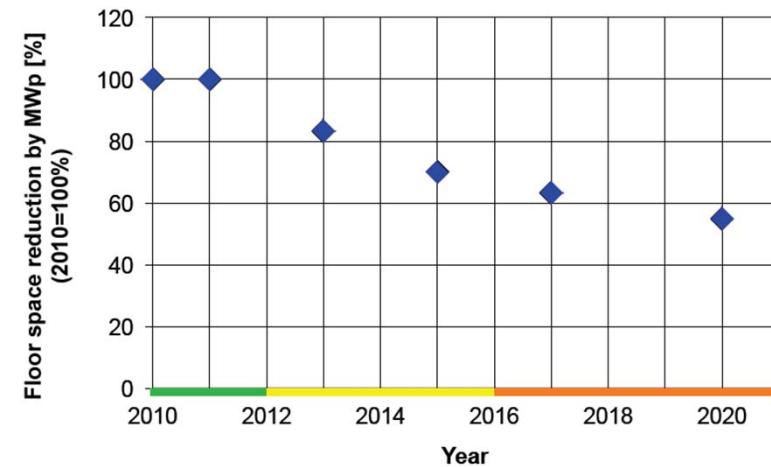


- **Labour:** number of Operators in state of the art cell production lines can be reduced as uptime and throughput increases



CoO Elements in ITRPV – Processes – Manufacturing

- **Floor space:** Module manufacturing equipment should occupy less floor space/MW_p over the next years



CoO-Tool: Base data

Base Data

		value	unit	comment
0.0	Production and Throughput			
0.0.1	Operations time	8.760	h/a	
0.0.1.1	Days/Year	365,00	d/a	
0.0.1.2	Shifts/Week	5		
0.0.1.3	Hours/Day	24,00	h/d	
0.0.2	Product Data			
0.0.2.1	Wafer area	243,36	cm ²	
0.0.2.2	Cell efficiency	20,0	%	
0.0.2.3	Power/Cell	4,87	Wp/cell	
0.0.2.5	Wafer cost	1,00	€/wafer	
0.1	Depreciation			
0.1.1	Depriciation Life	5	a	
0.2	Floor Space			
0.2	Floor Space Rate (Production Floor)	0,00	€/m ² /a	
0.2.1	Rent for Floor Space	0,00	€/m ² /a	
0.2.2	Additional Infrastructure Overhead	0,00	€/m ² /a	
0.3	Materials/Consumables			
0.3.1	Materials			
0.3.2	Consumables			
0.4	Utilities			
0.4.1	Electricity	0,00	€/kWh	
0.4.2	Compressed Air	0,00	€/m ³	
0.4.3	Cooling Water	0,00	€/m ³	
0.4.4	DI-Water	0,00	€/m ³	
0.5	Waste Disposal			
0.6	Labour and Salary			

CoO-Tool: Input

CoO-Template

based on SEMI E10, E35 and E79

Process:

Date:

Equipment:

Editor:

Details:

Technology Data

	value	unit	Comments
0 Production and Throughput			
0.1 Throughput Rate at Capacity	1.000	wafer/h	Operations time
0.2 Productive Time	8.551	h/a	8.760 h/a
0.2.1 Up Time	8.656	h/a	Intervall
0.2.2 Standby Time	52	h/a	Duration
0.2.3 Engineering Time	52	h/a	168 h
0.2.4 Scheduled Down Time	52	h/a	168 h
0.2.5 Unscheduled Down Time	52	h/a	168 h
0.3 OEE	0,974		1,0 h
0.3.1 Availability Efficiency	0,988		1,0 h
0.3.2 Performance Efficiency	0,988		1,0 h
0.3.3 Quality Efficiency	0,998		1,0 h
0.5.1 Annual Throughput (wafer)	8.551.429	wafer/a	
0.5.2 Annual Throughput (Area)	208.108	m ² /a	243,36 cm2
0.5.3 Annual Throughput (Power)	41,622	MWp/a	4,87 Wp/cell
			Cell Efficiency
			20,00 %
1 Depreciation	0	€/a	
2 Floor Space	0	€/a	
3 Materials/Consumables	0	€/a	
4 Utilities	0	€/a	
5 Waste Disposal	0	€/a	
6 Labour	0	€/a	
7 Cost of Yield Loss	17.094	€/a	Yield

CoO-Tool: Result

Add-on Process Costs by Cost Element

		good parts only			% of total	
8.1	Depreciation	0 €/a	0,0000 €/wafer	0,0000 €/m ²	0,0000 €/Wp	0,0 %
8.2	Floor space	0 €/a	0,0000 €/wafer	0,0000 €/m ²	0,0000 €/Wp	0,0 %
8.3	Materials/Consumables	0 €/a	0,0000 €/wafer	0,0000 €/m ²	0,0000 €/Wp	0,0 %
8.4	Utilities	0 €/a	0,0000 €/wafer	0,0000 €/m ²	0,0000 €/Wp	0,0 %
8.5	Waste Disposal	0 €/a	0,0000 €/wafer	0,0000 €/m ²	0,0000 €/Wp	0,0 %
8.6	Labour	0 €/a	0,0000 €/wafer	0,0000 €/m ²	0,0000 €/Wp	0,0 %
8.7	Cost of Yield Loss	17.094 €/a	0,0020 €/wafer	0,0823 €/m ²	0,0004 €/Wp	100,0 %
8.8	Cost of Ownership	17.094 €/a	0.0020 €/wafer	0,0823 €/m²	0,0004 €/Wp	100,0 %



Review & Closure

Supplier industry developments may be deduced from ITRPV

- Reduced wafer thickness requires tighter process windows and mature automation solutions
- new machine generations have to meet challenging throughput, yield learning, and manufacturing availability targets
- Fast efficiency and cost learning require the integration of quality tracking along the c-Si value chain (i.e integrated SPC, wafer tracking, automation, etc.)
- Standards will help to develop smart solutions suitable for c-Si PV manufacturers to ensure stable, cost efficient, high reliable, high volume production

Next Steps of ITRPV:

- include more manufactures from Asia and America
- further extension along the value chain

ITRPV serves as common platform for dialogue between suppliers, customers and R&D partners in order to:

- Reduce manufacturing costs without sacrificing product quality and reliability
- Stimulate technology developments having sufficient lead times before market introduction