

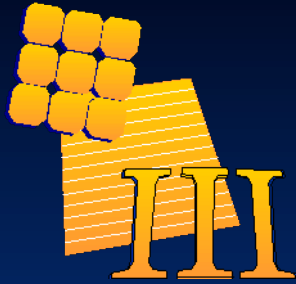
Trends in Global Photovoltaics

Stuart Wenham

Director

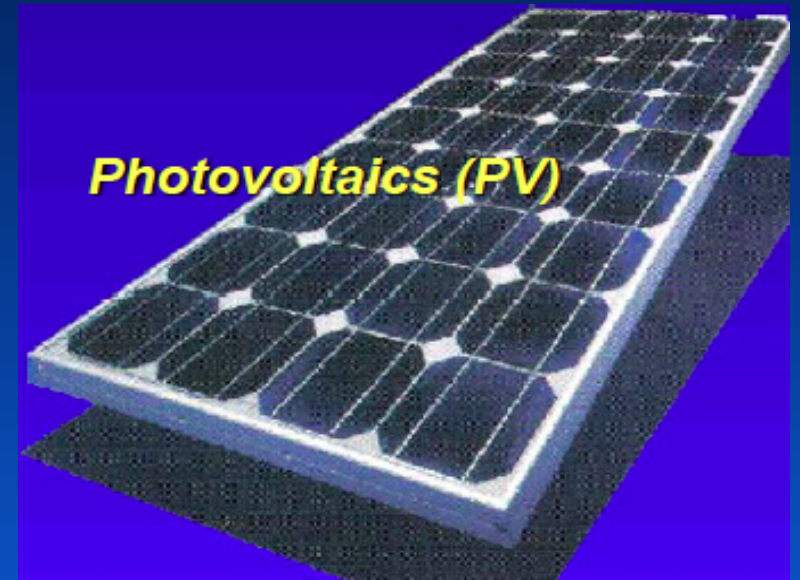
ARC Photovoltaics Centre of Excellence
The University of New South Wales

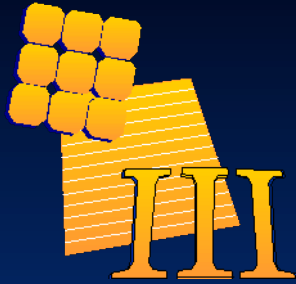
24th October, 2013



Photovoltaics – Magic Devices

- While generating electricity, there are:
 - No “wear-out” mechanisms
 - No noise
 - No waste products or pollution
 - No moving parts
 - No operating or maintenance costs
- Life expectancy >30 years
- Environmentally friendly electricity generation
- Modular and can be sized for any load
- The problem has always been cost – this has changed drastically



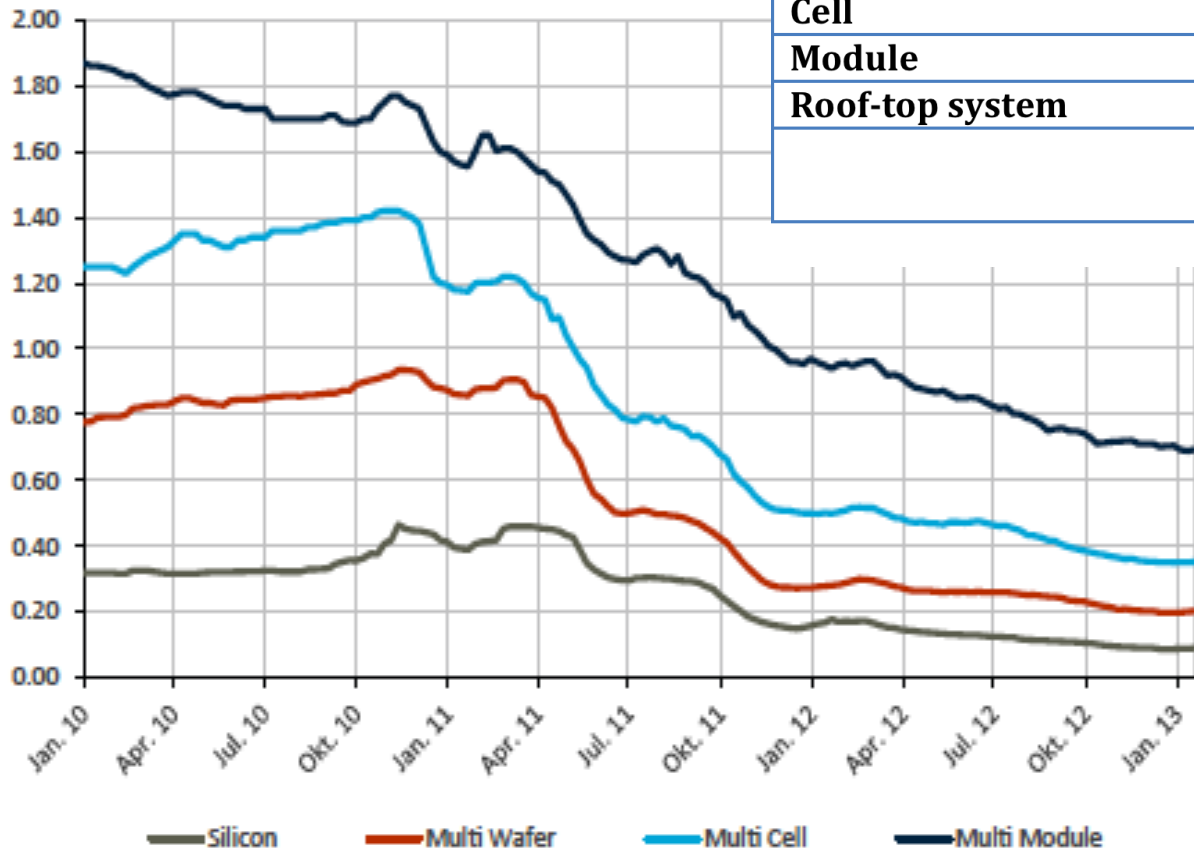


PV Cells

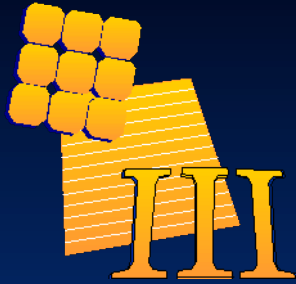
-Now only 10% of System Cost

	End 2011 \$/W _p	End 2012 \$/W _p	% reduction
Polysilicon wafer	0.22	0.12*	46%
Cell	0.30	0.21	29%
Module	0.49	0.34	31%
Roof-top system	0.96	0.66	31%

* \$15.40 per kg

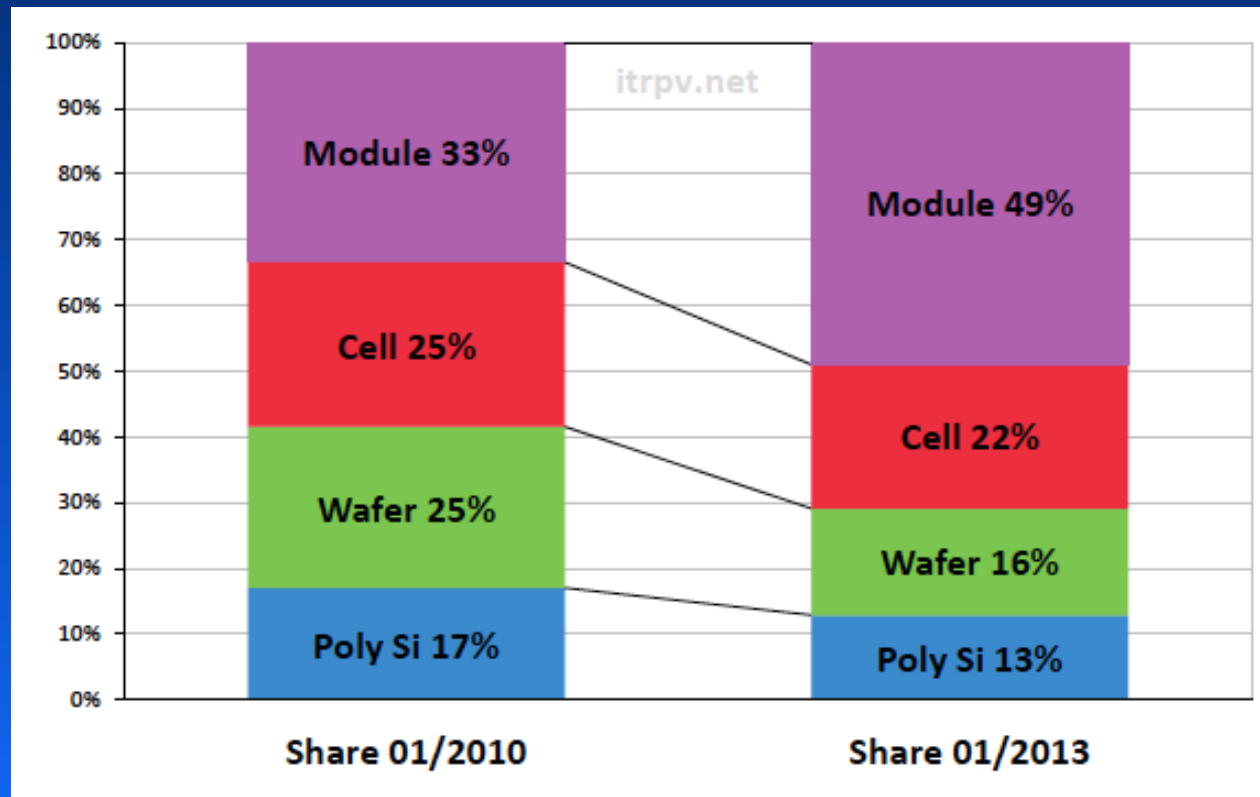


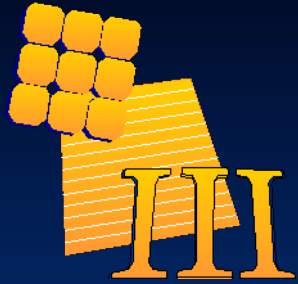
- PV module only 20-30% of system costs
 - Encapsulation now dominates module costs
 - Encapsulation quality determines durability
- Photovoltaics - Electricity from Sunlight*



Need to reduce Encapsulation Costs

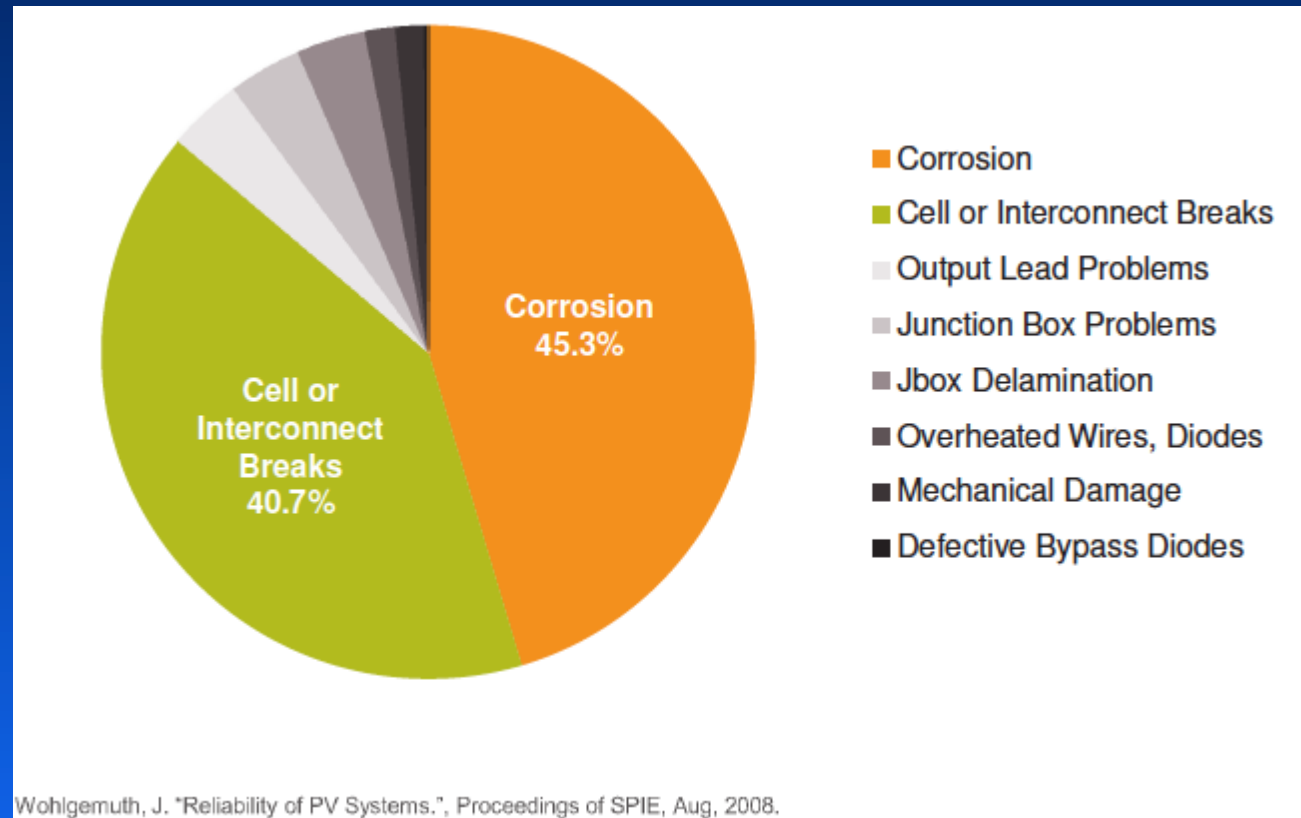
- But must not sacrifice durability
- But many appear to be

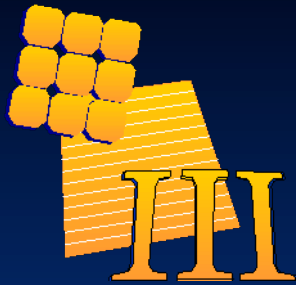




Falling Profitability Leads to Falling Quality

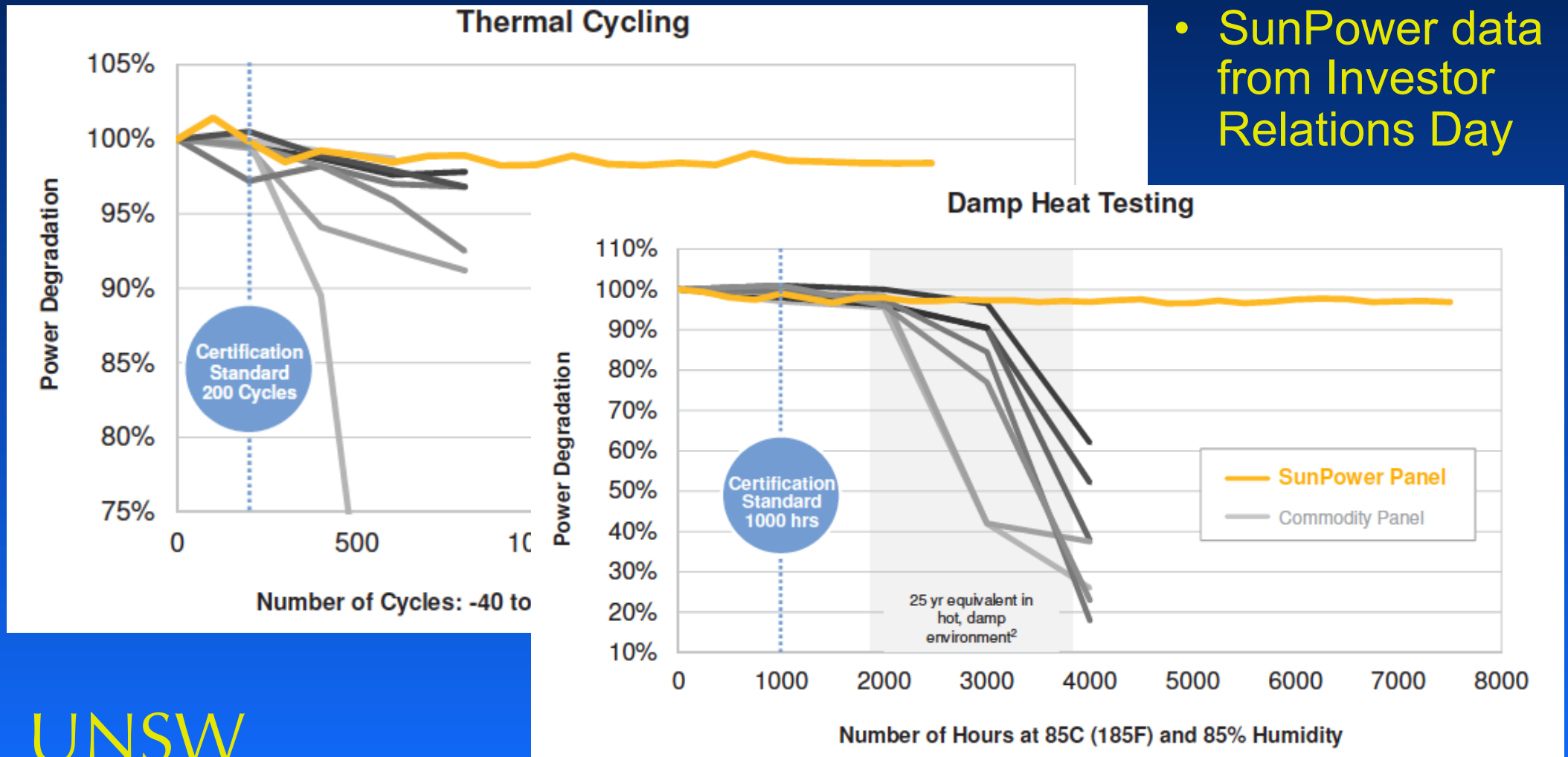
- Selling prices below cost prices leading to compromises in quality
 - Backing sheets
 - EVA
 - Junction boxes
- Many reports of poor quality and reliability
- Leading companies value their reputations

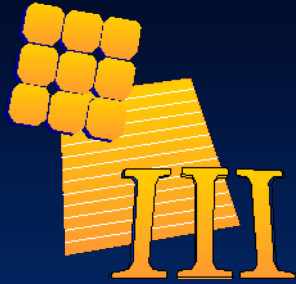




Quality and Reliability Concerns

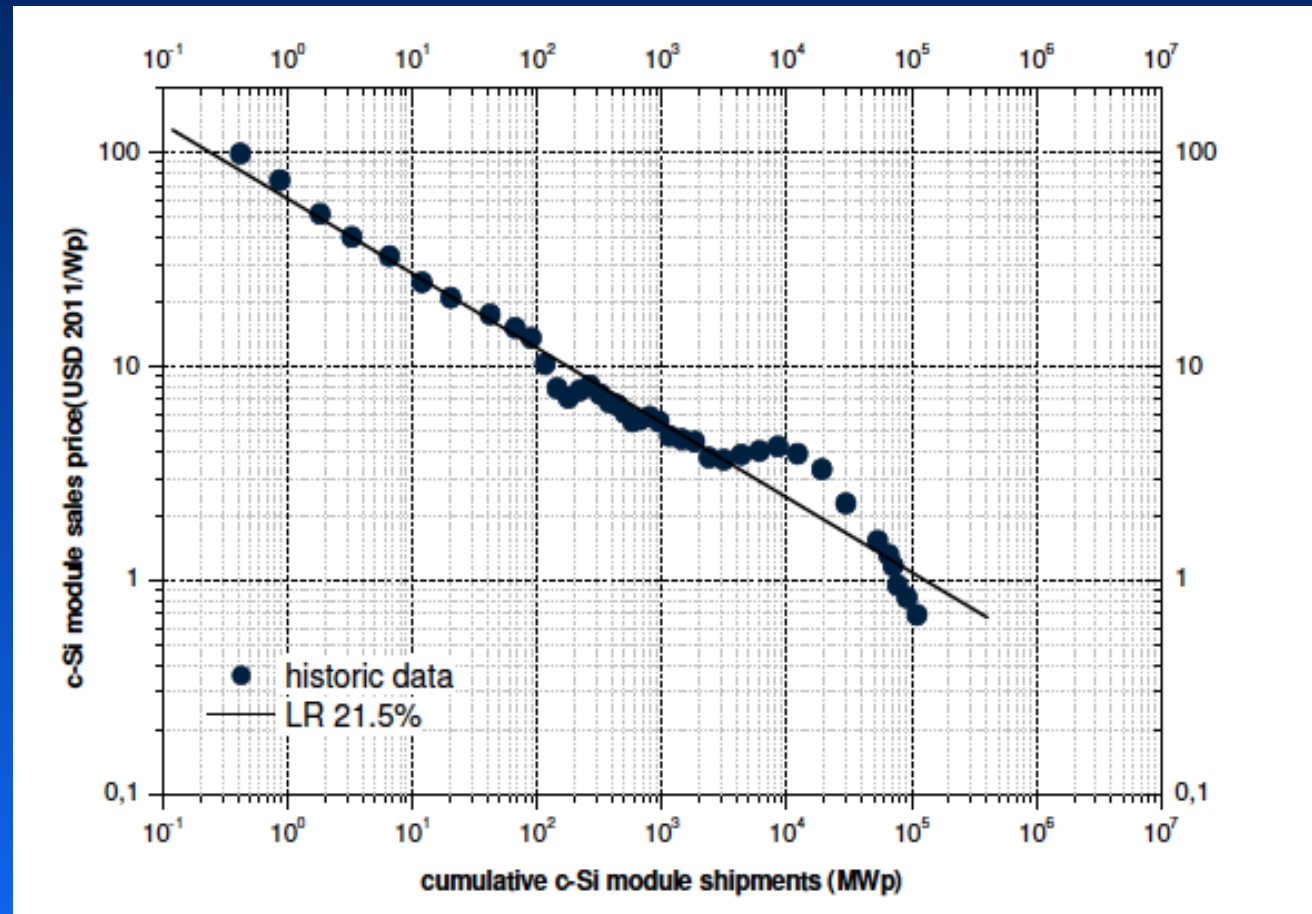
- SunPower data from Investor Relations Day

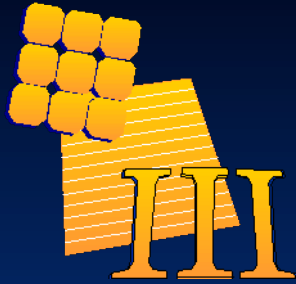




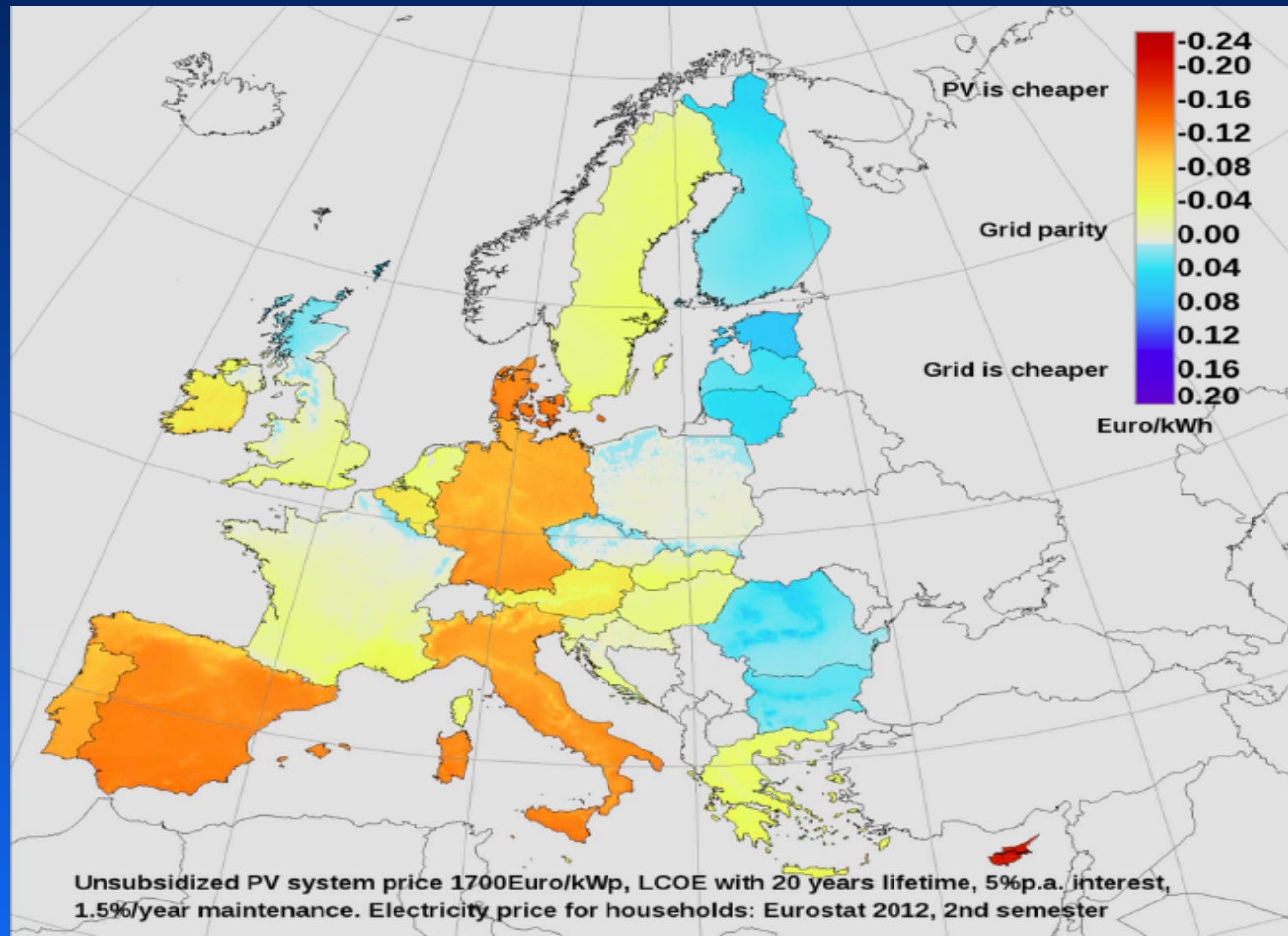
Relationship between Price and Market

- Recent instability fuelled by erratic government policy
- PV module costs down >80% in 5 yrs
- Reduced dependence on FITs and subsidies
- Grid parity reached in >100 countries
- Fastest growing industry world-wide

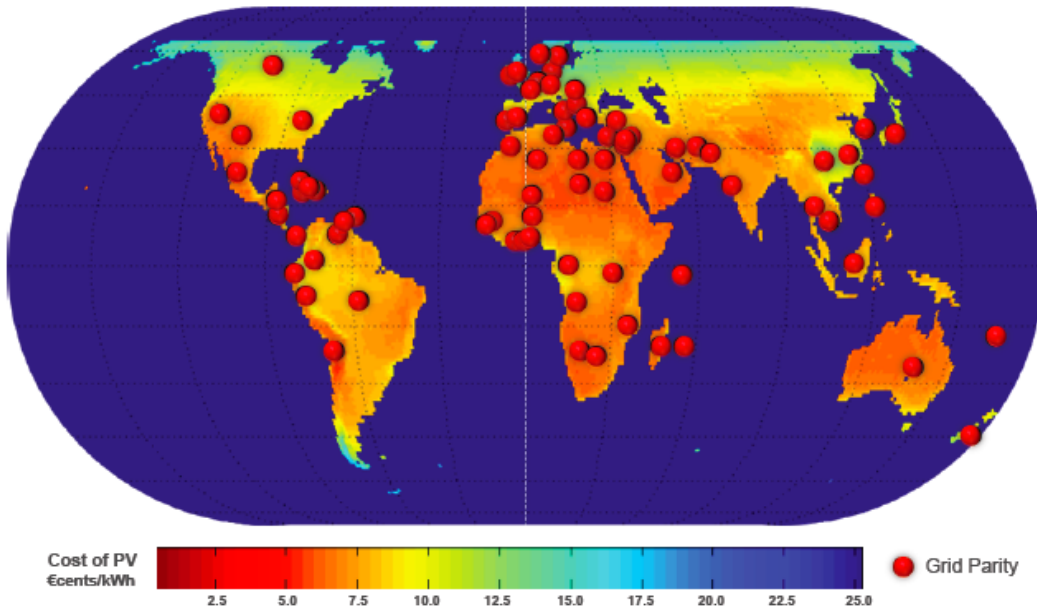




Grid-parity in Europe – EuPVSEC 2013



2012 Status: PV Solar at Grid Parity



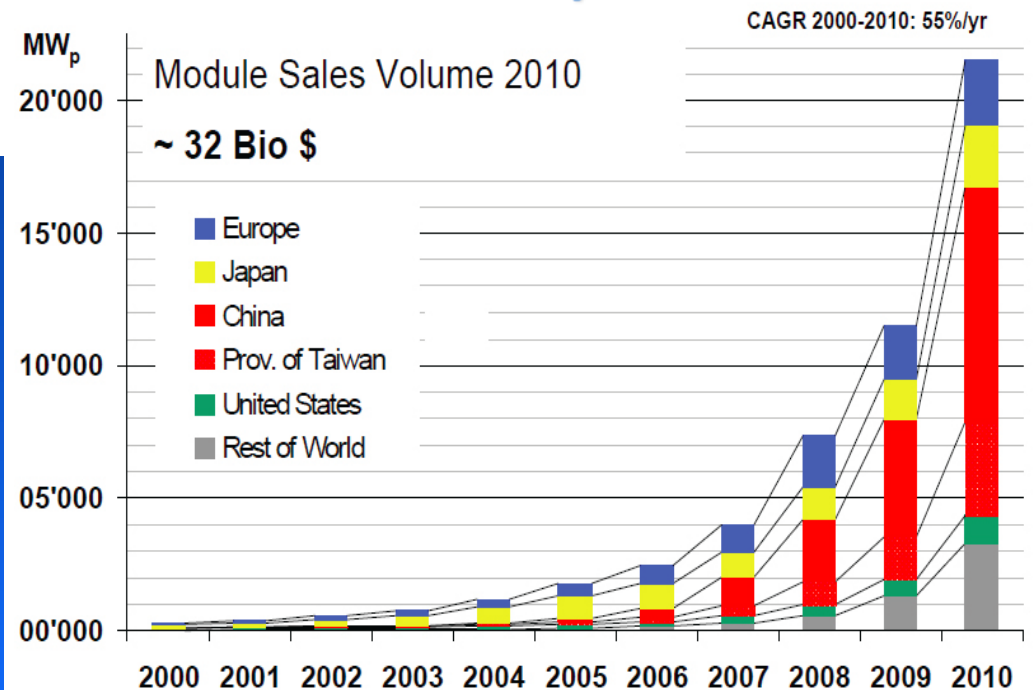
Now
2012
102
countries
have
reached
grid parity

**Grid-parity in
>100 countries**

**Fastest Growing
Industry World-wide**

UNSW

Annual PV Factory Production

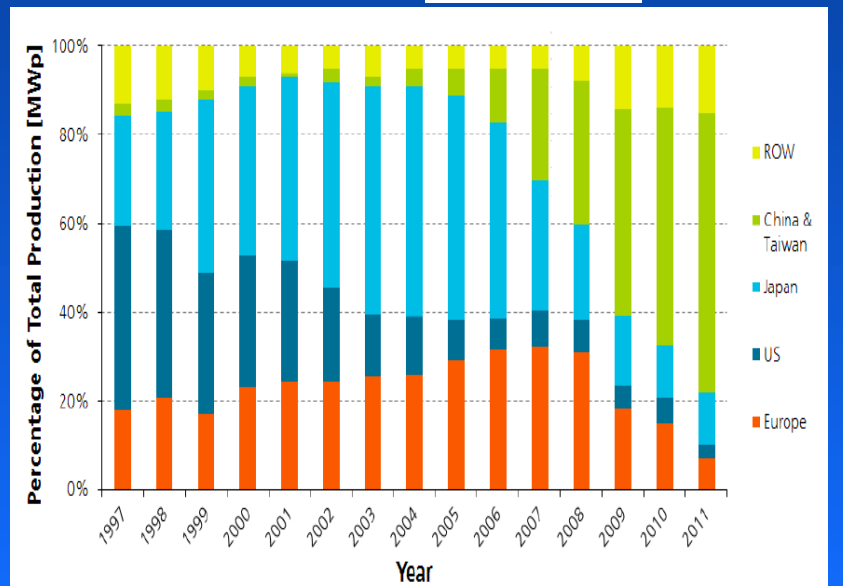


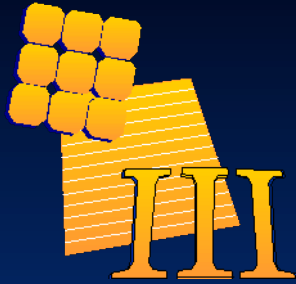
China's Dominance in Manufacturing



2007	MW	2008	MW	2009	MW	2010	MW	2011	MW
	389		582		1100		1573		2096
	363		504		704		1400		1721
	336		494		595		1300		1711
	207		473		586		1100		1695
	200		300		525		1000		1623

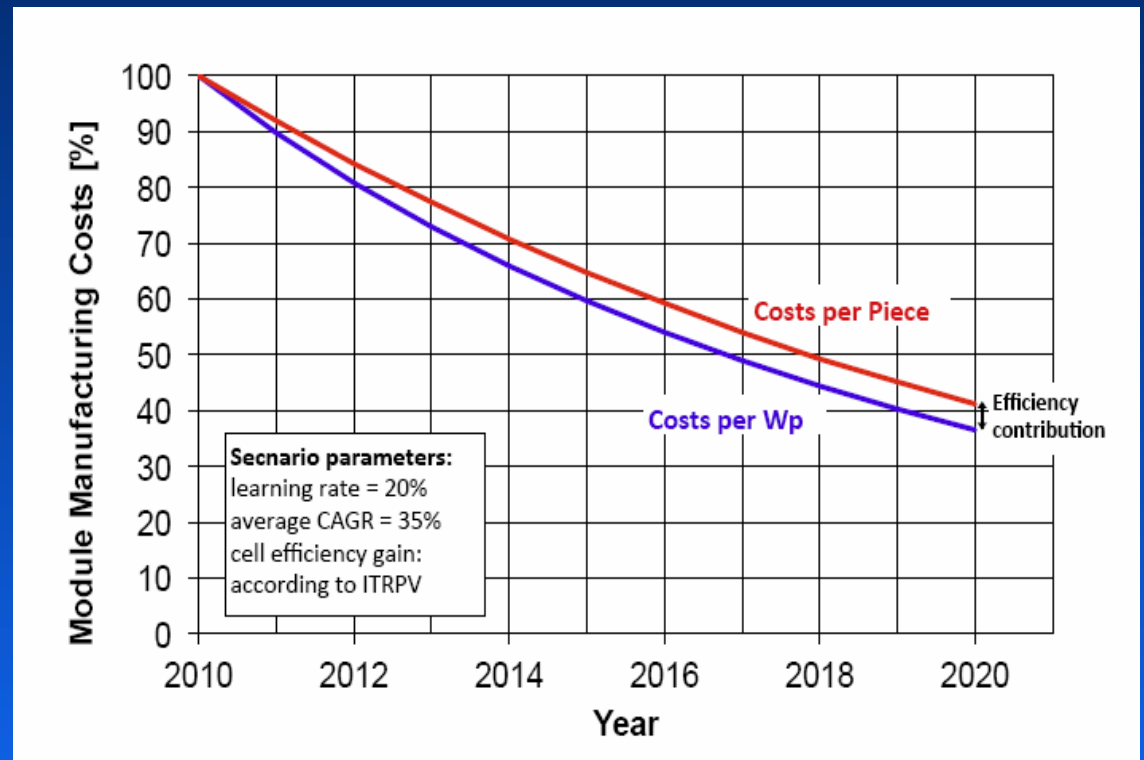
- China's PV manufacturing dominance
- Trade tariffs
- Emergence of Taiwan
- China helped drive down module prices 80% in recent years
- 80% of jobs downstream





Likely Future Trends - Costs

- Costs to keep falling
- Fuelled by technology improvements, economies of scale
- Hopefully not fuelled by compromises in quality



Likely Future Trends - Applications

- Increased importance of Centralised Power Systems
- Massive growth in developing country applications
- Grid-connected houses to resemble remote area power supplies



Alamosa Solar Power Plant - Colorado





Grid-connected Houses to Resemble RAPS

- Driven by subsidies & large “Time-of-Day” rate variations
- Needs batteries & energy management system
- Reduces impact of demand peaks on grid
- Suntech 2013 + others

DG Energy Solutions—2015

•SunPower 2015



Offering

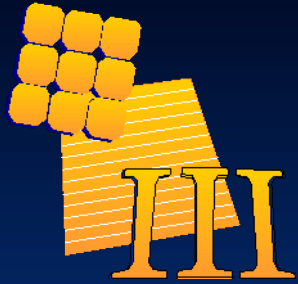
- X-Series panels, black
- BOS kits (inverters, mounting)
- Basic monitoring
- Energy Management System
- Storage

Customer Value

- Maximize renewable energy from roof
- Outstanding aesthetics
- Credible, guaranteed energy, for life
- Reduce energy bill
- Optimize PV energy self-consumption



Photovoltaics - Electricity from Sunlight



Utility Scale – Central Power Stations

- Driven by Tax credits and subsidies
- Distribution costs high
- more suitable for wind etc

Elecnor Solar Power Plant

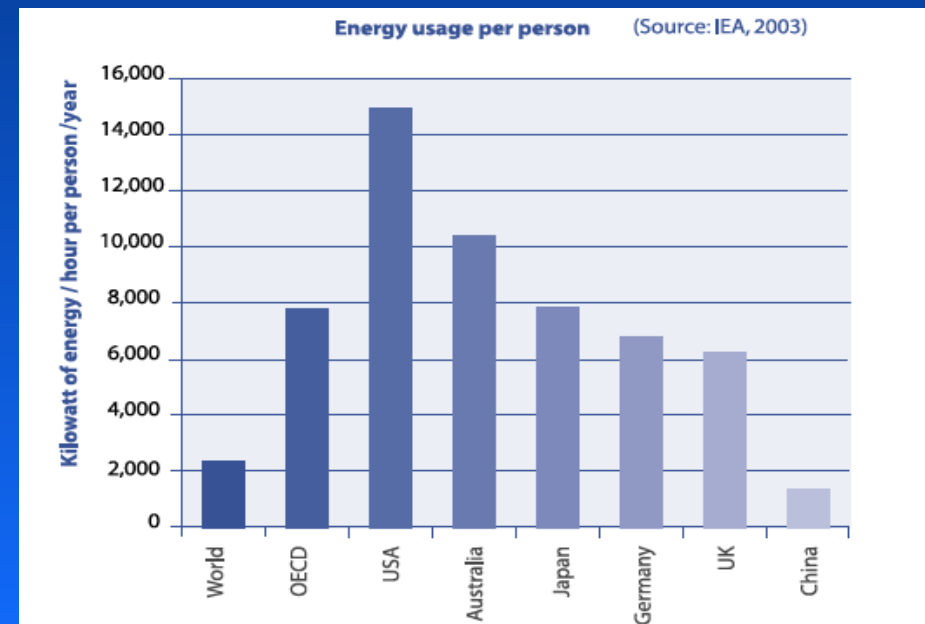
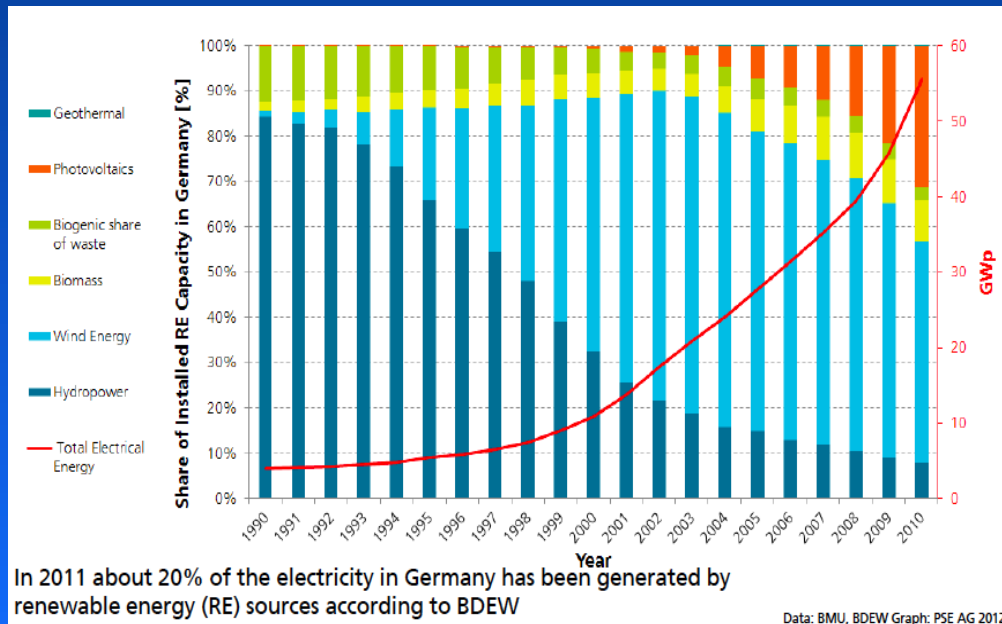
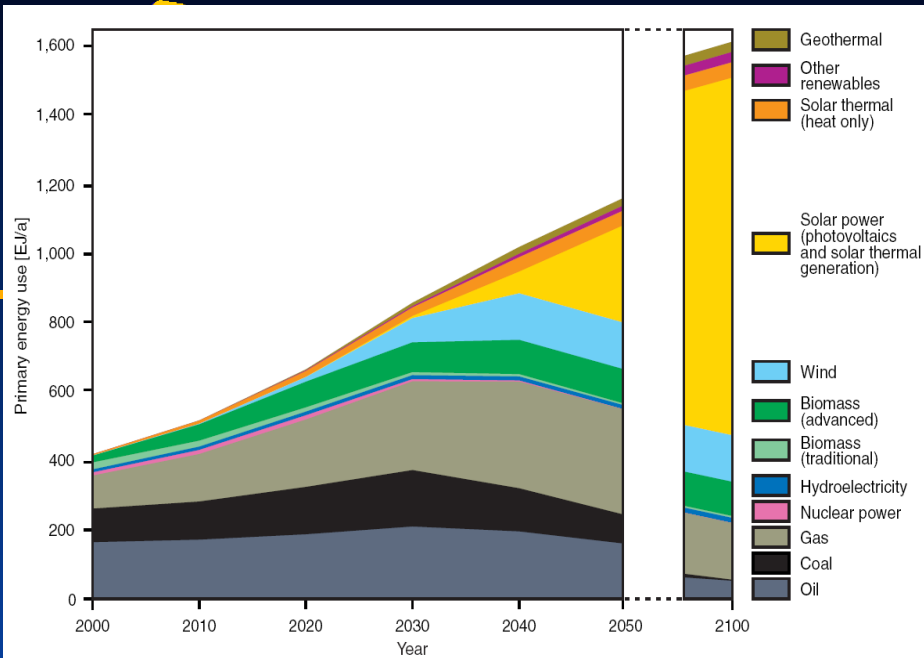


35 MW – Trujillo, Spain

Alamosa Solar Power Plant - Colorado



Stand-alone Systems





Experts Predict Future Technology Trends

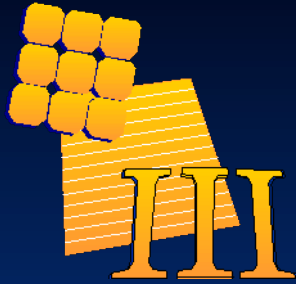
Q.CELLS SCHOTT solar SOLARWORLD INNOVATIONS[®] BOSCH Technik fürs Leben systaic

Solland sovello sunways Photovoltaic Technology BLUE CHIP ENERGY

PVGroup aleo CONERGY PILLAR GROUP pv crystalox

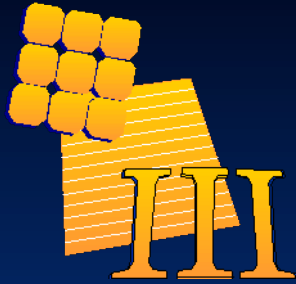
Photovoltech INNOVATIVE PHOTOVOLTAIC TECHNOLOGY[®] solar|glass Scheuten SOLARWATT[®] SOLON

Supported by



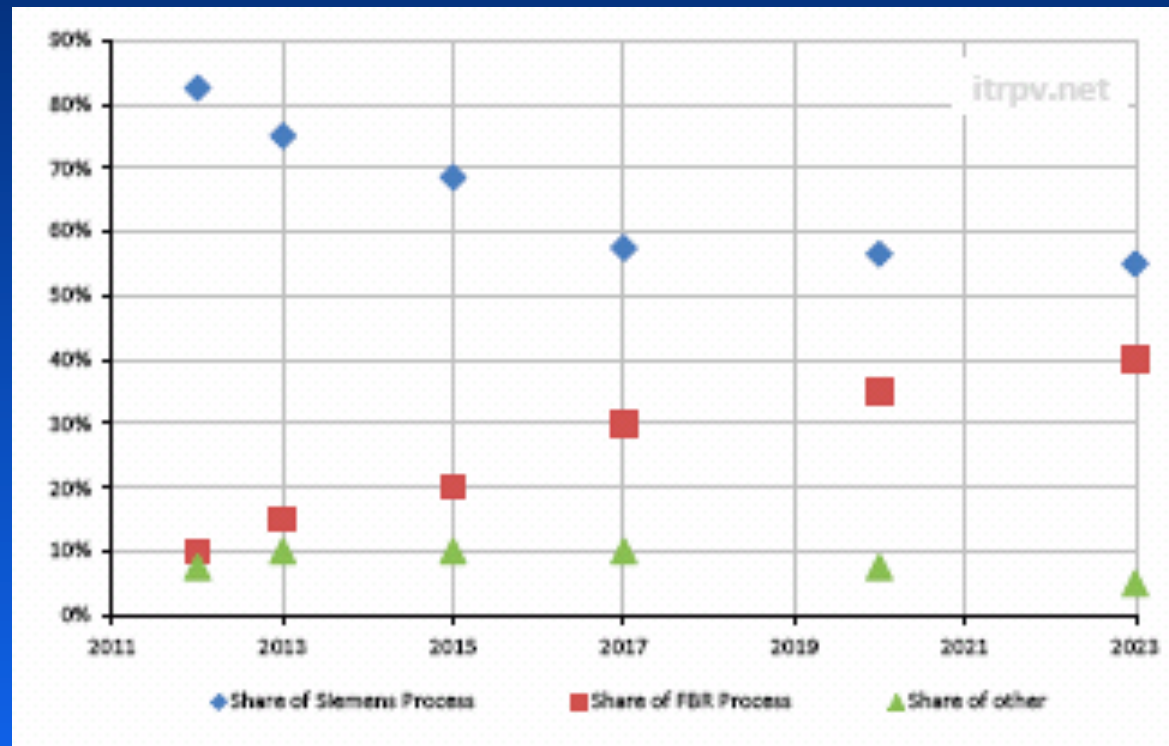
Expected Future Technology Trends

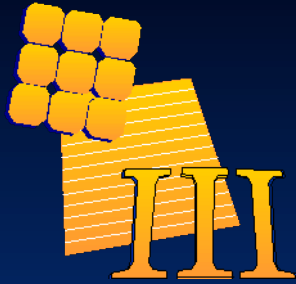
- Silicon
 - Siemens Process and FBR to dominate
- Wafers
 - Diamond-wire sawing to dominate
 - Thickness down to 100 microns in 10 years
 - 70% p-type in 10 years, HP multi to dominate
 - B-O and other defects solved by hydrogenation
- Contacts
 - Reduced Ag, 30 micron SP lines in 10 years
 - Plating to dominate over SP by 2017
 - Rear localised contacts + rear surface passivation
 - Increased use of single-sided contacts
- Efficiency
 - Multi > 20%, B-CZ > 21-22%, P-CZ > 22%
- Modules
 - lower cost encapsulation techniques & materials
 - Increased use of frameless modules



Expected Future Technology Trends

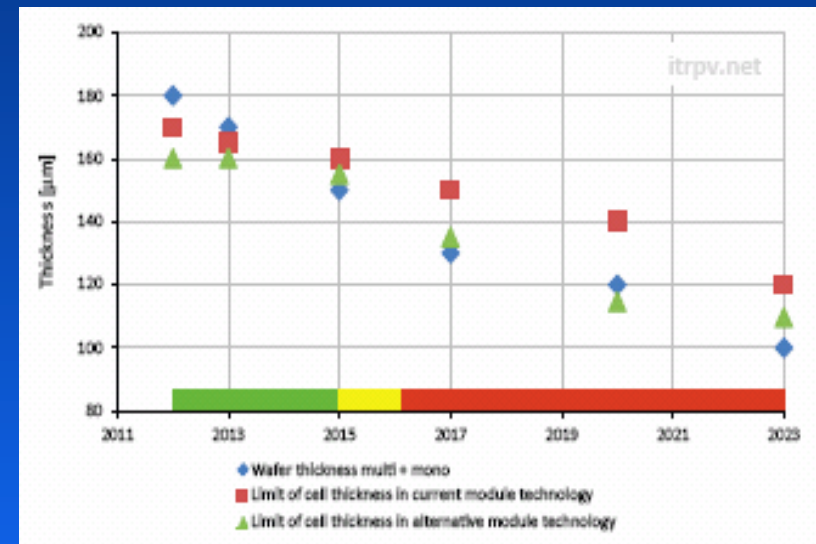
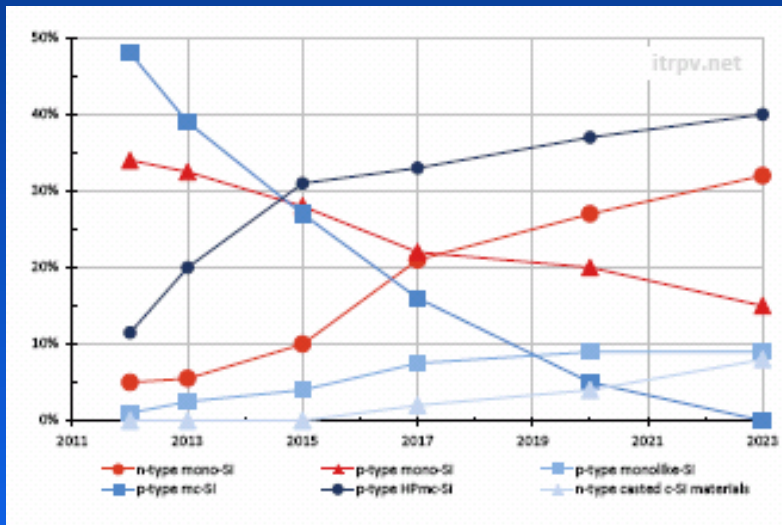
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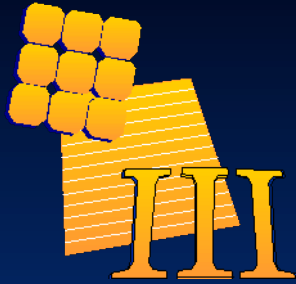




Expected Future Technology Trends

- Wafers
 - Diamond-wire sawing to dominate
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 - B-O and other defects solved by hydrogenation

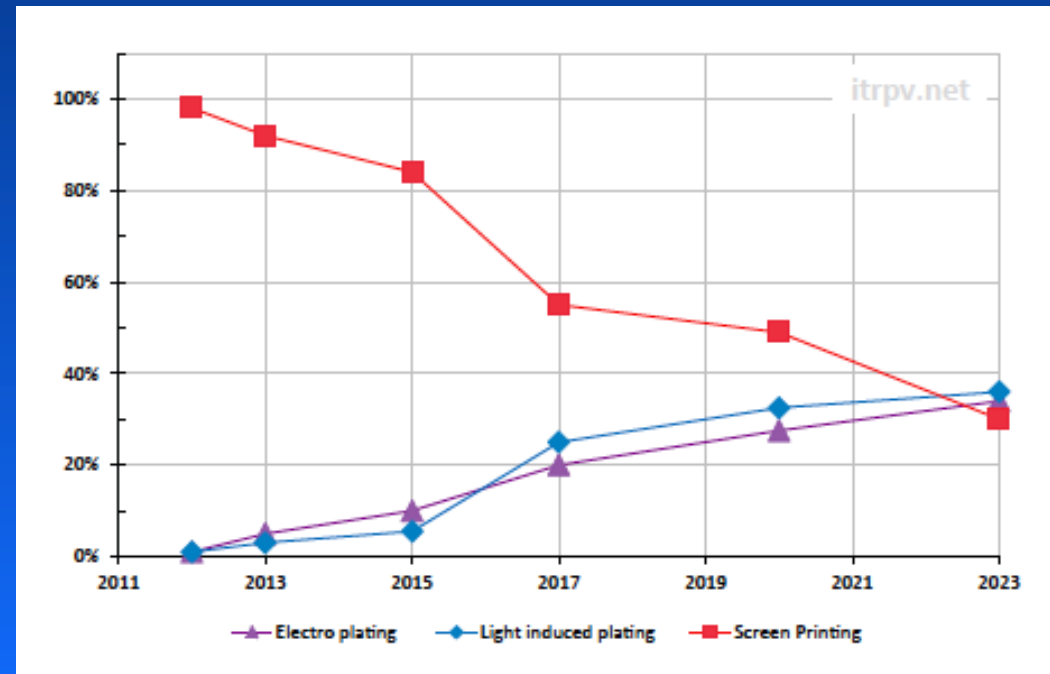
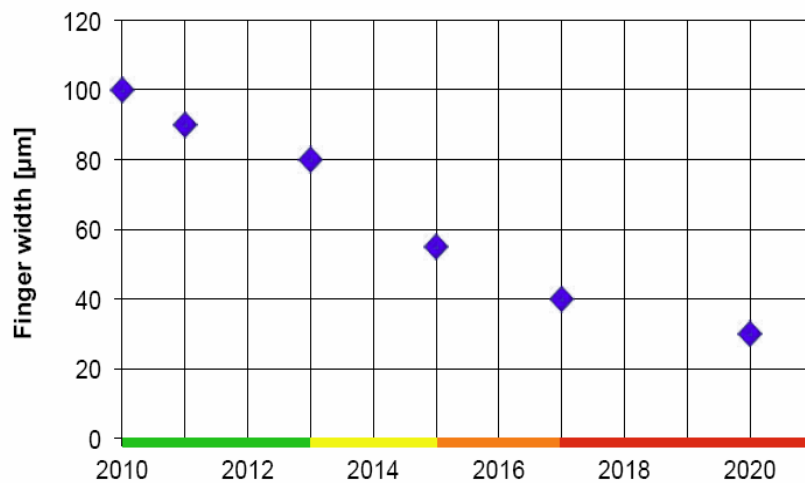
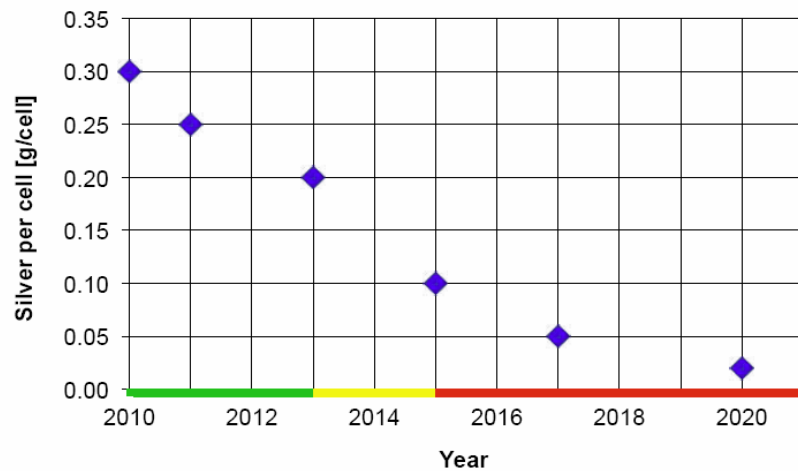


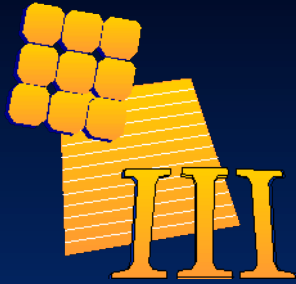


Expected Future Technology Trends

- Metal Contacts

- Reduced Ag, 30 micron SP lines in 10 years
- Plating to dominate over SP by 2017
- Rear surface passivation + localised contacts
- Increased use of single-sided contacts

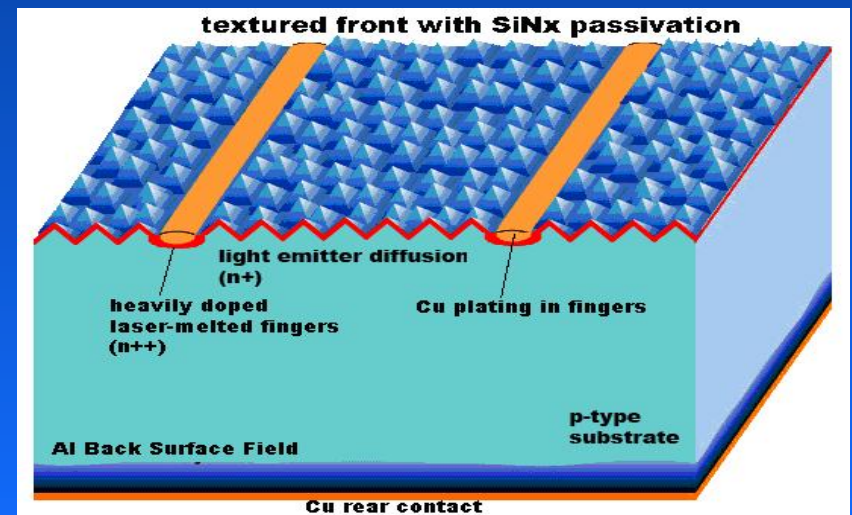
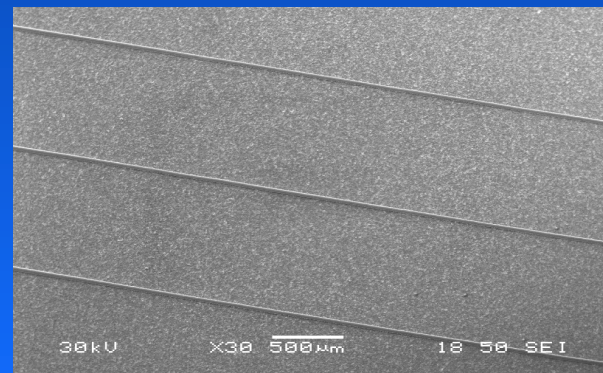
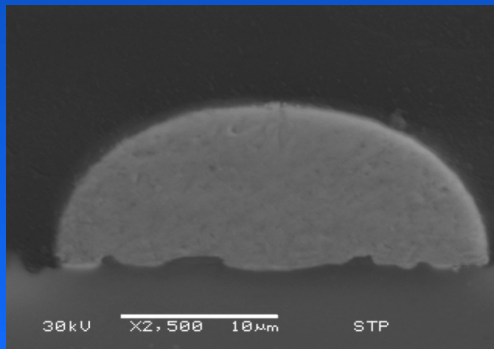
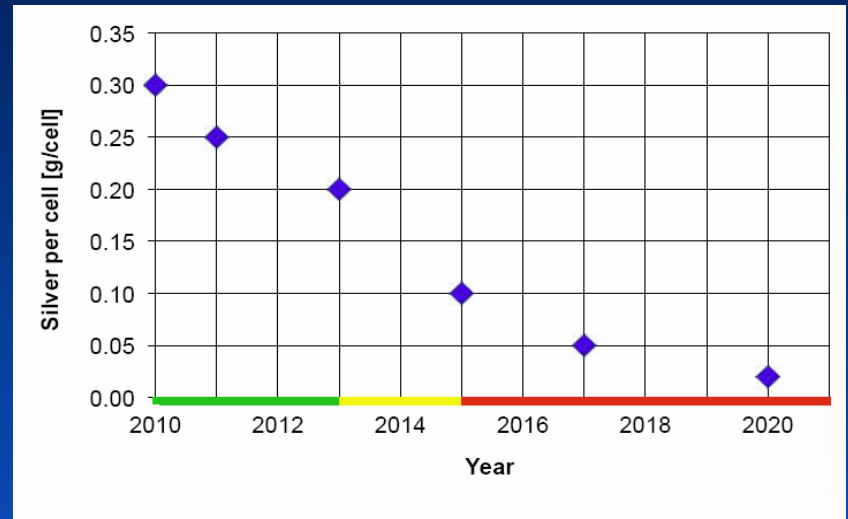
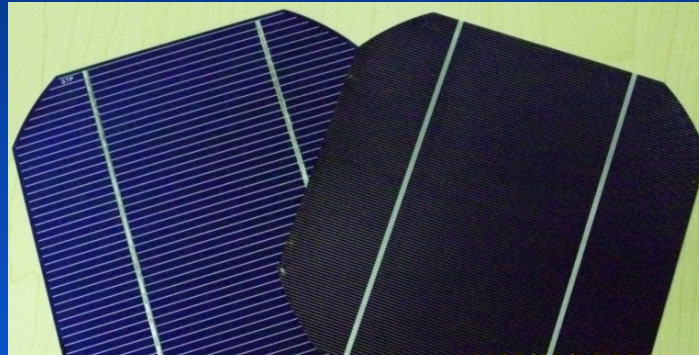




Trend towards Cu replacing Ag

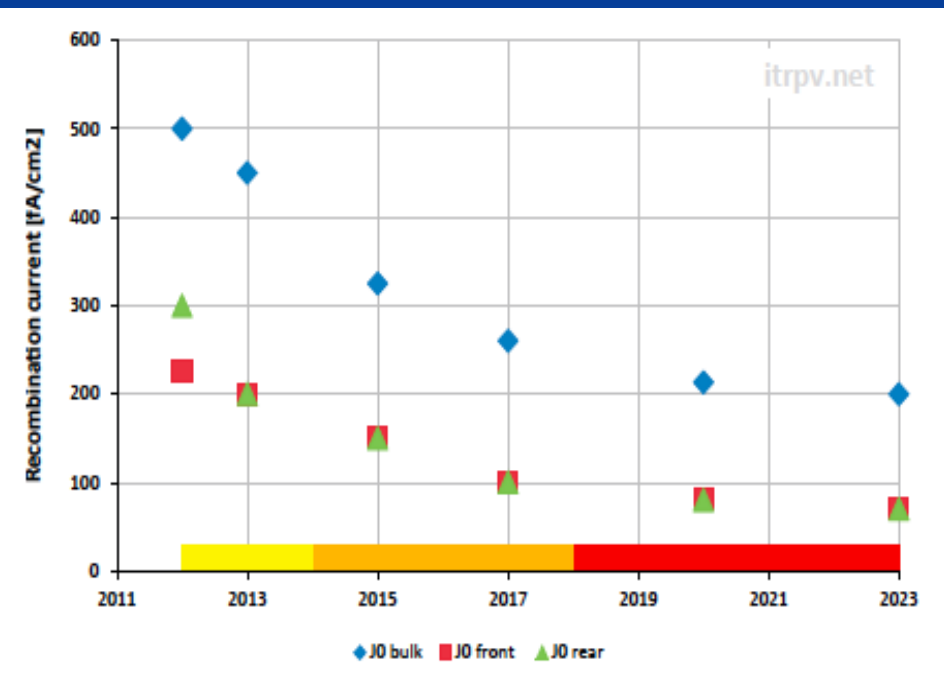
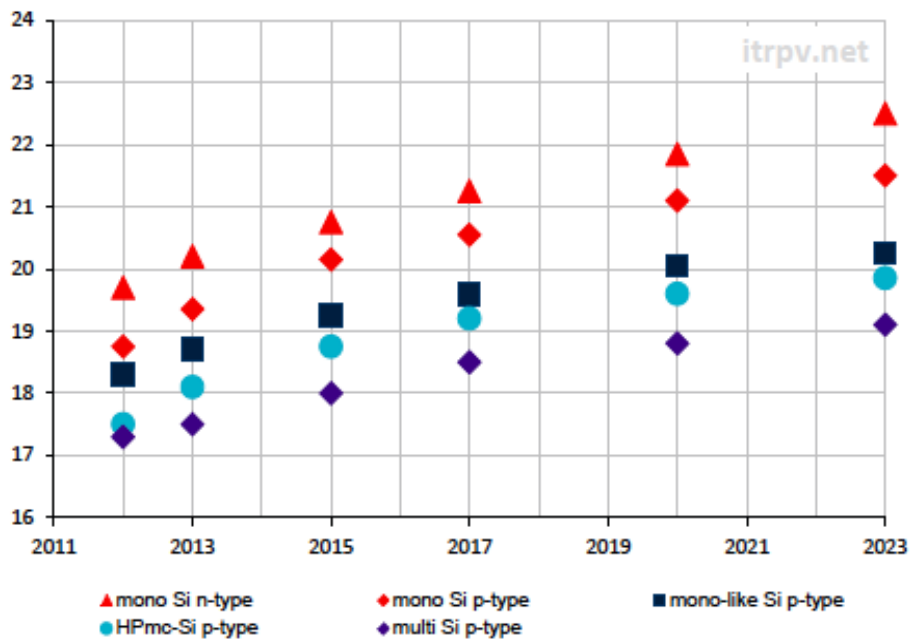
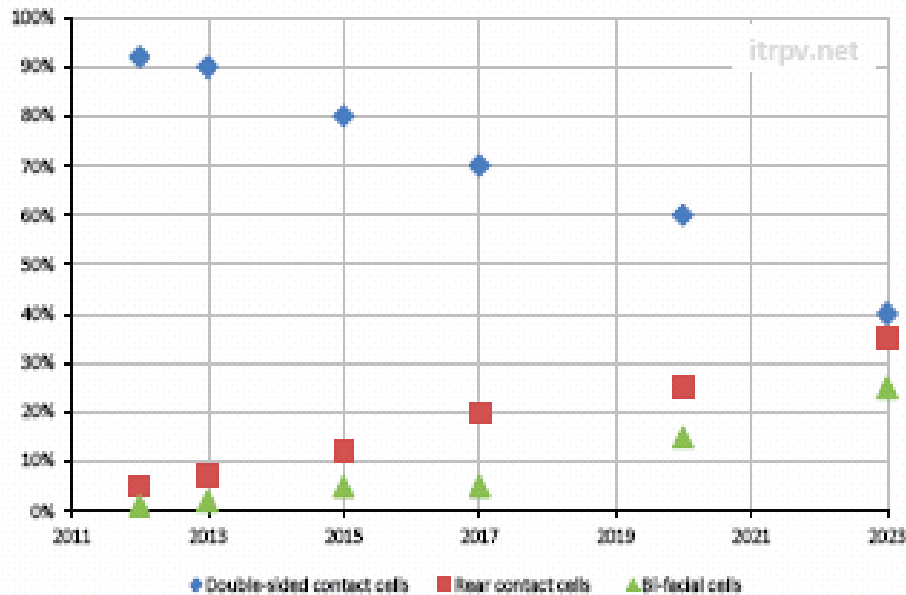
1. Focus of many companies
2. Kuttler plating baths now available!
3. Printed seed layer plated with Cu
4. Good results also with all plated contacts:

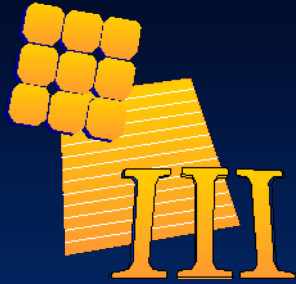
- Suntech
- IMEC
- HHI
- Shinsung
- UNSW
- RENA



Expected Future Technology Trends

- Efficiency - Multi > 20%,
- B-CZ 21 - 22%,
- P-CZ > 22%





Trends in Cell Encapsulation

1. Encapsulation costs now dominating.

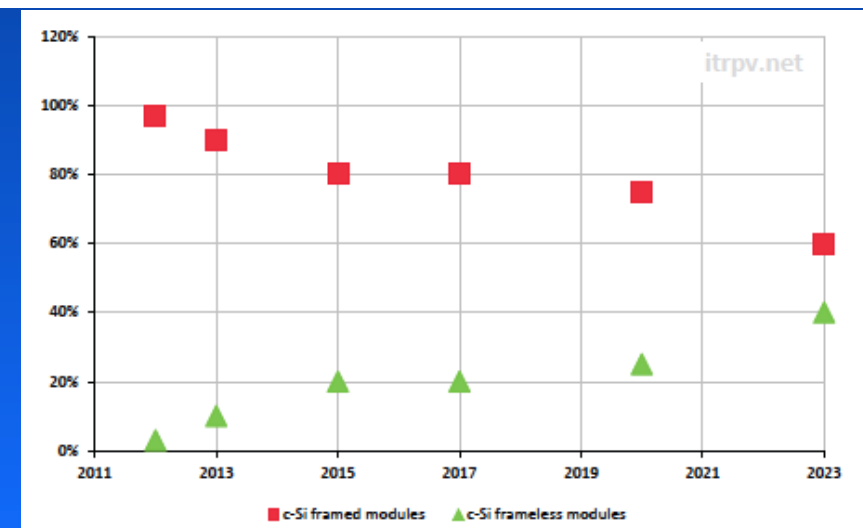
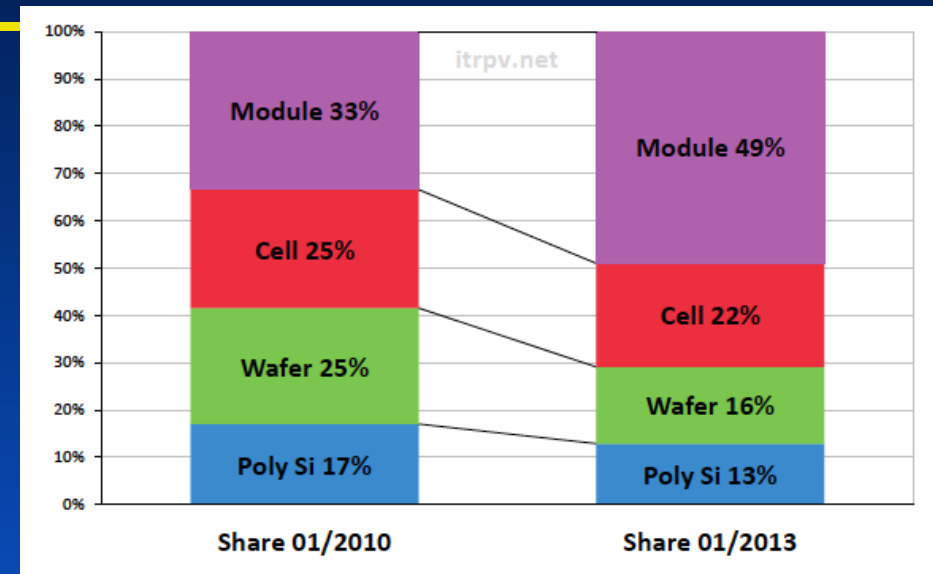
- \$0.21 Wafer
- \$0.13 cell conversion
- \$0.32 encapsulation

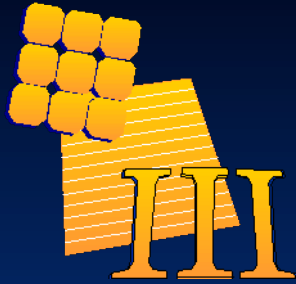
2. Increased use of frameless modules

3. Manufacturers very conservative but cost pressures may lead to compromises (25yr warranty)

4. Importance of bankability

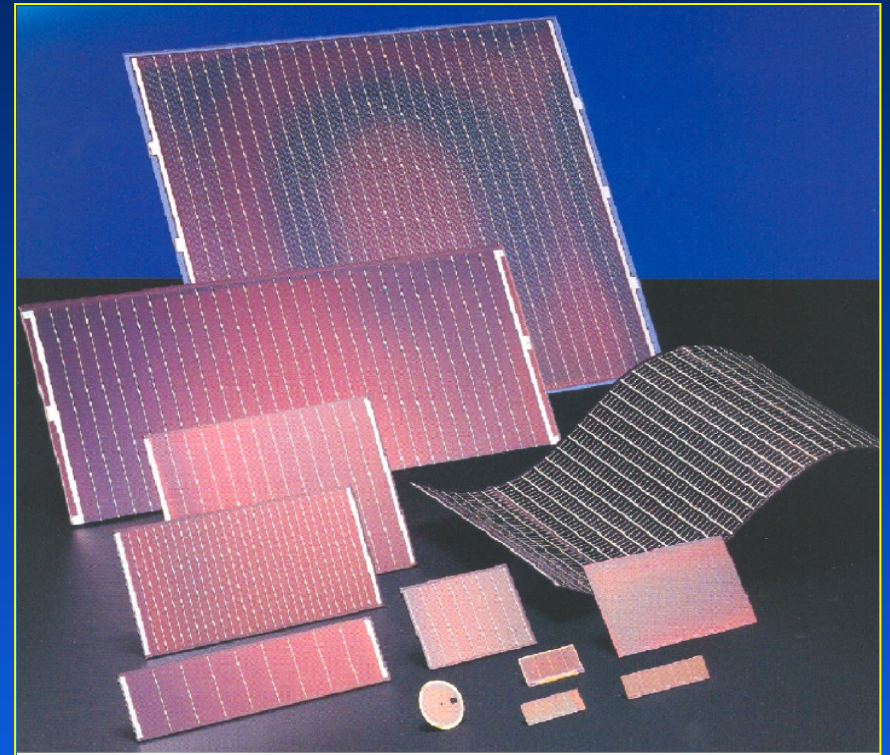
UNSW





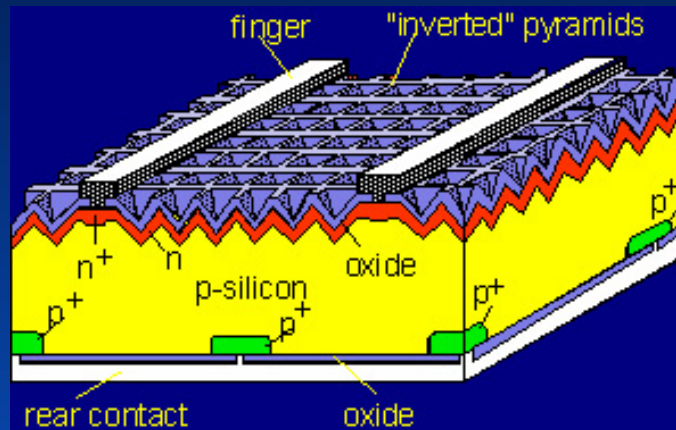
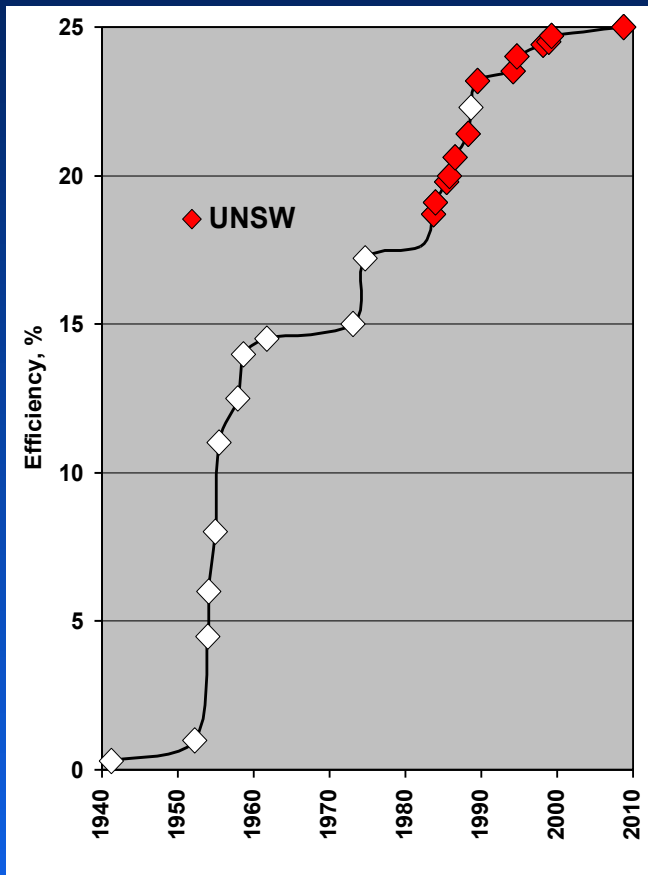
Challenge for Thin-Films

- Silicon efficiencies increasing while costs are falling rapidly
- Falling market share
- Recent durability concerns in hot environments
- No thin-films have as yet demonstrated long-term stability or durability
- Dependence on rare elements
- Eventually thin-films need to succeed for pv to reach its full potential

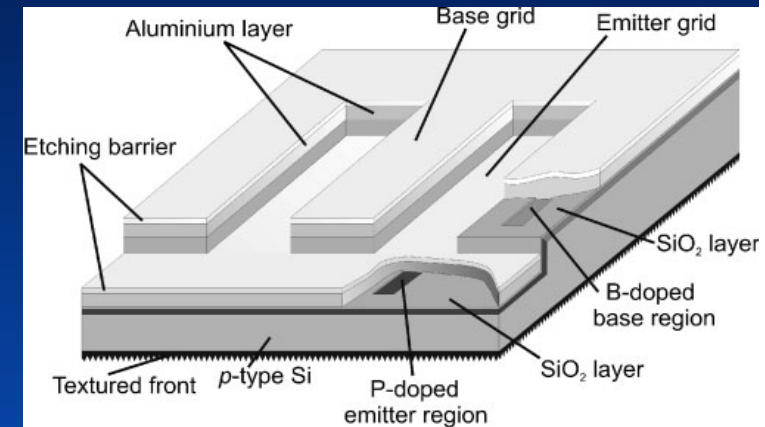




Trends in High Efficiency Technologies - n-type dominance?



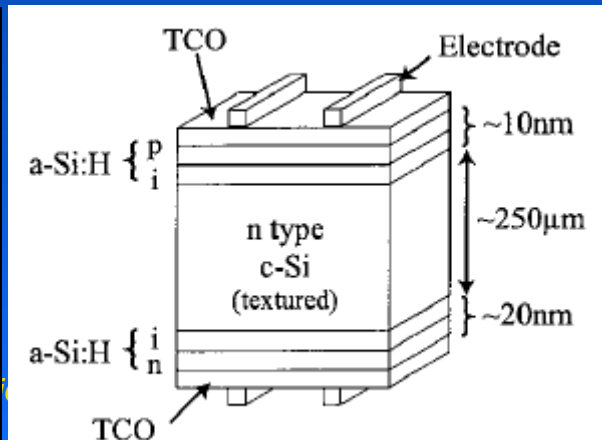
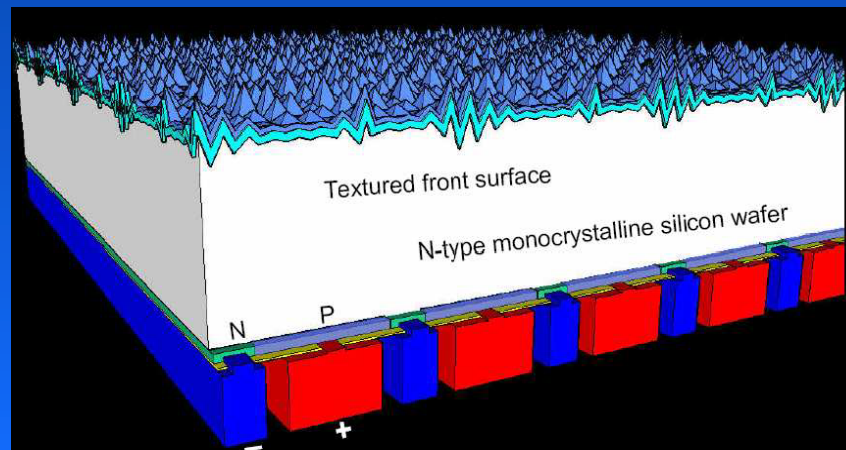
UNSW – 25% PERL cell

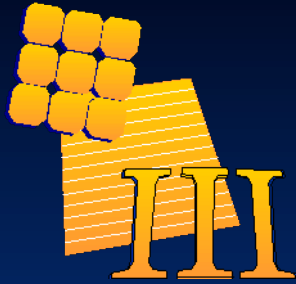


ISFH – 22.4% RISE cell

Stanford – 24% Rear Point Contact

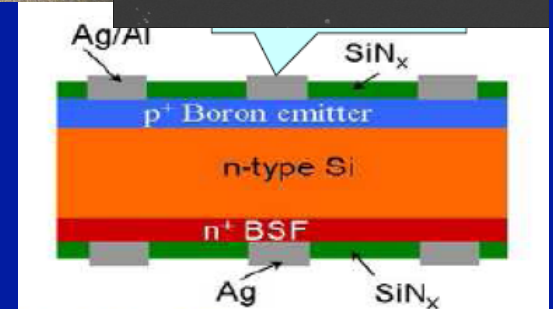
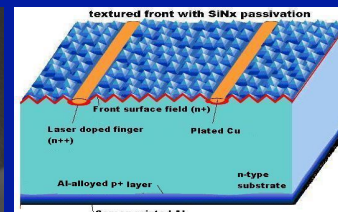
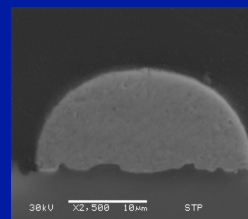
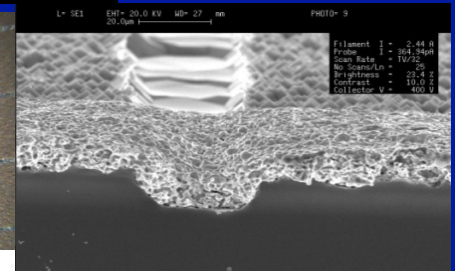
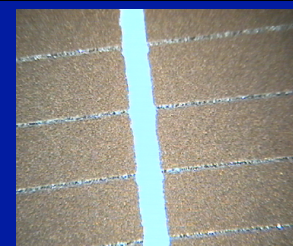
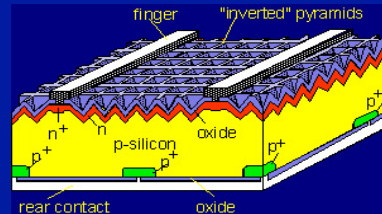
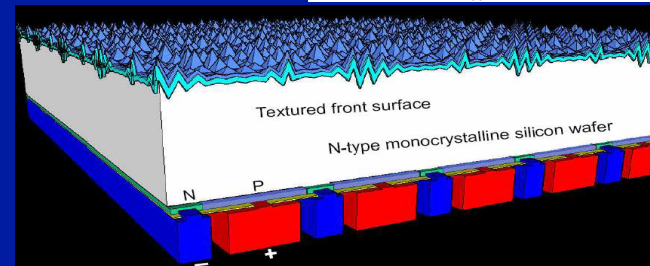
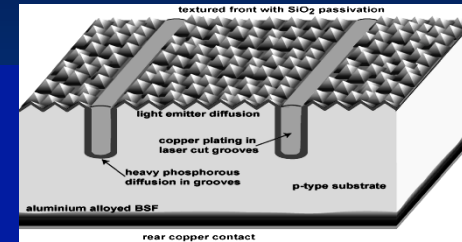
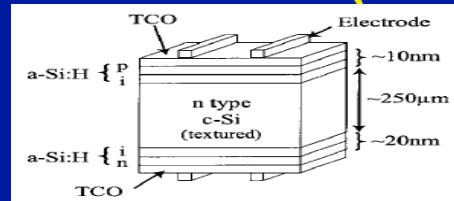
Sanyo – 23% HIT cell

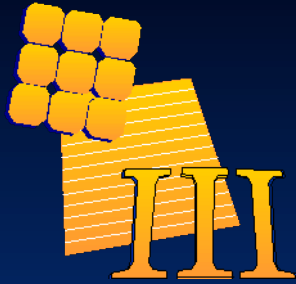




Commercialisation of High Efficiency, Low Cost Technology

- Buried Contact Solar Cells (Australian)
- HIT cell (Japan)
- Rear Point Contact Cell (USA)
- Pluto (Australia)
- Semiconductor Finger Cells (Australia)
- Yingli n-type Panda technology (Netherlands)
- Laser Doping (Australia)
- Innovalight (USA)





Australians in Senior Management Positions of Most Major PV Companies

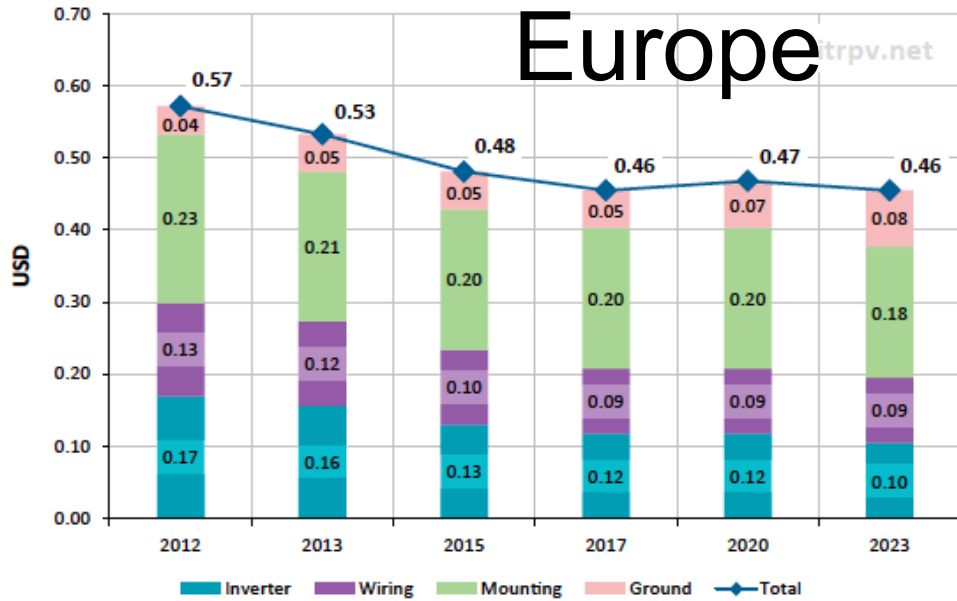
- Includes 8 of China's 10 largest cell manufacturers in present or former positions
- 22 former UNSW students as CTO's or VP's of Technology World-wide

* denotes current position

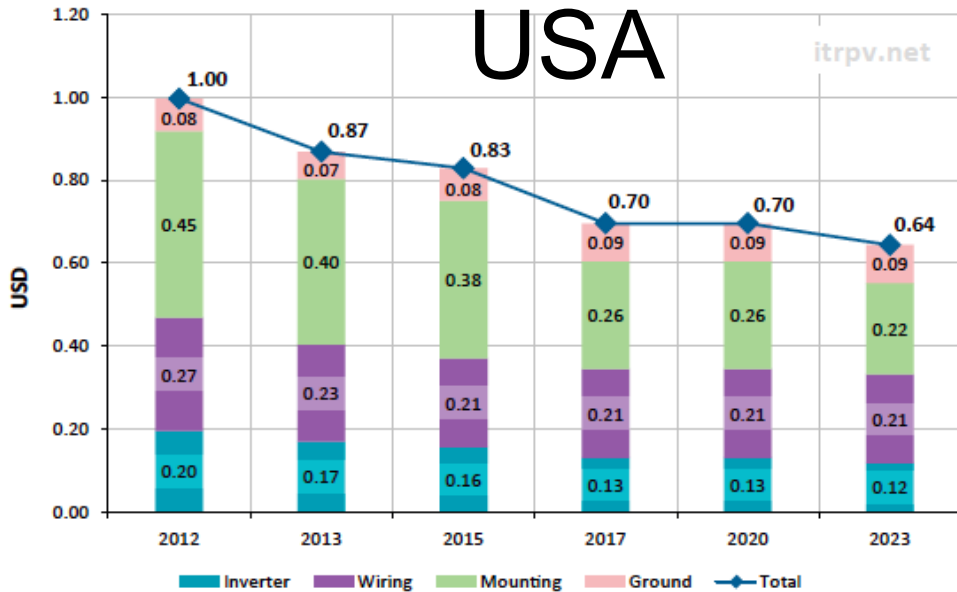
Song, Dengyuan	* Yingli Solar
Narayanan Mohan	Trina Solar
Dai Ximing	JA Solar
Yun Fei	* LDK Solar
Yao, GuoXiao	JinkoSolar
Guo, Allen	* Jinko Solar
Wenham, Stuart	* Suntech-Power
Narayanan Mohan	* Hanwha
Wang Aihua	* China Sunergy

BOS Costs – large systems >100kW

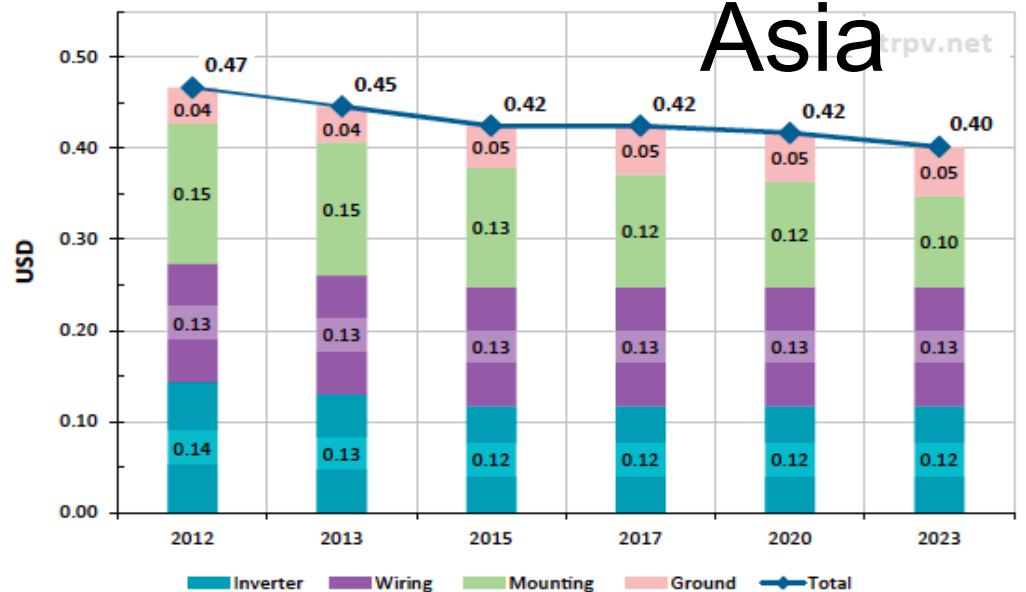
Europe

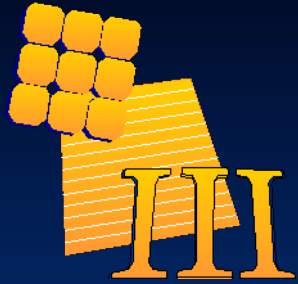


USA



Asia





Thank You