

2010

2020

2030

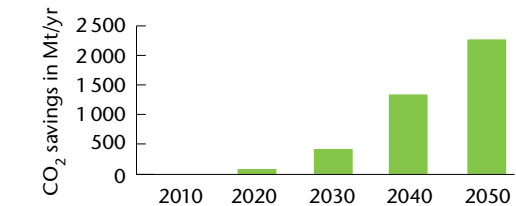
2040

2050

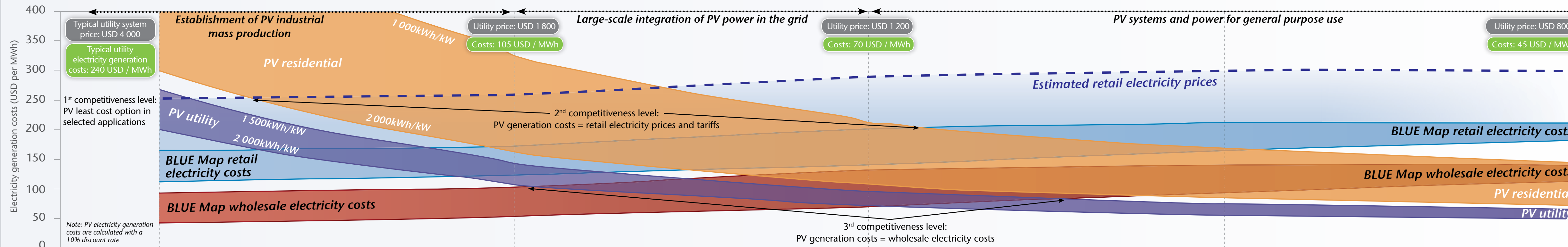
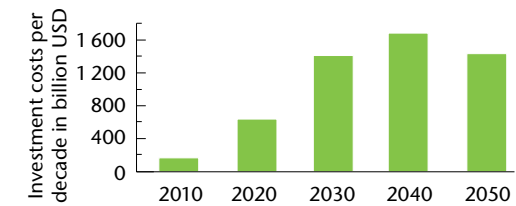
Key findings

- Solar photovoltaic (PV) power is a commercially available and reliable technology with a significant potential for long-term growth in nearly all world regions. This roadmap estimates that by 2050, PV will provide around 11% of global electricity production and reduce 2.3 gigatonnes (Gt) of CO₂ emissions per year.
- PV will achieve competitive parity with the power grid by 2020 in many regions. Achieving this will require a strong and balanced policy effort in the next decade to allow for optimal technology progress, cost reduction and ramp-up of industrial manufacturing for mass deployment.
- As grid competitiveness is achieved, the policy framework should evolve towards fostering self-sustained markets, with the progressive phase-out of economic incentives, grid access guarantees, and sustained R&D support.
- As PV matures into a mainstream technology, grid integration and management and energy storage become key issues. The PV industry, grid operators and utilities will need to develop new technologies and strategies to integrate very large amounts of PV into flexible, efficient and smart grids.

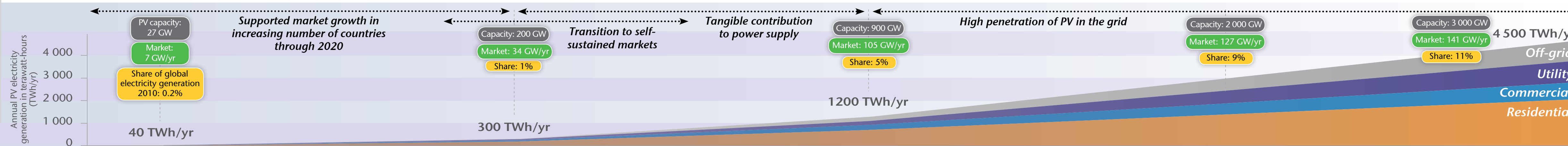
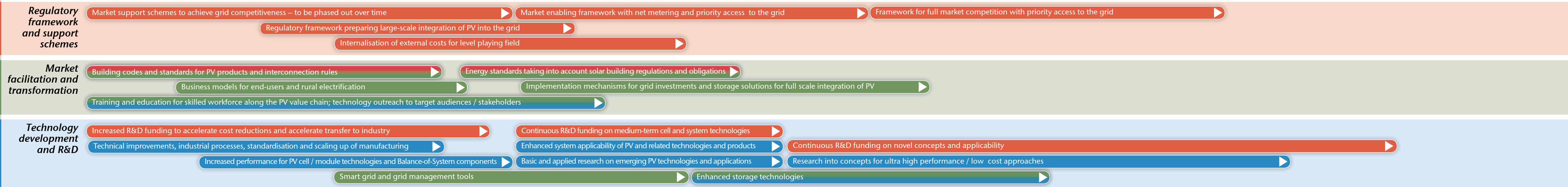
Annual CO₂ equivalent emissions avoided through PV



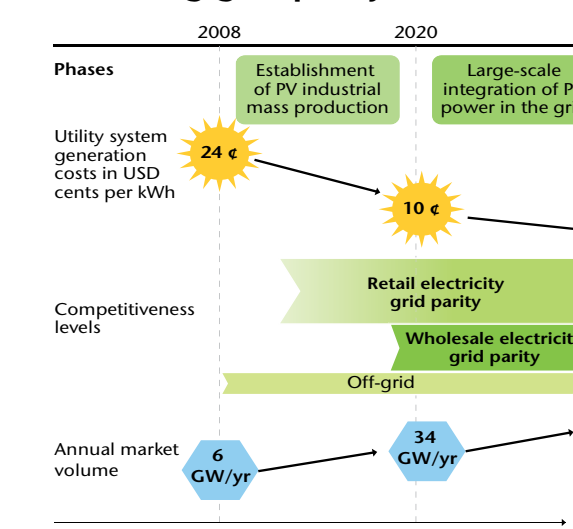
PV investment by decade



Roadmap action plan: key milestones and respective leading roles for Government stakeholders, Market stakeholders (demand side), and R&D and PV industry stakeholders (supply side).



Next 10 years: achieving grid parity for PV



Achieving this roadmap's targets will require the rapid expansion of the PV industry by 2020. This will imply a six-fold increase of annual industrial production up to 34 GW/yr by 2020, and reducing system and generation costs by more than 50% to achieve grid parity in many markets. Typical generation costs in medium-high irradiation regions will range from 10 - 21 USD cents/kWh depending on the type of application and irradiation level.

Reaching these goals will require sustained and consistent policy frameworks and incentives in more countries in order to support markets, trigger investments and foster industrial improvement worldwide.

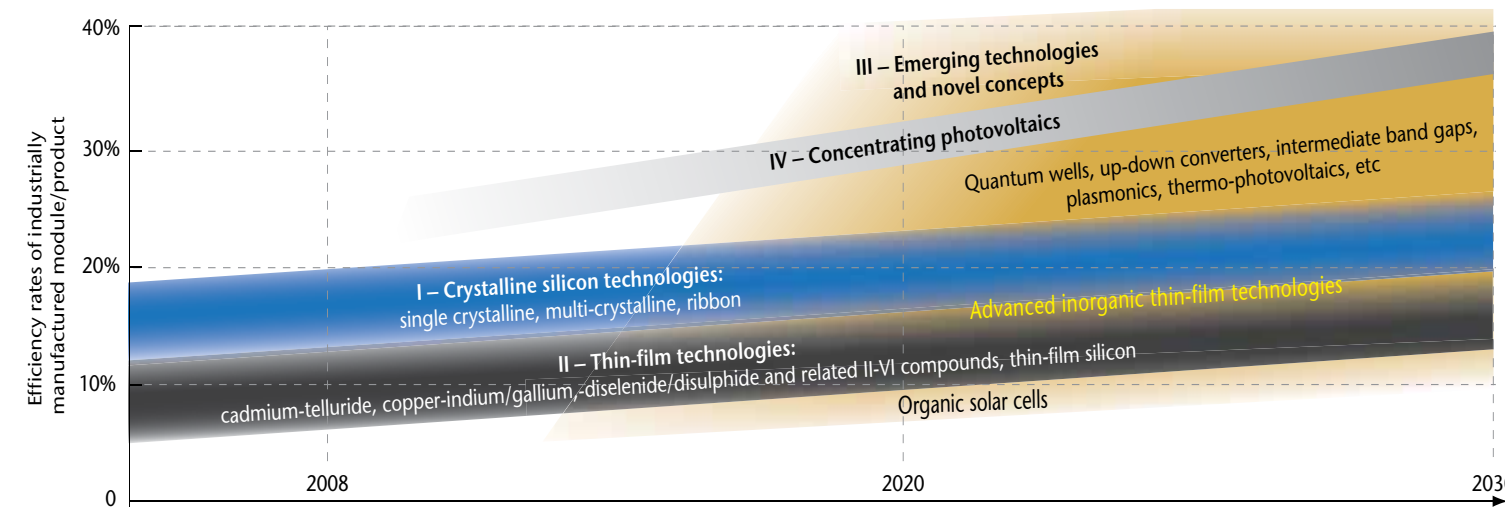
Moreover, it will be important to sustain R&D efforts. This will allow to improve crystalline silicon and thin film systems, as well as to accelerate the development of emerging technologies and novel devices.

Key actions 2010-2020

- Provide long-term targets and supporting policies to build confidence for investments in manufacturing capacity and deployment of photovoltaic systems.
- Implement effective and cost-efficient PV incentive schemes and financing mechanisms; incentive schemes will be transitional and decrease over time to foster innovation and technological improvement.
- Increase R&D efforts to reduce costs and ensure PV readiness for rapid deployment, while also supporting longer-term breakthroughs.

Solar PV technology milestones

PV technology status and prospects



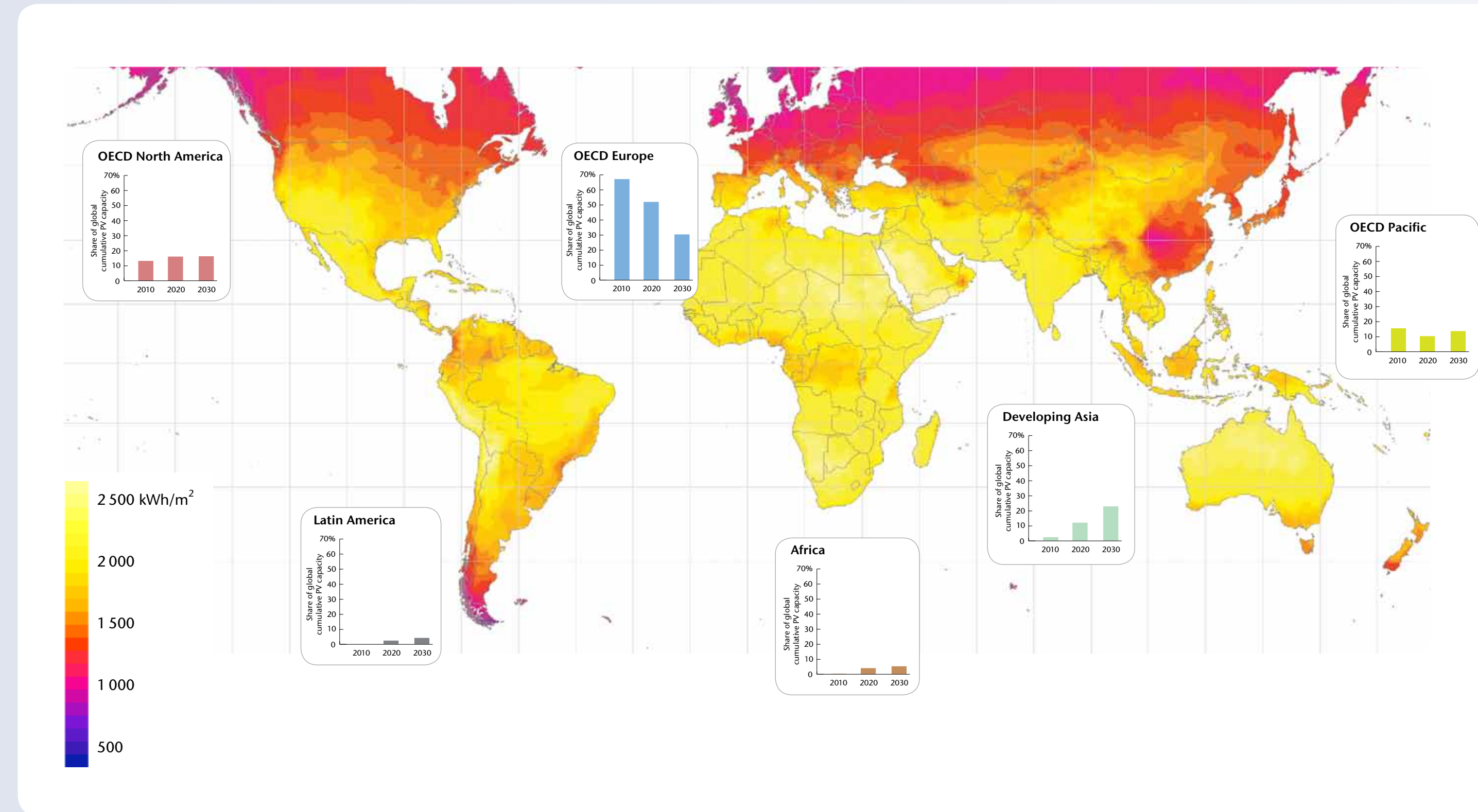
PV efficiency targets: the role of R&D

Crystalline silicon technologies	2010 - 2015	2015 - 2020	2020 - 2030 / 2050
Efficiency targets (commercial modules)	<ul style="list-style-type: none"> Single-crystalline: 21% Multi-crystalline: 17% 	<ul style="list-style-type: none"> Single-crystalline: 23% Multi-crystalline: 19% 	<ul style="list-style-type: none"> Single-crystalline: 25% Multi-crystalline: 21%
Industry manufacturing aspects	<ul style="list-style-type: none"> Silicon (Si) consumption < 5 grams / watt (g/w) 	<ul style="list-style-type: none"> Si consumption < 3 g/W 	<ul style="list-style-type: none"> Si consumption < 2 g/W
R&D aspects	<ul style="list-style-type: none"> New silicon materials and processing Cell contacts, emitters and passivation 	<ul style="list-style-type: none"> Improved device structures Productivity and cost optimisation in production 	<ul style="list-style-type: none"> Wafer equivalent technologies New device structures with novel concepts
Thin film technologies	2010 - 2015	2015 - 2020	2020 - 2030
Efficiency targets (commercial modules)	<ul style="list-style-type: none"> Thin film Si: 10% Copper-indium/gallium (CIGS): 14% Cadmium-telluride (CdTe): 12% 	<ul style="list-style-type: none"> Thin film Si: 12% CIGS: 15% CdTe: 14% 	<ul style="list-style-type: none"> Thin film Si: 15% CIGS: 18% CdTe: 15%
Industry manufacturing aspects	<ul style="list-style-type: none"> High rate deposition Roll-to-roll manufacturing Packaging 	<ul style="list-style-type: none"> Simplified production processes Low cost packaging 	<ul style="list-style-type: none"> Large high-efficiency production units
R&D aspects	<ul style="list-style-type: none"> Large area deposition processes Improved substrates and transparent conductive oxides 	<ul style="list-style-type: none"> Improved cell structures Improved deposition techniques 	<ul style="list-style-type: none"> Advanced materials and concepts

	Concentrating PV	Emerging technologies	Novel technologies
Type of cell	<ul style="list-style-type: none"> High cost, super high efficiency 	<ul style="list-style-type: none"> Low cost, moderate performance 	<ul style="list-style-type: none"> Very high efficiency; Full spectrum utilisation
Status and potential	<ul style="list-style-type: none"> 23% alternating current (AC) system efficiency demonstrated Potential to reach over 30% in the medium-term 	<ul style="list-style-type: none"> Emerging technologies at demonstration level (e.g. polymer PV, dye PV, printed CIGS) First applications expected in niche market applications 	<ul style="list-style-type: none"> Wide variety of new conversion principle and device concepts at lab level Family of potential breakthrough technologies
R&D aspects	<ul style="list-style-type: none"> Reach super high efficiency over 45% Achieve low cost, high-performance solutions for optical concentration and tracking 	<ul style="list-style-type: none"> Improvement of efficiency and stability to the level needed for first commercial applications Encapsulation of organic-based concepts 	<ul style="list-style-type: none"> Proof-of-principle of new conversion concepts Processing, characterisation and modelling of especially nanostructured materials and devices

Solar resource and regional shares of world PV capacity

Yearly sum of global irradiance and shares of global cumulative installed PV capacity per region



Solar map source: Meteotest; database Meteornorm (www.meteornorm.com)

Solar PV economic milestones

Targets for residential sector	2008	2020	2030	2050
Typical turn-key system price (2008 USD/kW) *	6 000	2 700	1 800	1 200
Typical electricity generation costs (2008 USD/MWh)	2 000 kWh/kW	360	160	65
	1 500 kWh/kW	480	210	90

* Assumptions: Interest rate 10%, technical lifetime 25a (2008), 30a (2020), 35a (2030), 40a (2050), operations and maintenance 1%

Targets for commercial sector	2008	2020	2030	2050
Typical turn-key system price (2008 USD/kW)	5 000	2 250	1 500	1 000
Typical electricity generation costs (2008 USD/MWh)	2 000 kWh/kW	300	130	55
	1 500 kWh/kW	400	175	75

Targets for utility sector	2008	2020	2030	2050
Typical turn-key system price (2008 USD/kW) **	4 000	1 800	1 200	800
Typical electricity generation costs (2008 USD/MWh)	2 000 kWh/kW	240	105	45
	1 500 kWh/kW	320	140	60

** Best system prices lower than 3 000 USD/kW were reported in 2009

Photovoltaic electricity generation in TWh ***	2010	2020	2030	2040	2050
Residential	23	153	581	1 244	1 794
Commercial	4	32	144	353	585
Utility	8	81	368	910	1 498
Off-grid	3	32	154	401	695
Total	37	298	1 247	2 907	4 572
Share of global electricity generation in %	0.2	1.3	4.6	8.5	10.8

*** Average electricity generation per kW is 1 300 kWh/kW in the residential sector, 1 450 kWh/kW in the commercial sector, 1 650 kWh/kW in the utility sector and 1 500 kWh/kW in the off-grid sector

Photovoltaic capacity in GW	2010	2020	2030	2040	2050
Residential	17	118	447	957	1 380
Commercial	3	22	99	243	404
Utility	5	49	223	551	908
Off-grid	2	21	103	267	463
Total	27	210	872	2 019	3 155

Annual photovoltaic market in GW	2010	2020	2030	2040	2050
Residential	4.1	18	50	55	53
Commercial	0.7	4	13	17	20
Utility	1.6	8	28	37	44
Off-grid	0.6	4	14	19	24
Total annual market	7.0	34	105	127	141