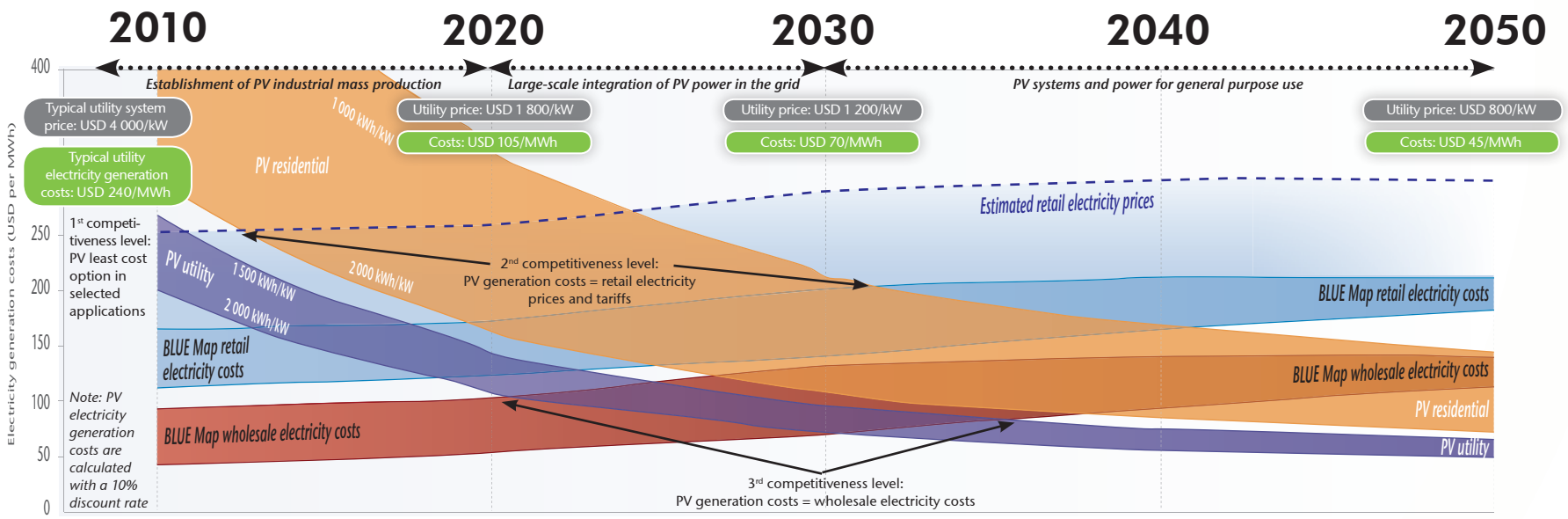
SOLAR PHOTOVOLTAIC ROADMAP

International Energy Agency

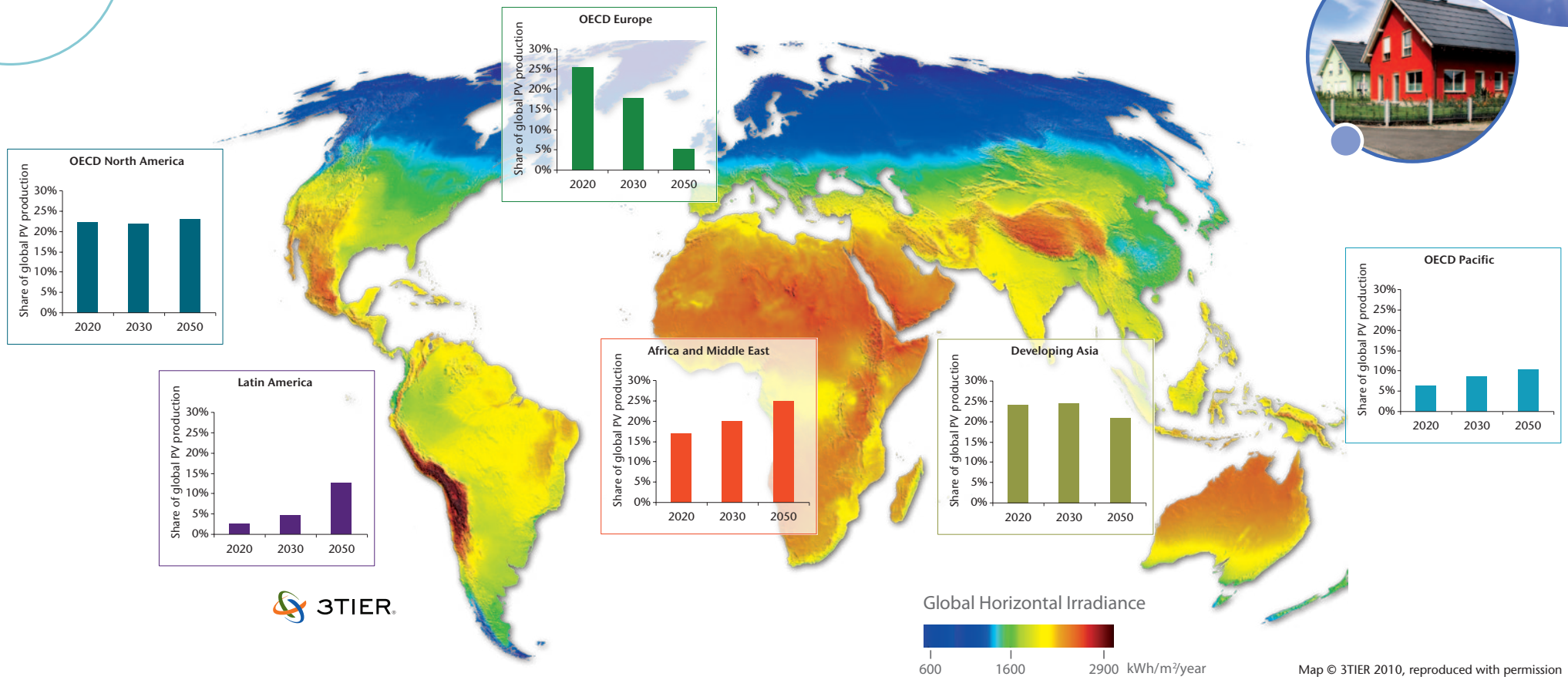
Solar PV price competitiveness and growth pathway, 2000-2050



Key findings

- By 2050, PV global cumulative installed capacity could reach 3 000 gigawatts, providing 4 500 TWh per year, *i.e.* around 11% of global electricity production. In addition to avoiding 2.3 gigatonnes (Gt) of CO_2 per year, this level of PV would deliver substantial benefits in terms of the security of energy supply and socio-economic development.
- In the first decade, PV is expected to reduce system and generation costs by more than 50%. PV residential and commercial systems will achieve the first level of grid parity – *i.e.* parity with electricity retail prices – by 2020 in many regions. As grid parity is achieved, the policy framework should evolve towards fostering self-sustained markets, with the progressive phase-out of economic incentives, but maintaining grid access guarantees and sustained R&D support.
- Towards 2030, typical large-scale utility PV system generation costs are expected to decrease to USD 7 to USD 13 cents/kWh. 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 large amounts of PV into flexible, efficient and smart grids.
- Governments and industry must increase R&D efforts to reduce costs and ensure PV readiness for rapid deployment, while supporting longer-term technology innovations.
- There is a need to expand international collaboration in PV research, development, capacity building and financing to accelerate learning and avoid duplicating efforts.
- Emerging major economies are already investing substantially in PV research, development and deployment; however, more needs to be done to foster rural electrification and capacity building. Multilateral and bilateral aid organisations should expand their efforts to express the value of PV energy in low-carbon economic development.

Solar resource and regional shares of world PV production



2010 — PV capacity: 27 GW; Market: 7 GW/yr; Share of global electricity generation 2010: 0.2%

Supported market growth in increasing number of countries through 2020

2020 — Capacity: 200 GW; Market: 34 GW/yr; Share: 1%

Tangible contribution to power supply

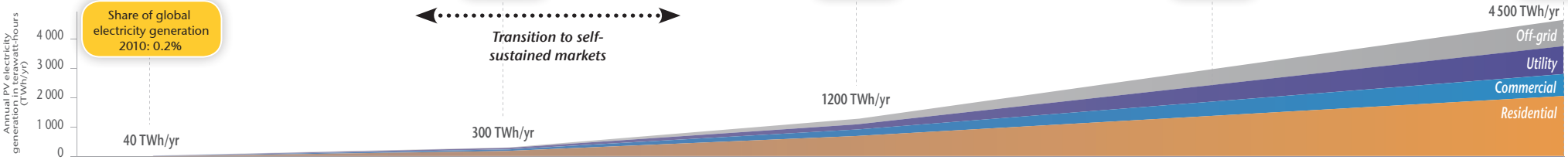
2030 — Capacity: 900 GW; Market: 105 GW/yr; Share: 5%

High penetration of PV in the grid

2040 — Capacity: 2 000 GW; Market: 127 GW/yr; Share: 9%

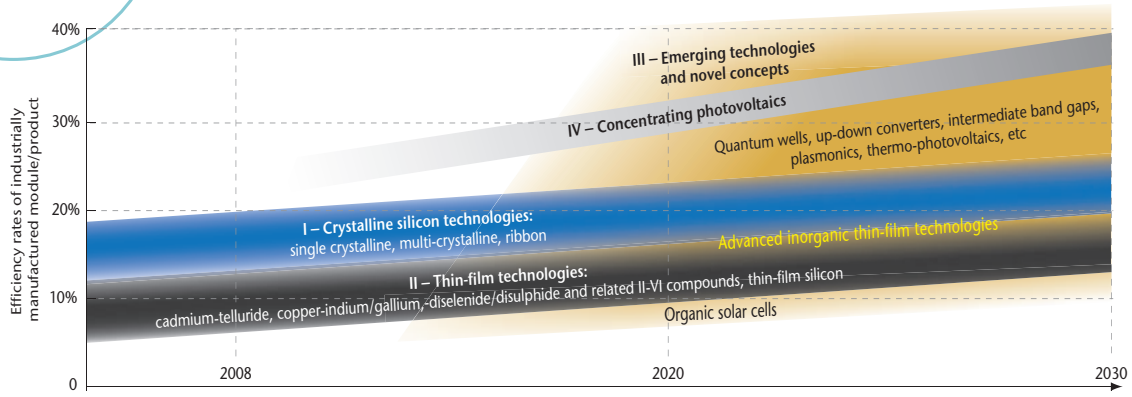
2050 — Capacity: 3 000 GW; Market: 141 GW/yr; Share: 11%

Transition to self-sustained markets



Solar PV technology milestones

PV technology status and prospects



Crystalline silicon technologies	2010 - 2015	2015 - 2020	2020 - 2030 / 2050
Efficiency targets (commercial modules)	• Single-crystalline: 21% • Multi-crystalline: 17%	• Single-crystalline: 23% • Multi-crystalline: 19%	• Single-crystalline: 25% • Multi-crystalline: 21%
Industry manufacturing aspects	• Silicon (Si) consumption < 5 grams / watt (g/w)	• Si consumption < 3 g/W	• Si consumption < 2 g/W
R&D aspects	• New silicon materials and processing • Cell contacts, emitters and passivation	• Improved device structures • Productivity and cost optimisation in production	• Wafer equivalent technologies • New device structures with novel concepts

Thin film technologies	2010 - 2015	2015 - 2020	2020 - 2030
Efficiency targets (commercial modules)	• Thin film Si: 10% • Copper-indium/gallium (CIGS): 14% • Cadmium-telluride (CdTe): 12%	• Thin film Si: 12% • CIGS: 15% • CdTe: 14%	• Thin film Si: 15% • CIGS: 18% • CdTe: 15%
Industry manufacturing aspects	• High rate deposition • Roll-to-roll manufacturing • Packaging	• Simplified production processes • Low cost packaging	• Large high-efficiency production units
R&D aspects	• Large area deposition processes • Improved substrates and transparent conductive oxides	• Improved cell structures • Improved deposition techniques	• Advanced materials and concepts

	Concentrating PV	Emerging technologies	Novel technologies
Type of cell	• High cost, super high efficiency	• Low cost, moderate performance	• Very high efficiency; full spectrum utilisation
Status and potential	• 23% alternating current (AC) system efficiency demonstrated • Potential to reach over 30% in the medium-term	• Emerging technologies at demonstration level (*e.g.* polymer PV, dye PV, printed CIGS) • First applications expected in niche market applications	• Wide variety of new conversion principle and device concepts at lab level • Family of potential breakthrough technologies
R&D aspects	• Reach super high efficiency over 45% • Achieve low cost, high-performance solutions for optical concentration and tracking	• Improvement of efficiency and stability to the level needed for first commercial applications • Encapsulation of organic-based concepts	• Proof-of-principle of new conversion concepts • Processing, characterisation and modelling of especially nanostructured materials and devices

Solar PV economic milestones

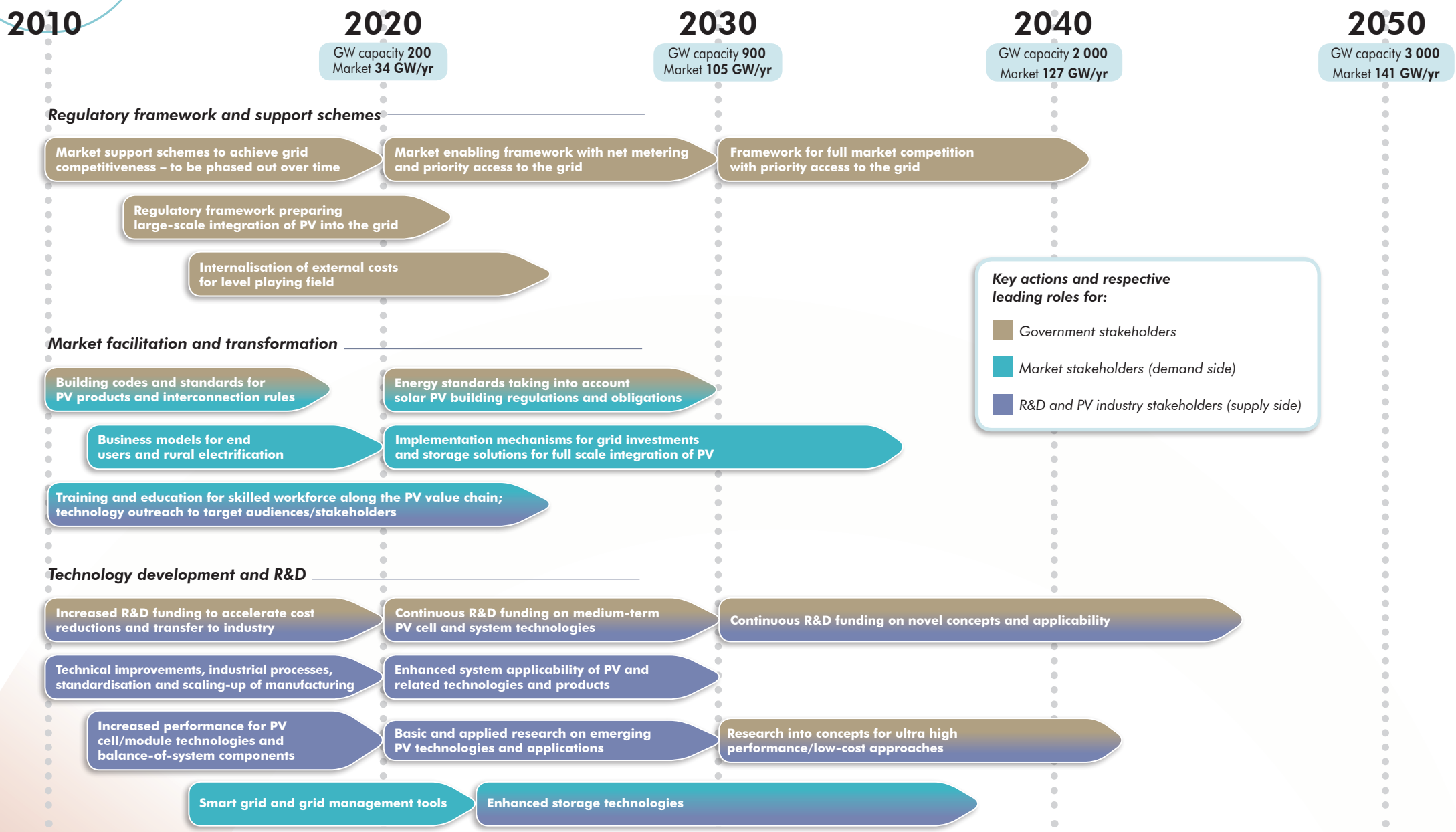
Targets for residential sector		2008	2020	2030	2050
*Typical turn-key system price (2008 USD/kW) **		6 000	2 700	1 800	1 200
Typical electricity generation costs (2008 USD/MWh)	2 000 kWh/kW	360	160	100	65
	1 500 kWh/kW	480	210	135	90
	1 000 kWh/kW	720	315	205	135
Targets for commercial sector		**2008**	**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	85	55
	1 500 kWh/kW	400	175	115	75
	1 000 kWh/kW	600	260	170	110
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	70	45
	1 500 kWh/kW	320	140	90	60
	1 000 kWh/kW	480	210	135	90
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*
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*

** Assumptions: Interest rate 10%, technical lifetime 25a (2008), 30a (2020), 35a (2030), 40a (2050), operations and maintenance 1%*
*** Best system prices lower than 3 000 USD/kW were reported in 2009*
**** 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*

www.iea.org/roadmaps

International Energy Agency

Solar photovoltaic roadmap milestones



International Energy Agency

www.iea.org/roadmaps