Photovoltaics: technology and market developments – the role of Germany

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Outline

I am a free-lance consultant working closely with the German Solar Industry Association BSW-solar. Therefore I partly use BSW-solar documentation.

1. Germany – growth dynamics of the world's largest PV market (BSW-solar)
2. Market challenges ahead
3. Innovation & emerging technologies
4. Fostering an international learning process

GERMANY – GROWTH DYNAMICS OF THE WORLD'S LARGEST PV MARKET

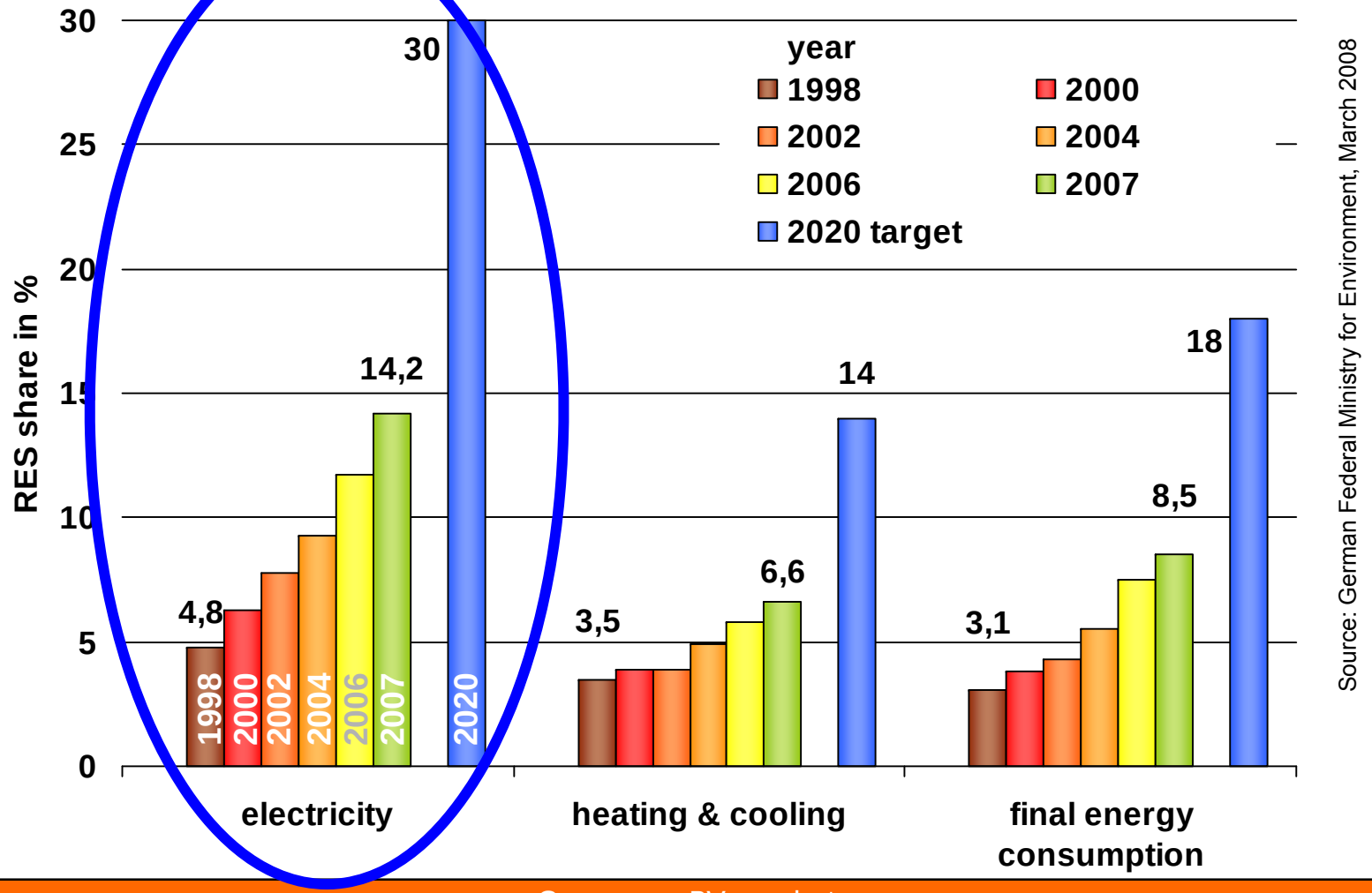
German Solar Industry Association

Bundesverband Solarwirtschaft – BSW-Solar

TASK	Represent the German solar industry in the solar thermal energy and photovoltaics sectors
VISION	A worldwide sustainable energy supply provided by solar energy
ACTIVITIES	Lobbying, political advice, public relations, market observation, standardization
TIME	Over 25 years of activity in the solar energy sector
MEMBERS	More than 600 solar producers, suppliers, wholesalers, installers and other companies active in the solar business
HEADQUARTERS	Berlin

Basis of the German Success in Renewable Energy Sources: A Clear and Continous Policy to Increase the Share of RES

Development of the share of Renewable Energy Sources in final energy consumption

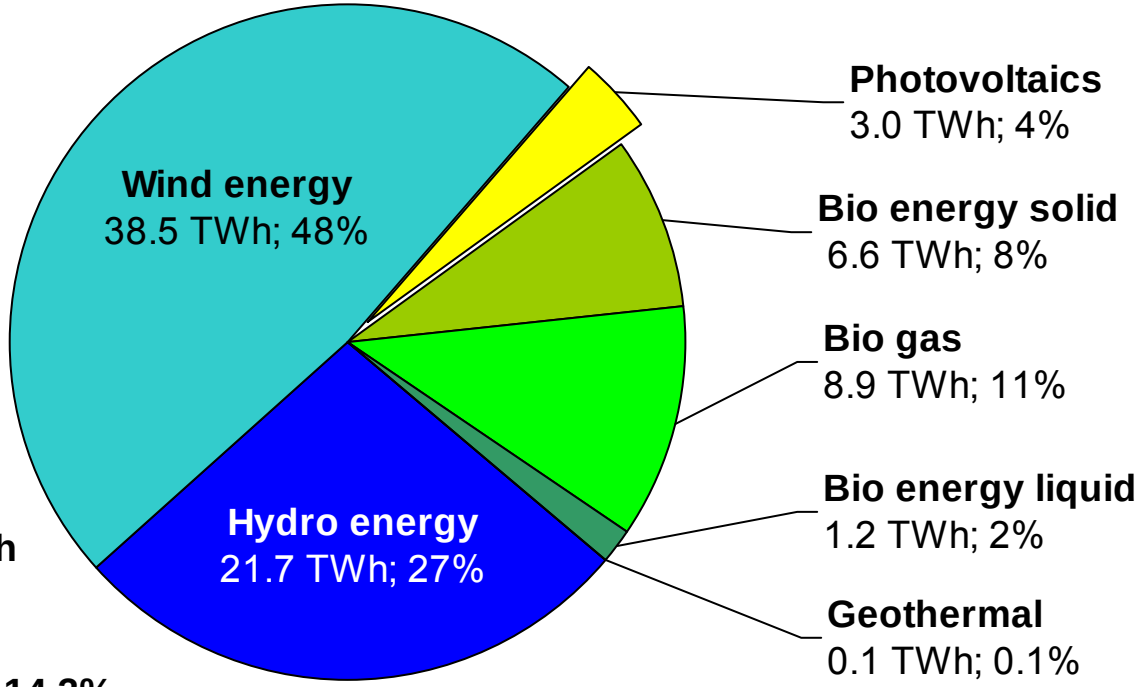


Source: German Federal Ministry for Environment, March 2008

Share of Solar Electricity in Germany

Share of PV electricity
- of electricity consumption 2007: 0.6% (2006: 0.44%)
- of renewable energy electricity 2007: 3.5% (2006: 3.1%)

Distribution of Renewable Energy Electricity Production in Germany 2007



Total RES electricity production 2007: 86.7 TWh
RES share of electricity consumption: 14.3%

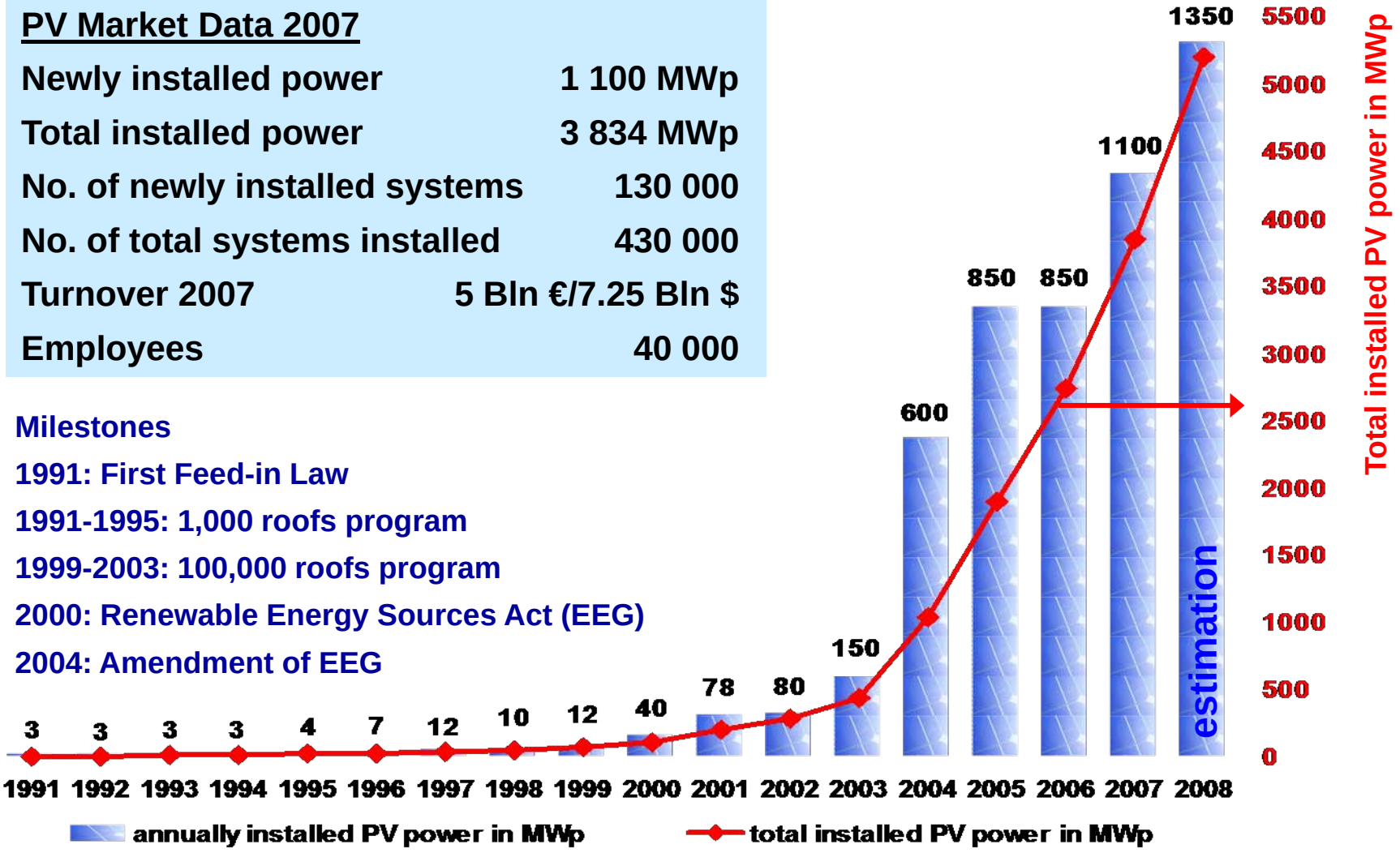
Source: BEE, Jan 2008

Development of the German PV market

PV Market Data 2007	
Newly installed power	1 100 MWp
Total installed power	3 834 MWp
No. of newly installed systems	130 000
No. of total systems installed	430 000
Turnover 2007	5 Bln €/7.25 Bln $
Employees	40 000

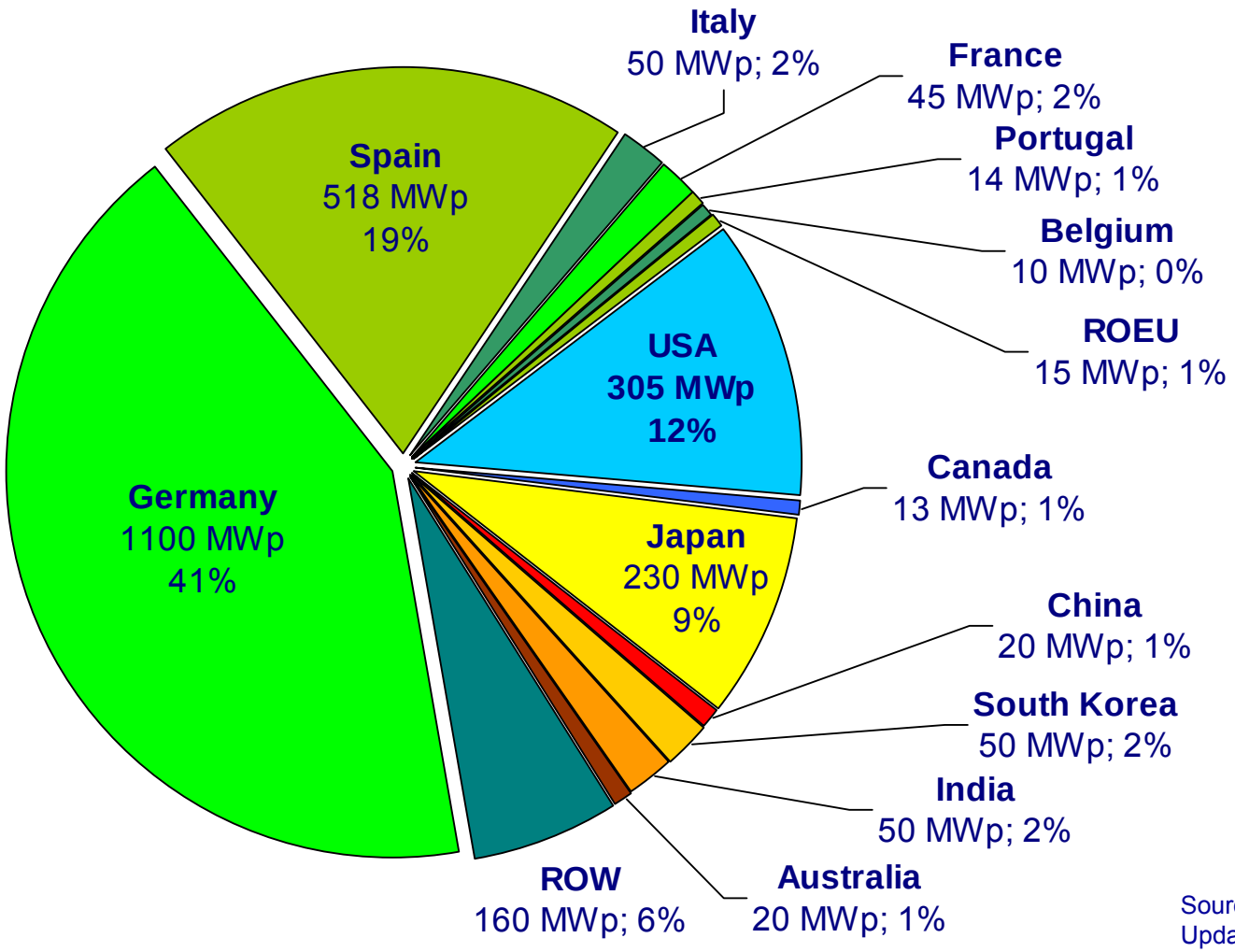
Milestones

- 1991: First Feed-in Law
- 1991-1995: 1,000 roofs program
- 1999-2003: 100,000 roofs program
- 2000: Renewable Energy Sources Act (EEG)
- 2004: Amendment of EEG



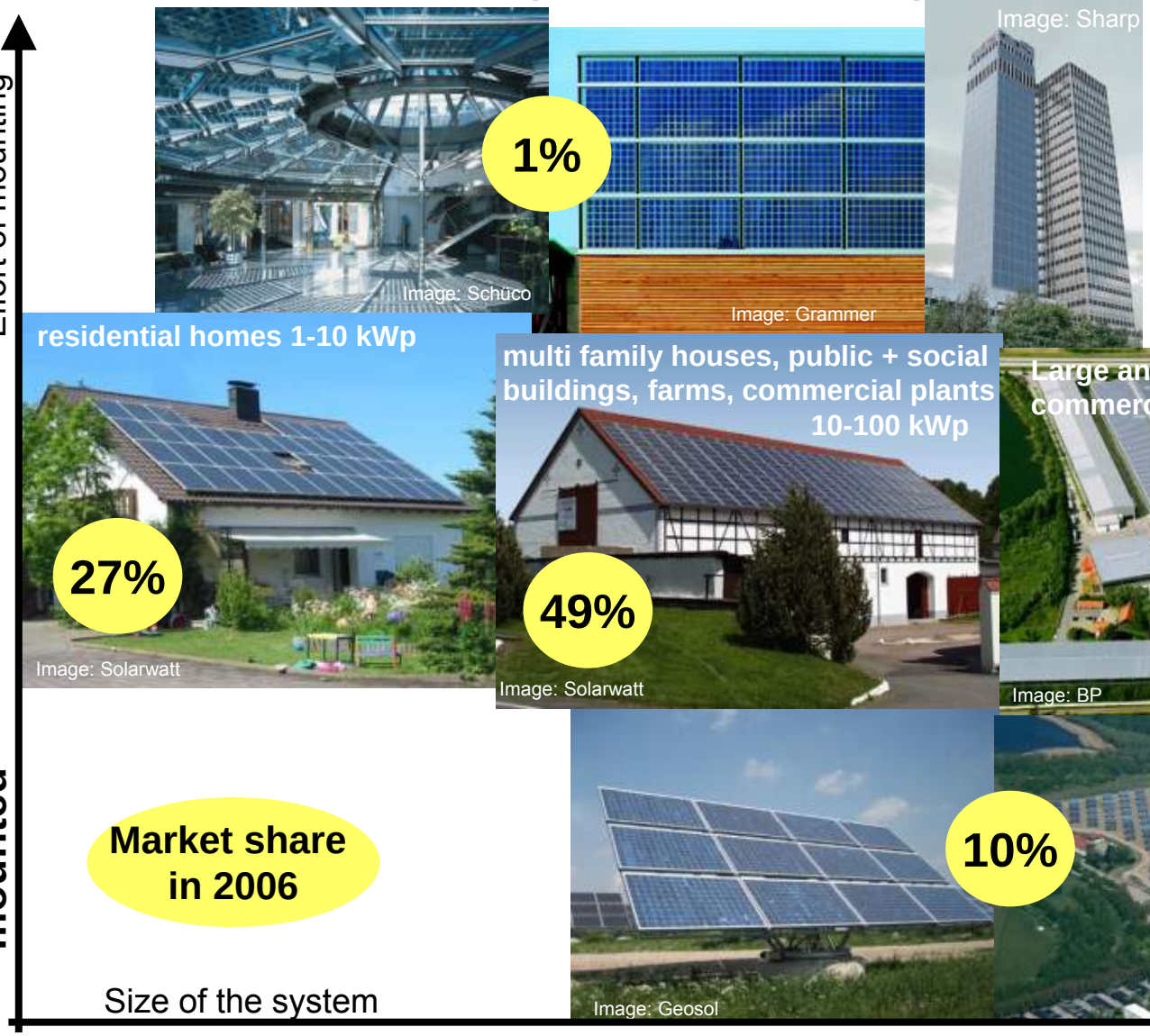
Photovoltaic World Market

Newly installed PV Power in 2007: 2.6 GWp

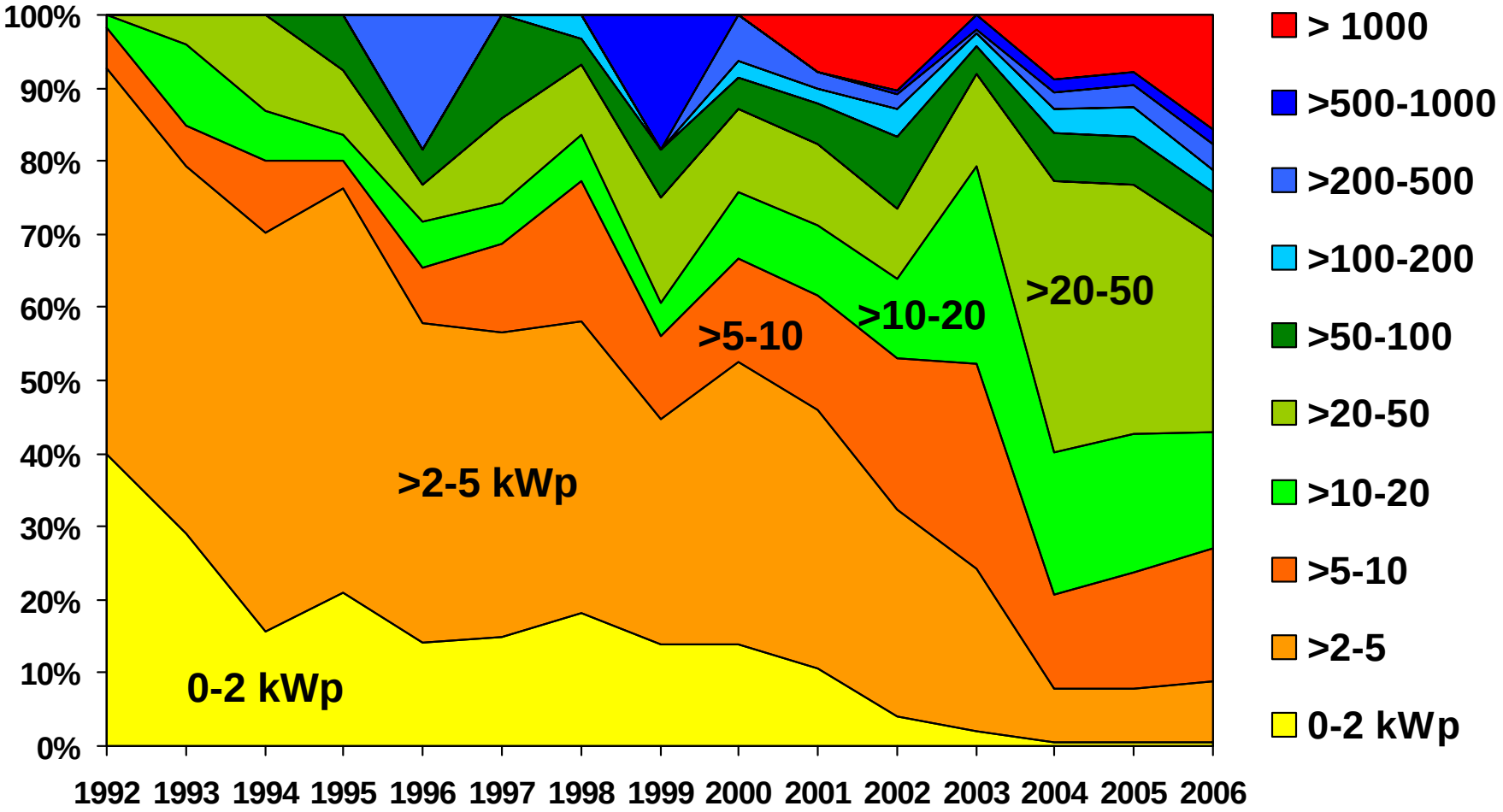


Source: BSW-Solar, EPIA, NNPVA
Updated 5 September 2008

Germany: Market Segments of on-grid PV Systems



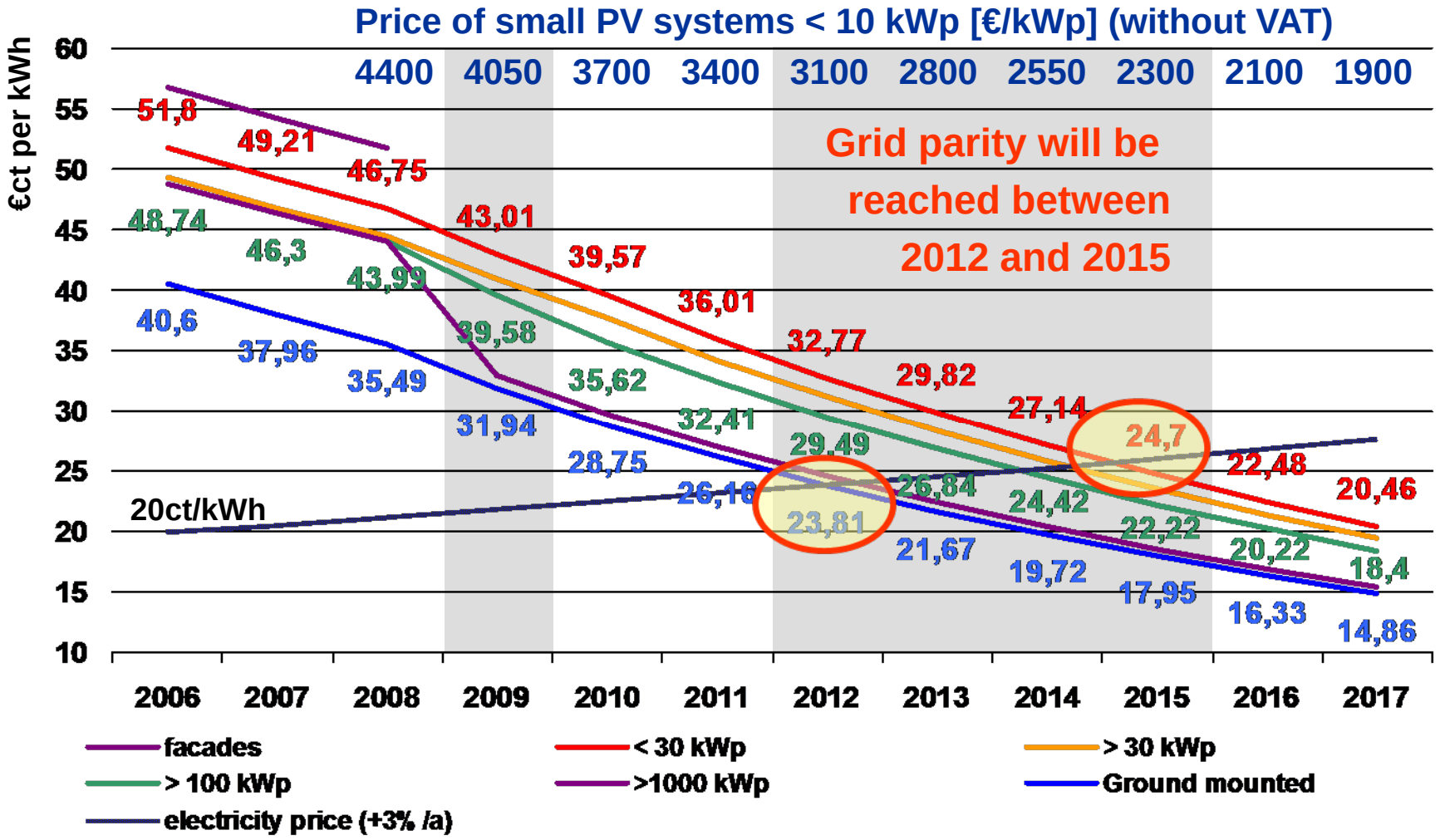
Market share of PV systems according to size



Source: BSW-Solar, calculated from data of 2.2 GWp PV systems from EnBW, EON, RWE, Vattenfall

Feed-in Tariffs for PV within the German EEG

Based on degression rates decided on June 6th, 2008



Photovoltaic market entrance strategy

1. Create PV demand by:
- Granting the right of solar electricity production and grid connection
- Making solar electricity production financially attractive

2. Building up:
- PV market
- PV production
- Installation capacitie

Reduction of costs
Less energy import
Creation of jobs

3. PV will become:
- Cost-competitive
- An important pillar of the sustainable energy system

First results

- **More than €15 billion have been invested in PV systems since 2000**
- **More than €3 billion have been invested in manufacturing plants since 2000**
- **Drop in costs** for PV systems of
  - approx. 25% from 1999 to 2003
  - approx. 5% annually since mid 2006

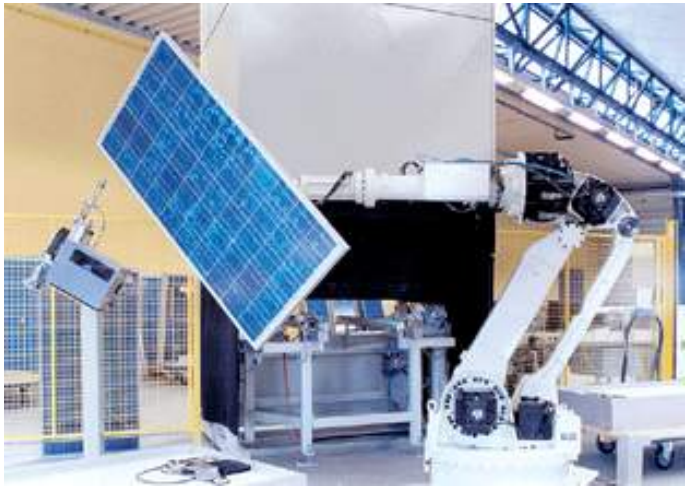
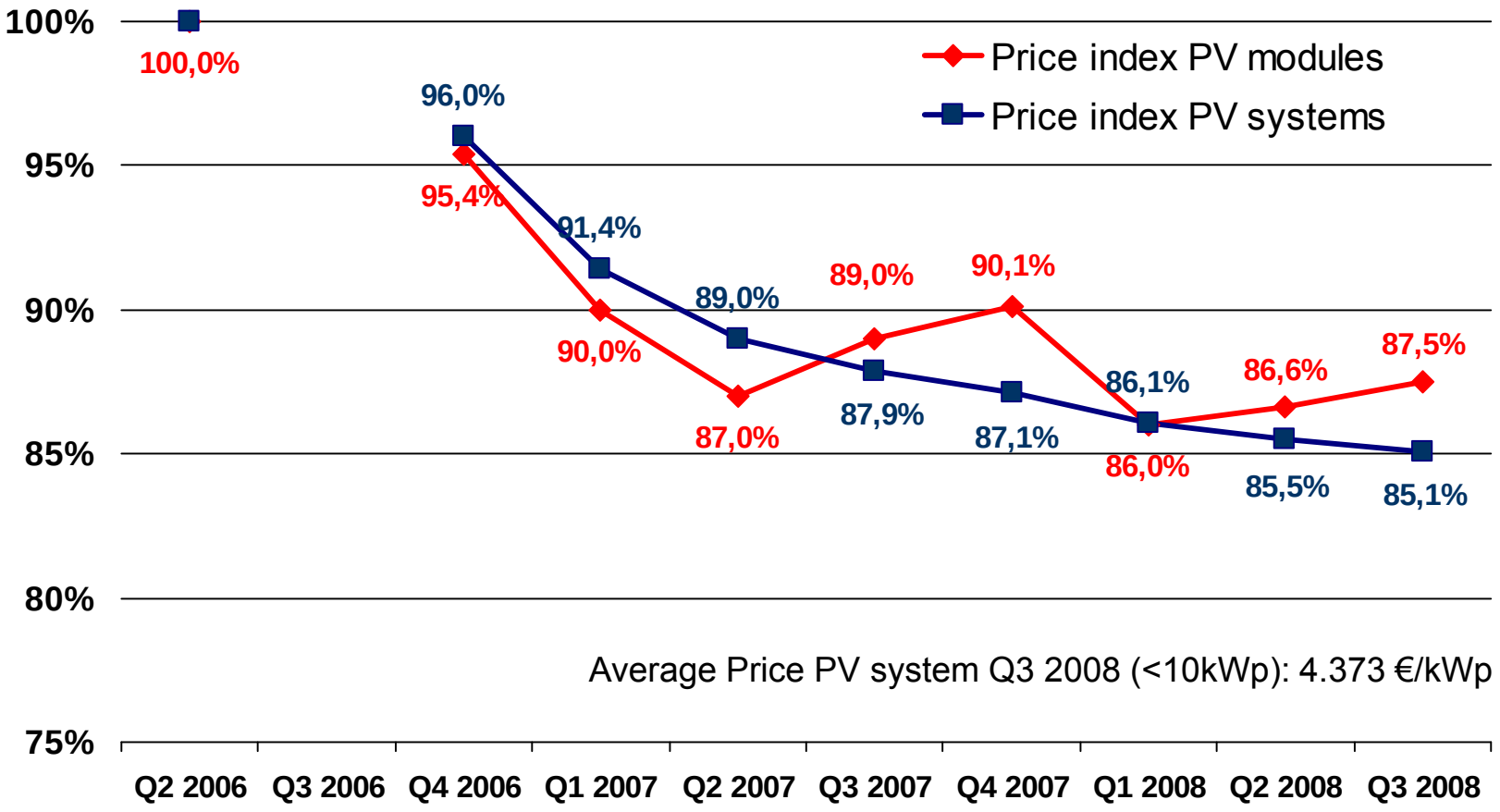


Image: Aleo

BSW-Solar German PV Price Index



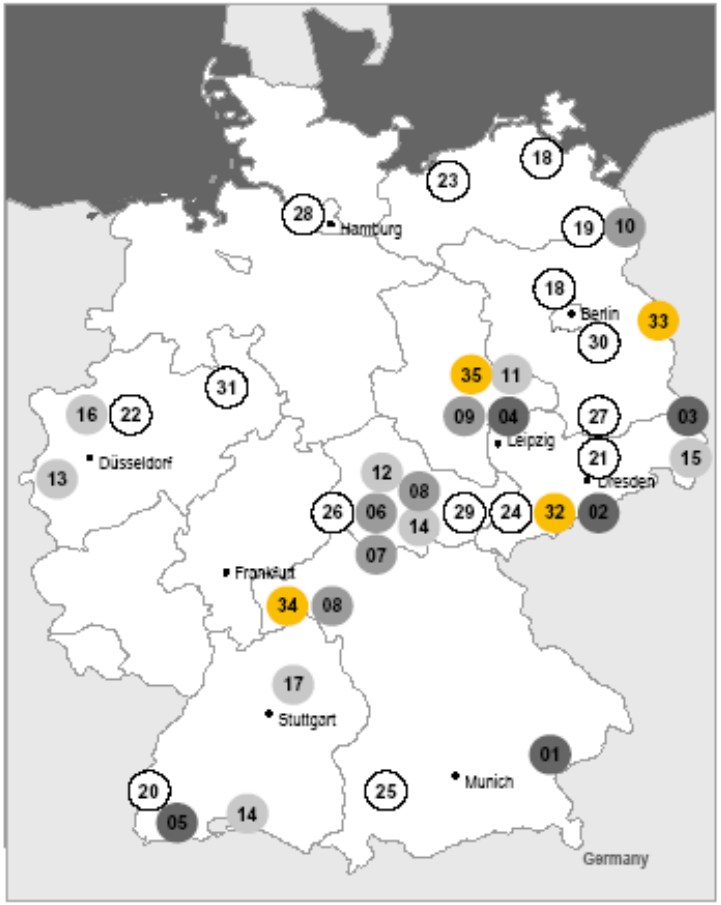
PV Moduls = Wholesale price for installer, PV systems = final customer price, ready installed

Source: Representative independent poll of 100 installers by EUPD-Research on behalf of BSW-Solar

Germany hosts the world's largest PV cluster (1) Companies in wafer-based technologies

Value Chain	No.	Company	Location	Capacity 2008 [MWp]	Current Empl.
Silicon	1	Wacker Chemie	Burghausen	10,000t	960
	2	Scheuten Solar World Solizium	Freiberg[1]	1000t	n/a
	3	Sunways	Spreewitz[1]	1000t	n/a
	4	PV Silicon	Bitterfeld-Wolfen[1]	900t	20
	5	Joint Solar Silicon	Rheinfelden[1]	850t	10
Wafers	6	PV Silicon[2]	Erfurt	290	160
	7	ASi Industries[3]	Arnstadt	180	480
	8	Wacker Schott Solar	Alzenau, Jena[1]	120	300
	9	Q-Cells	Thalheim[1]	80	10
	10	Mola Solaire	Pasewalk[1]	n/a	n/a
Cells	11	Q-Cells	Thalheim	760	1900
	12	Ersol Solar Energy	Erfurt, Arnstadt	220	300
	13	Solland Solar Cells	Aachen	170	300
	14	Sunways	Konstanz, Arnstadt	120	290
	15	Arise Technologies	Bischofswerda	35	10
	16	Scheuten Solar Cells	Gelsenkirchen	35	80
	17	Solarwatt	Heilbronn	15	60
Modules	18	Solon	Berlin, Greifswald	260	400
	19	Aleo Solar	Prenzlau	170	425
	20	Solar-Fabrik	Freiburg	130	290
	21	Solarwatt	Dresden	120	430
	22	Scheuten Solar Technology	Gelsenkirchen	90	140
	23	Centrosolar / Solara	Wismar	80	160
	24	Heckert Solar	Chemnitz	60	120
	25	Webasto Solar	Landsberg/Lech	35	20
	26	Asola	Erfurt	30	100
	27	Algatec	Elsterwerda	15	65
	28	Solarnova	Wedel	10	30
	29	GSS	Löbichau	10	30
	30	PVflex Solar	Fürstenwalde	5	30
	31	Schüco Solar	Bielefeld	5	450
Fully Integrated (Wafers/Cells/ Modules)	32	Solarworld[5]	Freiberg	450/300/250	1200
	33	Conergy[2]	Frankfurt (Oder)[1]	250/250/250	370
	34	Schott Solar[6]	Alzenau	160/275/200	450
	35	EverQ	Thalheim	100/100/100	1000

Source: Invest in Germany Research, Information provided by the respective company, July 2008



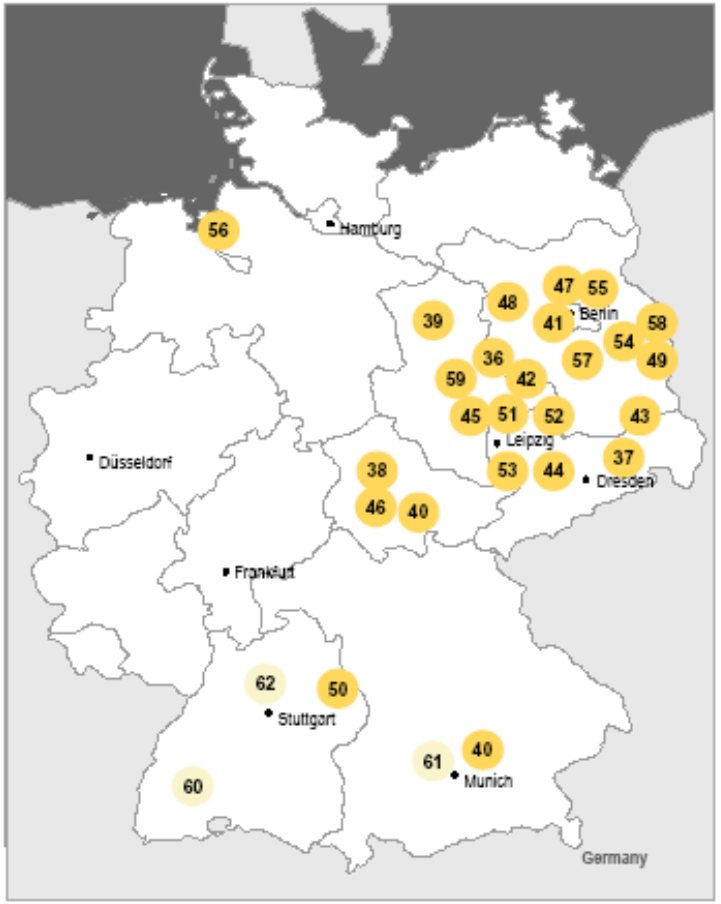
1) Planned/under construction
2) Excluding ingots
3) Subsidary of Ersol
4) Subsidary of Q-Cells
5) Subsidaries of Solarworld: Deutsche Solar, Deutsche Cell, Solar Factory
6) Wafer production by Wacker Schott Solar No. 8

Germany hosts the world's largest PV cluster (2) Companies in thin-film technologies

Value Chain	No.	Company	Location	Capacity 2008 [MWp]	Current Empl.
Thin Film					
Poly-Si	36	CSG Solar	Thalheim	20	150
a-Si	37	Sunfilm	Großröhrsdorf[1]	60	50
a-Si/µc-Si	38	Ersol Thin Film	Erfurt	40	180
	39	Malibu	Osterweddingen[1]	40	150
	40	Schott Solar Thin Film	Jena, Putzbrunn[1]	30	160
	41	Inventux	Berlin[1]	30	n/a
	42	Sontor[4]	Thalheim	25	60
	43	EPV	Senftenberg[1]	25	n/a
	44	Signet Solar	Mochau	20	70
	45	Intico Solar	Halle[1]	n/a	n/a
	46	Masdar PV	Arnstadt[1]	n/a	n/a
CIS	47	Global Solar Energy	Berlin[1]	35	n/a
CIGS	48	Johanna Solar Technology	Brandenburg	30	100
CIGSSe	49	Odersun	Frankfurt (Oder), Fürstenwalde[1]	30	90
	50	Würth Solar	Schwäbisch Hall	30	220
	51	Solibro[4]	Thalheim[1]	25	150
	52	Avancis	Torgau[1]	20	60
	53	Solarion	Leipzig	10	35
	54	PVflex Solar	Fürstenwalde	Pilot	130
	55	Sulfurcell	Berlin	Pilot	120
	56	CIS-Solartechnik	Bremerhaven	Pilot	20
	57	Nanosolar	Luckenwalde[1]	n/a	n/a
CdTe	58	First Solar	Frankfurt (Oder)	175	500
	59	Calyxo[4]	Thalheim	25	40

Companies in concentrator technologies

Value Chain	No.	Company	Location	Capacity 2008 [MWp]	Current Empl.
CPV	60	Concentrix Solar	Freiburg	25	70
	61	SolarTec	Munich	10	50
	62	Archimedes Solar	Stuttgart	n/a	n/a



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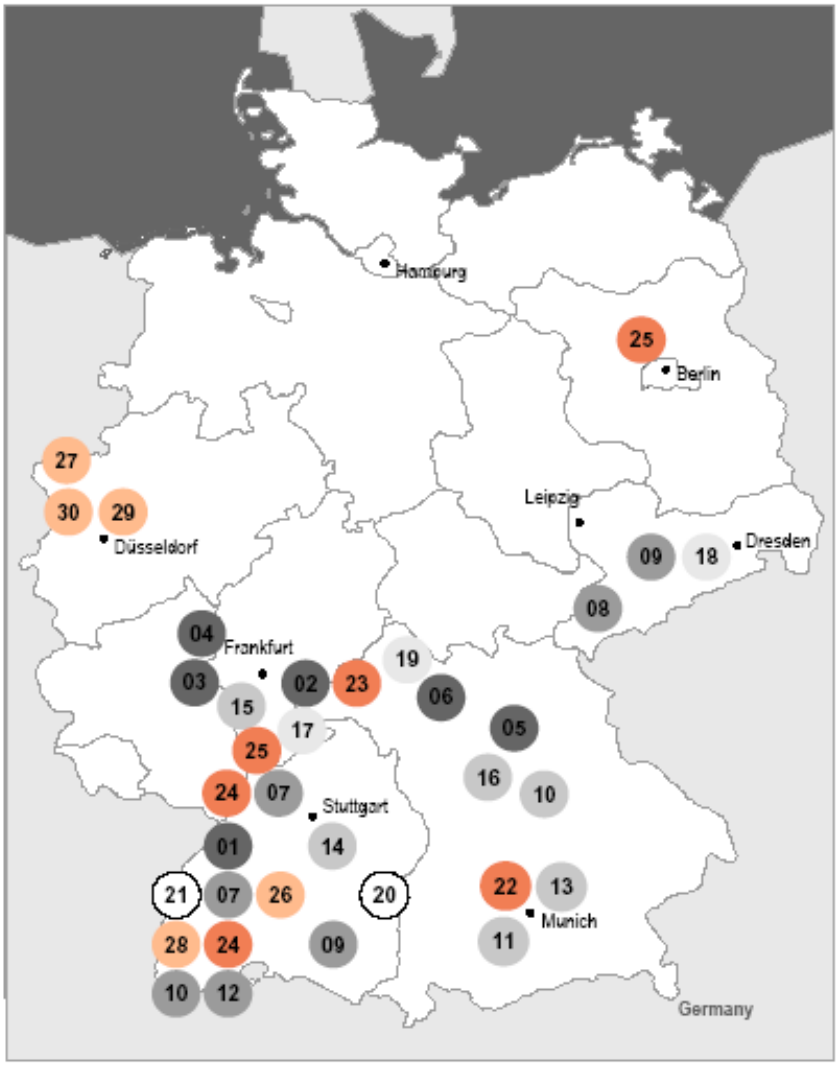
Source: Invest in Germany Research, Information provided by the respective company, July 2008

Proximity to leading PV equipment companies accelerates production ramp-up (1)

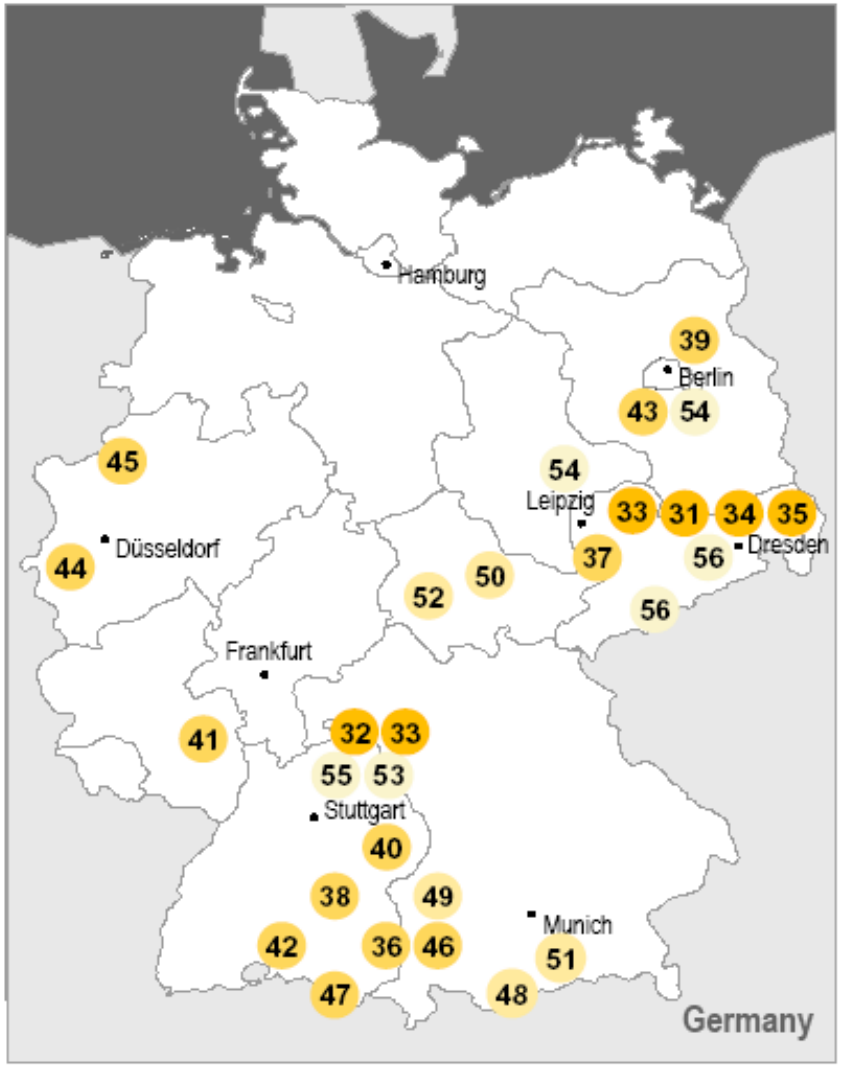
Equipment	No.	Company	Location	Empl.
Ingots/Wafers - Equipment	1	Gebrüder Schmid	Freudenstadt	380
	2	ALD Vacuum Technologies	Hanau	360
	3	Herbert Arnold	Weilburg	130
	4	CGS / PVA Tepla	Asslar	50
	5	G&N	Erlangen	40
	6	Logomatic	Mainaschaff	20
Cells - Turnkey Lines	7	Gebrüder Schmid	Freudenstadt , Schwetzingen	430
	8	Roth & Rau	Hohenstein-Ernstthal	300
	9	Centrotherm Photovoltaics	Blaubeuren, Dresden	200
Cells - Wet Chemistry	10	Rena	Gütenbach, Berg	450
	11	Stangl Semiconductor	Eichenau, Puchheim	100
	12	Lotus Systems	Gutmadingen	70
	13	Ramgraber	Hofolding b. Braunthal	40
	14	HMS Höllmüller	Herrenberg	40
	15	M-O-T	Speyer	20
	16	Decker	Berching	30
Cells - Anti-reflective Coating	17	Applied Materials	Alzenau	500
	18	Von Ardenne Anlagentechnik	Dresden	400
	19	Singulus	Kahl	300
Cells -Screenprinters	20	Manz Automation	Reutlingen	400
	21	Thieme	Teningen	350
Modules - Turnkey Lines	22	Kuka Systems	Augsburg	1200
	22	Reis Robotics	Obernburg	720
	23	Gebrüder Schmid	Freudenstadt, Niedereschach	530
	24	Teamtechnik	Freiberg am Neckar, Berlin	350
Modules - Tabbers, Stringers, Laminators	25	Robert Bürkle	Freudenstadt	350
	26	Meier Vakuumtechnik	Bocholt	170
	27	Somont	Umkirch	100
	28	Robust	Remscheid	50
	29	SunWare	Duisburg	20
	30	Solarwatt	Dresden	20



Source: Invest in Germany Research, Information provided by the respective company, March 2008

Proximity to leading PV equipment companies accelerates production ramp-up (2)

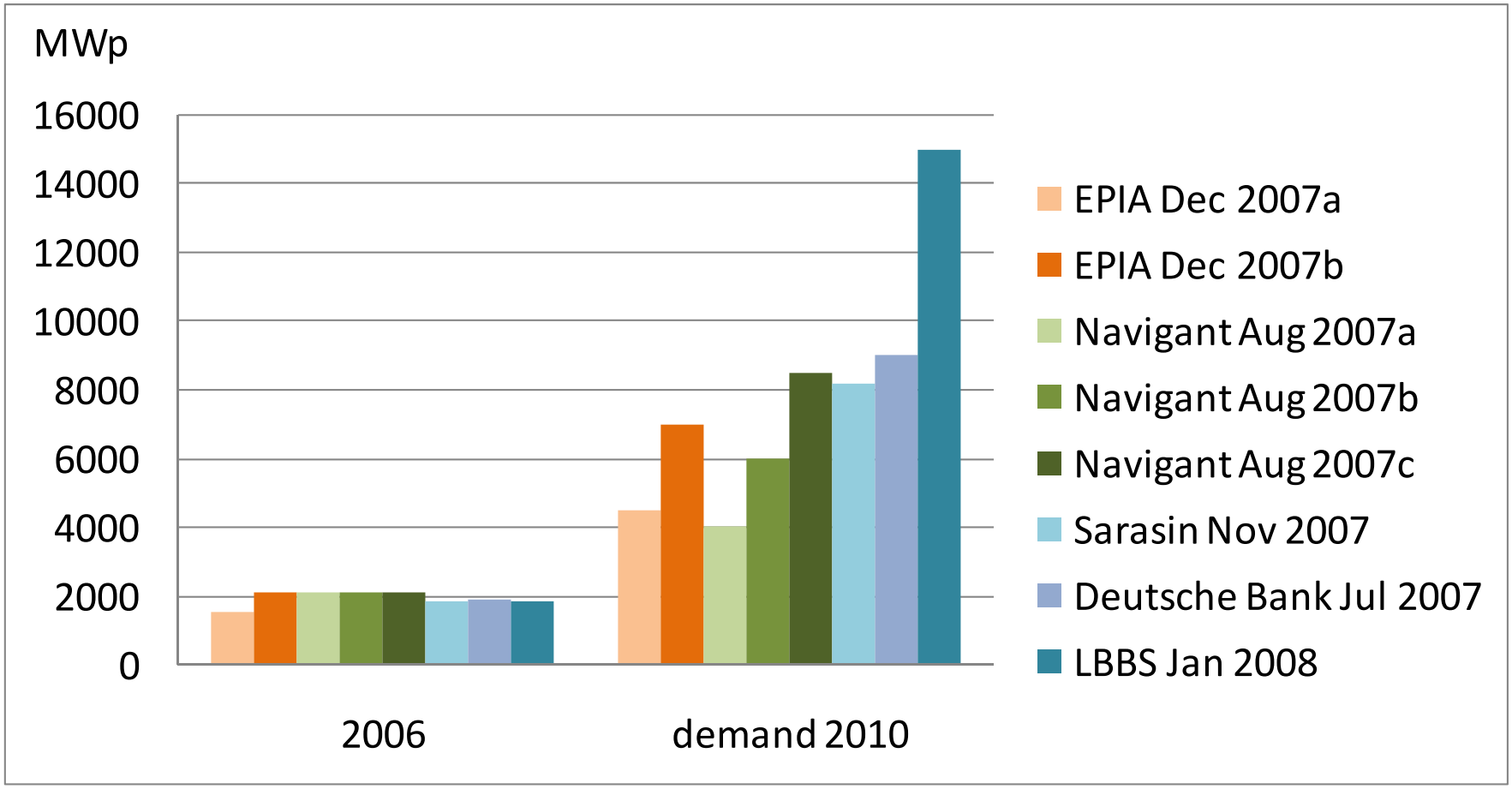
Equipment	No.	Company	Location	Empl.
Thin Film - Vacuum Deposition	31	Applied Materials	Alzenau	500
	32	Von Ardenne Anlagentechnik	Dresden	400
	33	Leybold Optics	Alzenau, Dresden	320
	34	FHR Anlagenbau	Ottendorf-Okrilla	90
Automation	36	ASYS Automatisierungssysteme	Dornstadt	300
	37	USK Karl Utz Sondermaschinen	Limbach-Oberfrohna	260
	38	Manz Automation	Reutlingen	250
	39	Jonas & Redmann Photovoltaics	Berlin	240
	40	Schiller Automation	Sonnenbühl-Genkingen	200
	41	Minitec Maschinenbau	Waldmohr	140
	42	ACI-ecotec	St. Georgen	70
	43	Feintool Automation	Berlin	60
	44	Maschinenbau Gerold	Nettetal	50
	45	Olbricht	Hamminkeln-Brünen	30
	46	Amb bernhard brain	Gersthofen	20
	47	Mondragon Assembly	Stockach	20
Laser Processing	48	Carl Baasel	Stamberg	350
	49	Manz Automation	Reutlingen	300
	50	Jenoptik Automatisierungstechnik	Jena	170
	51	InnoLas	Krailling	80
	52	LPKF SolarQuipment	Suhl-Friedberg	40
Fab Engineering and Planning	53	M+W Zander FE	Stuttgart	400
	54	IB Vogt	Berlin, Thalheim	160
	55	Caverion	Stuttgart	160
	56	AiC	Chemnitz, Dresden	80



Source: Invest in Germany Research, Information provided by the respective company, March 2008

CHALLENGES AHEAD

Large variations in global PV market forecasts for 2010

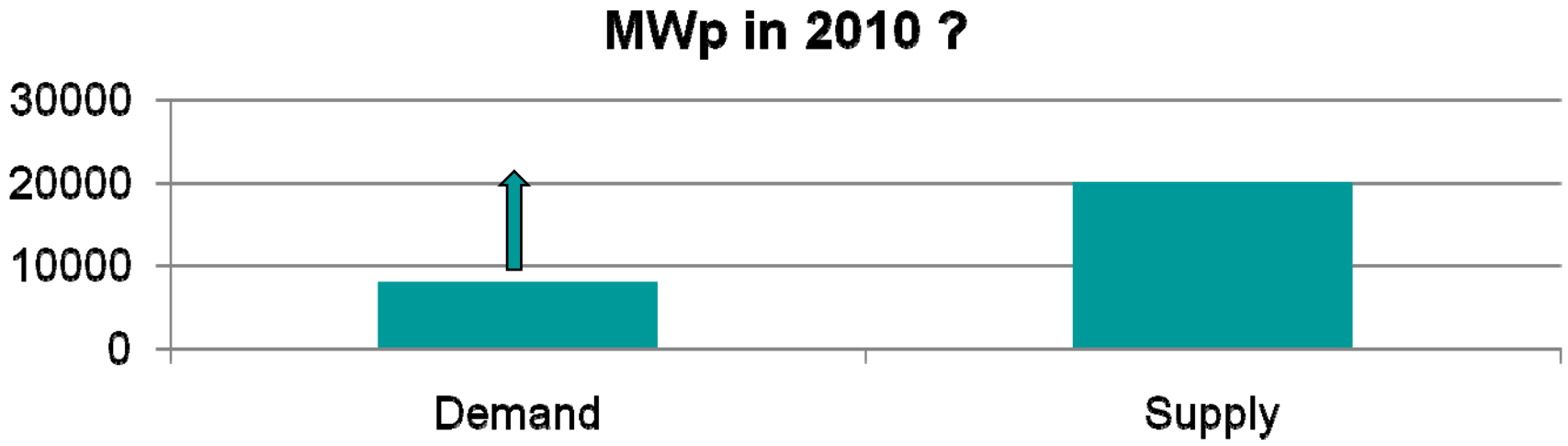


Worldwide PV overcapacity coming soon?

- Announcements for production in 2010 amount to nearly 20 GWp
- Demand estimates range between 4 and 14 GWp

→ Big efforts in market development are necessary for avoiding overcapacity

→ Only strong and high quality producers will survive



EPIA: Grid Parity Competitive Market in the EU

Learning curves
- realistic: 100% increase of installed PV → 20% cost reduction
- conservative: 100% increase of installed PV → 15% cost reduction

Grid electricity price increases

→ Step by step grid parity will be reached in all important markets in the coming years

Share of EU electicity markets where grid parity is reached:

	2008	2012	2016	2020
15% learning curve	0%	5%	25%	60%
20% learning curve	0%	10%	50%	90%

Source: EPIA / Millner, September 2008

Which part of this volume is really accessible?

New EPIA targets for 2020

- Cumulative PV installed in Europe 2020: 350 GWp
- PV Electricity production in Europe 2020: 420 TWh
- PV share of EU electicity generation: 12%
- CAGR of installed PV base: 40%

EPIA proposes to set this as target for EU energy policies:

→ appropriate policies must be developed

→ Ensuring market growth

→ Development of technologies

Source: EPIA / Millner, September 2008

INNOVATION AND EMERGING TECHNOLOGIES

Boosting innovation in photovoltaics

The new PV markets opened since 2003 by the German feed-in-tariff, enlarged by Spain and later followers have boosted innovation activities in the PV sector:

- Increased and lower cost silicon production
- Lower costs and efficiency gains in c-Si cells
- Thin film technologies: aSi, µc-Si, micromorph Si, CIGS, CdTe …
- Concentrating photovoltaic systems CPV
- New PV concepts
- Building integration of PV (BIPV)
- Tracking and support systems
- Grid integration concepts

→Innovation and cost reduction are accelerating

Innovations in c-Si technology

- Crystalline Silicon technology will provide the bulk of PV production for many years
- A wide range of innovations promises further cost reductions, the most important are:

  - The use of upgraded metallurgical silicon
    → considerably reduced silicon production costs

    Germany: Fraunhofer ISE is one of the research pioneers in this field;
    Q-Cells pioneers in using upgraded metallurgical Silicon in large quantities

  - Back-contact cells
    → improved efficiency; facilitated automation; improved aesthetics

    Germany: ISE, Q-cells, SolarWorld and others are preparing new products

New developments in thin film PV

- More than 100 companies have announced time frames and capacities for TF PV production [1]
  - 40 Europe, 27 China, 12 Taiwan, 19 USA, 8 Japan
  - 82 Si, 19 CIGS, 7 CdTe, 5 Dye & others
- More than 12 companies offer “turn-key” production systems [1]
- Estimates for 2010: nearly 5 GW [2]
- Steady correlation since 30y: doubling volume → 22% cost reduction
- Thin film factories mushrooming, also in Germany
  - Q-cells (a-Si/µc-Si, CdTe/CdS, CIGS)
  - Ersol – now a Bosch subsidiary aiming at rapid expansion (a-Si)
  - Masdar initiative (Si, Applied Materials)
  - A series of smaller companies (see map)
  - Equipment providers (Manz, Centrotherm, etc.)

[1] Jaeger-Waldau 2008 [2] LBBW 2008

Thin film PV brings new challenges

- Estimated growth (LBBW): CAGR 65%
- Turnkey factories from large equipment producers
- All production steps in one line at one site
- Large modules (5,7 m^2 with Applied Materials)
- Lower efficiency than c-Si

→ New players enter the market
→ Logistics become important (higher weight per power output)
→ New opportunities for Building Integrated PV

All major TF technologies – a-Si/µc-Si, CdTe and CIGS – have interesting prospects with different characteristics

The importance of system costs

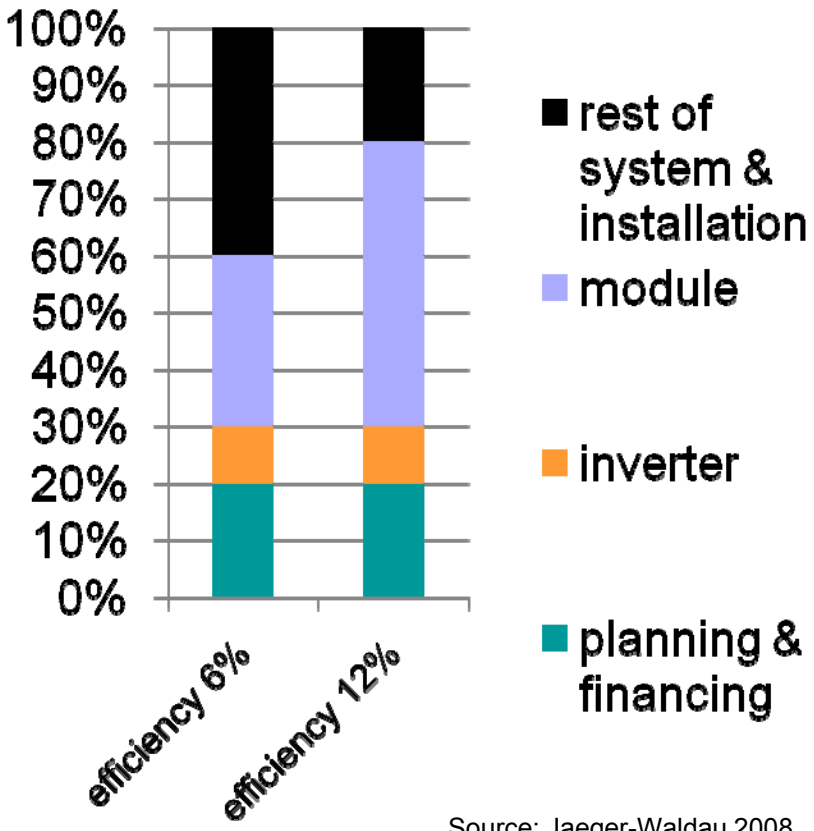
- Lower efficiency requires larger surfaces
- At low efficiency module costs may make up for only 1/3 of system costs

→ Efficiency matters

→ Costs of the rest of the system matter

→ Interesting prospects for innovative BIPV with low cost cells

Cost components at overall system costs of 2 € / Wp



Source: Jaeger-Waldau 2008

New PV concepts

A series of innovative PV concepts has made new progress. Examples:

- Organic polymer cells show increased stability offer fascinating new characteristics
  - High flexibility with polymer substrates
  - Choice of colours and transparency
  - Easy production with printing processes
  - Low costs
  - Konarka about to start production in large roll to roll printing process

- Organic fluorescent cells make substantial progress
  - Concentrating light at (plexi-)glass edges makes progress due to new dyes
  - High yield cells become availabe at reasonable cost
  - High concentration factors without tracking → new BIPV opportunities

Concentrating Photovoltaic Systems CPV

- Low-concentration (factor < 10) and high-concentration (factor >100) systems
- Low concentration modules (10x) with conventional Si-cells: high yield with low system costs
  Germany: Archimedes (ZEW Stuttgart spin-off)
- New high-yield cells open new prospects
  - World record 40,8% efficiency with triple-junction cells
  - European record (Fraunhofer ISE) 39,7 % efficiency
- Integrated concentrator modules (500x) promise low costs for sunny regions
  - 5,6 MW plant near Sevilla with Concentrix fresnel-lens modules shows 23% efficiency (Concentrix is an ISE spin-off with Albengoa capital)
  - new Concentrix modules: efficiency over 27%, energy payback time <1 year
  - automated 25 MW production line opened Sept 2008 in Freiburg

© Archimedes

© Concentrix

Building Integrated PV (BIPV)

- Whole roofs as a first step
- Other components of the building shell require more sophisticated solutions / integration with
  - standard building components
  - planning and building processes
  - construction industry
- Very high potential but little commercial progress in the last years
- Research in Germany: Fraunhofer ISE etc.
- Innovative Systems and Components:
  - Schott
  - Schüco
  - Systaic
- New opportunities with thin film products

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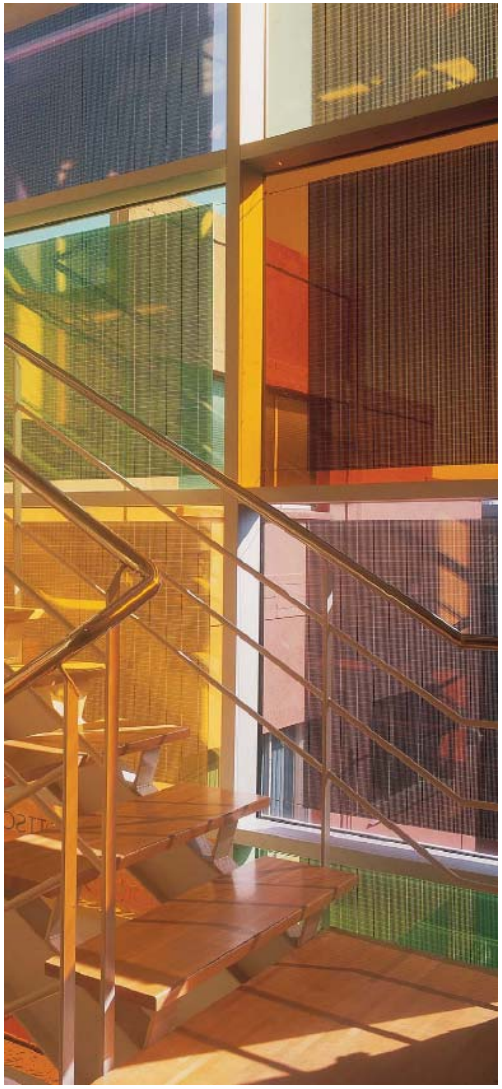
Building Integrated PV (BIPV) 2

- Wide range of possible applications
- Increasing aesthetical options
- Low or no additional costs for support structures
- System solutions required



© Schott

Building Integrated PV (BIPV) 3

© Saint Gobain

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Building Integrated PV (BIPV) 3

Combining PV electricity and solar heat generation on the same surface can

- improve PV efficiency (lower temperatures)
- make optimal use of available surfaces
- decrease overall costs

Different system types

- PV/T- water collectors
- PV/T- air collectors
- concentrating PV/T collectors
- air-cooled PV collector systems with heat recovery (picture)

© AKAFÖ

Grid integration, mini-grids & hybrid systems

- Established grids:
  - Inverters have to take over tasks in grid stabilisation
  - Reduced scepticism concerning grid management:
    Inverter industry : no problem with up to 50% solar electricity in German grid
  - “Kombi-Kraftwerk”: virtual hybrid power station combining wind, solar, biogas & hydro has shown high performance in matching demand
  - slow but systematic progress in net metering
- Mini-grids:
  - improved inverters & controls → bottom-up construction of grids increasingly attractive: scalable mini-grids with usual 230V appliances
  - hybrid systems combining PV, wind and biofuels increasingly standardised
- PV markets off centralised grids with huge potential
  - high diesel costs call for new approaches
  - declining costs of PV-focused mini-grids offer new solutions
  - rural population needs electricity
- Important contributions from research institutes and industry
  (ISET Kassel, Fraunhofer ISE, SMA, Steca, Fronius, Energiebau ..)

A COLLECTIVE INTERNATIONAL LEARNING PROCESS

Fascinating challenges asking for joint efforts

- PV will be able to deliver large parts of worldwide electricity at competitive costs
- Huge growth opportunities for the PV industry

<u>Challenges</u>

→ Bridging of the cost gap until grid parity, ensuring continuous market growth (► politics)

→ Reducing administrative barriers for PV (► administration,politics)

→ Bringing down the costs through continuous innovation (► industry, research)

→ Ensuring high quality with qualified personnel (► industry, training institutions)

→ Creating new markets with new applications, BIPV (► industry)

→ Supporting the growth of PV markets worldwide (► industry, politics)

Rapid growth requires to learn quickly: avoid known traps in time

Rapid growth, rapid innovation, rapid cost reduction:

→ Managing growth requires rapid learning

→ Adapting to evolving technologies, costs & markets is essential

- Unbalanced growth and disruptive changes in market regulation – such as in Spain – destroy capacities and confidence in the new technology
- Bad quality installations undermine confidence in the whole sector
- Possible bottlenecks need to be identified in time: qualified personnel, key materials, grid capacity, financing
- Difficult transition from a vendor's to a buyer's market
- Large potentials untapped: creating new markets can be more rewarding than competing for existing ones

Rapid learning requires co-operation

- Co-operation along the value creation chain
- Co-operation between research and industry
- Co-operation between national industry associations
- Co-operation between governments in order to ensure a balanced market growth

- The new **International Renewable Energy Agency IRENA** may play an important role for enhancing co-operation and improving frame conditions
  - negotiations for an international treaty next week in Madrid
  - Germany, Spain & Denmark main promotors
  - foundation scheduled for January