## PV system market

<table>
<thead>
<tr>
<th>Country</th>
<th>2011 Newly connected capacity (MW)</th>
<th>2011 Cumulative installed capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Italy</td>
<td>9,000</td>
<td>12,500</td>
</tr>
<tr>
<td>Germany</td>
<td>7,500</td>
<td>24,700</td>
</tr>
<tr>
<td>China</td>
<td>2,000</td>
<td>2,900</td>
</tr>
<tr>
<td>USA</td>
<td>1,600</td>
<td>4,200</td>
</tr>
<tr>
<td>France</td>
<td>1,500</td>
<td>2,500</td>
</tr>
<tr>
<td>Japan</td>
<td>1,100</td>
<td>4,700</td>
</tr>
<tr>
<td>Australia</td>
<td>700</td>
<td>1,200</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>700</td>
<td>750</td>
</tr>
<tr>
<td>Belgium</td>
<td>550</td>
<td>1,500</td>
</tr>
<tr>
<td>Spain</td>
<td>400</td>
<td>4,200</td>
</tr>
<tr>
<td>Greece</td>
<td>350</td>
<td>550</td>
</tr>
<tr>
<td>Slovakia</td>
<td>350</td>
<td>500</td>
</tr>
<tr>
<td>Canada</td>
<td>300</td>
<td>500</td>
</tr>
<tr>
<td>India</td>
<td>300</td>
<td>450</td>
</tr>
<tr>
<td>Ukraine</td>
<td>140</td>
<td>140</td>
</tr>
<tr>
<td>Rest of the World</td>
<td>1,160</td>
<td>6,060</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>27,650</strong></td>
<td><strong>67,350</strong></td>
</tr>
</tbody>
</table>
Germany leads the way

Increase of Renewable Energy Sources in Germany 1990 - 2010

- June 2011:  
  > 900,000 plants
  80% of the capacity in low voltage grids

- 17 GW PV
- 27 GW Wind
- 5 GW Biomass
- 5 GW Hydro

end 2011: + 6 GWp  
(4% of electricity)

target 2020: 70-80 GWp  
(12% of electricity)
Germany leads the way
PV is far beyond a niche already

Contribution of PV on 8 May 2011 in Germany
(Estimation: 13 GW, >30%, PV+Wind: >50%)

Source: Online Information of German TSOs

Prof. Dr.-Ing. Martin Braun
"The Development of Smart Grids - High Penetration of PV Into the Grid"
6th General Assembly of the European Photovoltaic Technology Platform
30 June 2011 – European Parliament, Brussels, Belgium
© Fraunhofer IWES
PV is far beyond a niche already

Contribution of PV on 8 May 2011 in TenneT control area
(Estimation: 6 GW, > 50%, PV+Wind: > 100%)

Source: http://www.tennetgroup.de

Prof. Dr.-Ing. Martin Braun
"The Development of Smart Grids - High Penetration of PV into the Grid"
6th General Assembly of the European Photovoltaic Technology Platform
30 June 2011 – European Parliament, Brussels, Belgium

© Fraunhofer IWES
Price evolution solar modules (Europe)

Evolution of the average PV module price in Europe

source: Price data based on Paula Mints (Navigant Consulting).
Price-experience curves solar modules
the combined effect of volume and innovation

source: Navigant Consulting, EPIA.
PV system price development – German rooftops
(BSW-Solar, 2011)
A competitive solution well before 2020

Competitiveness is analysed by comparing PV’s generation cost with the PV revenues (dynamic grid parity) and/or with the generation cost of other electricity sources (generation value competitiveness).

“Dynamic grid parity” is defined as the moment at which, in a particular market segment in a specific country, the present value of the long-term revenues (earnings and savings) of the electricity supply from a PV installation is equal to the long-term cost of receiving traditionally produced and supplied power over the grid.

“Generation value competitiveness” is defined as the moment at which, in a specific country, adding PV to the generation portfolio becomes equally attractive from an investor’s point of view to investing in a traditional and normally fossil-fuel based technology.
Competitive position solar electricity ("dynamic grid parity"): residential systems

Dynamic grid parity for residential PV systems in Europe
Competitive position solar electricity ("dynamic grid parity"): **gas-fired power plants (CCGT)**

- Generation value competitiveness of large ground-mounted applications in Europe

![Diagram showing competitive position of solar electricity compared to gas-fired power plants (CCGT). The diagram illustrates the cost of electricity generation over time, with a focus on the competitive parity of solar energy.]
USA DoE SunShot Initiative
Cost-competitive utility-scale PV by 2020

«At $0.05–$0.06 per kWh, the system cost is approximately $1 per watt»
Solar Generation 6

Long-term price development utility-scale systems

source: Greenpeace/EPRA
Solar generation VI 2010.
Solar Generation 6

Long-term market growth scenarios

High(er) expectations & ambitions

Table 11.1 Indicative global capacities and electricity generation

<table>
<thead>
<tr>
<th>Technology</th>
<th>Capacity (GW)</th>
<th>Electricity generation (TWh/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV</td>
<td>12,000</td>
<td></td>
</tr>
<tr>
<td>CSP</td>
<td>*6,000</td>
<td></td>
</tr>
<tr>
<td>Solar fuels</td>
<td>*3,000</td>
<td></td>
</tr>
<tr>
<td>Wind power</td>
<td>10,000</td>
<td></td>
</tr>
<tr>
<td>Base load (Geothermal, nuclear, solid biomass w. CCS)</td>
<td>*3,000</td>
<td></td>
</tr>
<tr>
<td>Natural gas</td>
<td></td>
<td>9,000</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>90,000</td>
</tr>
</tbody>
</table>

* Thermal storage may result in average capacity factor of almost 50%. **Shared capacities.

Figure 11.4 Global electricity generation by technology in 2060

- Natural gas 1%
- PV 20%
- CSP 28%
- Solar fuels 2%
- Wind power 28%
- Hydropower 10%
- Base load 11%
High(er) expectations & ambitions

Table 11.1 Indicative global capacities and electricity generation

<table>
<thead>
<tr>
<th>Technology</th>
<th>Capacity (GW)</th>
<th>Electricity generation (TWh/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV</td>
<td>12,000</td>
<td>18,000</td>
</tr>
<tr>
<td>CSP</td>
<td>*5,000</td>
<td>25,000</td>
</tr>
<tr>
<td>Solar fuels</td>
<td>*3,000</td>
<td>2,000</td>
</tr>
<tr>
<td>Wind power</td>
<td>10,000</td>
<td>25,000</td>
</tr>
<tr>
<td>Hydro power and marine</td>
<td>1,600</td>
<td>9,000</td>
</tr>
<tr>
<td>Base load (Geothermal, nuclear, solid biomass w. CCS)</td>
<td>1,200</td>
<td>10,000</td>
</tr>
<tr>
<td>Natural gas</td>
<td></td>
<td><strong>3,000</strong></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td><strong>9,000</strong></td>
</tr>
</tbody>
</table>

* Thermal storage would give CSP plants an average capacity factor of almost 50%. **Shared capacities.

Figure 11.4 Global electricity generation by technology in 2060

- Base load 11%
- Hydropower 10%
- Wind power 28%
- Natural gas 1%
- PV 20%
- CSP 28%
- Solar fuels 2%

Key point

Solar energy could provide half the global electricity generation in 50 years.
PV power plant installations in >50 MW, 6.8% WACC, 1.4 $/€, system adapted to local conditions, 30% industry growth rate, 15-20% learning rate

PV Cost Dynamics

0-axis fixed tilted local LCOE in year 2013, scenario: realistic

PV power plant installations in >50 MW, 6.8% WACC, 1.4 $/€, system adapted to local conditions, 30% industry growth rate, 15-20% learning rate

PV power plant installations in >50 MW, 6.8% WACC, 1.4 $/€, system adapted to local conditions, 30% industry growth rate, 15-20% learning rate

PV Cost Dynamics

0-axis fixed tilted local LCOE in year 2020, scenario: realistic

PV power plant installations in >50 MW, 6.8% WACC, 1.4 $/€, system adapted to local conditions, 30% industry growth rate, 15-20% learning rate

Conclusions

- ongoing fast PV cost reduction is very likely
- PV is still negligible in terms of currently cumulative installed capacities
- Grid-parity start right now (driven by end-user electricity prices)
- Fuel-parity start right now (driven by solar resource quality)
- high (economic) demand for adapted off-grid PV solutions
- economic PV market potential by 2020 roughly 2,800 – 4,300 GWp
- cumulative installed capacity by 2020 roughly 600 – 1,600 GWp
- most institutions cannot imagine a fast PV diffusion (except EPIA, Greenpeace)
Contents

The PV challenges quantified
• what is needed for TW-scale use?

Building blocks for the solution
• technology portfolio & system approaches

Economics and markets
• state of the art and projections

Sustainability
• a multidimensional concept

Outlook

Background photo: www.bso.vvs.be
Materials shortages or price risks? – no consensus yet

Short-Term (Present–2015) Criticality Matrix

Medium-Term (2015–2025) Criticality Matrix
Materials shortages or price risks? – no consensus yet

<table>
<thead>
<tr>
<th>Metal</th>
<th>Market Factors</th>
<th></th>
<th>Political Factors</th>
<th></th>
<th>Overall risk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Likelihood of rapid demand growth</td>
<td>Limitations to expanding production capacity</td>
<td>Concentration of supply</td>
<td>Political risk</td>
<td></td>
</tr>
<tr>
<td>Dysprosium</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Neodymium</td>
<td>High</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Tellurium</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Gallium</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Indium</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Niobium</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Vanadium</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Tin</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Selenium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Silver</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Hafnium</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Nickel</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Cadmium</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
</tr>
</tbody>
</table>
Materials shortages or price risks? – no consensus yet

Figure 11: The toolbox containing the elements of hope, the frugal elements and the critical elements:
PGM = Platinum-Group Metals;
REM = Rare-Earth Metals;
the red elements are non-metals;
B, Si, Ge, As, Sb, Te are metalloids

André Diederen (2009)
Energy payback time

on-roof installation in Southern Europe
1700 kWh/m².yr irradiation on optimally-inclined modules

Energy payback time (years)

- mono
- multi
- CdTe
- μc-Si
- CIGS

2010
- 2008
- 2009
- 2010
- 2012e
- 2010

14.4% 14.1%
11.3% 10.0%
11.0%
210-960 MWp 120 MWp 20 MWp

Mariska de Wild-Scholten 8 September 2011
Contents

The PV challenges quantified
• what is needed for TW-scale use?

Building blocks for the solution
• technology portfolio & system approaches

Economics and markets
• state of the art and projections

Sustainability
• a multidimensional concept

Outlook

Background photo: www.bso.vvs.be
Outlook

- Cost reduction: \( \approx \text{factor 3} \)
- Efficiency enhancement: \( \approx \text{factor 3} \)
- Volume increase: \( > \text{factor 100} \)
thank you for your attention!