PV’s significant Role to Power the Future Global Energy Needs with 100% Renewables

Becquerel Prize Award
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SMA Management Board Representative to the EPIA
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PV’s significant Role to Power the Future Global Energy Needs with 100% Renewables

- Future global energy needs
- Boundary conditions for 100% Renewables
- PV’s significant role
- The 100% Renewable World

Source: WHff
Future Global Energy Needs

• ~¾ of today’s ~100,000 TWh Secondary Energy Needs are used by only ¼ of the global (~7 bn) population
Future Global Energy Needs

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- Technology development allows to decrease significantly the specific energy needs: „same quality of life with much less energy“
  examples: solid state lighting,
  electric mobility (...with renewable electricity!),
  house insolation (to decrease heating and cooling), etc

Source: WHff
Future Global Energy Needs

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• Technology development allows to decrease significantly the specific energy needs: „same quality of life with much less energy“ examples: solid state lighting,
  electric mobility (...with renewable electricity!),
  house insolation (to decrease heating and cooling)
... and many, many more

• The future 10-12 bn people can be energized with ~200,000 TWh Secondary Energy (some scientists are even projecting less, old forecasts are significantly higher) – with a similar quality of life for everyone

Source: WHff
Future Global Secondary Energy Needs

Total secondary energy\(^1\) (incl. energy efficiency means)

Source: WHff
Total electricity production will increase from 20,000 TWh in 2010 to ~60,000 TWh in 2050+ at low growth for Renewables.
Total electricity production will increase from 20,000 TWh in 2010 to ~ 120,000 TWh in 2050+ at high growth for Renewables.
Boundary conditions for 100% Renewables

- 6 €/t CO2 is not sustainable!
Boundary conditions for 100% Renewables

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- LCOE for Renewables to become lower compared to nuclear, coal and gas (wind on-shore with 6€ct/kWh competitive to new coal, PV in sunny regions today with less than 10 €ct/kWh competitive to peak gas power)

Source: WHff
Competitiveness of PV Solar Electricity

... the story of „Grid parity“

- Photovoltaics
- Retail prices private and small business
- Large power consuming industries (Base-load cost & margin)

market support programs necessary:

Source: WHff 1999
Boundary conditions for 100% Renewables

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- Old technologies – nuclear, coal and gas – will become more and more expensive (fuel price, approval procedures, CCS for fossil ... if technically possible)
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- Old technologies – nuclear, coal and gas – will become more and more expensive (fuel price, approval procedures, CCS for fossil ... if technically possible)
- Renewable technologies are „riding down“ their respective Price Experience Curve – no fuel cost, specific cost decrease due to technology development like in other high volume products (semiconductors, flat panel displays, glass coatings and many more)

Source: WHff

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PV Price Experience Curve

Price Experience Curve

Driven by Technology

- Wafer thickness
  0,7mm → 0,15mm
- Kerf loss
  0,5mm → 0,10mm
- Efficiency
  8% → 22%
- Automation
  Industrial manufacturing
- Economy of scale
  0,1MW → 200MW
- Modularity – same building block from kW to GW systems

source: NAVIGANT
Further development of PV PEC

1. PEC for c-Si will continue

2. Reason for different PEC and PEF for Thin Film PV

3. Different growth rates for global PV installations as parameter

4. Different fraction of TF/c-Si as parameter

Price Experience Curve

Source: NAVIGANT
Photovoltaic – Future Price Development
... with “healthy” module prices ...

Case A: Baseline
TF share 15% const
TF PEF 20%

Case B: Paradigm Shift
TF share 15% → 35%
TF PEF 25%

c-Si Technology
price expectation in 2020
~ (70 +/- 10) $/W

Thin Film Technology
price expectation in 2020
~ (50 +/- 20) $/W

Source: WHff
„Healthy“ versus „market economy driven“ prices

PEC Scenario

Case A: Baseline
TF share 15% const
TF PEF 20%

c-Si Technology
price expectation in 2020
ca. 60 – 80 $ct/W

Thin Film Technology
price expectation in 2020
ca. 30 – 70 $ct/W

Actual volume
end 2011

Case B – cSi 20%

Case B – TF 25%

2011 price range

Actual volume
end 2011

Case B – cSi 20%

Case B – TF 25%

2011 price range
DRAM – Moore’s Law

Experience Curve

- DRAM Price [$cents / bit]
- Cumulated bits

Experience Curve

- DRAM Price [$cents / bit]
- Cumulated bits

PEF 40%
PEC for Flat Panel Display

Experience Curve

Driven by Technology

Relative Costs [%]

Cumulated Display Area [million m2]

PEF 35%

Display Substrate Area [m2]

Years


100,0
10,0
1,0
0,1

0,1
1,0
10,0
100,0


1%

10%

100%

1 10 100 1000

TV

Laptop

Desktop

announced

Winter 2012

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### Customer Needs served by PV

<table>
<thead>
<tr>
<th>on-grid</th>
<th>off-grid</th>
<th>consumer</th>
<th>high efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="On-grid Image" /></td>
<td><img src="image2" alt="Off-grid Image" /></td>
<td><img src="image3" alt="Consumer Image" /></td>
<td><img src="image4" alt="High Efficiency Image" /></td>
</tr>
</tbody>
</table>

- **€/kWh**
- **€/hr light**
- **W/m²**
- **g/W**

- **€/m² / aesthetics**
- **€/W**
- **flexibility**
- **W/mm²**

Source: Fraunhofer ISE

Source: WHff
Technology Evolution

- ribbon
- mg metallurgical grade Silicon
- mc multicrystalline
- Cz Czochralski
- CPV concentrated PV
- OPV organic PV

@ - (8 to 10) % price decrease per year

Source: WHff 2008
Record cell efficiencies of up to 21% on large area p-type Cz Si wafers achieved by SCHOTT Solar

Cell design

- Next generation manufacturing technologies demonstrate potential to reach 21% cell efficiency with simple and cost effective process sequences
- All steps are available in multiple process options

Results (best cells)

<table>
<thead>
<tr>
<th></th>
<th>Efficiency [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screen-printed Ag front contacts</td>
<td>21.0*</td>
</tr>
<tr>
<td>Electroplated NiCu front contacts</td>
<td>20.9*</td>
</tr>
</tbody>
</table>

* independently confirmed by ISE Callab

Source: SCHOTT Solar AG
Share of PV Technologies

Source: WHff 2008
PV 2011: ~70 GW (~ 80,000,000 MWh)
Corresponding to 53 full size 1,300MW nuclear reactors
... and energy wise to the annual output of 9 such reactors

Source: EPIA Market Workshop 2012
Actual annual growth for PV

<table>
<thead>
<tr>
<th>Decade</th>
<th>% growth p.a.</th>
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<tr>
<td>1990 - 2000</td>
<td>20</td>
</tr>
<tr>
<td>2000 - 2010</td>
<td>52</td>
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Source: WHff
Assumed growth rates and resulting power installed and energy produced

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<td>5</td>
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Result:

- Cumulative PV power 2050: 22,000 GW
- Annual energy production in 2050 at 1.3 kWh/W (average): 29,000 TWh

Source: WHff
Projection for Future RE Portfolio for a 100% Global End Energy Coverage

RES share in %

- Non RES
- Other RES
- Bio Mass
- Wind
- STC/ CPV
- Solar Thermie
- PV

Towards 2050

- e (electricity)
- p (power)
- h (heat/cool)

Towards 2100

Source: WHff
Development of the various energy sectors (approximate)

Source: WHff

Year 2000

- Electricity
- Mobility
- Power & Heat

Sum 100,000 TWh (secondary energy)

Year 2050+

- Electricity (incl. E-mobility)
- Non-e-mobility
- Power & Heat

Sum 200,000 TWh (secondary energy)
Total electricity production will increase from 20,000 TWh in 2010 to ~ 120,000 TWh in 2050+ at high growth for Renewables

Source: WHff
... getting interested in these thoughts?

Wiley is waiting for my story and the book should be ready around summer 2013

For better remembering take a flyer at the Wiley booth
Acknowledgements and thanks

- to all friends, colleagues and supporting seniors
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- to my family
  wife Anneliese with children Tobias and Elisabeth plus our sunshine & grandson Elija with his mother Miriam