Cost, Price, Markets, & Support Mechanisms

Lecture 18

MIT Fundamentals of Photovoltaics
2.626/2.627 – 11/22/2011

Prof. Tonio Buonassisi

Today's Topics: Cost, Price, and Markets

- What sets price (and profit)
- Energy future and overview of renewable energy sources
- Economics and market dynamics
- Fluctuations in supply and demand, drivers for oversupply/undersupply conditions, and what this means for profits.
- Subsidies: Why subsidize? How much to subsidize? Role of PV in the global energy market.

PV Cost and Price

Levers of Cost

Table 1: A simple model for module efficiency impacts on module cost.

Wafer Cost ($/m^2)	Cell Process Cost ($/m^2)	Module Process Cost ($/m^2)	Module Efficiency (%)	Module Manufacturing Cost ($/watt)
W_{hi}	C x W_{hi}	M x W_{hi}	η_{hi}	$W_{hi}(1 + C + M)/1000\eta_{hi}$
W_{low}	C x W_{hi}	M x W_{hi}	η_{low}	$(W_{low} + W_{hi}[C + M])/1000\eta_{low}$
Equating manufacturing costs: $W_{low}/W_{hi} = 1 - (1 - \eta_{low}/\eta_{hi})(1 + C + M)$				

T. Surek et al., Proc. 3rd World Conference on Photovoltaic Energy Conversion, Osaka, Japan (2003)

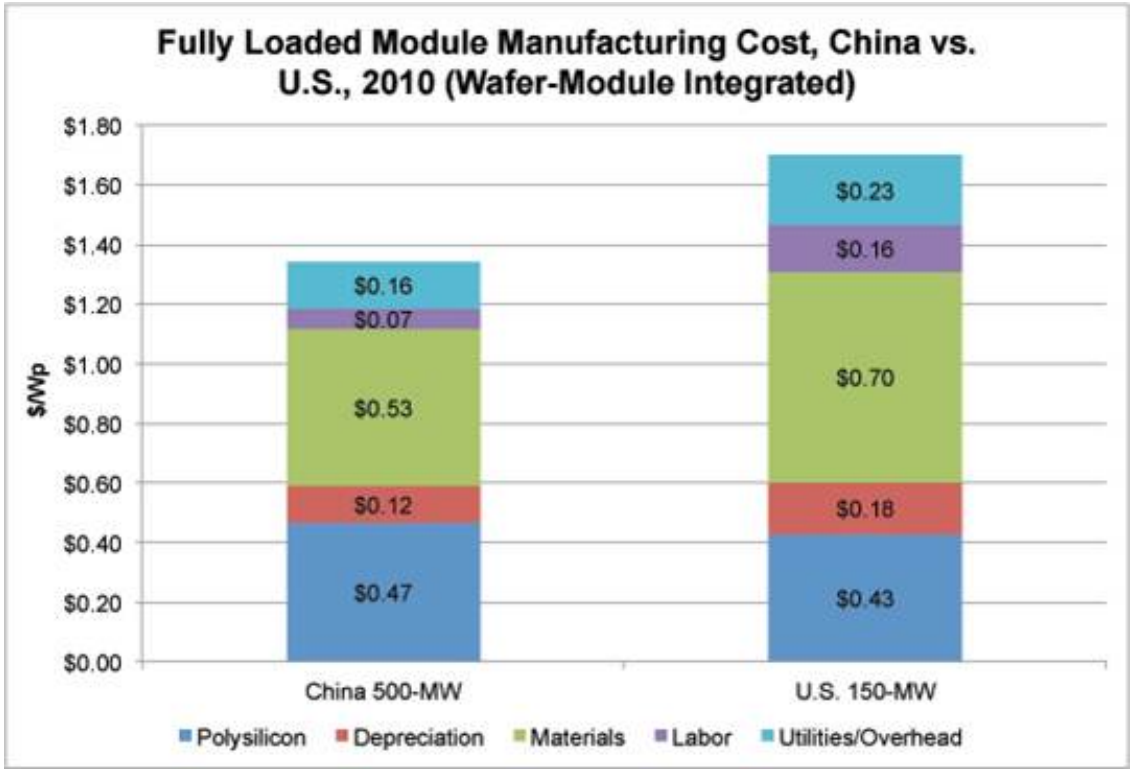
Cost Levers:

- Efficiency
- Processing Costs ($/m^2)
- Manufacturing Yield
- Capital equipment cost
- Overhead…
- Other…

More on Thursday 12/1/2011

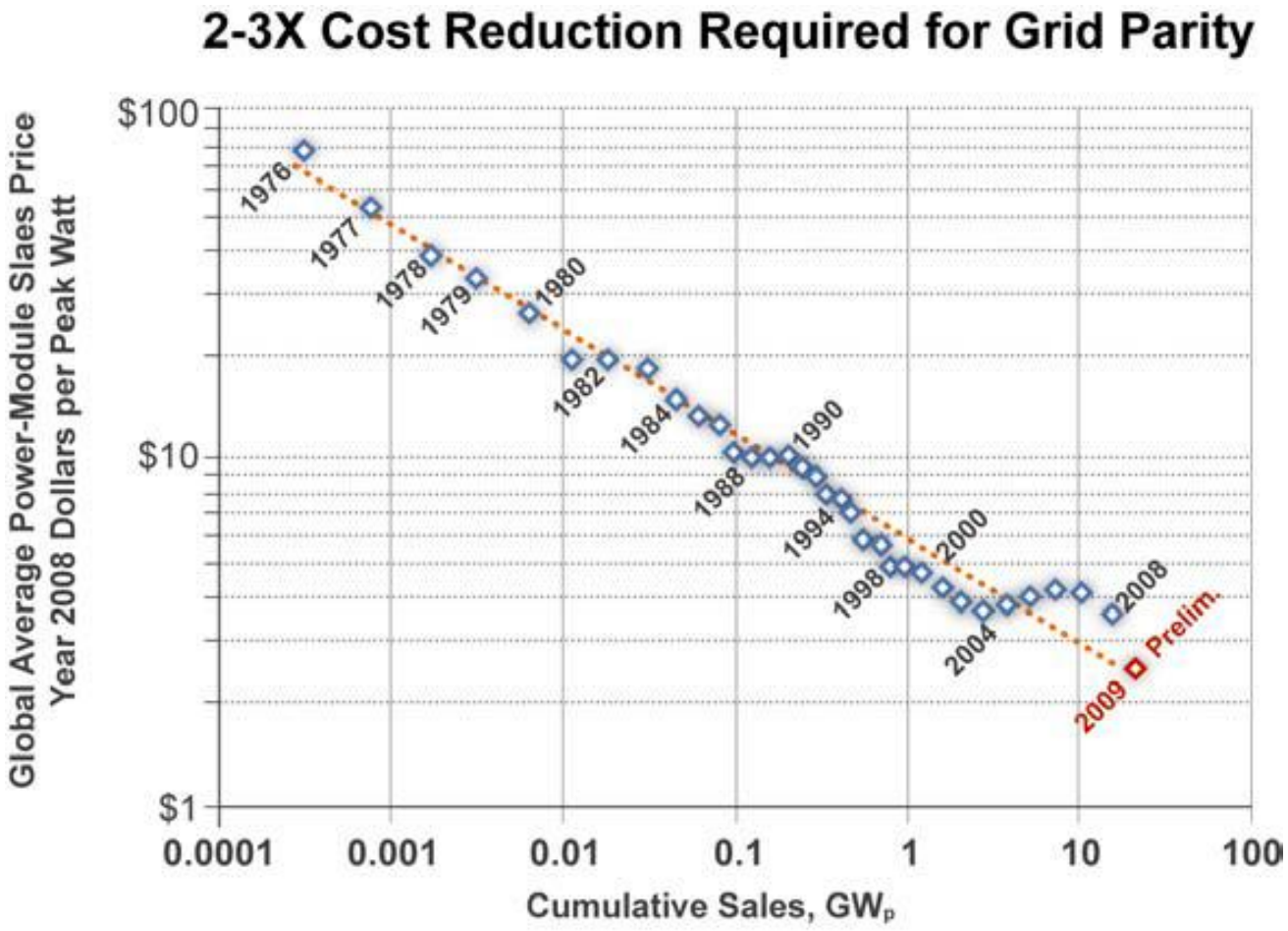
PV Cost Trends

- Available from expensive consultants, or…
  - "Tracking the Sun II: The Installed Cost of Photovoltaics in the U.S. from 1998-2008" Lawrence Berkeley National Laboratory, October 2009.
  - "Solar Summit 2011: Is U.S. PV Manufacturing Doomed to Failure?" *Greentech Solar*, March 7, 2011.
  - *Note caveats!*



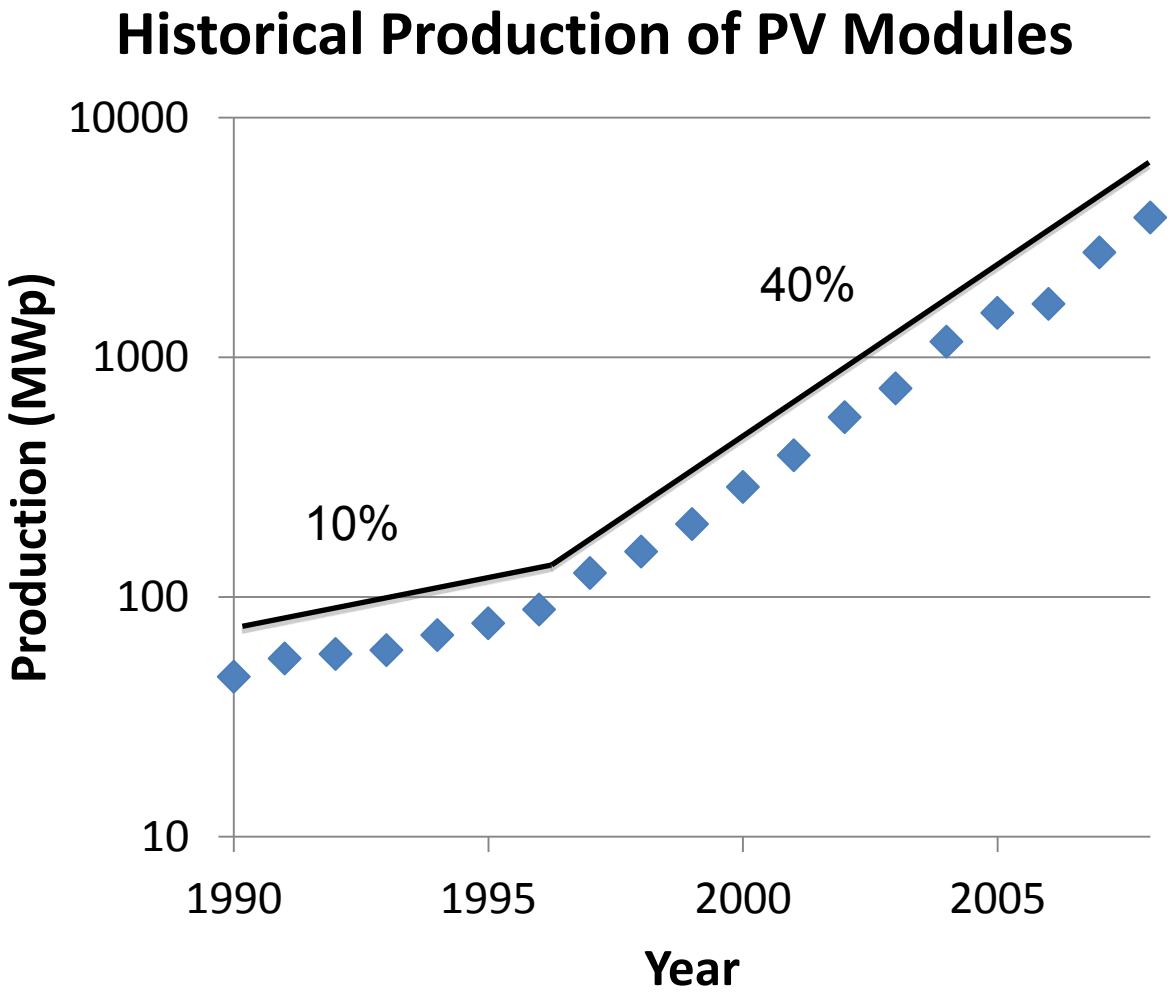
Courtesy of Greentech Media. Used with permission.

Price, Experience Learning Curve for PV

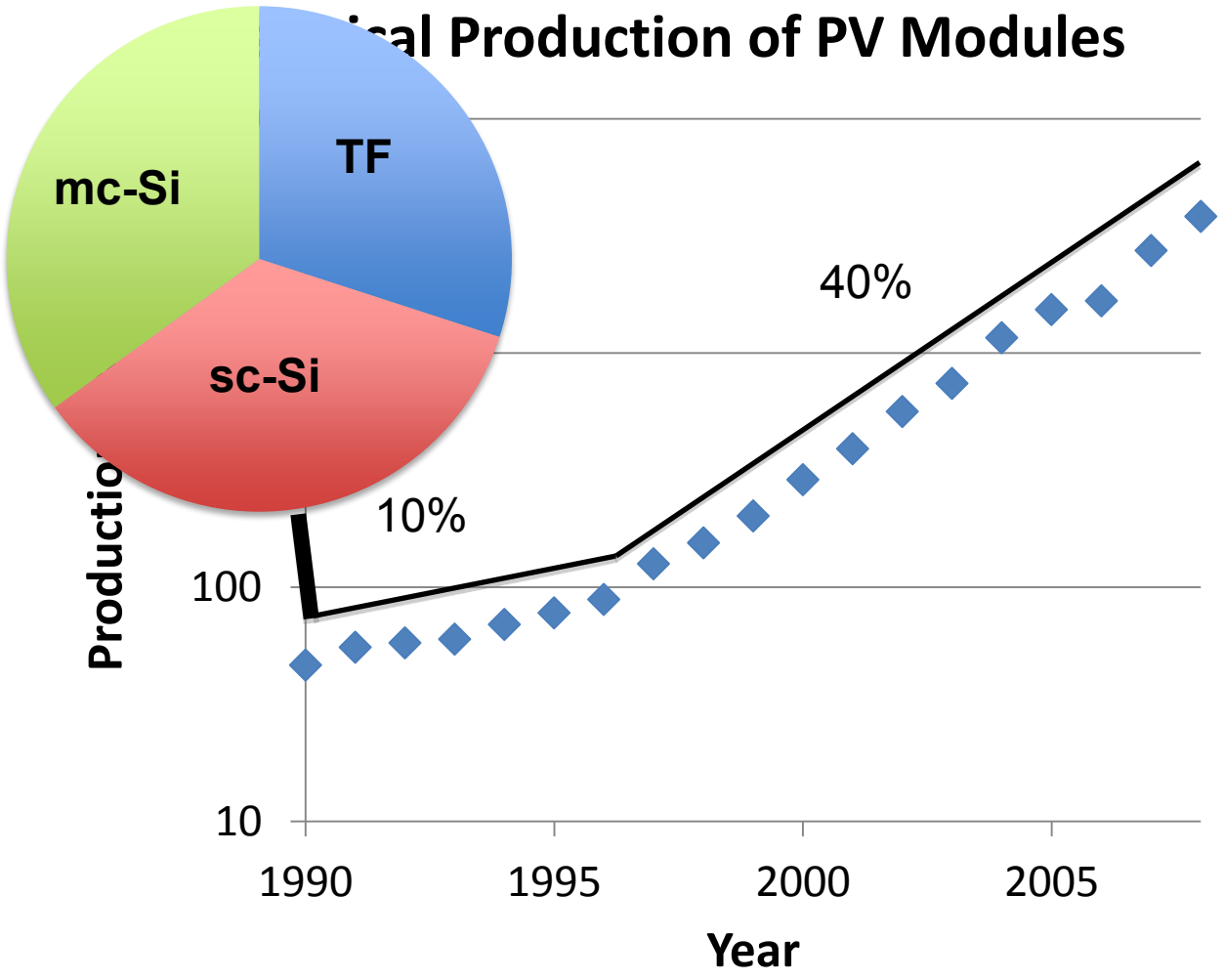


Source: http://www1.eere.energy.gov/solar/review_meeting/pdfs/prm2010_plenary_pv%20overview_le.pdf

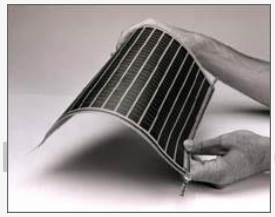
PV: Scale


Historical Production of PV Modules
10000
1000
100
10
Production (MWp)
10%
40%
1990
1995
2000
2005
Year

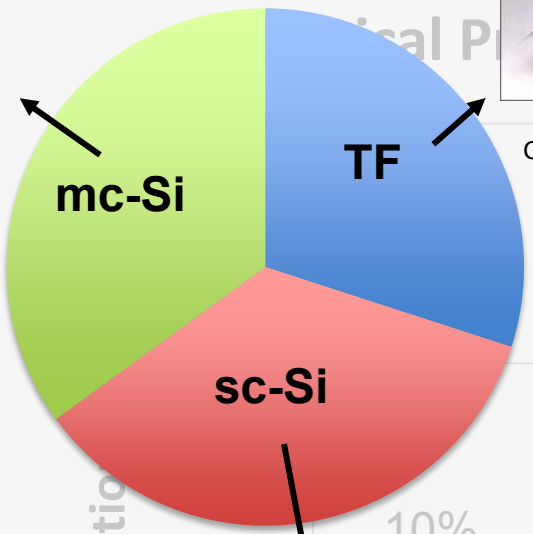
PV: Scale & Technologies

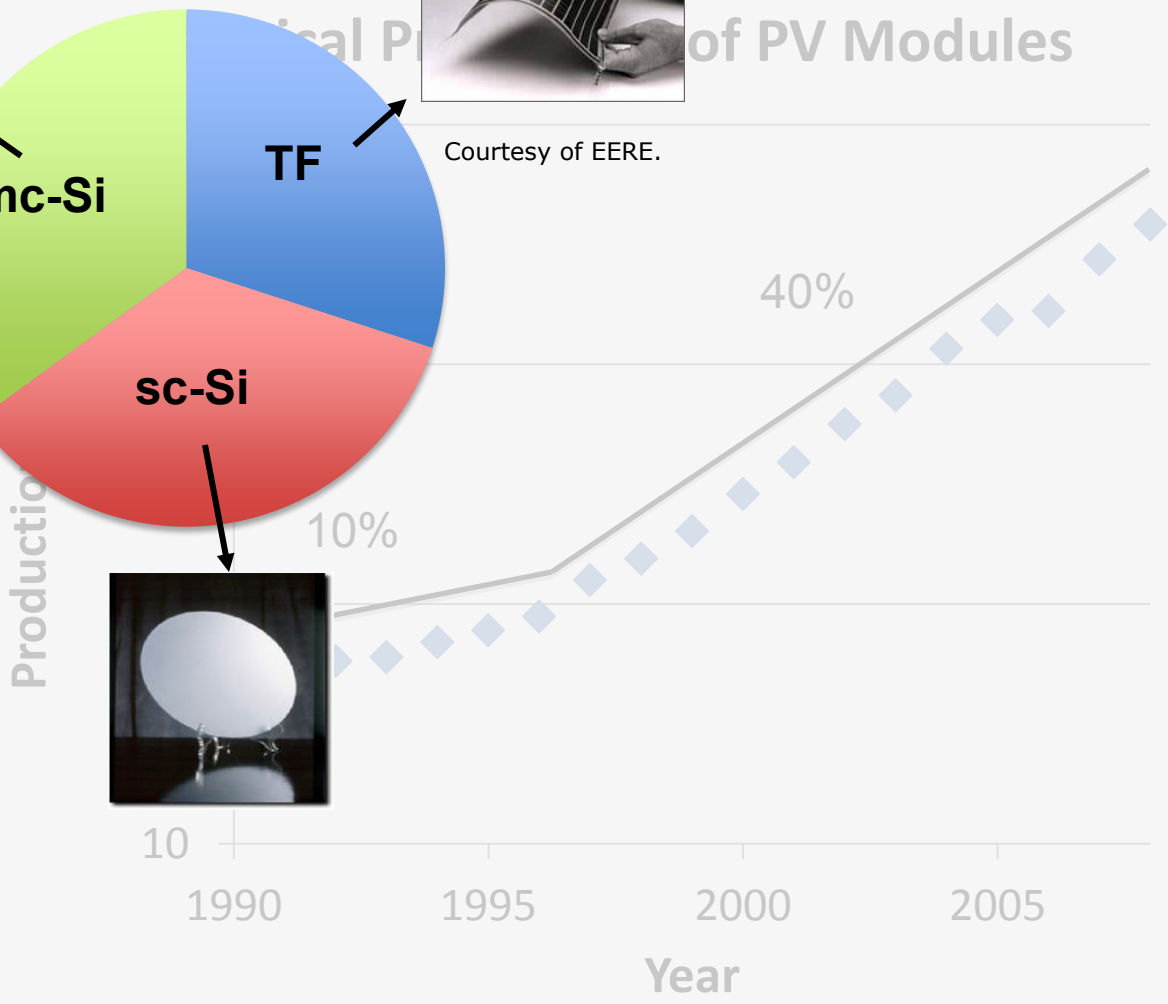


Photovoltaics: State-of-the-Art

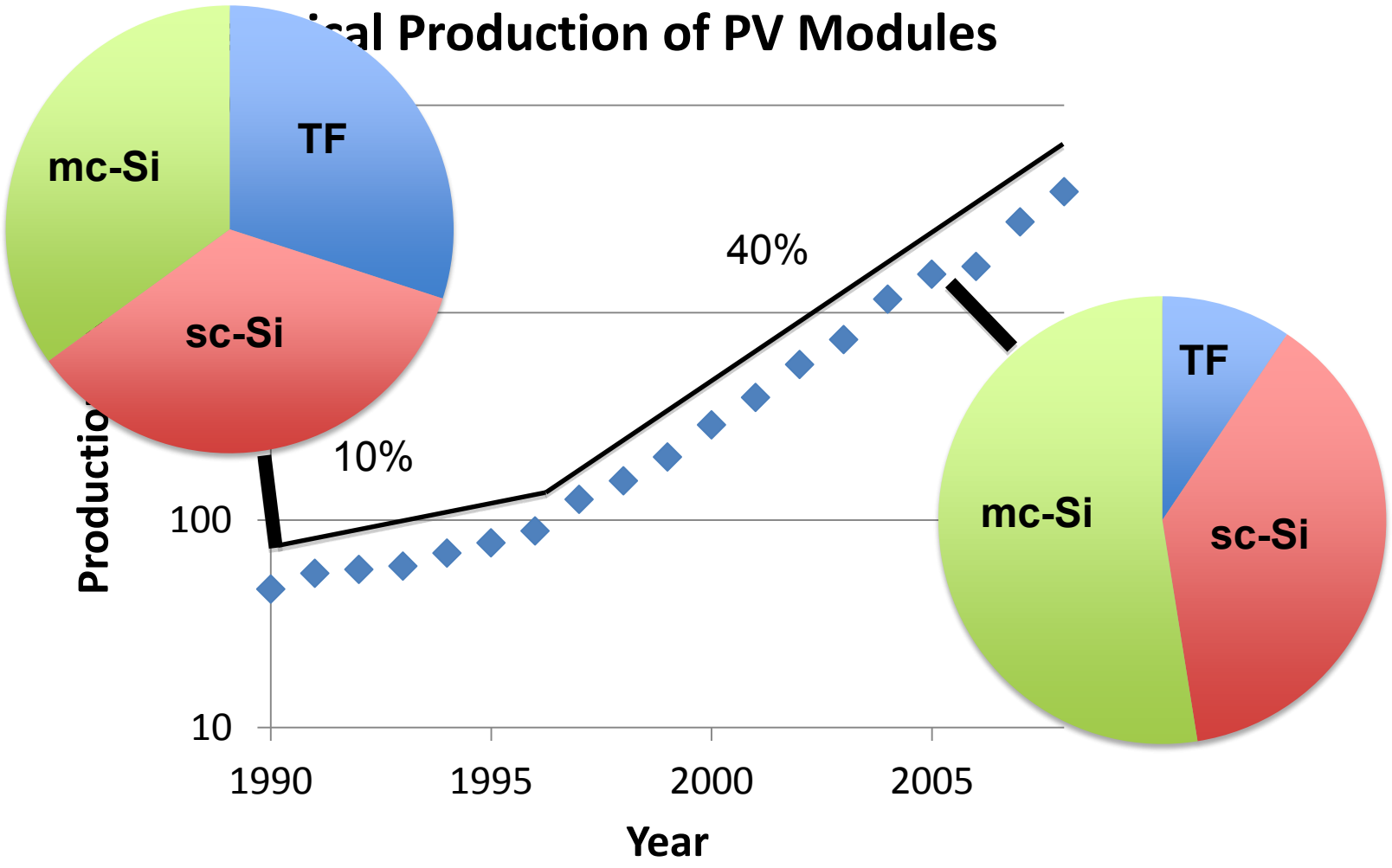


Courtesy of EERE.





PV: Scale & Technologies



Price, Markets & Subsidies

Customer Needs

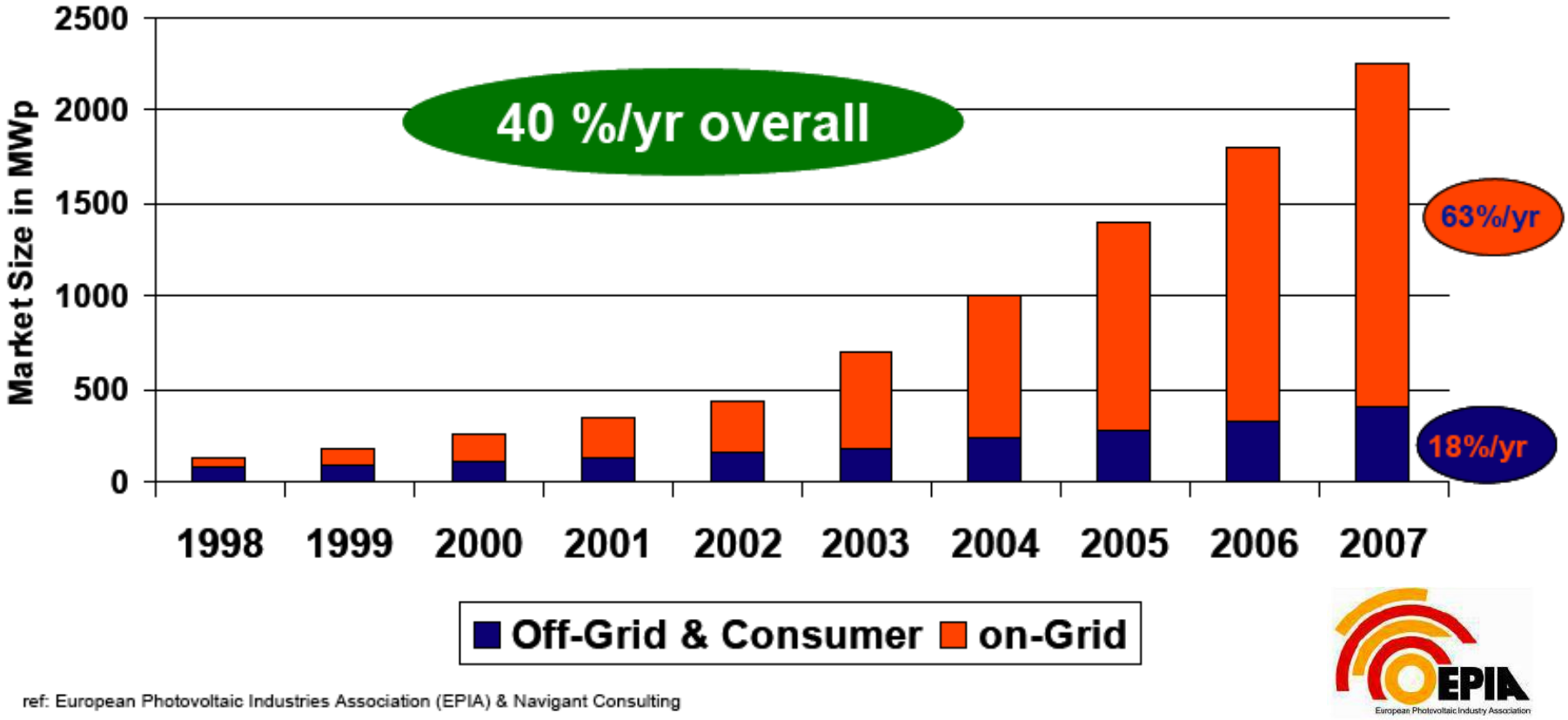
on-grid **off-grid** **consumer** **high efficiency**

Images removed due to copyright restrictions.
See the lecture 18 video.

Substitution Economics

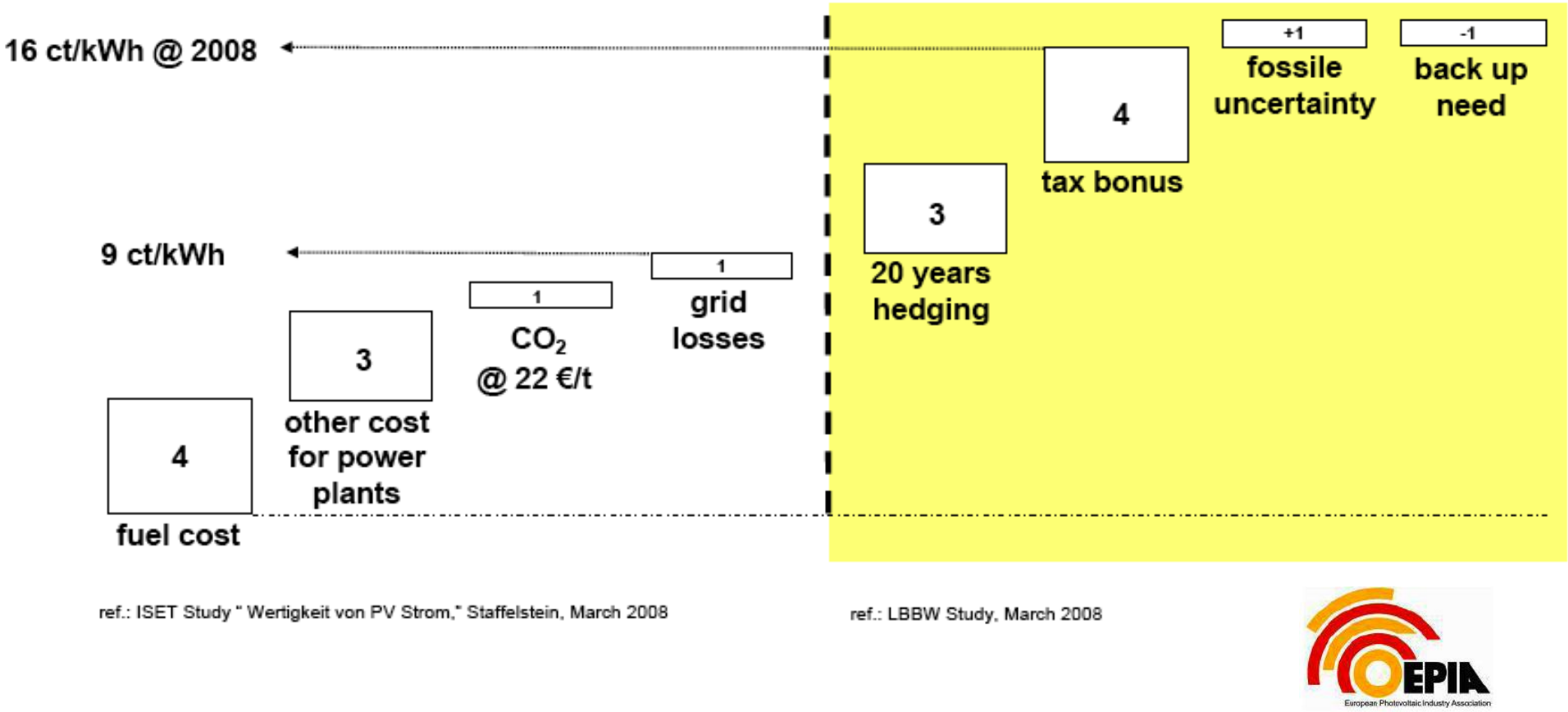
- What type(s) of grid electricity will PV substitute?
  - What will this mean for traditional gencos?
- What is a fair selling price for PV electricity?

Markets



ref: European Photovoltaic Industries Association (EPIA) & Navigant Consulting

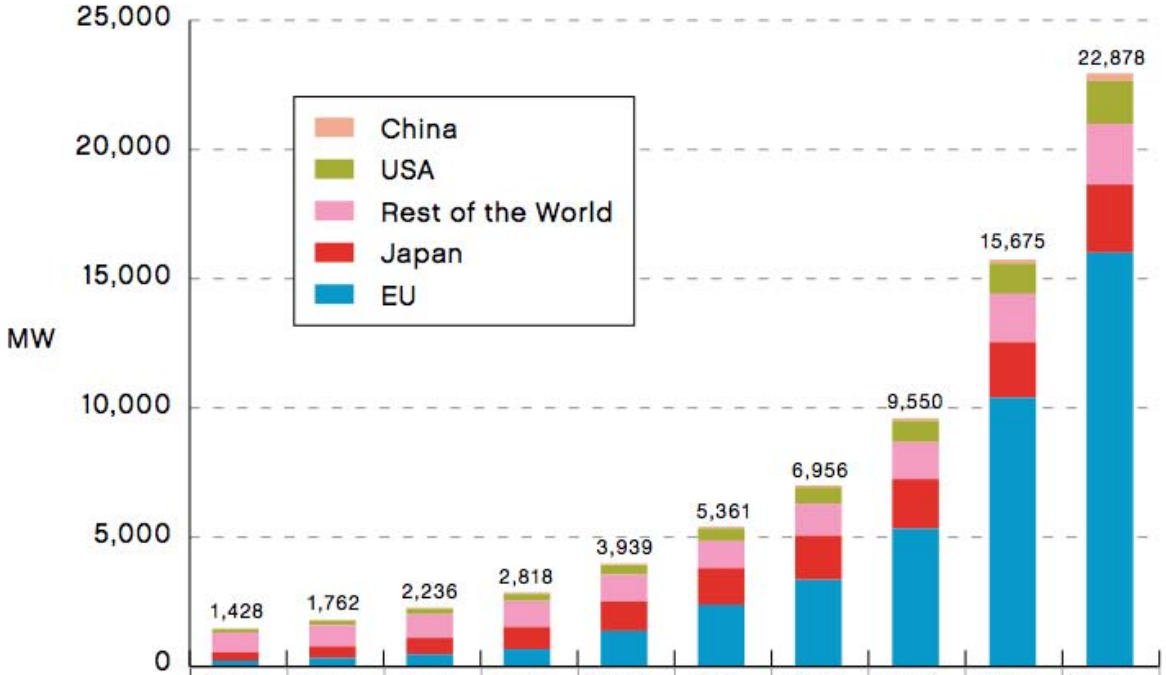
“Value” of PV Electricity



ref.: ISET Study " Wertigkeit von PV Strom," Staffelstein, March 2008

ref.: LBBW Study, March 2008

PV Installations Worldwide: Cummulative



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
China	19	30	45	55	64	68	80	100	145	305
USA	139	168	212	275	365	479	624	831	1,173	1,650
ROW	763	825	913	1,000	1,044	1,051	1,235	1,422	1,870	2,347
Japan	318	452	637	860	1,132	1,422	1,708	1,919	2,149	2,633
EU	189	286	429	628	1,334	2,341	3,309	5,279	10,338	15,943
Total	1,428	1,762	2,236	2,818	3,939	5,361	6,956	9,550	15,675	22,878

Figure 1 - Historical development of World cumulative PV power installed in main geographies

Source: "Global Market Outlook for Photovoltaics Until 2014." May 2010 update. EPIA. (PDF)

PV Installations Worldwide: Annual

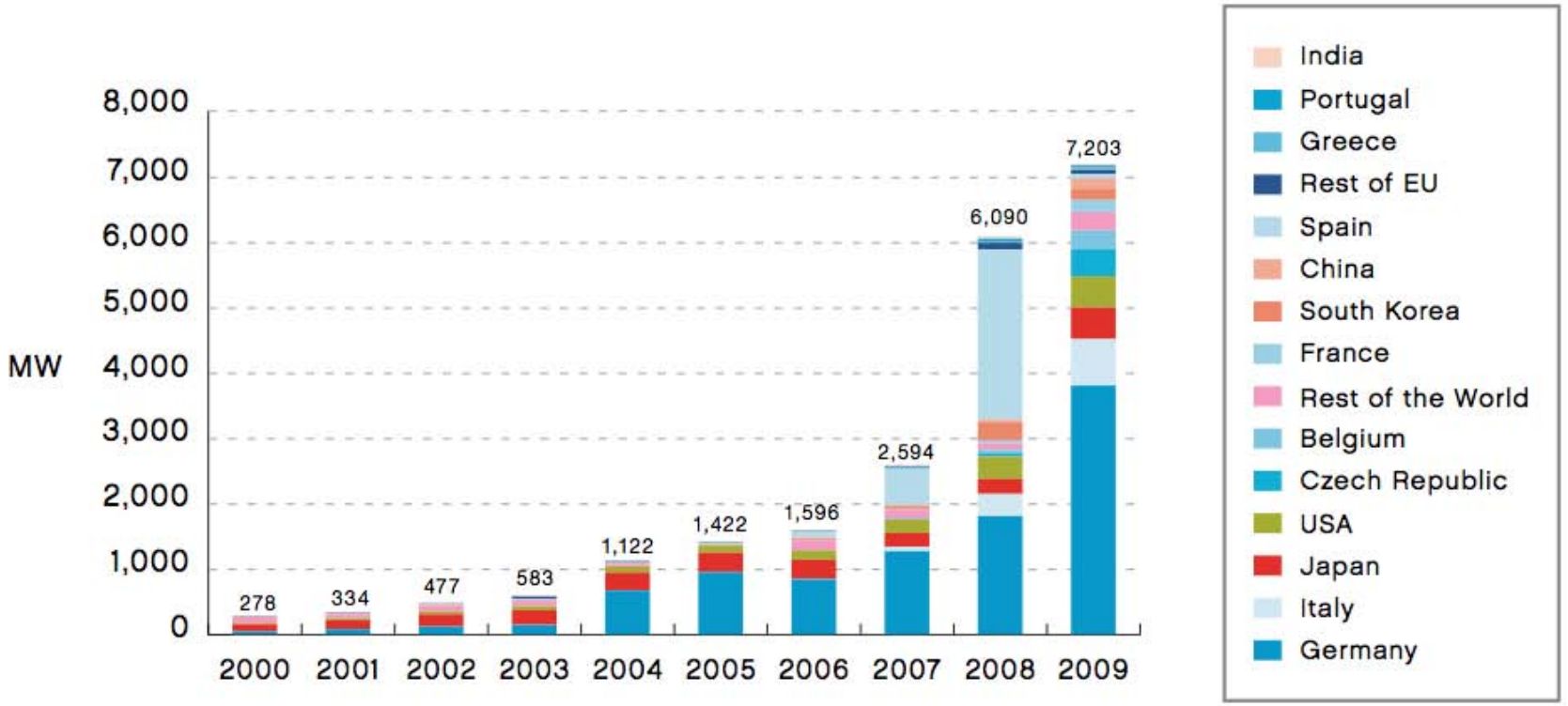
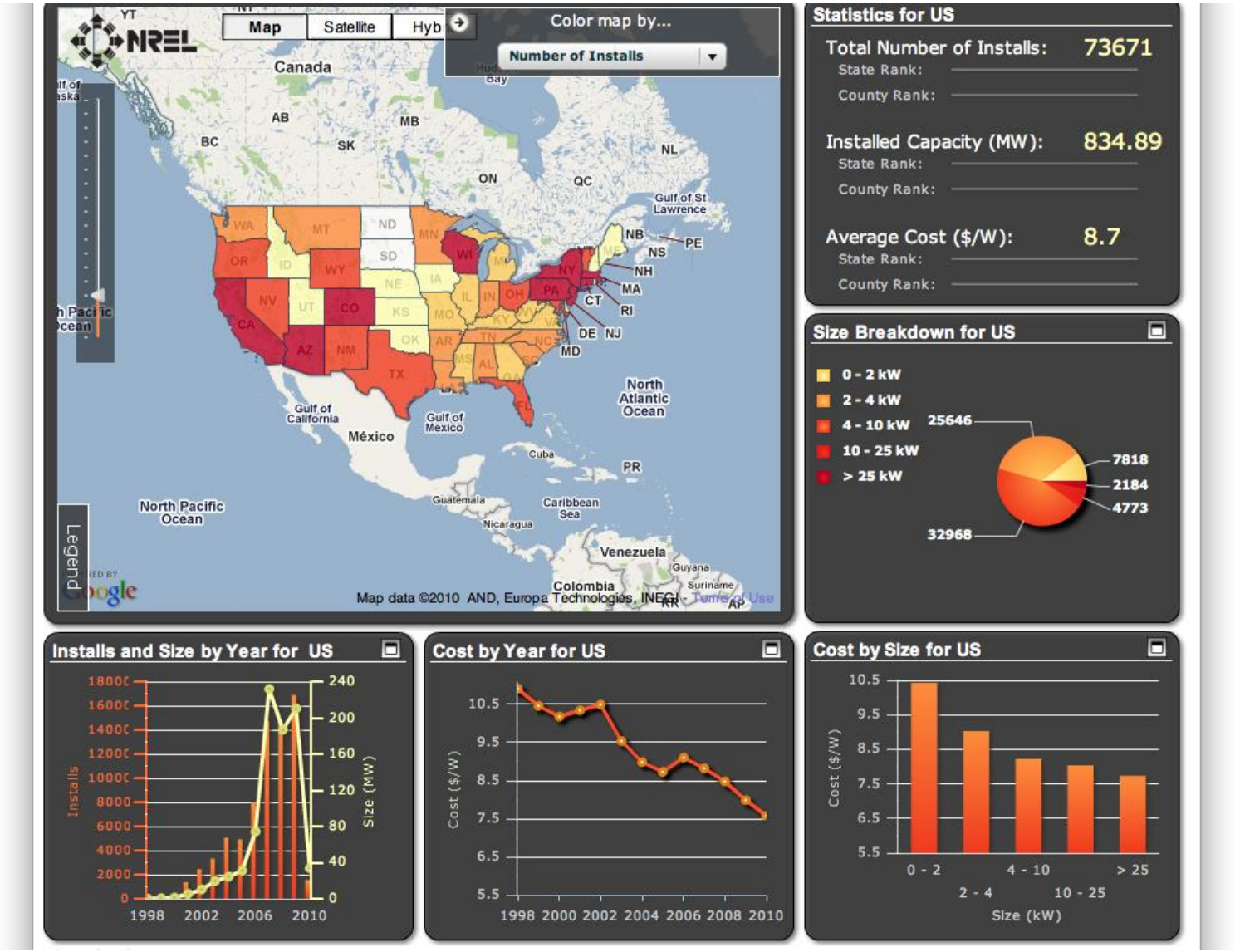


Figure 2 - Evolution of the World annual PV market 2000-2009

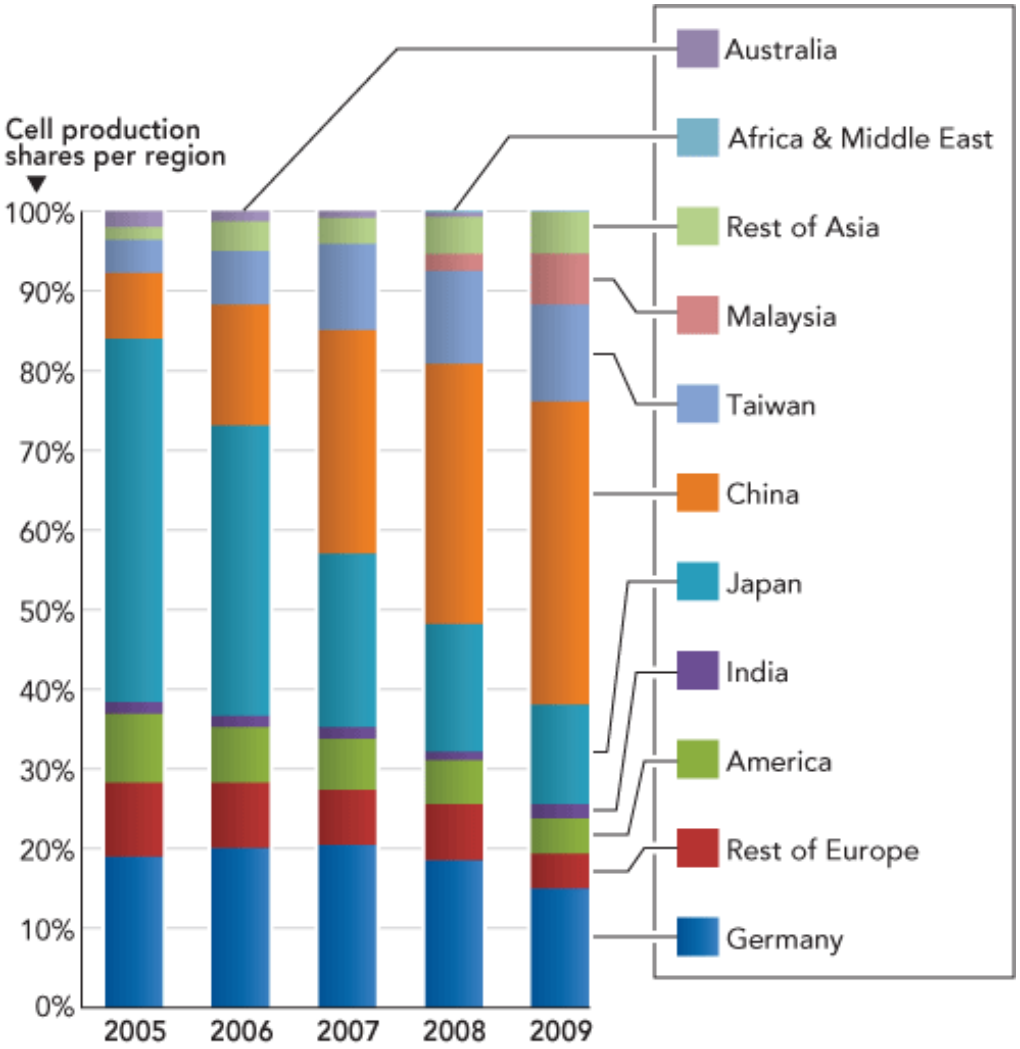
Source: "Global Market Outlook for Photovoltaics Until 2014." May 2010 update. EPIA. (PDF)

US Installs: NREL Database



https://openpv.nrel.gov/gallery

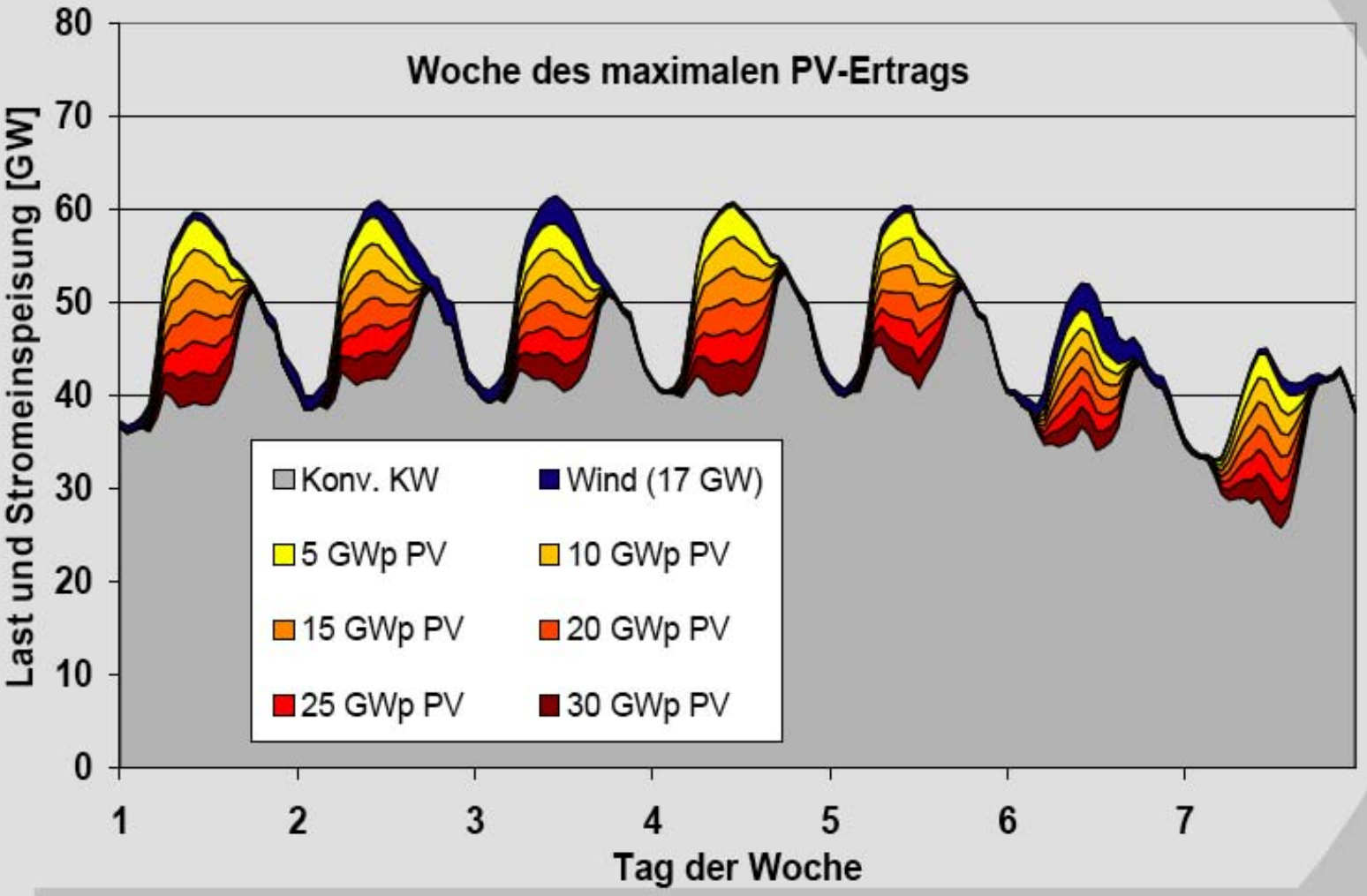
PV Manufacturing Worldwide: Annual



Singer, P. "Inside Taiwan's PV manufacturing push." *PV World*, October 28, 2010. Accessed Oct. 17, 2013.

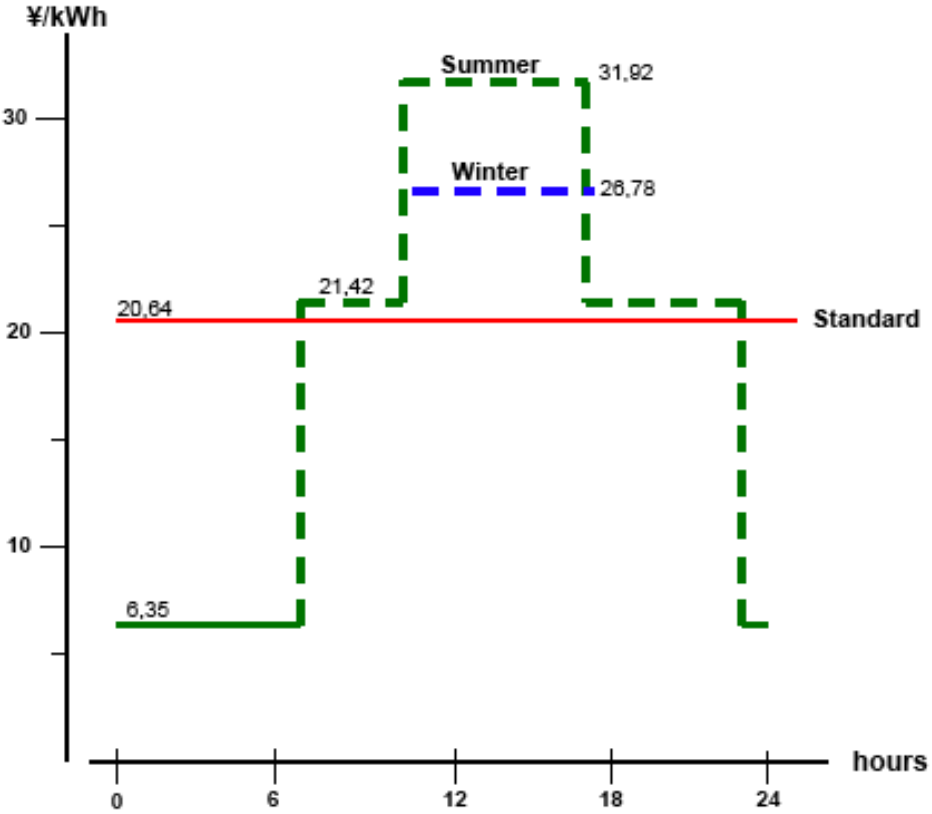
2. Korrelation der PV-Einspeisung mit dem Lastverlauf

Bis zu 30 GWp PV lassen sich ohne große Anforderungen integrieren!

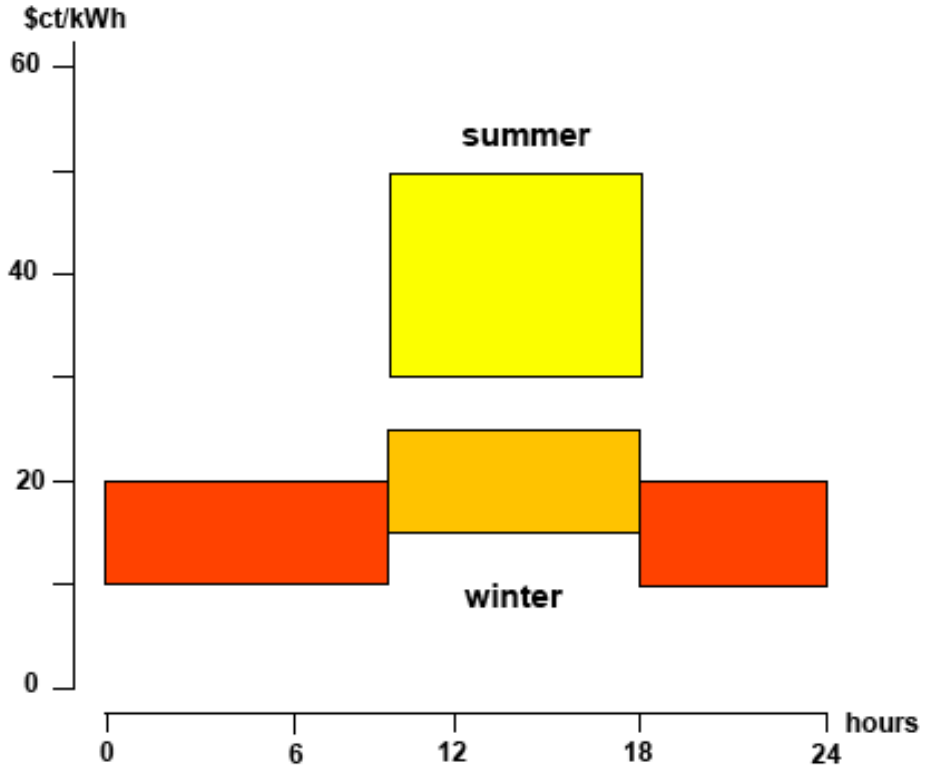


Seasonal and Diurnal Electricity Prices

Tokyo Electric Power Cooperation (Jp) Tariff 2005

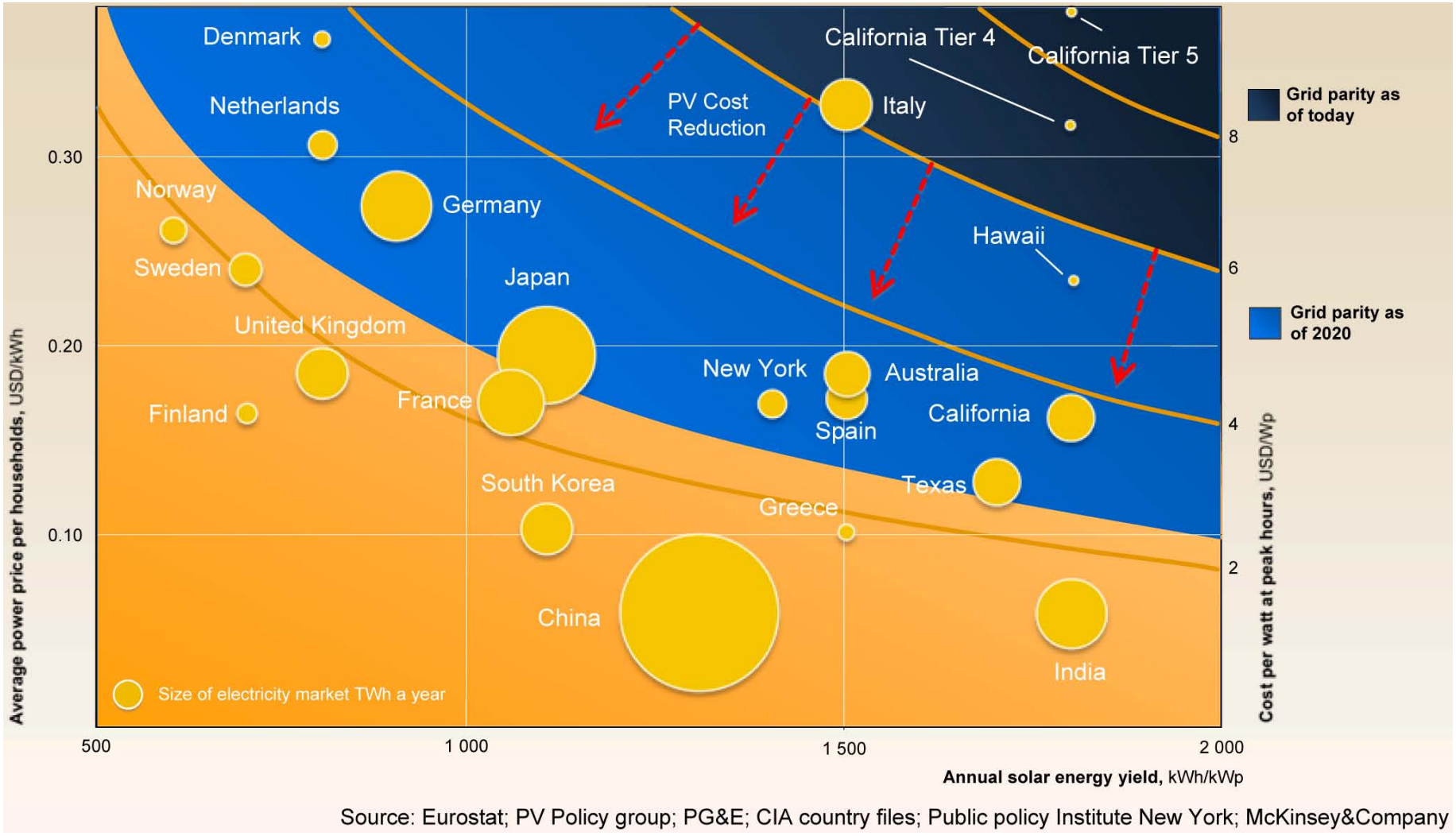


Range of Electricity Prices in California



ref: Japan = KEPCO office data ; California = Alison Hyde of BSW

Growing Markets: Predicting Where PV Will Go



Source: Eurostat; PV Policy group; PG&E; CIA country files; Public policy Institute New York; McKinsey&Company

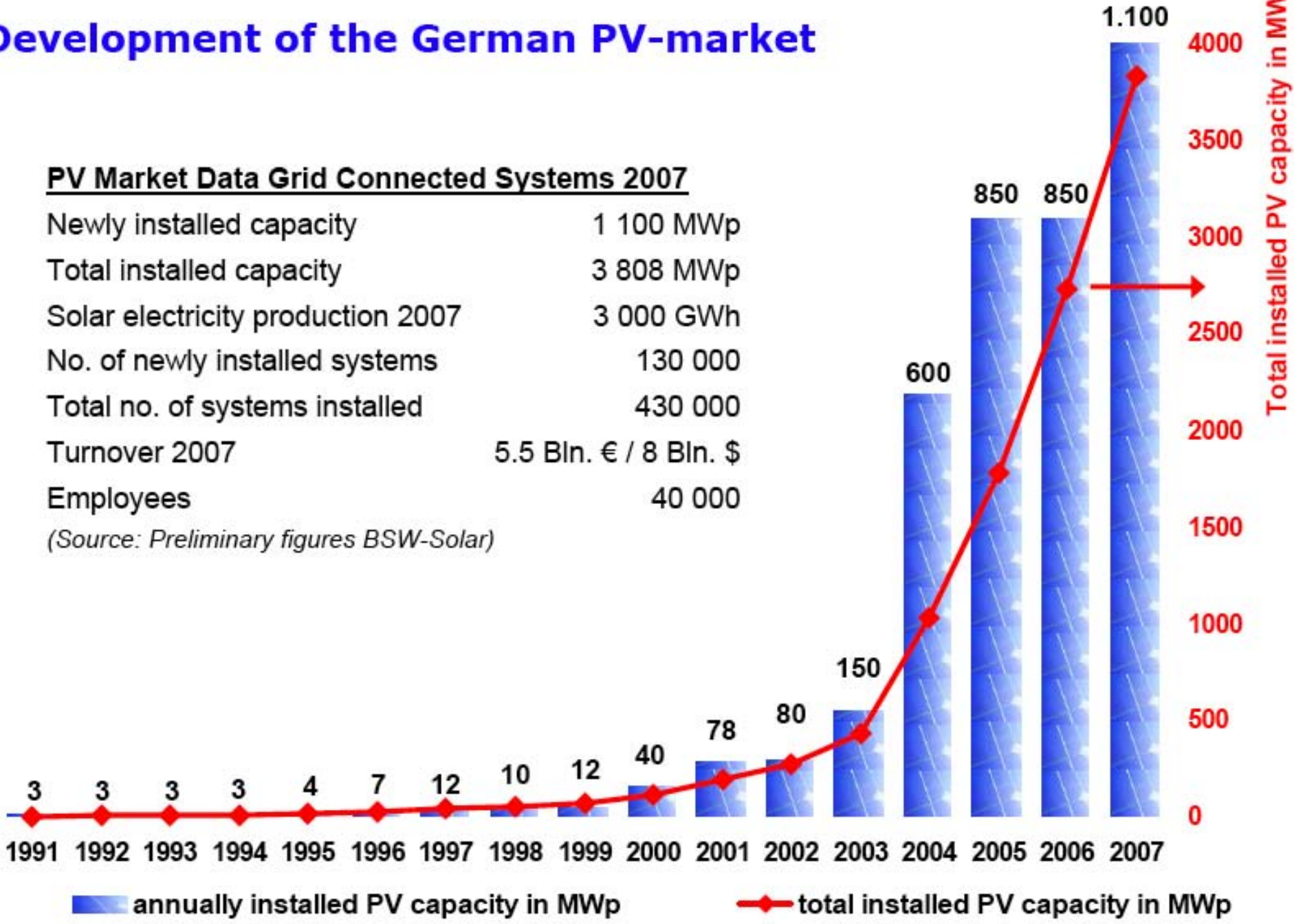
From Lorenz, P., D. Pinner, and T. Seitz. "The Economics of Solar Power." *McKinsey Quarterly, Sustainability & Resource Productivity Initiative*. June 2008.

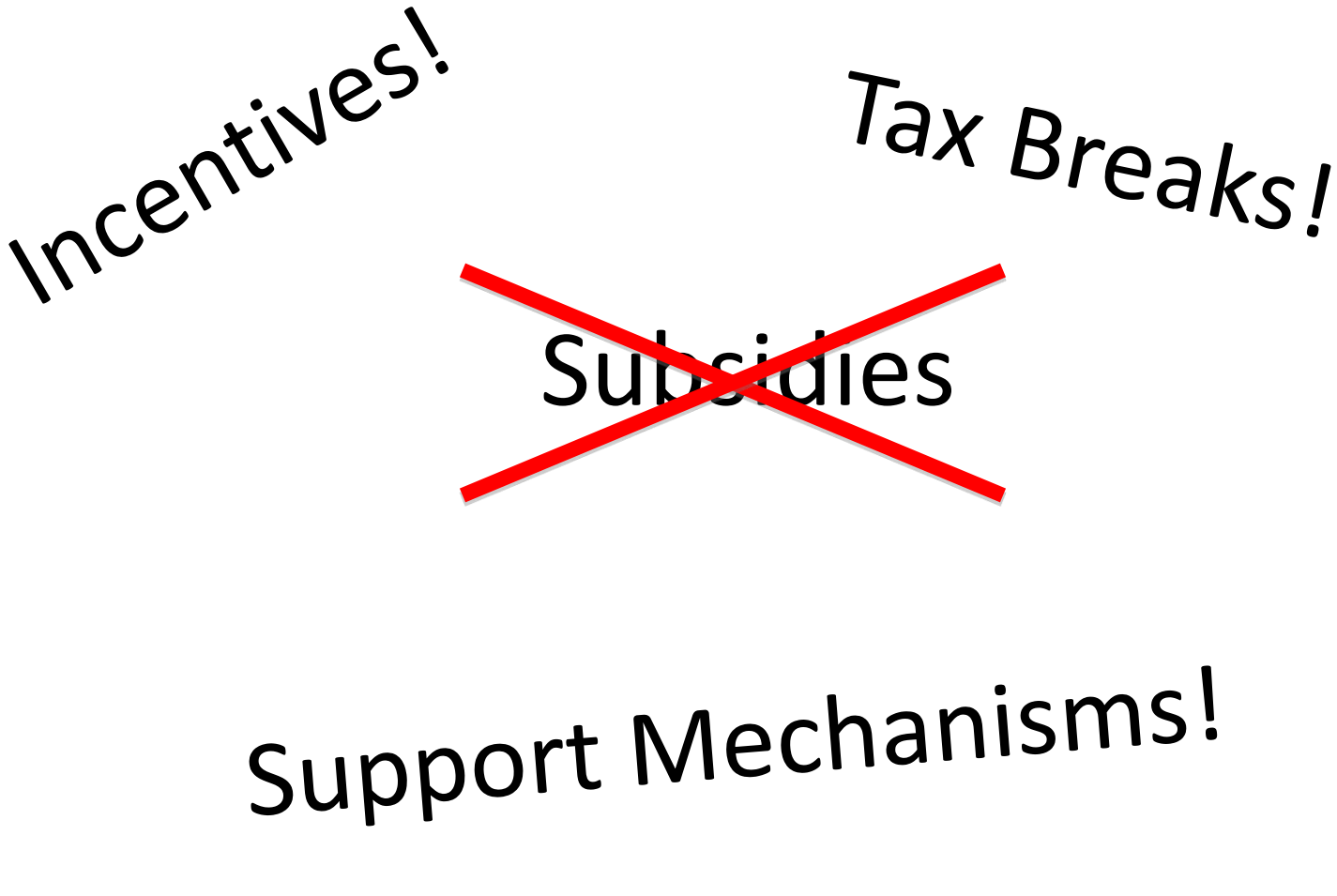
Development of the German PV-market

PV Market Data Grid Connected Systems 2007

Newly installed capacity	1 100 MWp
Total installed capacity	3 808 MWp
Solar electricity production 2007	3 000 GWh
No. of newly installed systems	130 000
Total no. of systems installed	430 000
Turnover 2007	5.5 Bln. € / 8 Bln. $
Employees	40 000

(Source: Preliminary figures BSW-Solar)




Incentives!
Tax Breaks!
Subsidies
Support Mechanisms!

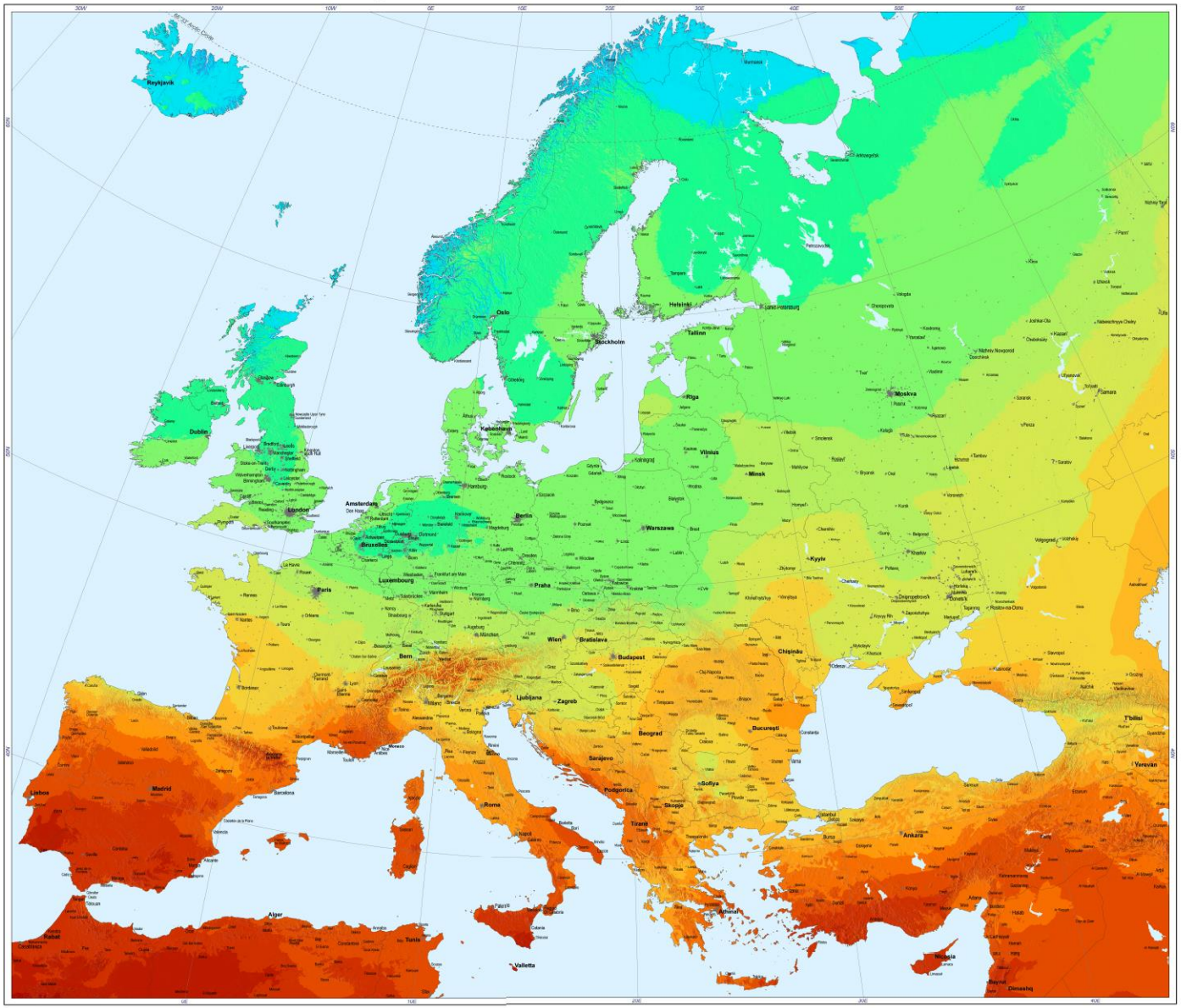
Summary of Support Mechanisms

Many forms of support

"best" depends on other policy objectives

	Measure	Advantages	Disadvantages	Examples
Margin enhancement	Feed-in tariff	Stable revenues. Technology specific	Uneconomic deployment	Germany/Spain/USA
	Premium to fossil market	Greater transparency	Greater uncertainty on fossil price	UK
	Tax relief	Simple	Too easily changed by Government	USA
	Grants/soft loans	Simple	Allocation procedure	EU member states, USA
Penalties	Carbon caps	Transparent	Customers pay premium for all generation	European emissions trading
Mixture	Renewable Obligations	Transparent, market driven. Technology independent	Price uncertainty Technology independent	UK

Photovoltaic Solar Electricity Potential in European Countries

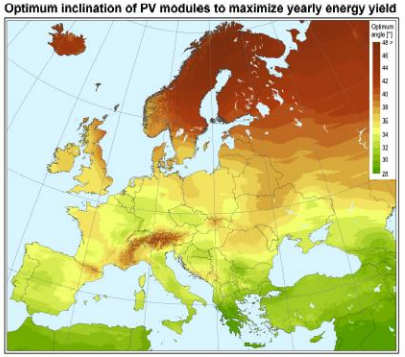


Global irradiation [kWh/m²]
<600 800 1000 1200 1400 1600 1800 2000 2200>
<450 600 750 900 1050 1200 1350 1500 1650>
Solar electricity [kWh/kWp]

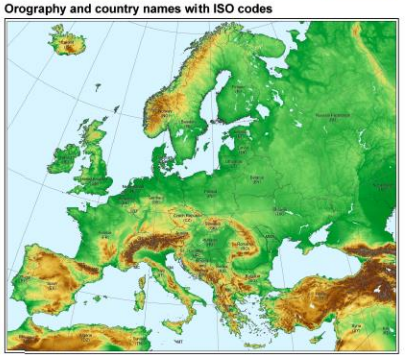
Yearly sum of global irradiation incident on optimally-inclined south-oriented photovoltaic modules
Yearly sum of solar electricity generated by 1 kWp system with optimally-inclined modules and performance ratio 0.75

0 100 200 300 400 500 km

Optimum inclination of PV modules to maximize yearly energy yield



Orography and country names with ISO codes



Data description

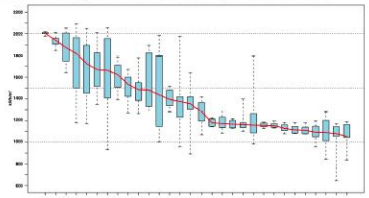
The PVGIS database is developed from measurements at 566 meteorological stations by combination of solar radiation model r aun and spatial interpolation. It contains monthly and yearly averages representing the period 1981-1990.
Grid resolution (enhanced by terrain): 1 km x 1 km
Map projection: Lambert azimuthal equal area, WGS 84, lat 48°, lon 18°

Ancillary data

- GISCO database © Eurostat 2006
- CORINE Land Cover 2000 (http://terrestrial.eionet.europa.eu/CLC2000)
- Global Land Cover 2000 (http://www-gvm.jrc.it/glc2000/)
- Digital terrain model SRTM-30 (http://srtm.usgs.gov/)
- City Population © Thomas Brinkhoff 2006 (http://www.citypopulation.de)

Note: the delineation of the international boundaries and geographical names must not be considered authoritative

Comparison of yearly global irradiation incident on optimally-inclined photovolataic modules in 25 European Union member countries and 5 candidate countries



The country averages are connected by the red line. The minima/maxima in each country are shown as dashed lines, while the boxes show the range in which 90% of built up areas in the country fit.

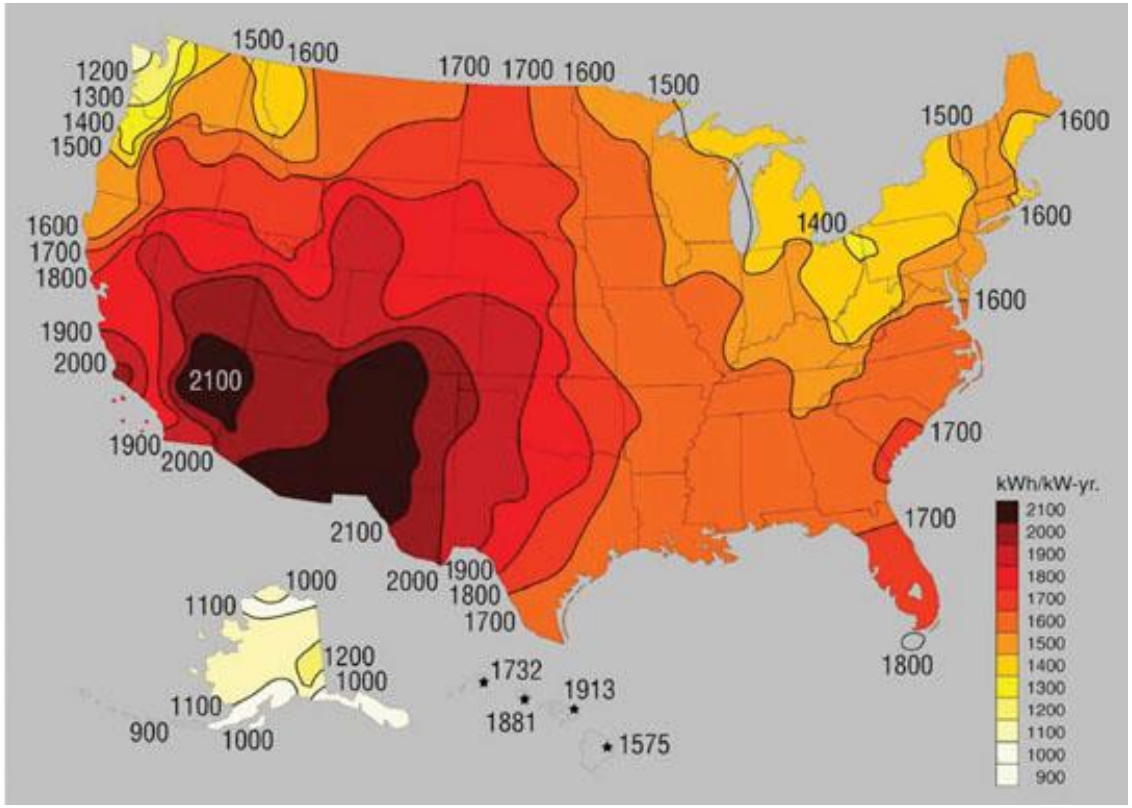
Authors
Marcel Šúri, Thomas A. Huld, Ewan D. Dunlop, Tomáš Cebecauer
European Commission - DG Joint Research Centre, Institute for Environment and Sustainability
Renewable Energies Unit, TP 450, I-21020 Ispra (VA), Italy

Printed in December 2006

http://sunbird.jrc.it/pvgis/countries/countries-europe.htm

Source: PVGIS © European Communities, 2001-2007. Used with permission.
Reference: Šúri M., Huld T. A., Dunlop E. D. Ossenbrink H. A. "Potential of solar electricity generation in the European Union member states and candidate countries." *Solar Energy* 81 (2007): 1295–1305, http://re.jrc.ec.europa.eu/pvgis/.

Germany & U.S. : A quick comparison



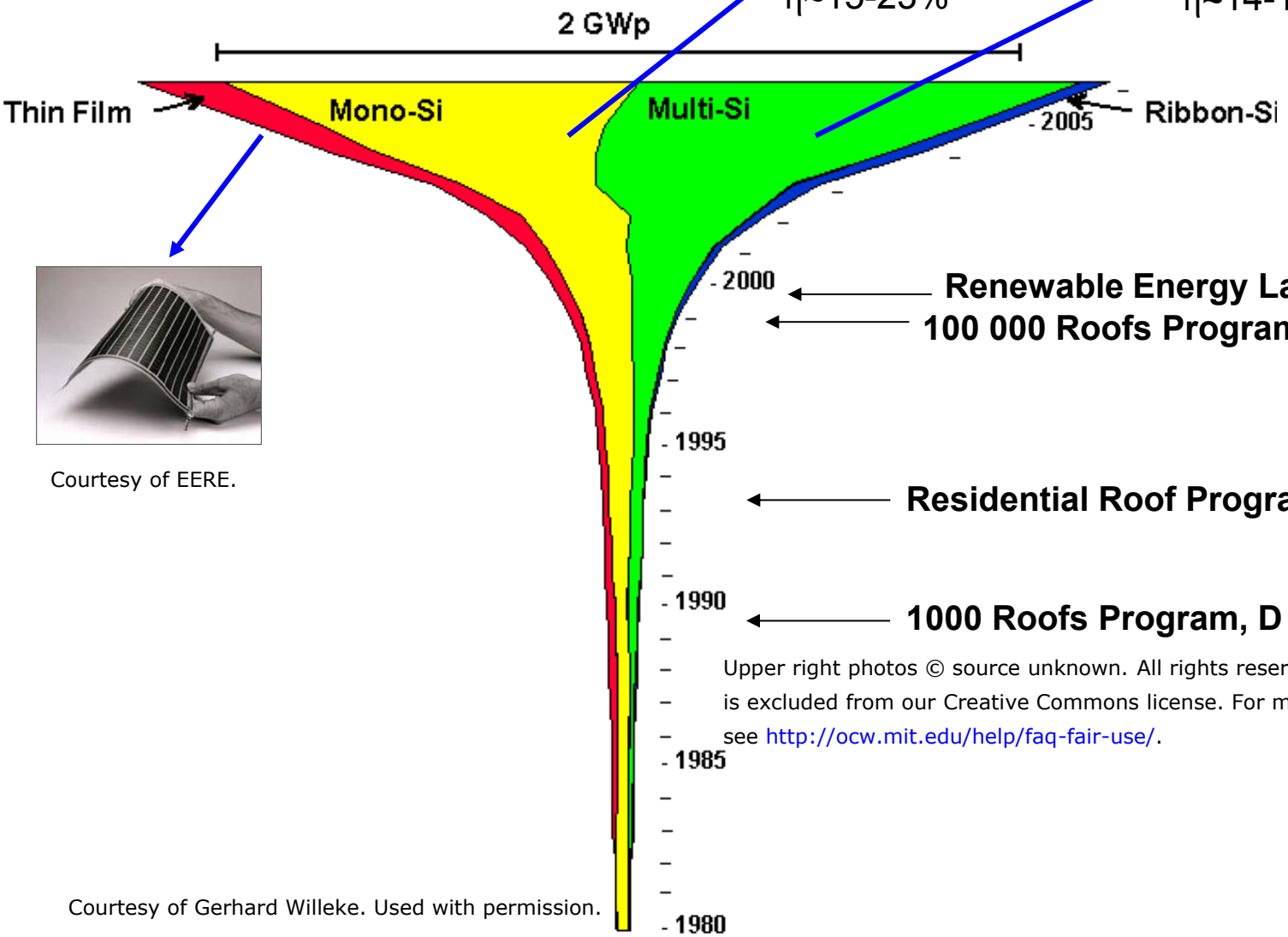
About half of all modules installed last year were installed in Germany…

PV: Effect of Market Pull

η≈15-23%

η≈14-16.5%

Courtesy of EERE.



Courtesy of Gerhard Willeke. Used with permission.

United States

- (Historical) lack of federal leadership led to fractionalized energy policy.
  - Huge state-to-state variation.
  - Website compiling all state-specific information: http://www.dsireusa.org/

DSIRESOLAR™

Database of State Incentives for Renewables & Efficiency

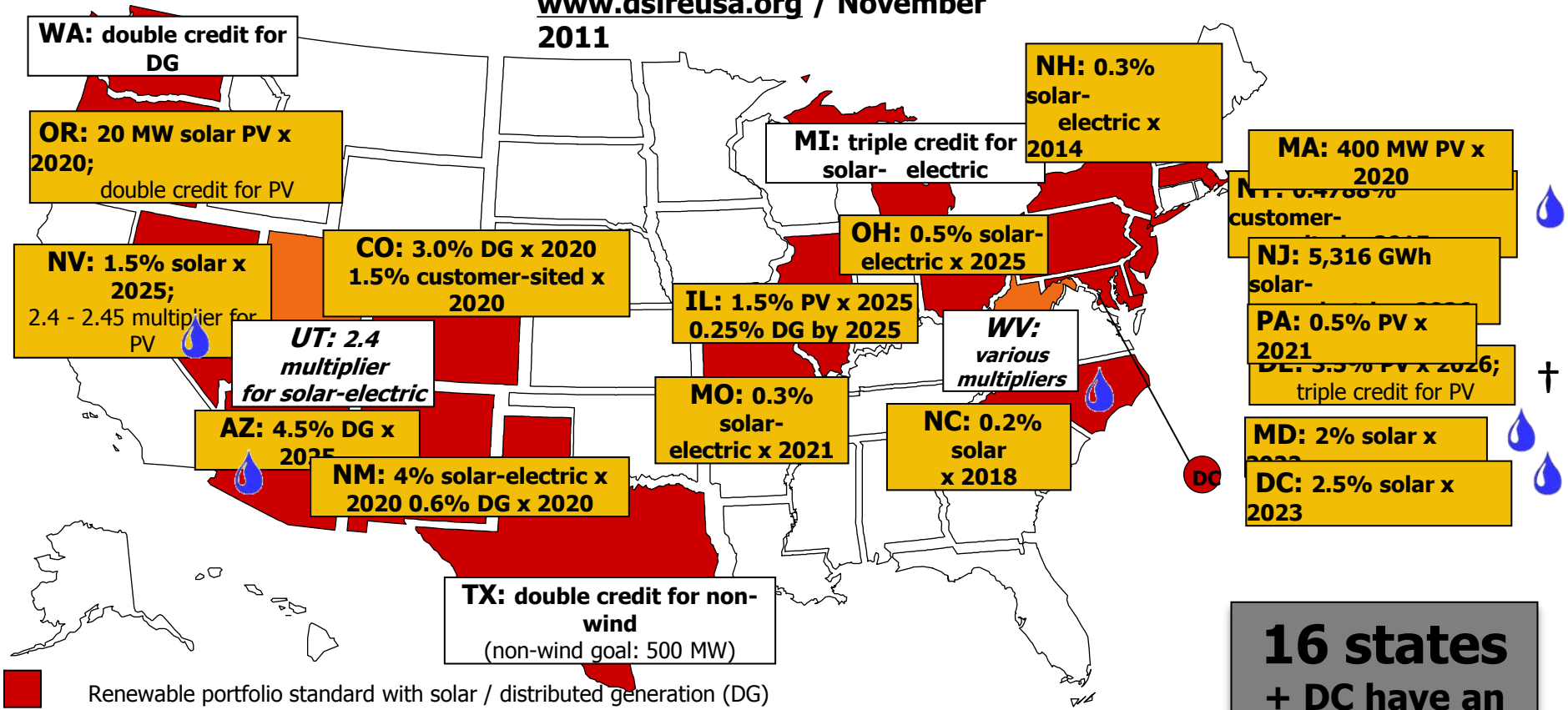
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

IREC Interstate Renewable Energy Council

North Carolina Solar Center

RPS Policies with Solar/DG Provisions

www.dsireusa.org / November 2011



Renewable portfolio standard with solar / distributed generation (DG) provision

Renewable portfolio goal with solar / DG provision

Solar water heating counts toward solar / DG provision

† Delaware allows certain fuel cell systems to qualify for the PV carve-out

16 states + DC have an RPS with solar/DG provisions

DSIRE™
Database of State Incentives for Renewables & Efficiency

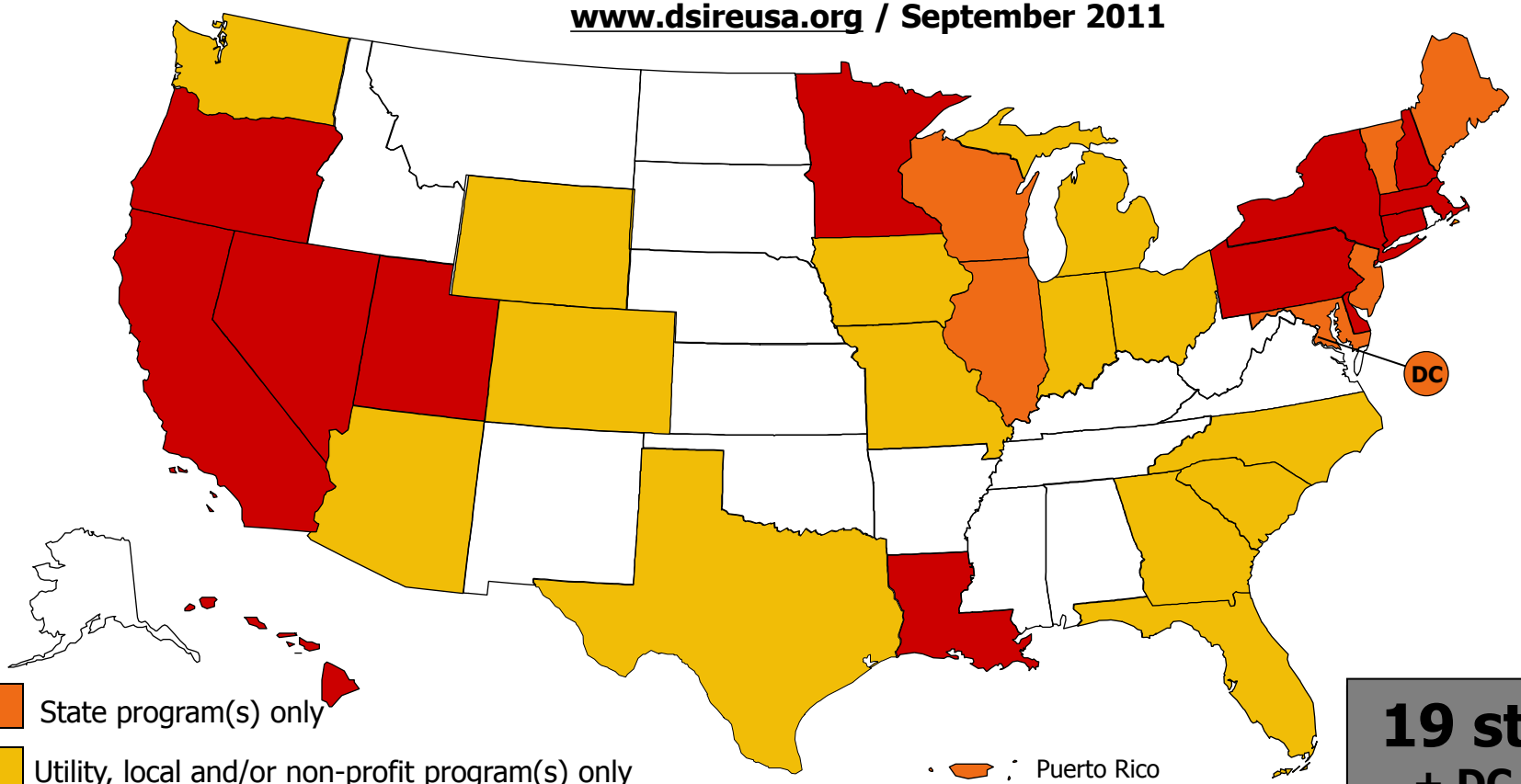
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

IREC Interstate Renewable Energy Council

North Carolina Solar Center

Rebate Programs for Renewables

www.dsireusa.org / September 2011



State program(s) only

Utility, local and/or non-profit program(s) only

State program(s) + utility, local and/or non-profit program(s)

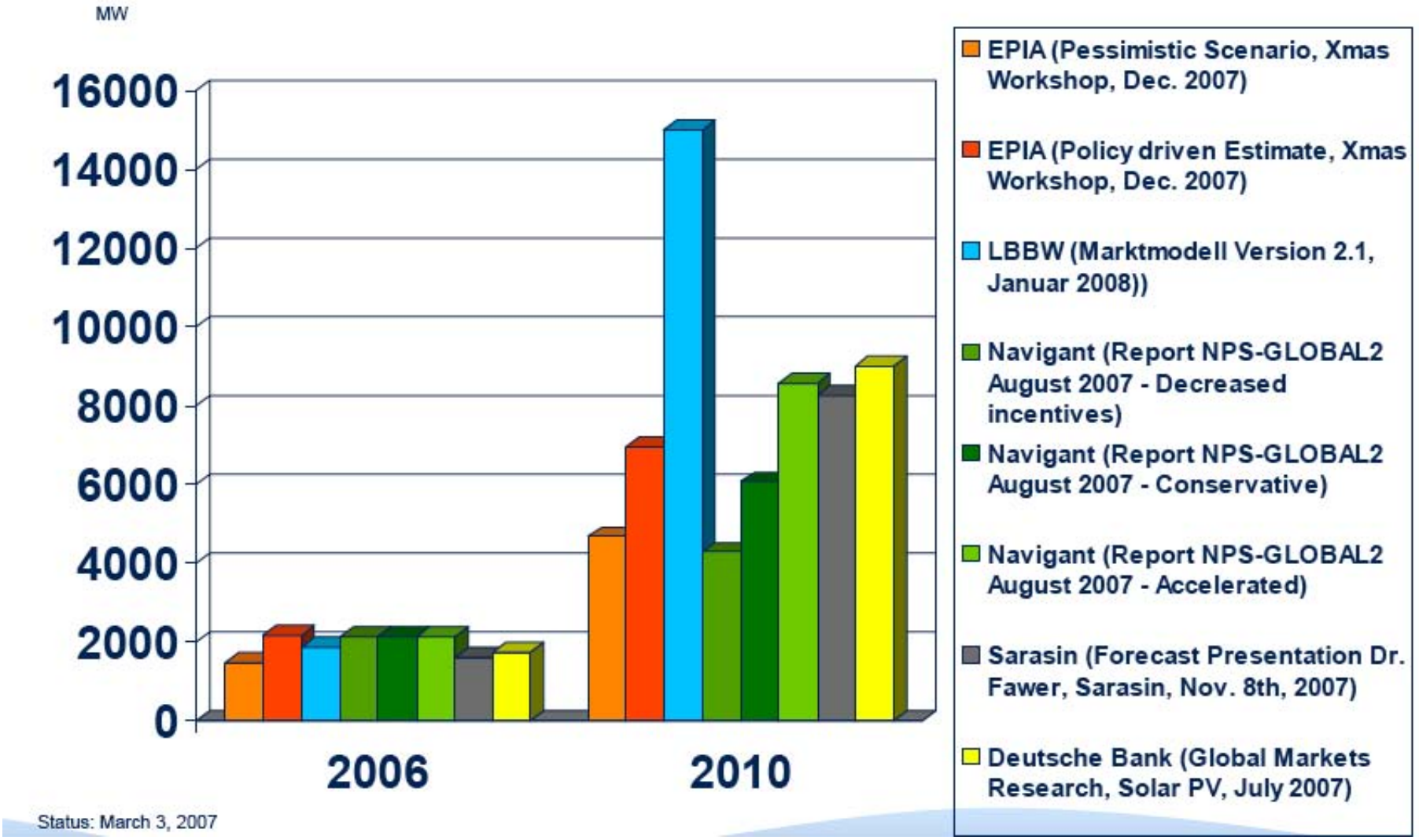
19 states + DC & PR offer rebates for renewables

Notes: This map does not include rebates for geothermal heat pumps , daylighting or other energy efficiency technologies. The Virgin Islands also offers rebates for certain renewable energy technologies.

Projections

Projections Are Historically Innaccurate

28.8 GW *Photon Consulting*



PV Growth Projections, Various Scenarios

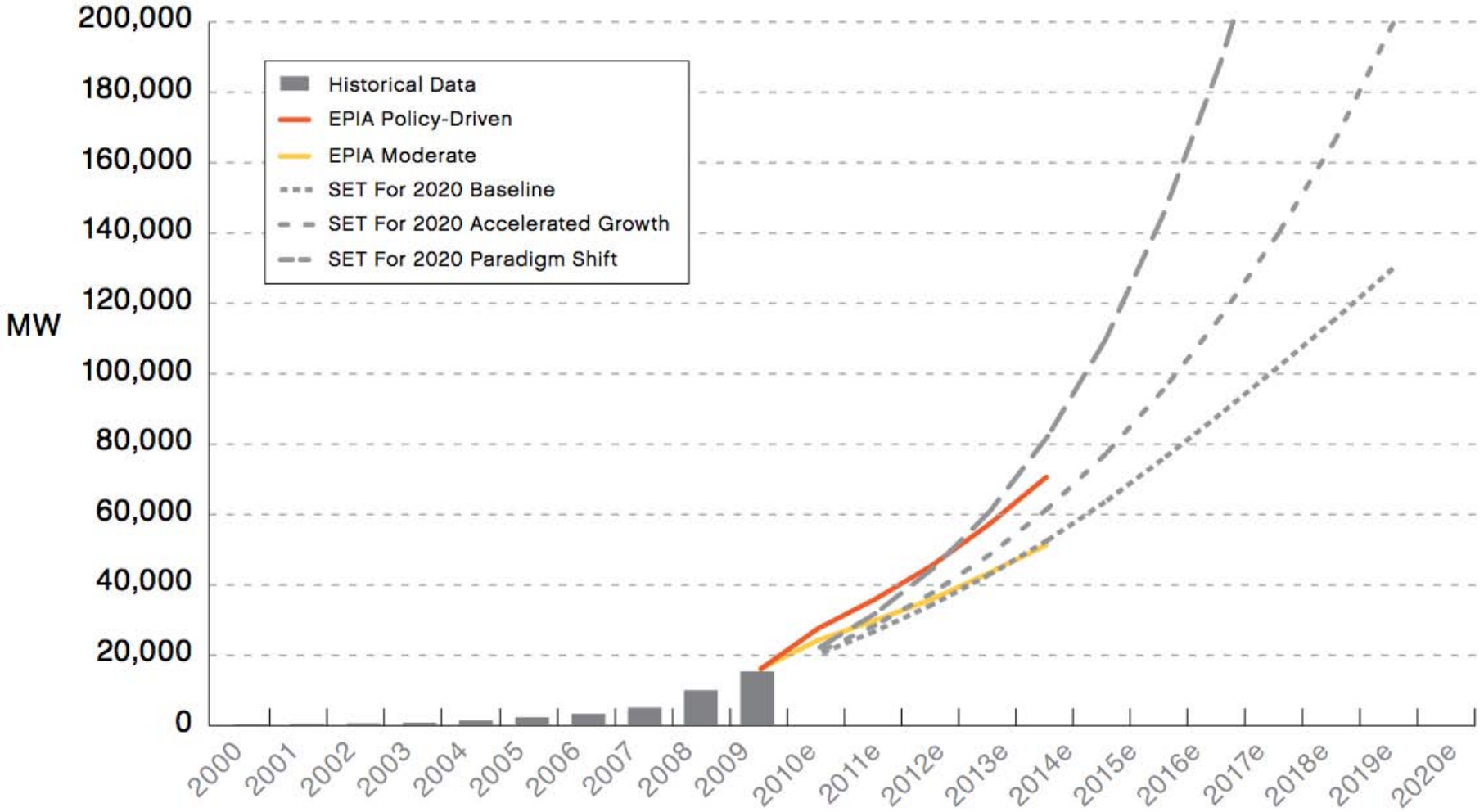


Figure 18 - Market forecasts compared to "SET For 2020" targets

Source: "Global Market Outlook for Photovoltaics Until 2014." May 2010 update. EPIA. (PDF)

2.627 / 2.626 Fundamentals of Photovoltaics

Fall 2013