ECE 333 – GREEN ELECTRIC ENERGY

16. *PV* Status and Issues

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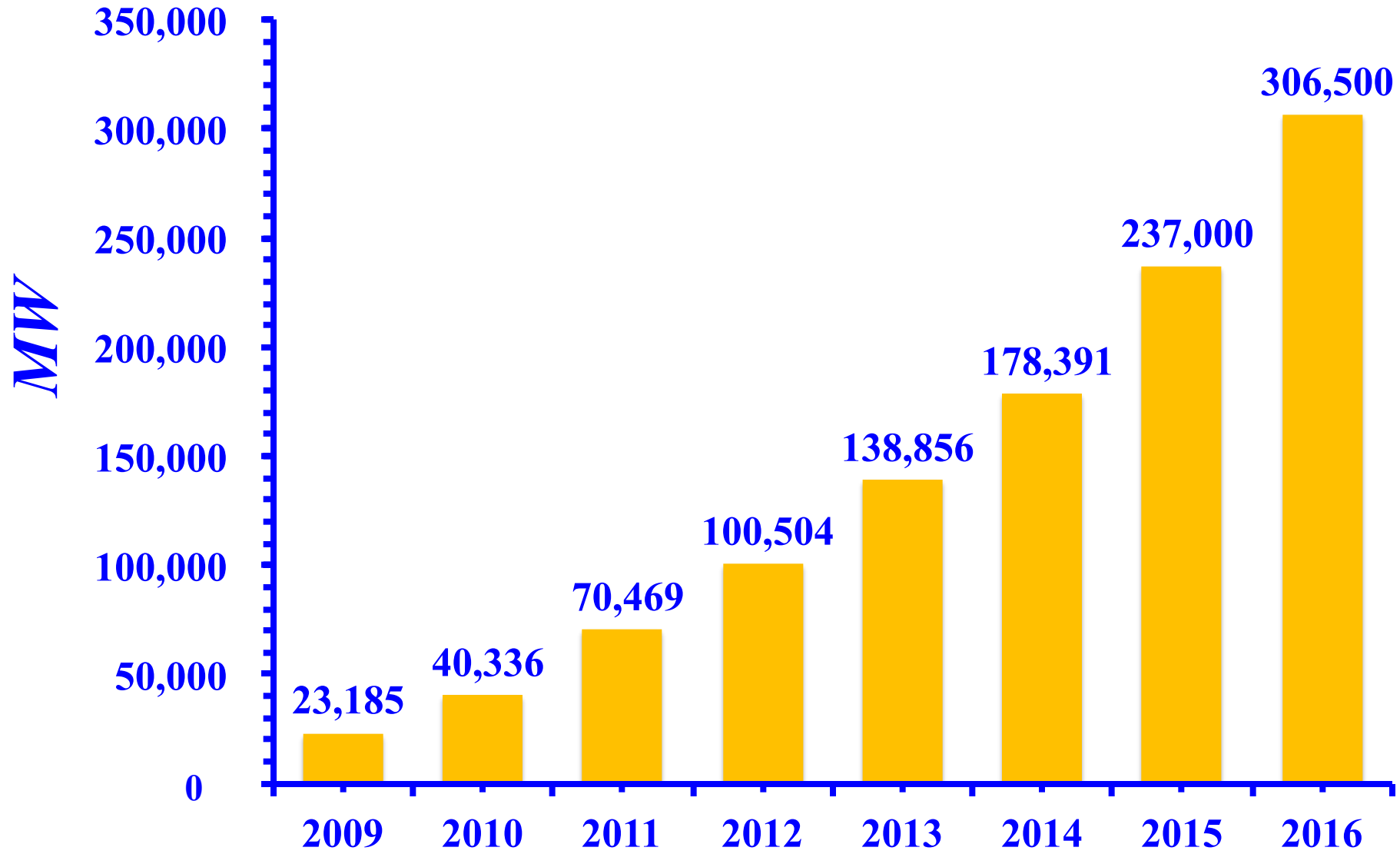
OUTLINE

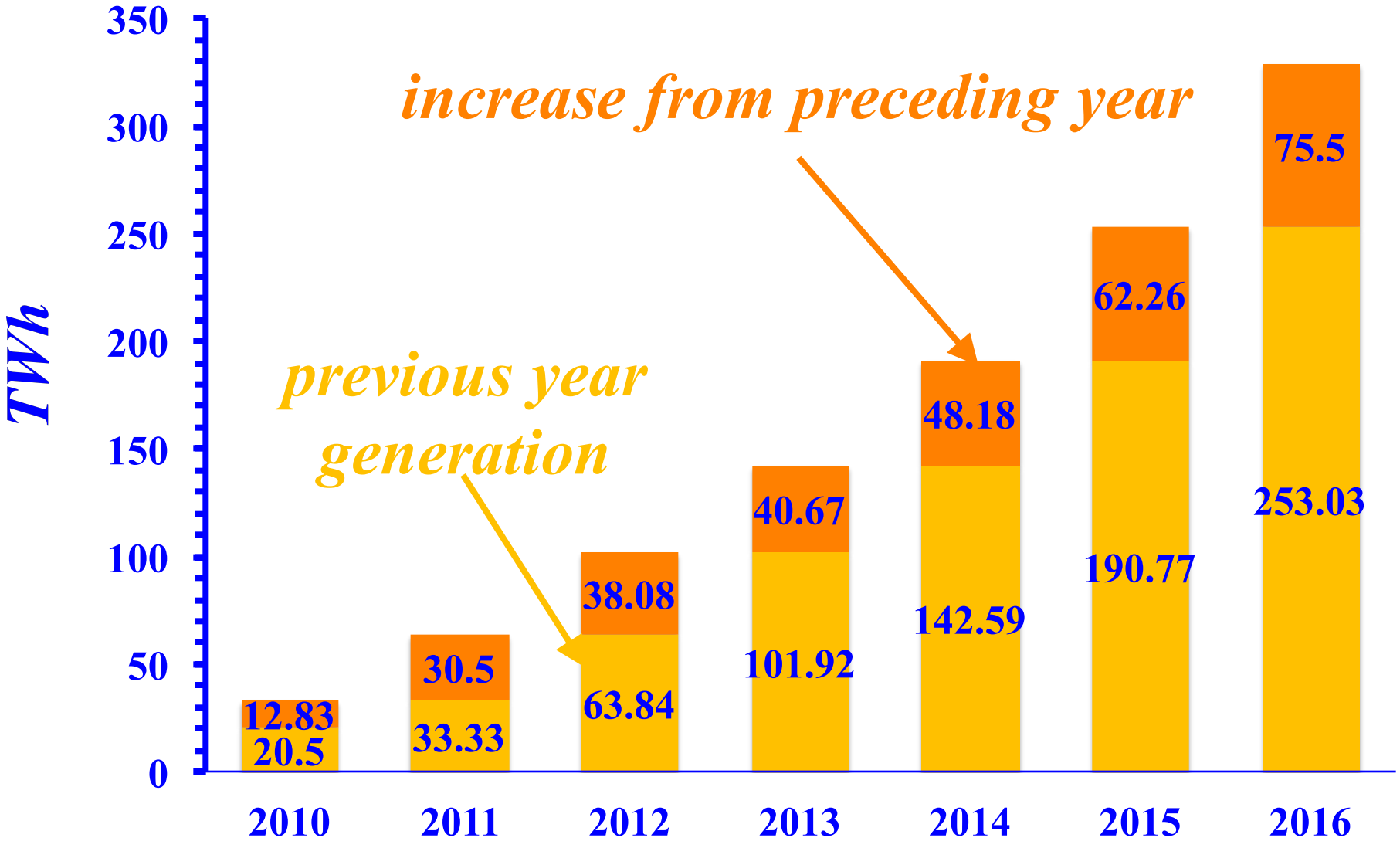
- *PV* solar system status
- *PV* technology benefits
- Key drivers of the *PV* system growth
- *PV* system installation costs
- Major challenges facing the *PV* solar resources

2009 – 2016 GLOBAL CUMULATIVE *PV* CAPACITY



Source:http://www.solarpowereurope.org/fileadmin/user_upload/documents/WEBINAR/Free_SolarPower_Webinar_Global_Market_Outlook_2017-2021.pdf

2010 – 2016 WORLDWIDE *PV* ELECTRICITY GENERATION



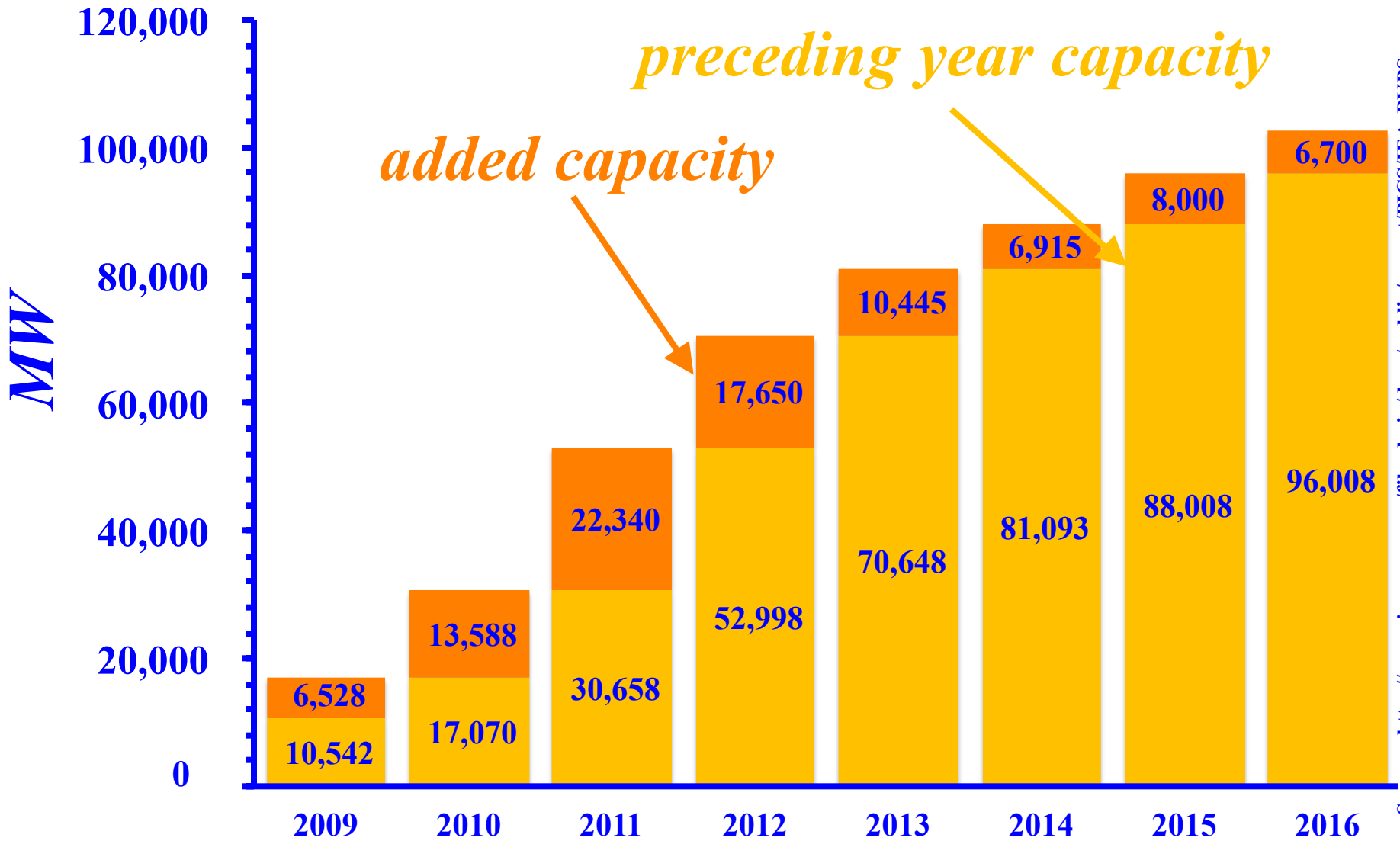
Source: http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/downloads.html/

2016 WORLD STATUS OF THE *PV* SYSTEMS

- The addition of more than 76.6 *GW* of new capacity increased the cumulative worldwide *PV* capacity to 306.5 *GW* in 2016
- Europe with nearly 103 *GW* remains the world's leading region in terms of cumulative installed capacity – about 33 % of the world's total *PV* capacity – a marked decrease from 40 % in 2015

Source:http://www.solarpowereurope.org/fileadmin/user_upload/documents/WEBINAR/Free_SolarPower_Webinar__Global_Market_Outlook_2017-2021.pdf

2009 – 2016 EUROPE *PV* CAPACITY ANNUAL ADDITIONS



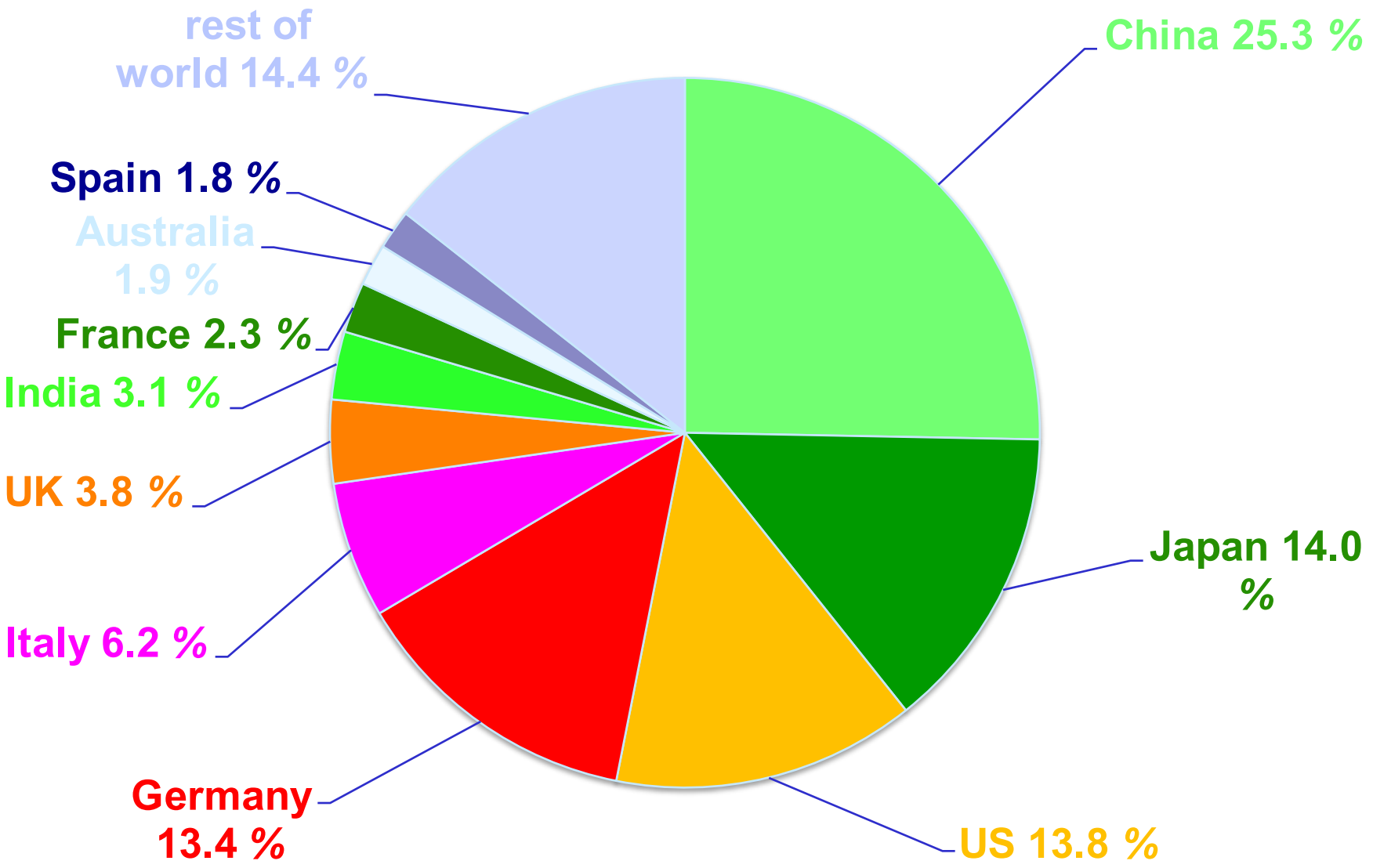
2016 WORLD STATUS OF *PV* SYSTEMS

- *China*, *US* and *Japan* were the top three nations in terms of *PV* capacity additions in 2016
- *China* installed 34.5 *GW* of *PV*, an amount higher than the sum of the capacity additions of the next two countries
- *US* ranks second in capacity additions in 2016 with 14.7 *GW*
- In *Japan*, 8.6 *GW* of *PV* capacity was installed – less than the capacity added in 2015

2016 WORLD STATUS OF *PV* SYSTEMS

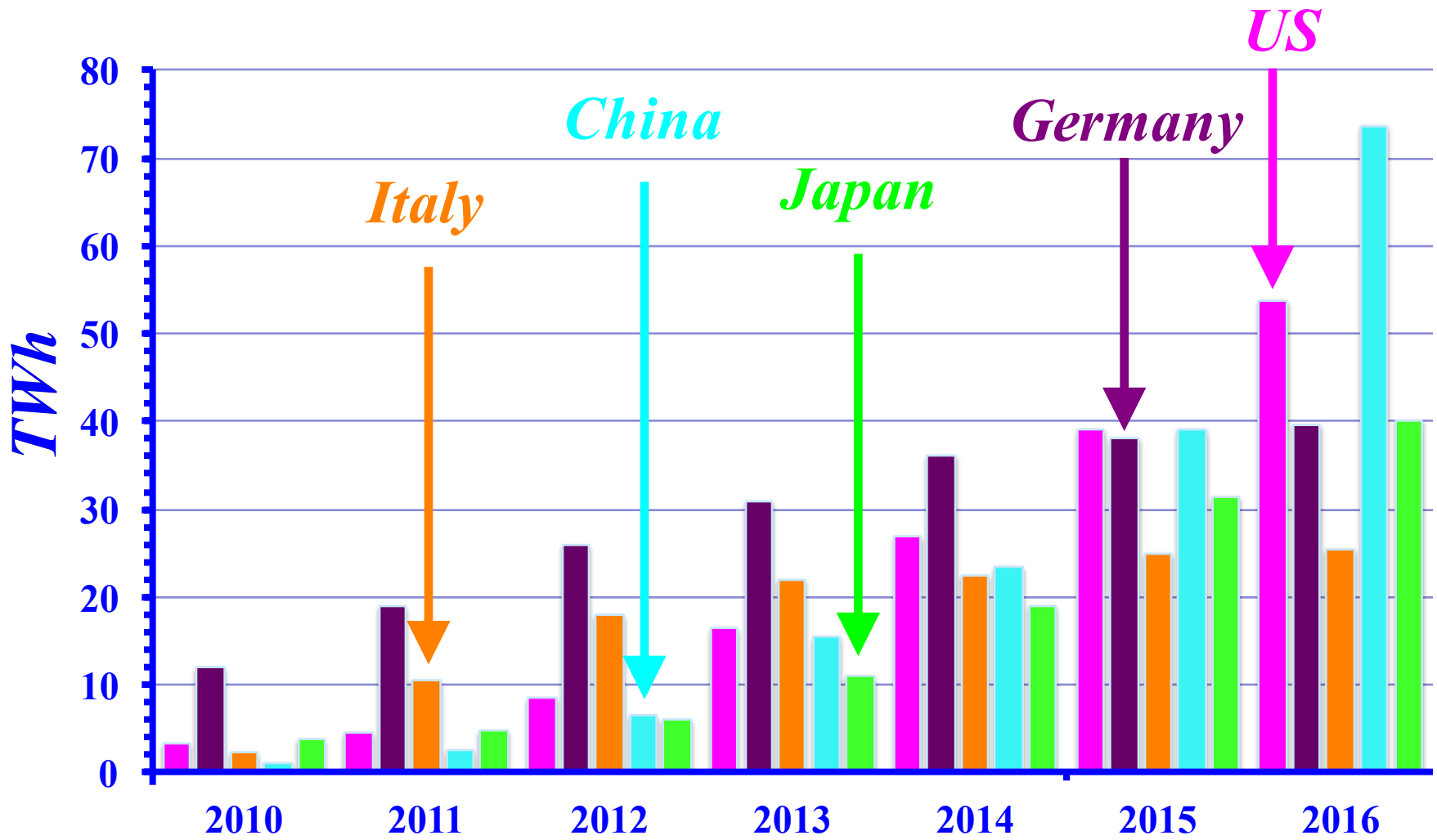
- European markets for *PV systems* slowed down in 2015 and continued this trend in 2016
- The weak 6.7–*GW* added capacity shrank Europe's share to 33 % of the global *PV* capacity
- For the third time in a row, the *UK* led Europe with its 2–*GW* addition
- Solar *PV* covered more than 7 % of electricity demand in Italy, Germany and Greece

2016 GLOBAL CUMULATIVE *PV* CAPACITY



Source:http://www.solarpowereurope.org/fileadmin/user_upload/documents/WEBINAR/Free_SolarPower_Webinar__Global_Market_Outlook_2017-2021.pdf. Page: 5

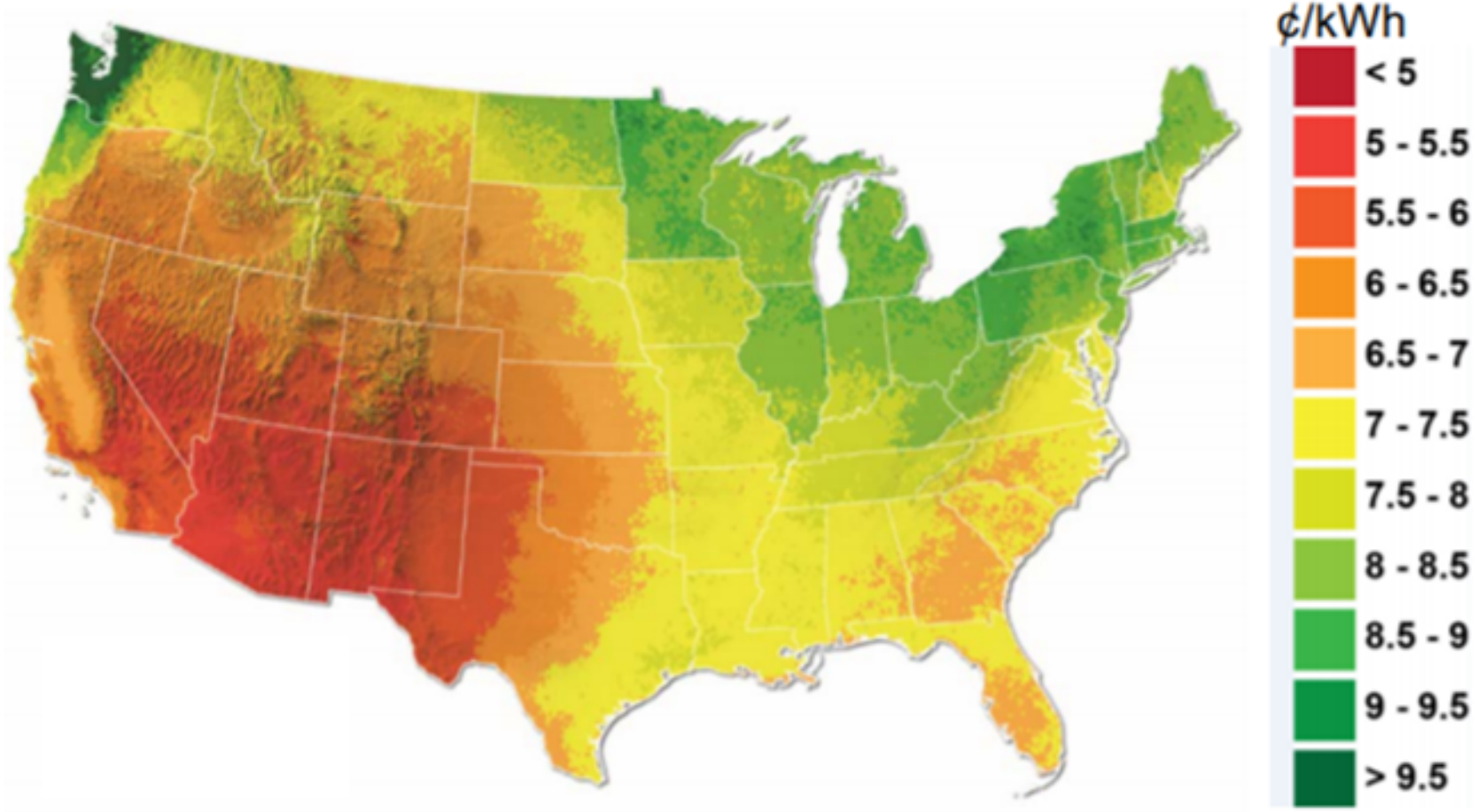
2010 – 2016 *PV* ELECTRICITY GENERATION BY LEADING NATIONS



Soruce:http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/downloads.html

JANUARY – APRIL 2016 *US* AVERAGE MONTHLY *PV* POWER OUTPUT RATIO

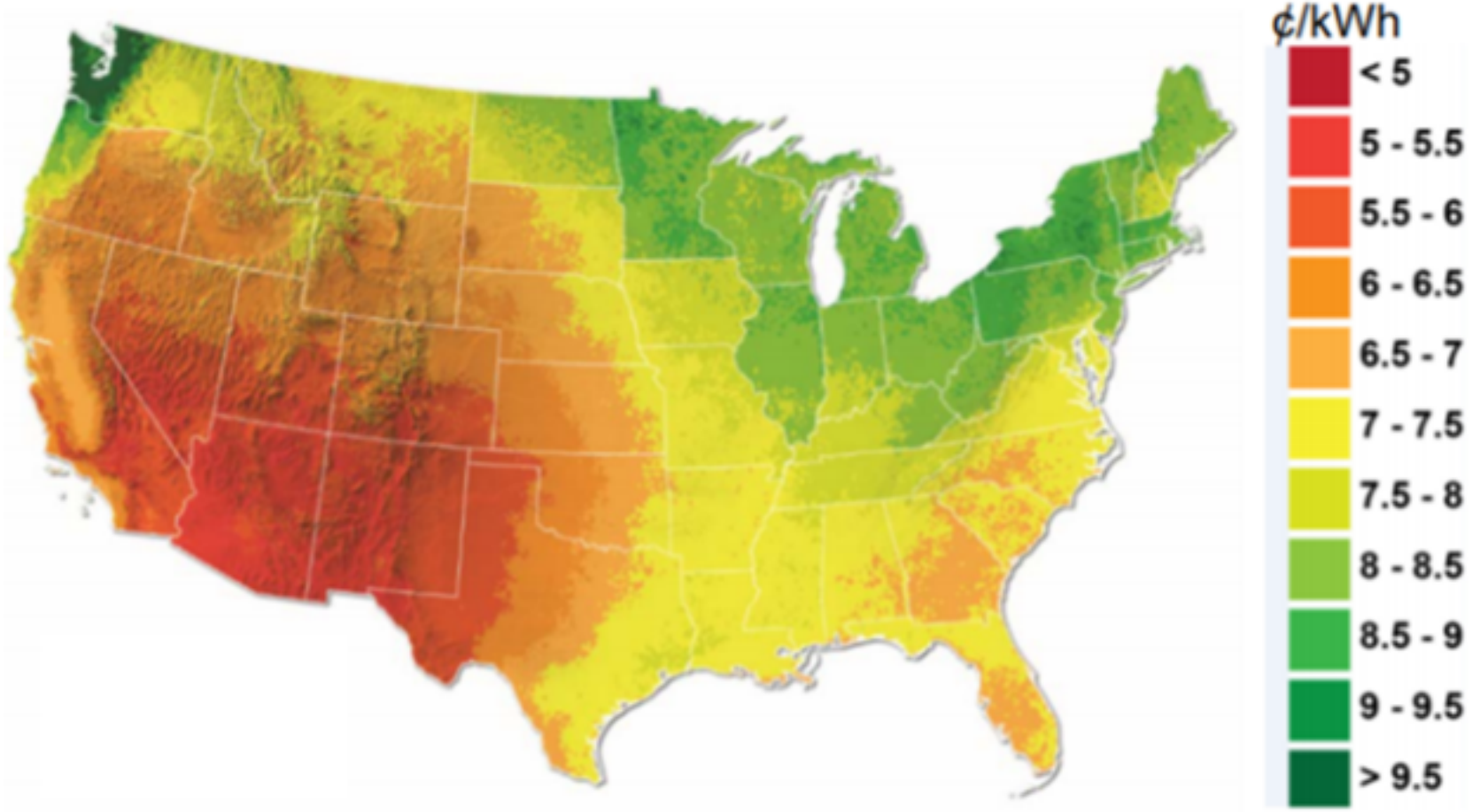
$$\frac{\textit{monthly energy output (kWh)}}{\textit{PV system capacity } (kW_p)}$$



Source: https://www.nrel.gov/docs/fy16osti/67142.pdf

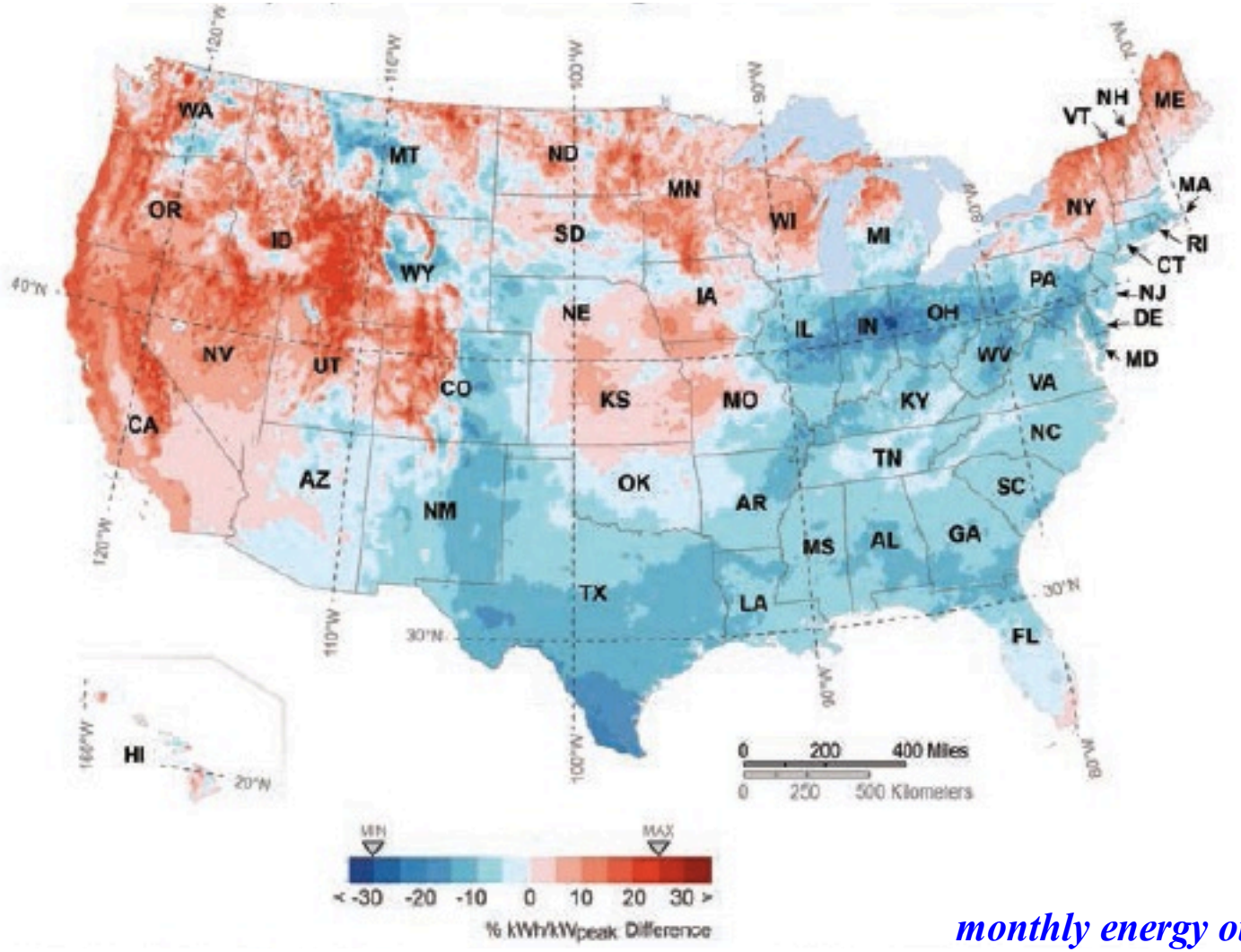
US PV SOLAR *LCOE* DEPENDS ON LOCATION

2016 *$ LCOE*



Source: https://www.nrel.gov/docs/fy16osti/67142.pdf

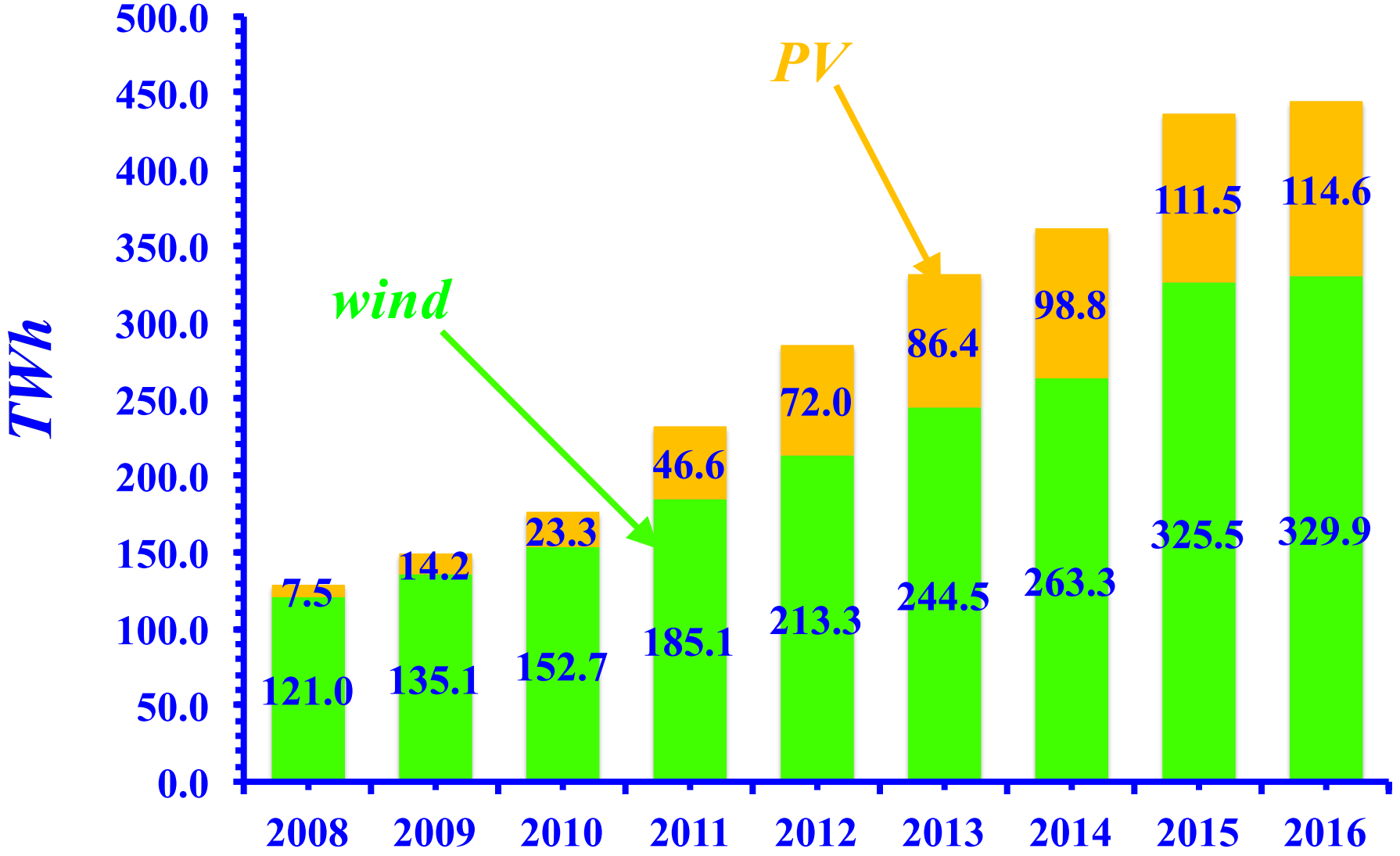
JANUARY – APRIL 2016 *US PV* POWER OUTPUT RATIO VARIANCE



$$\frac{\textit{monthly energy output (kWh)}}{\textit{PV system capacity } (kW_p)}$$

Source: http://solartoday.org/2015/07/pv-generation-potential-for-january-april-2015/

2008 – 2016 EUROPEAN ELECTRICITY GENERATION FROM WIND AND *PV*

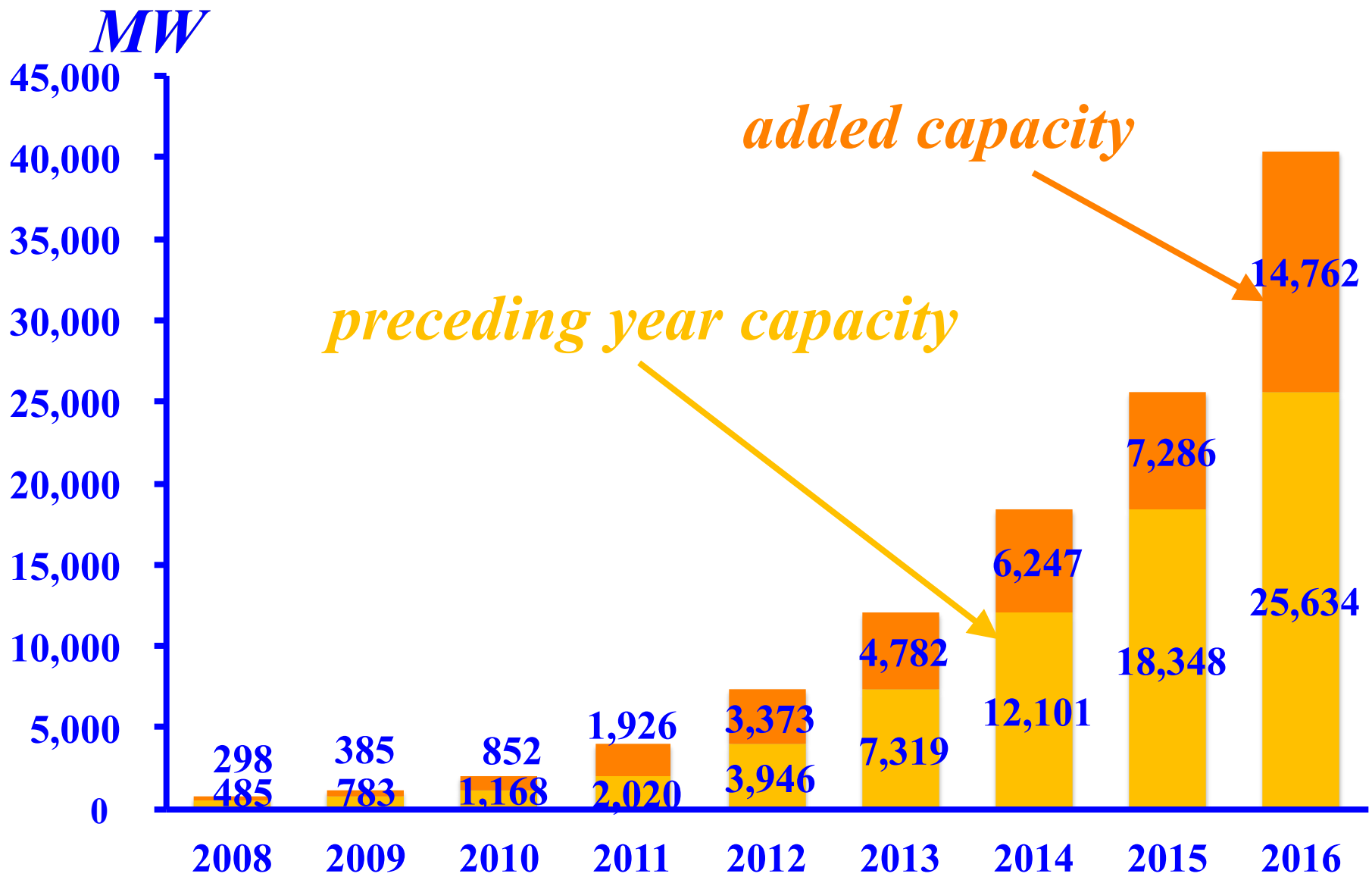


Sourcehttp://www.bp.com/en/global/corporate/energy-economics/statistical-review-of world-energy/downloads.html

THE 2016 STATUS OF *US PV* SYSTEMS

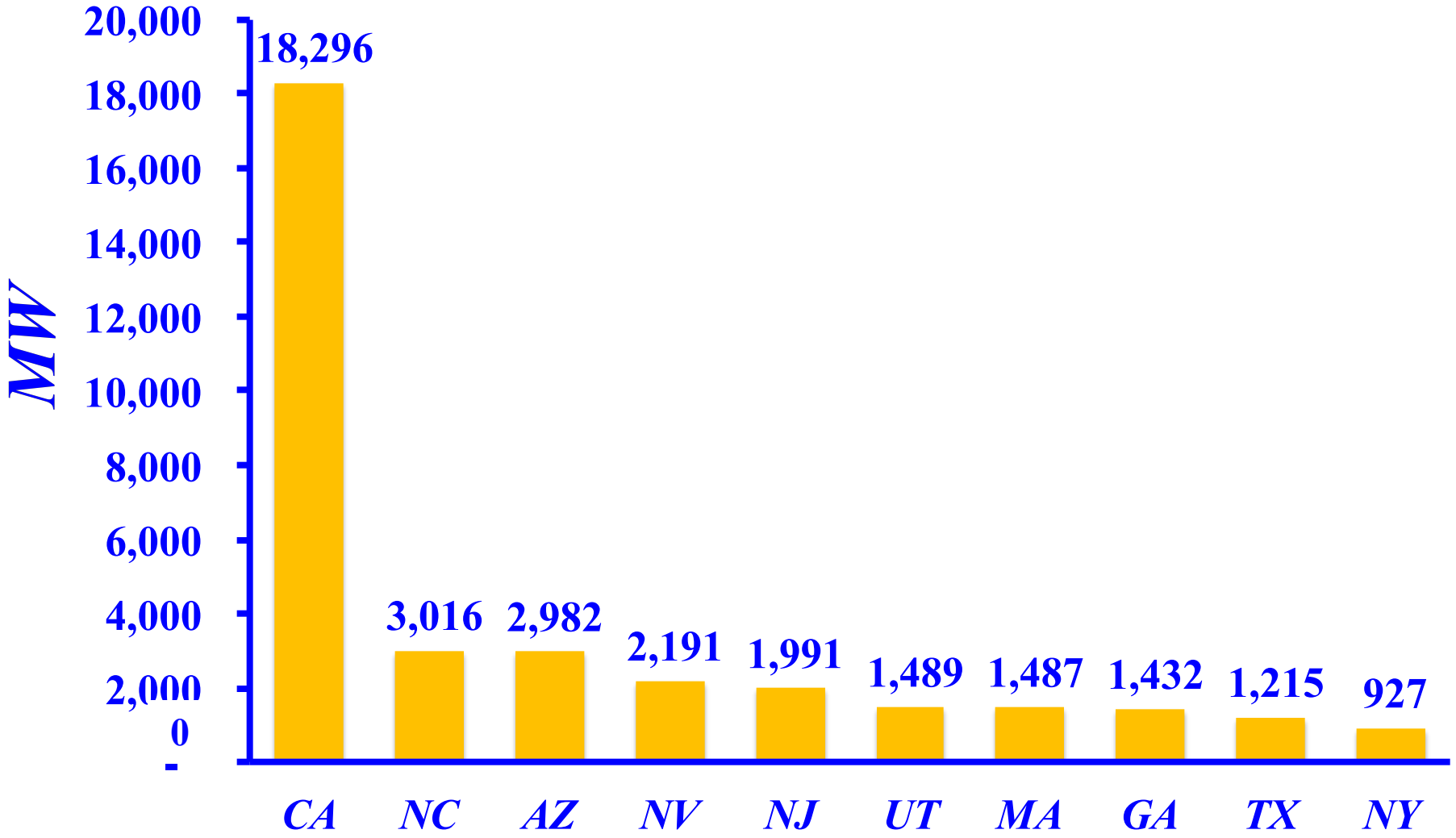
- *US* is a relatively small, but growing, part of the global solar capacity and energy
- The 2016 *US* cumulative *PV* capacity increased to roughly 40.3 *GW*, with 14.7 *GW* of new *PV* capacity added in 2016
- The 14.7 *GW PV* capacity installed in 2016 was over 2 times the 2015 amount of installed *PV* capacity

2008 – 2016 *US* CUMMULATIVE AND INSTALLED *PV* CAPACITY



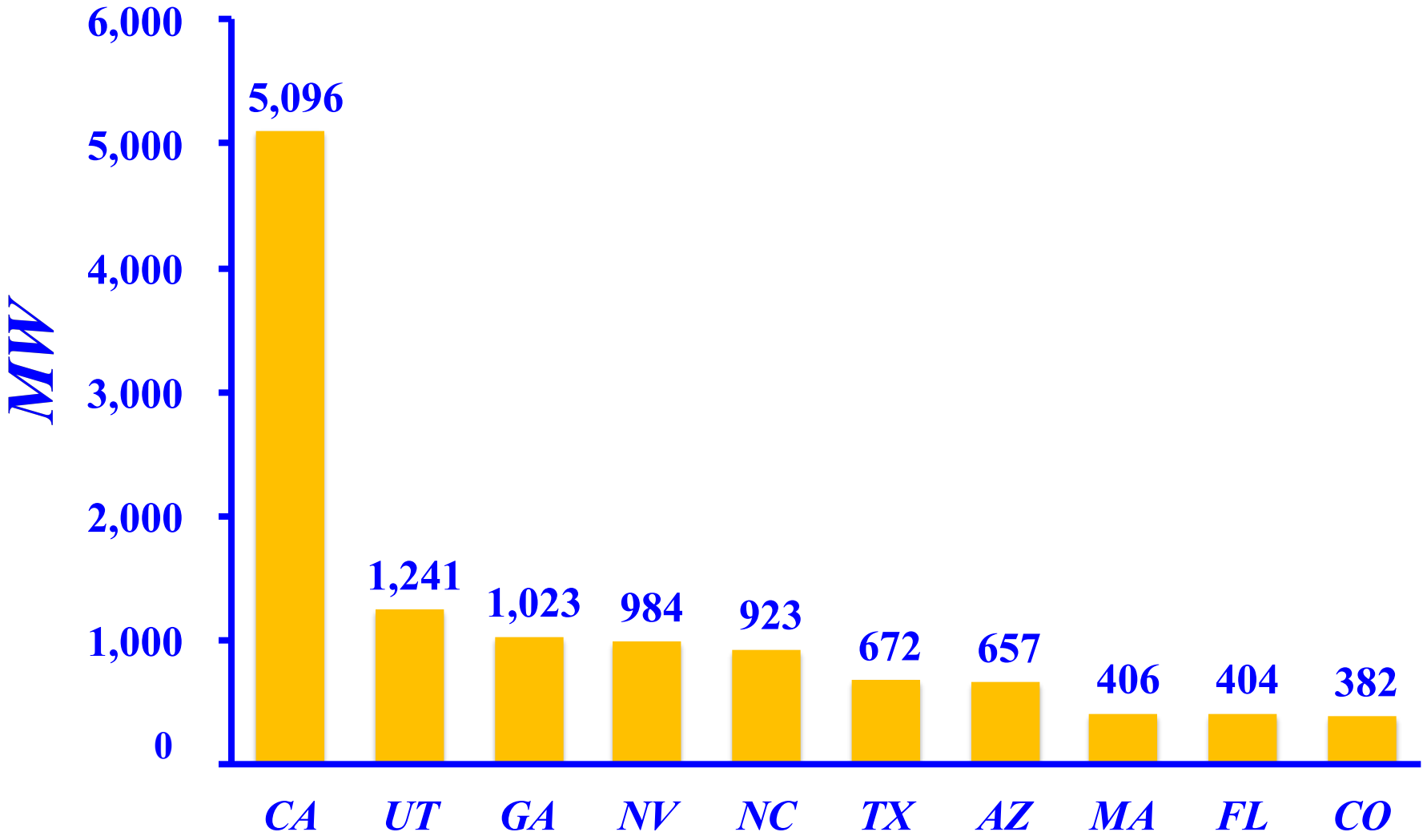
Source: http:www.solarpowereurope.orgindex.phpeID=tx_nawsecuredl&u=0&g=0&t=1447019117&hash=ee83f75dac0e7f7c58d7ae6daec1c7e9facf08cc&file=fileadmin/user_upload/secure/Global_Market_Outlook_2015_-2019_lr_v23.pdf

US TOP 10 STATES WITH LARGEST *PV* CAPACITY IN 2016



Source: https://www.seia.org/research-resources/top-10-solar-states

US TOP 10 STATES WITH LARGEST *PV* CAPACITY ADDITIONS IN 2016

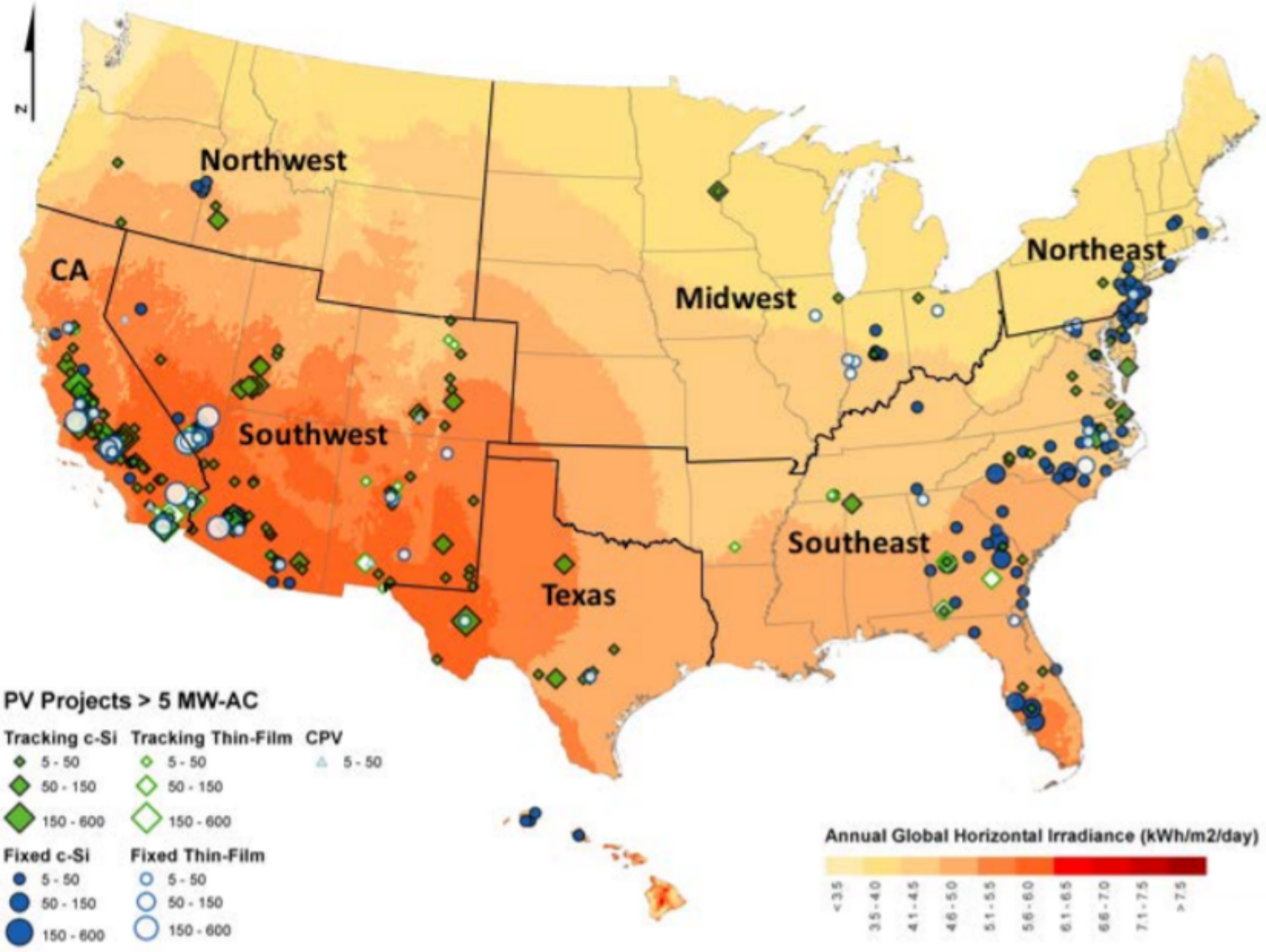


Source: https://www.seia.org/research-resources/top-10-solar-states

2016 *US* STATUS OF *PV* SYSTEMS BY STATES

- More than 1/3 of the *US PV* capacity installations were in *CA*
- In *Q*3 2016, California became the first state ever to add more than 1 *GW* of utility *PV* in a single quarter
- *CA, NC, AZ* and *NV* account for nearly 1/3 of the *US* cumulative *PV* capacity

2015 *US* UTILITY – SCALE SOLAR PROJECTS



Source: https://emp.lbl.gov/sites/default/files/utility-scale-solar-2016-slides.pdf

THE 5 LARGEST 2016 *US PV* INSTALLATIONS

plant	*location*	*capacity (MW)*	*year built*	*owner*	*electricity purchaser*
Solar Star	*Rosamond, CA*	579	2015	*BHE Renewables*	*SCE*
Desert Sunlight Solar Farm	*Riverside County, CA*	550	2013	*NextEra, Sumitomo*	*PG&E & SCE*
Topaz Solar Farm	*San Luis Obispo, CA*	550	2014	*Mid American Solar*	*PG&E*
Copper Mountain Solar Facility	*Boulder City, NV*	552	2015	*Sempra Generation*	*PG&E & SC Public Power Authority*
Agua Caliente Solar	*Yuma County, AZ*	290	2014	*Mid American Solar, NRG Energy*	*PG&E*

http://www.imeche.org/news/news-article/top-10-solar-photovoltaic-plants-in-the-world

SOLAR STAR FARM

Source: http://www.techspot.com/images2/news/bigimage/2014/11/2014-11-28-image-4.jpg

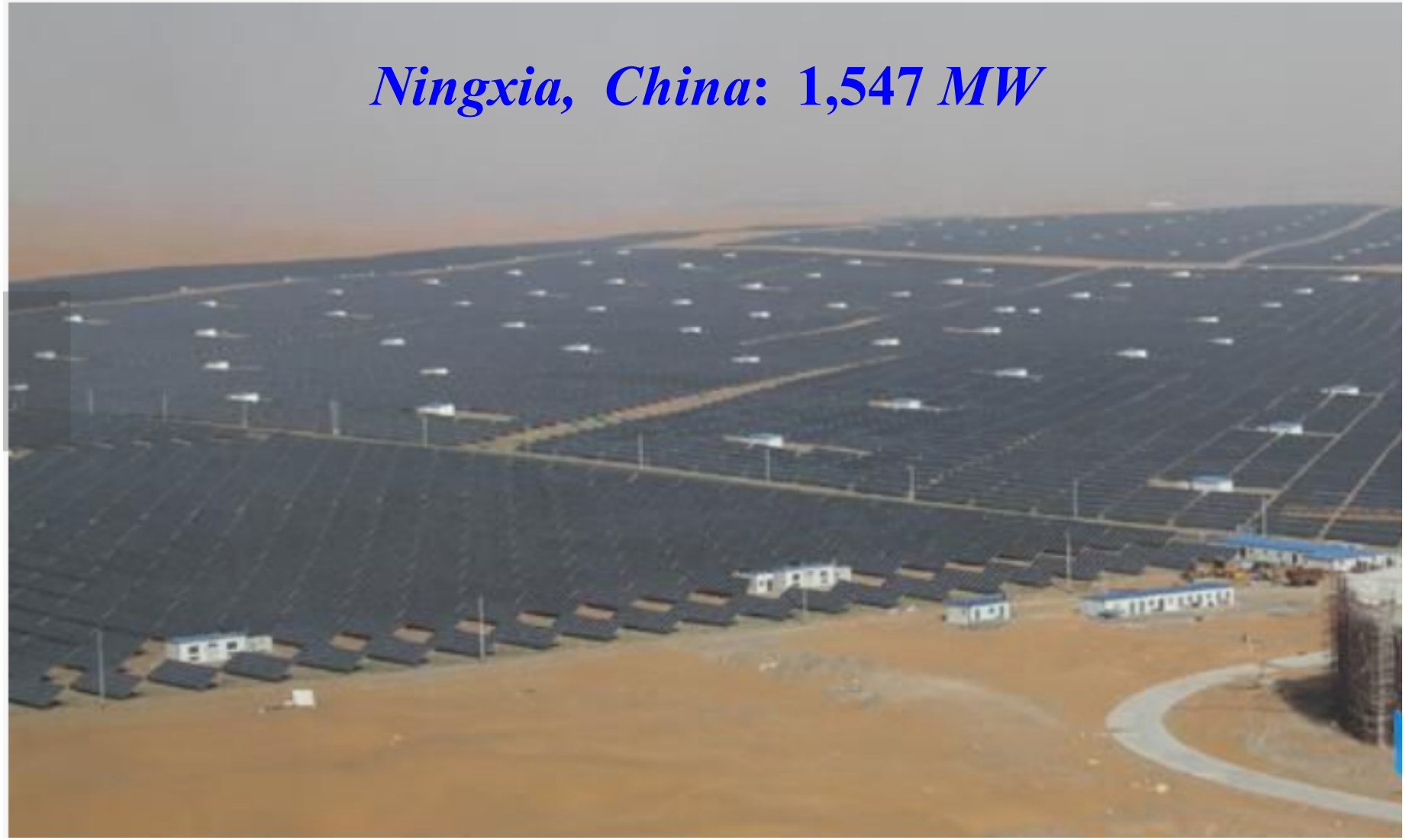
SOLAR STAR FARM

- The *Solar Star Farm* is a 579–*MW PV* power station located in *Antelope Valley* near Rosamond, *CA*
- Completed in June 2015 by *SunPower*, *Solar Star* was the world's largest solar farm in terms of capacity from its 1.7 *million* solar panels on a 13 km^2 (3,200 *acres*) area

SOLAR STAR FARM

- Compared to other large plants, *Solar Star* uses a smaller number of arrays, each array is mounted on a single–axis tracker and has higher efficiency
- Generation of clean electricity form the farm is expected to power about 255,000 homes and avoid the annual emission of 570,000 *tons* of CO_2

TENGGER DESERT SOLAR PARK



Source: https://www.solarinsure.com/largest-solar-power-plants

TENGGER DESERT SOLAR PARK

- The world's largest *PV* plant is the 1547-*MW* *Tengger Desert Solar Park*, which is located in, Ningxia, China

- The *Tengger Desert Solar Park* was built on a 42 km^2 (10,378 *acres*) area and the installation was completed in 2015

CESTAS SOLAR FARM

Source: http://solar.schneider-electric.com/new-300-mw-solar-farm-to-be-built-in-cestas-france/

CESTAS SOLAR FARM

- With a total capacity of 300 *MW*, *Cestas Solar Farm* is the largest *PV* plant in Europe
- This solar park is located at Cestas, in Southwest France, and is expected to supply electricity to meet the needs of 250,000 people
- Electricity is sold under a 20–*year PPA* with the French utility *EDF* at a price of 105 €/*MWh*

ROOFTOP SOLAR

Source: http://assets.inhabitat.com/wpcontent/blogs.dir/1/files/2012/12

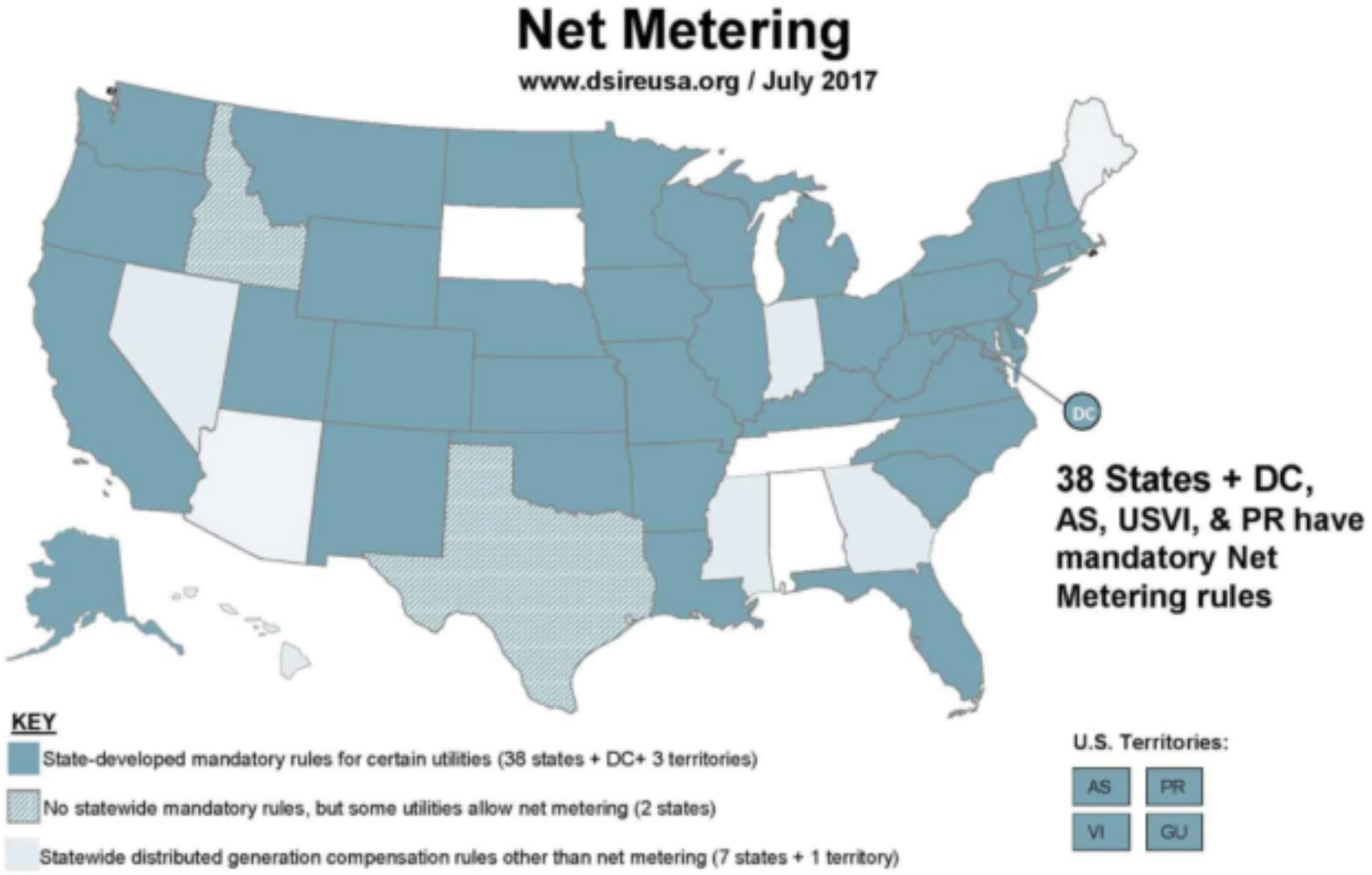
ROOFTOP SOLAR IN *US*

- The *US* Energy Information Administration (*EIA*) indicates that rooftop solar electricity represents less than 0.47 % of the *US* electricity generation
- Government incentives aimed at promoting solar energy have made the installations of rooftop solar widespread in the Western states – *CA*, *AZ*,

ROOFTOP SOLAR IN *US*

- Incentives include tax credits, installation cost re-bates and *net metering* for customers with rooftop solar panels; incentives are location dependent
- At present 41 states, the *District of Columbia* and 3 territories offer net metering

NET METERING STATUS IN THE *US*



Source: http://www.dsireusa.org/resources/detailed-summary-maps/

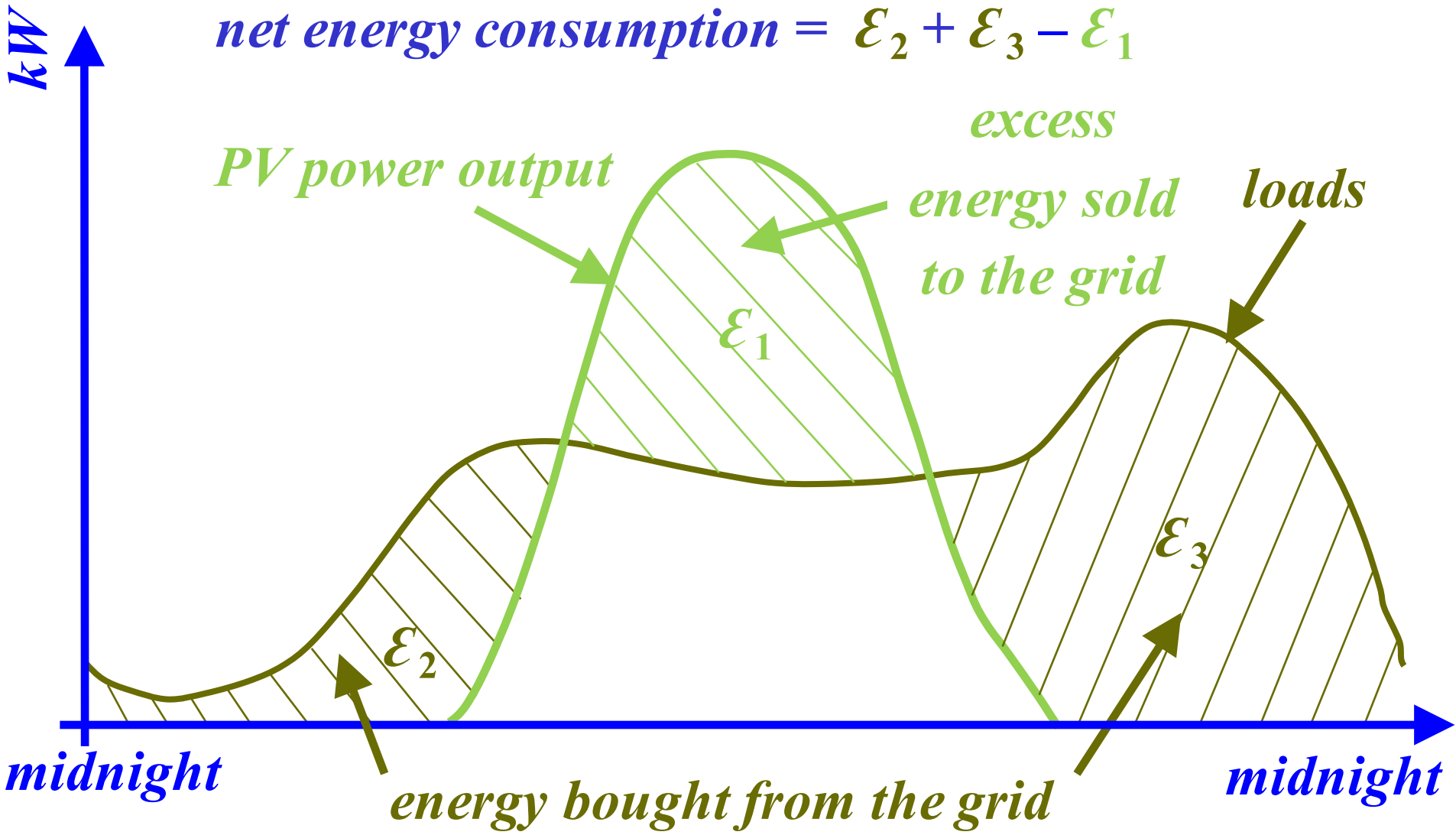
NET METERING

- Under net metering – a billing mechanism that credits solar energy system owners for the energy injected into the grid – customers pay only for the electricity consumed that exceeds the amount fed into the grid, the so-called *net energy*

NET METERING

Source: http://www.seia.org/policy/distributed-solar/net-metering//

NET METERING



NET METERING

- The implementation of net metering varies from one jurisdiction to another
- In *CA*, solar owners receive federal tax credits, rebates under the *CA Solar Initiative*, which is being phased out, and net metering; *CA* has more installed capacity than the rest of the country combined

NET METERING

- The payment foregone by the net metered solar owners are pushing the distribution utilities to shift the collection of the electricity infrastructure to the non-solar-owner customers; utilities view this development as the "death spiral"

RENEWABLE ENERGY CERTIFICATE (*REC*)

- The *REC*, also known as the *green tag* or *renewable energy credit* is a tradable and non–tangible energy commodity that provides proof of the production of 1–*MWh* electricity from a renewable resource
- Every renewable energy resource gets paid for its production from two sources: the energy is compensated through sales into the electricity markets or via *PPA*s; in addition, the trading of the *REC*s, which represent renewable energy genera–tion is an additional revenue stream

RENEWABLE ENERGY CERTIFICATES (*RECs*)

- The *RECs* convey the environmental benefits of the renewable resource electricity and, under a tracking mechanism, provide direct accounting to meet the *RPS* goals in each jurisdiction
- The *RECs* provide auditable proof of the amount of renewable energy production injected into the grid

RECs

- However, since the energy and the *RECs* are sold separately and possibly to different buyers, the consumption of the green energy and the proof of the production may be in different jurisdictions
- The prices of *RECs* vary from one jurisdiction to another and their use across different states are subject to the *non-uniform rules* across the states
- *RECs* provide buyers and sellers flexibility in trading renewable energy across state borders

KEY *PV* BENEFITS

- Residential and commercial *PV* system installations reduce the amount of electricity such customers purchase from the local utility
- As *PV* systems produce the most power when the insolation is highest at noon, their contributions can reduce the need for the expensive and polluting fossil generation at those operating times

KEY *PV* BENEFITS

- *PV* systems as energy resources lessen the nation's dependence on fossil fuels
- The clean and renewable electricity generated by *PV* systems helps reduce the *GHG* emissions – a major contributor to global climate change
- The growing *PV* industry provides local jobs and economic development opportunities to states and regions to support sustainable energy

THE KEY DRIVERS OF *US PV* GROWTH

- A most important driver is the *declining costs of installed PV*; in addition, the legislative and regulatory initiatives at the federal and state levels helped the growth of *US PV* in the past few years
- The federal drivers include
  - *tax incentives* that were established to accelerate the *PV* installations;
  - *loan guarantees* enabled by the 2009 *American Recovery and Reinvestment Act* (*ARRA*) allowed the

THE KEY DRIVERS OF *US PV* GROWTH

US DoE to provide preferential financing sup–port to qualifying renewable energy projects;

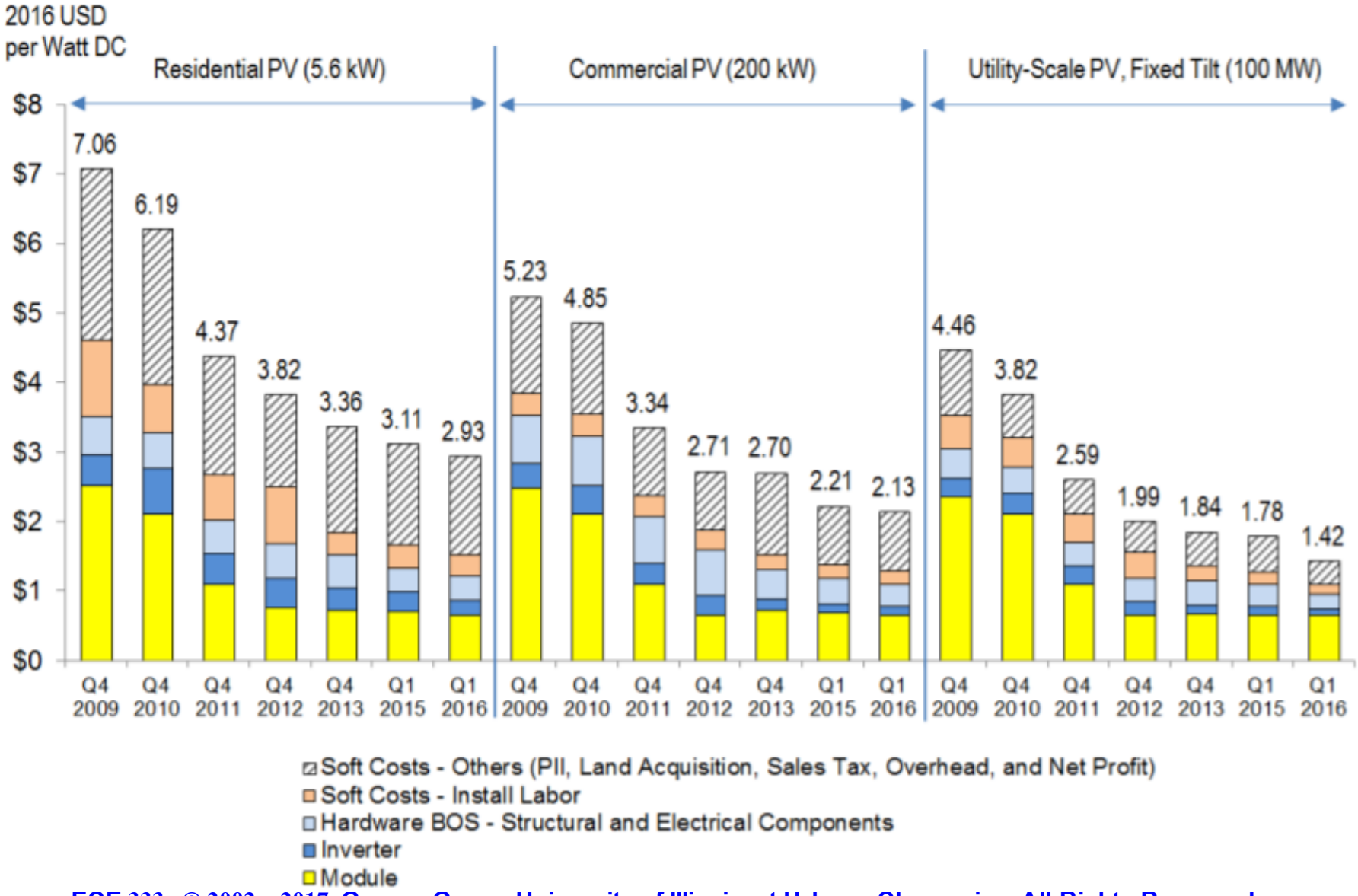
- *cash grants* provided commercial installations with the alternative to the tax credit in the form of a cash grant – essentially, a rebate

- At the state level, the drivers include
  - *RPS requirements* that encourage investments in solar plants to meet the prescribed goals of renewable resource electricity generation

THE KEY DRIVERS OF *US PV* GROWTH

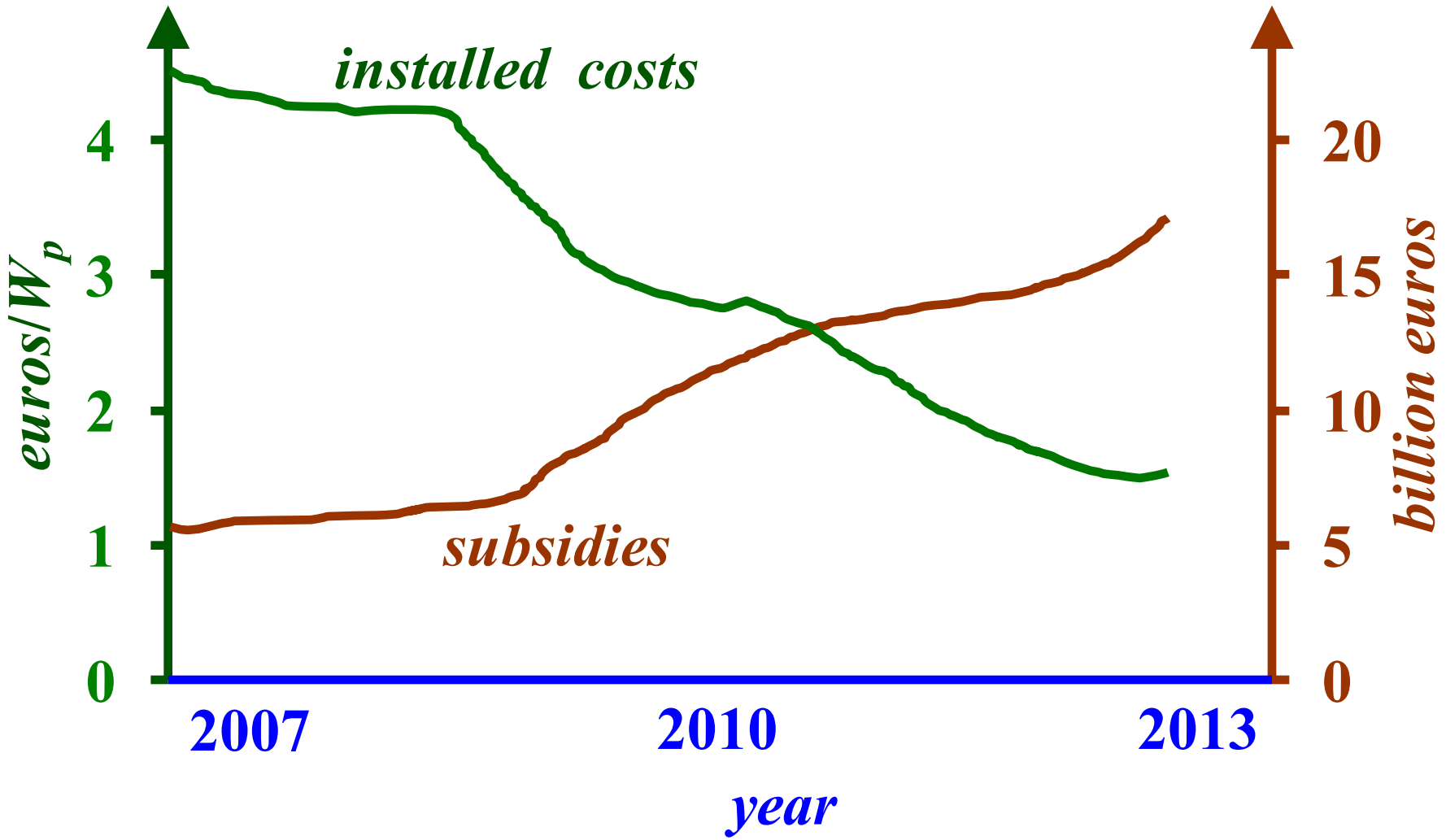
- *rebate programs* enacted to reduce the total investment costs of *PV* systems, especially for residential/commercial *PV* installations
- *net metering and TOU rates* that allow customers to offset their monthly electricity bills by producing their own energy from the *PV* systems and even selling excess energy to the grid

PV INSTALLATION COSTS BY SECTORS



Source: http://www.nrel.gov/docs/fy15osti/64746.pdf

GERMANY *PV* INSTALLATION COSTS AND SUBSIDIES

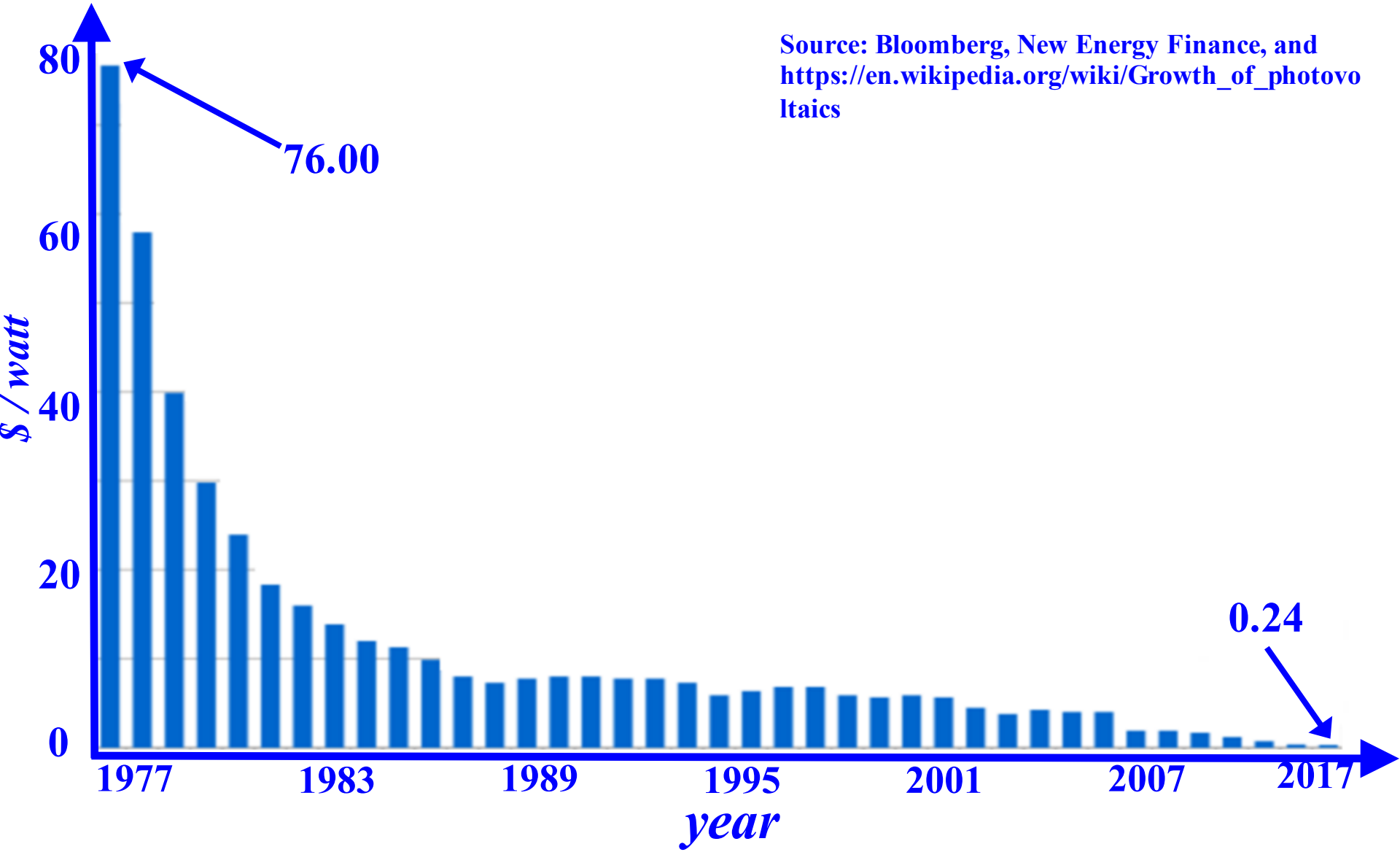


2016 INSTALLED COST TREND

- The total installed costs for *PV* systems dropped by 21 – 36 % from 2013 to 2016
- The 2016 utility–scale *PV* installed cost decline was 20.3 % – the largest among all market segments
- The declining trend for total installed *PV* costs continued in *Q*1 2017, hardware costs – and module prices, in particular – declined markedly in *Q*1 2017 due to an imbalance in the global module

Source: https://www.nrel.gov/docs/fy17osti/68925.pdf page: viii

PV SOLAR CAPACITY PRICE DECLINE



2016 *PV* MODULE MANUFACTURING STATUS

- The top ten manufacturing companies supplied 36.4 *GW* of *PV* modules in 2016 – a growth of their market share to 52 % from 48 % in 2015
- Six of the top ten companies are publicly–listed, vertically-integrated, *China*-based crystalline silicon (*c-Si*) solar panel manufacturers

Source: https://www.nrel.gov/docs/fy17osti/68425.pdf Page: 52

2016 *PV* MODULE MANUFACTURING STATUS

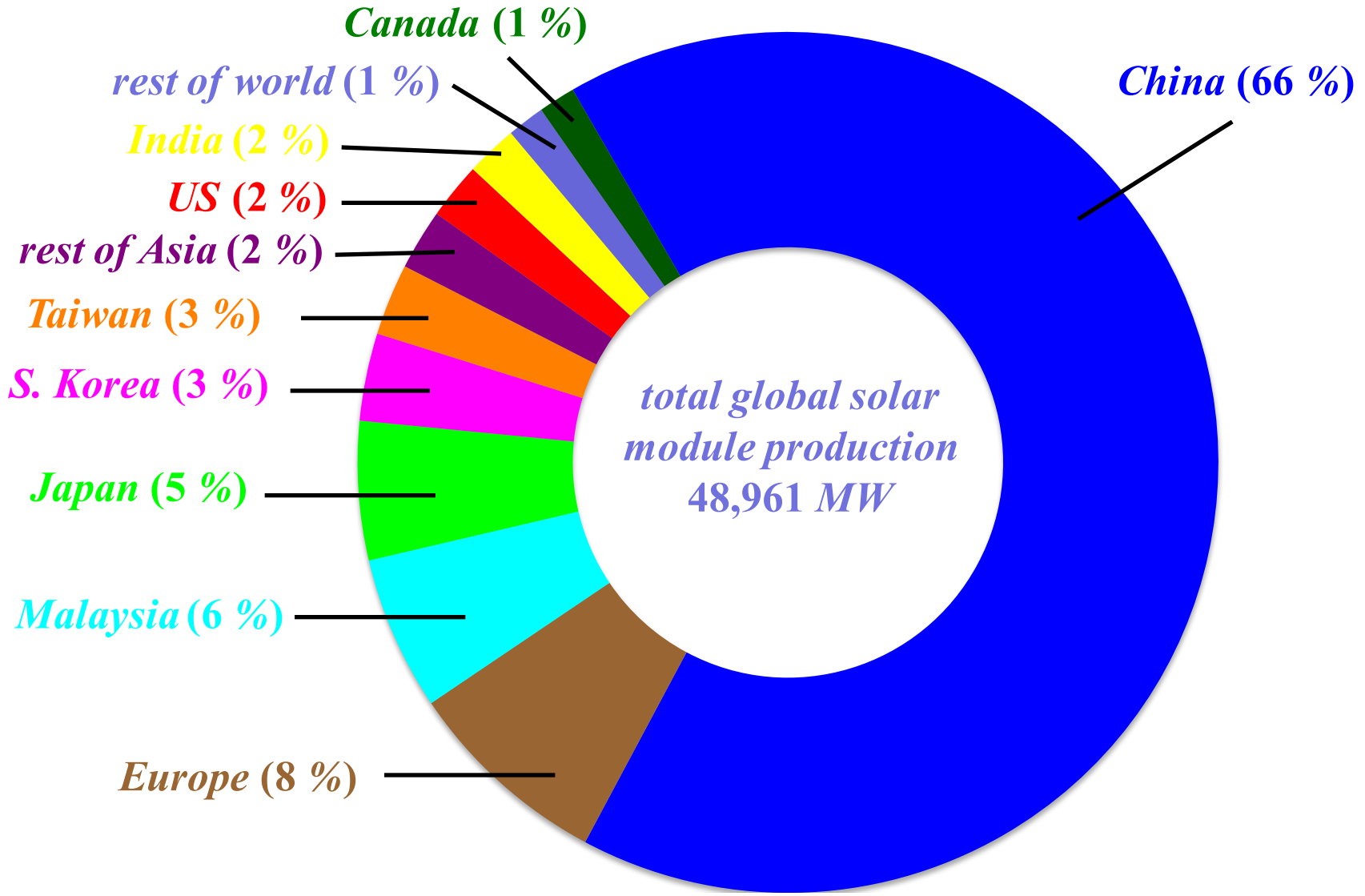
- *Trina Solar*, *First Solar* and *SunPower* are the leaders in module shipments to meet *US* market needs
- In Japan, the leading domestic *PV* module suppliers are *Sharp*, *Kyocera* and *Panasonic*
- The top two suppliers in European *PV* module market are *Schott Solar* and *SolarWorld* in Germany

2016 TOP TEN *PV* MODULE MANUFACTURERS

Company	*Country*
Trina Solar	*China*
JA Solar	*China*
Hanwha Q-CELLS	*Korea*
Jinko Solar	*China*
Motech Solar	*Taiwan*
First Solar	*US*
Longi Lerri	*China*
Canadian Solar	*Canada*
Yingli Solar	*China*
Suntech	*China*

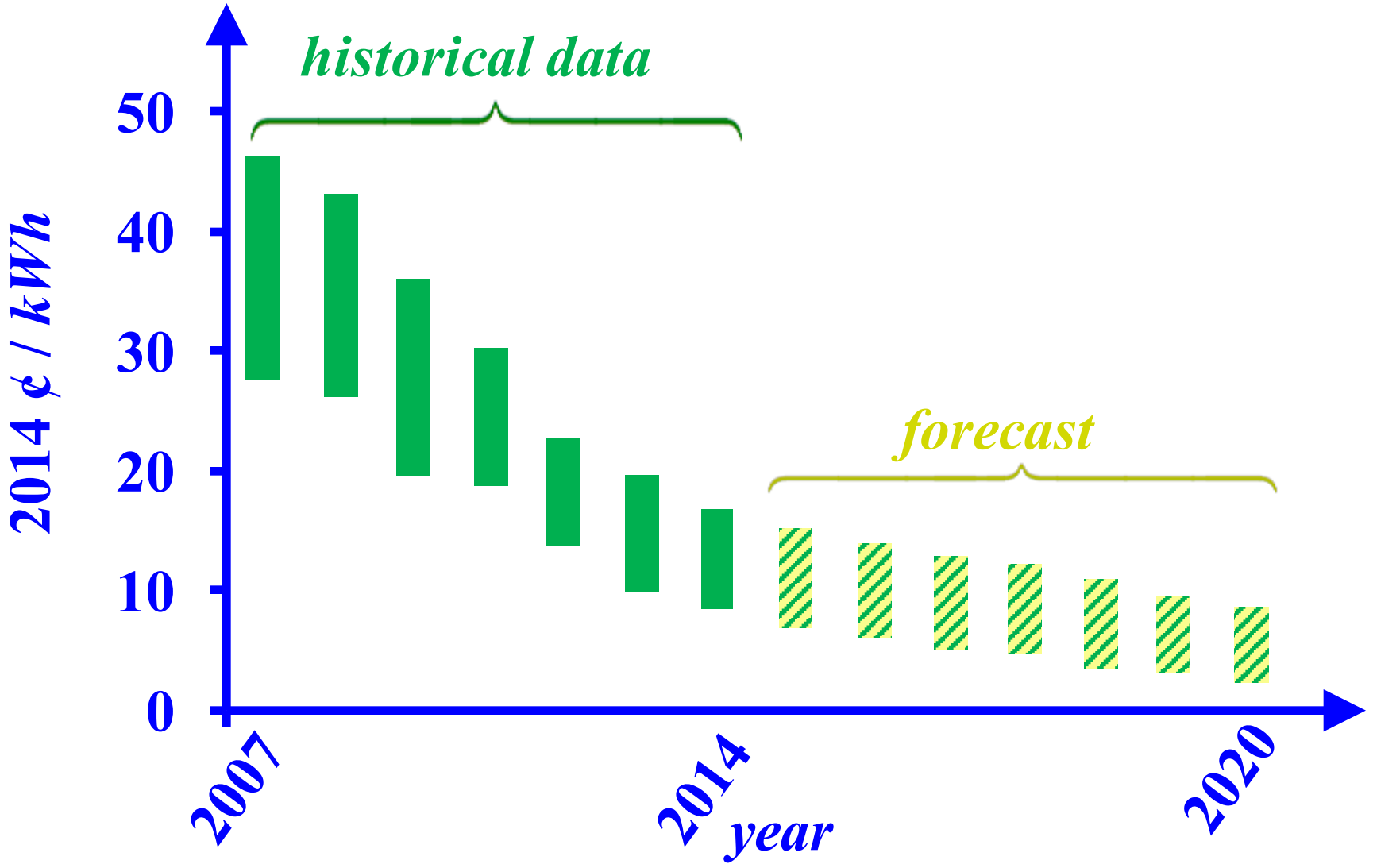
Source: https://www.nrel.gov/docs/fy17osti/68425.pdf Page: 52

2014 *PV* MODULE MANUFACTURING BY COUNTRY



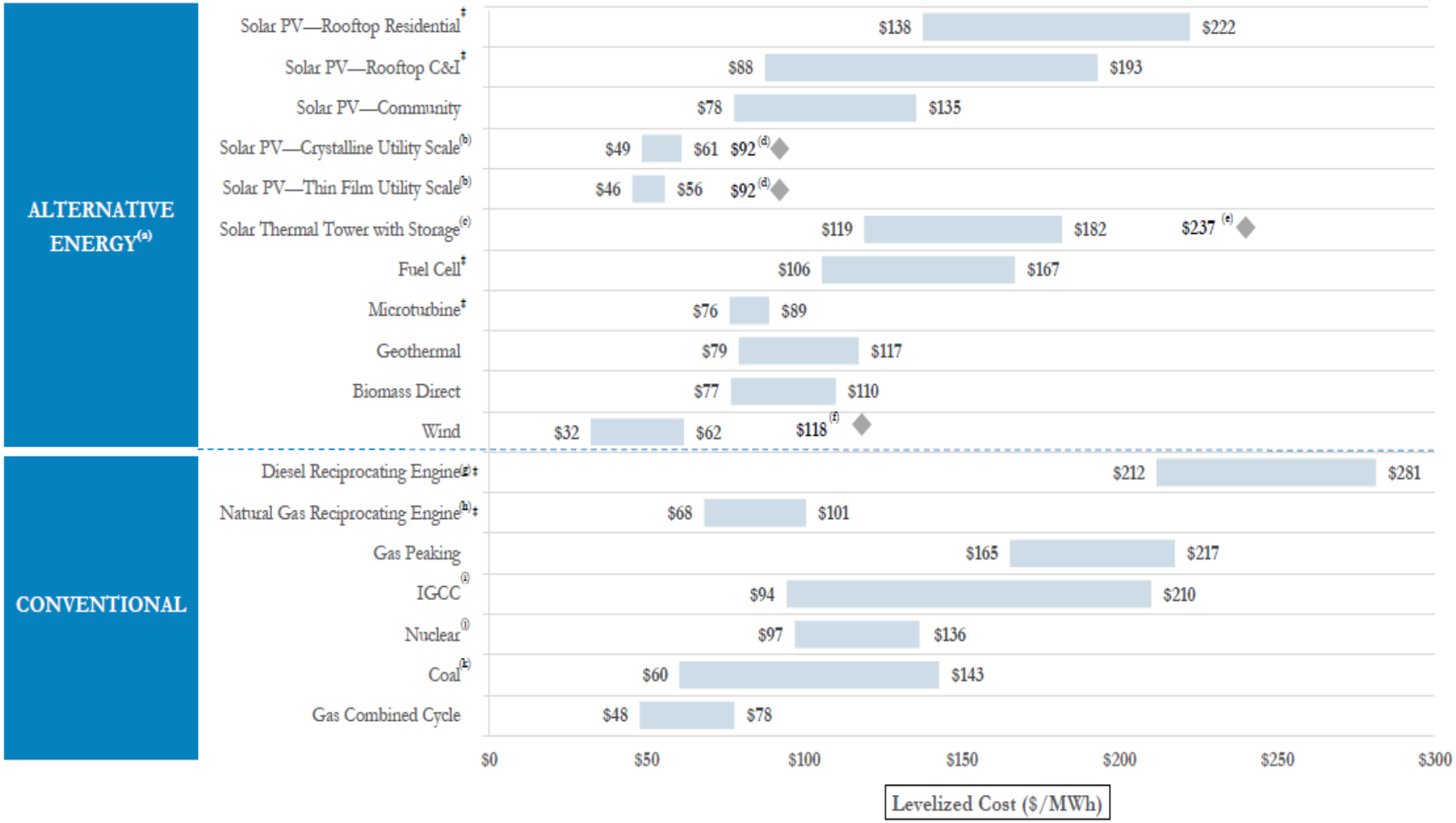
Source: http://www.nrel.gov/docs/fy16osti/64720.pdf

GLOBAL *PV LCOE* TRENDS



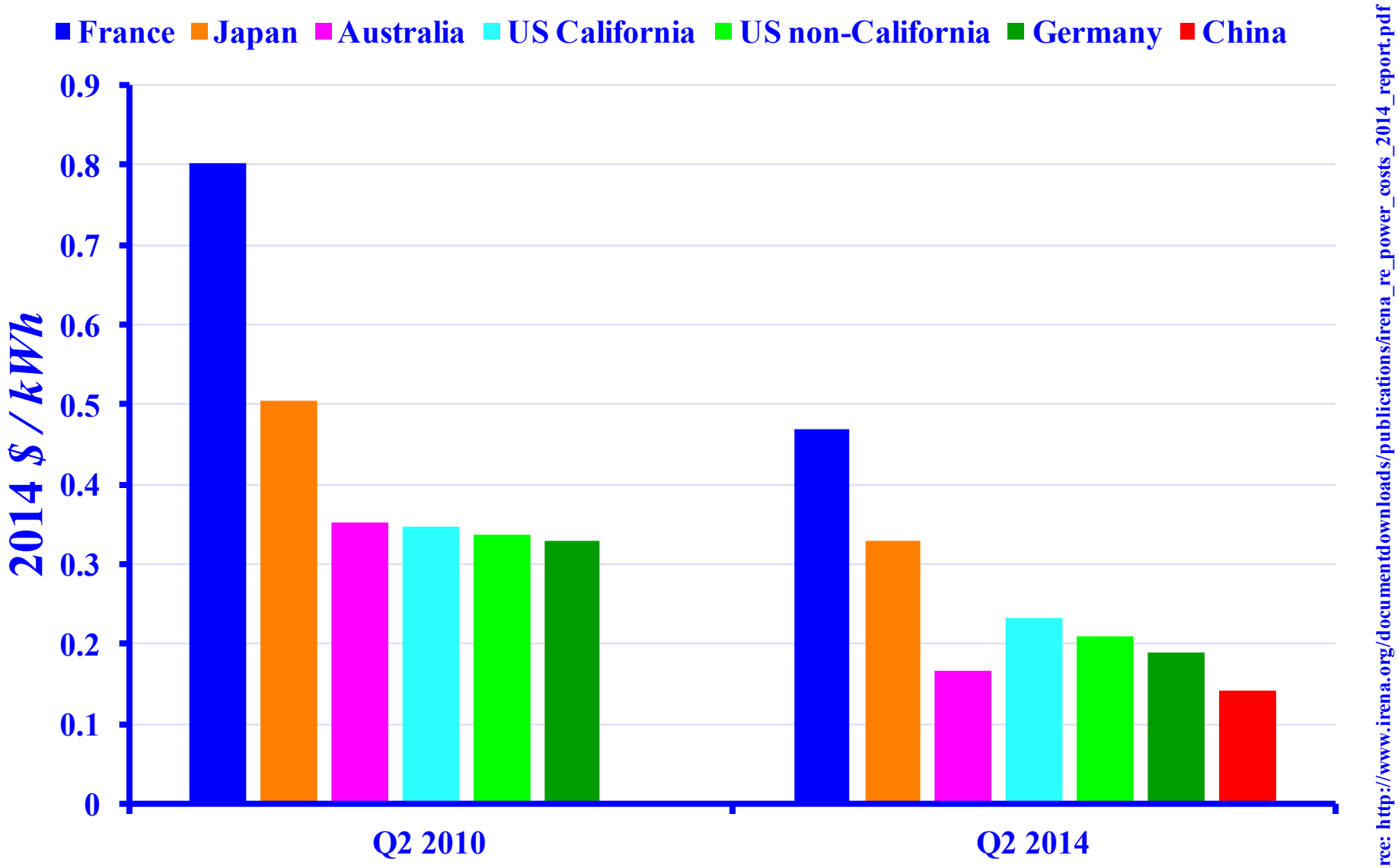
Source: http://climatecommercial.wordpress.com/page/2/

2017 UNSUBSIDIZED LEVELIZED COSTS OF ENERGY



Source: Lazard Levelized Cost of Energy Analysis, December 2016, pg. 2

RESIDENTIAL *PV LCOE* BY COUNTRY



Source: http://www.irena.org/documentdownloads/publications/irena_re_power_costs_2014_report.pdf

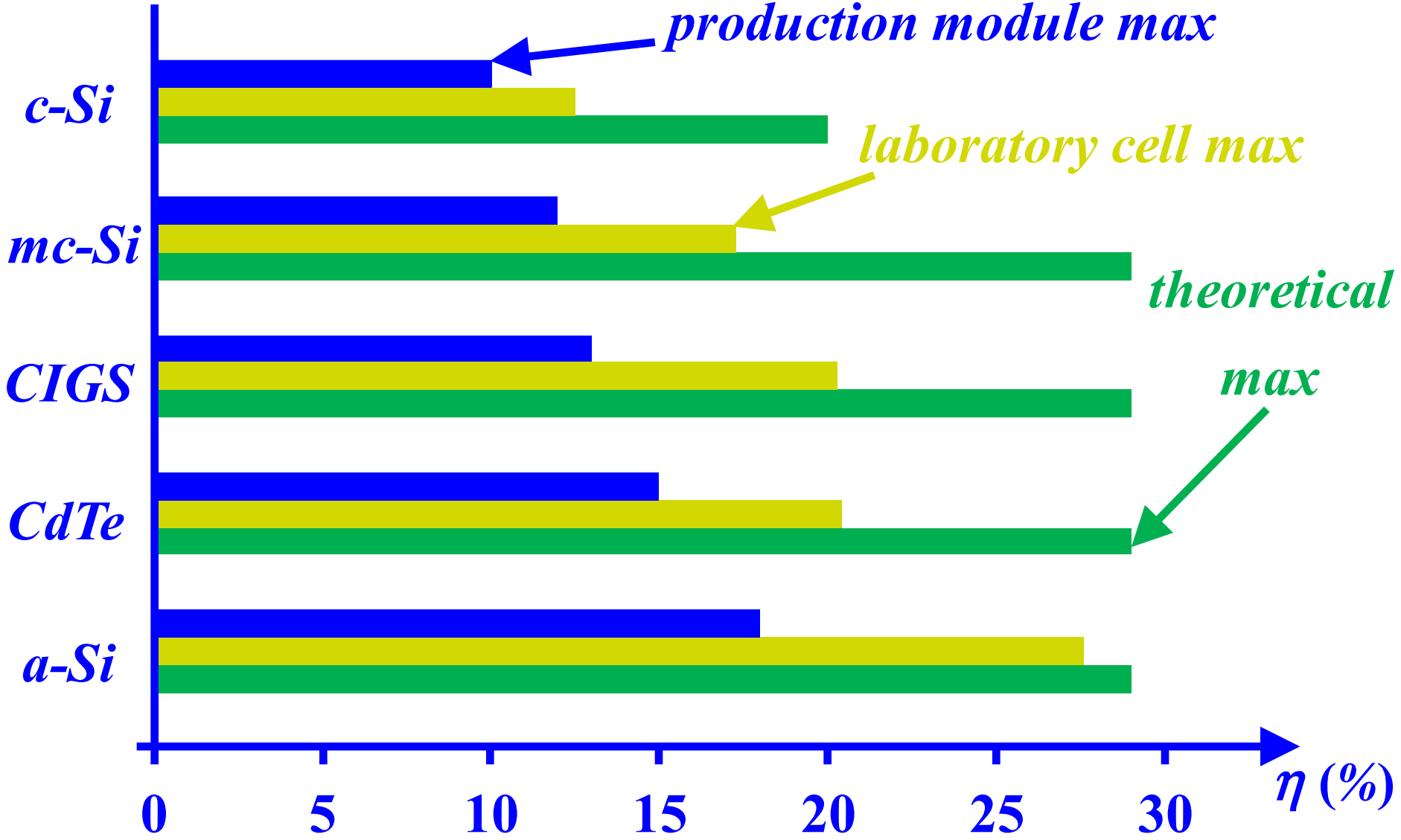
DOE SOLAR PROGRAM GOALS

- The *US* Department of Energy *Sunshot Initiative* is a national collaborative effort to make solar energy cost–competitive with fossil–fired generation technology by the end of this decade
- The goals for *PV* by 2020 are 4 – 5 ¢/*kWh* in the residential sector, 5 – 6 ¢/*kWh* in the commercial sector, and 4 – 6 ¢/*kWh* in the utility sector

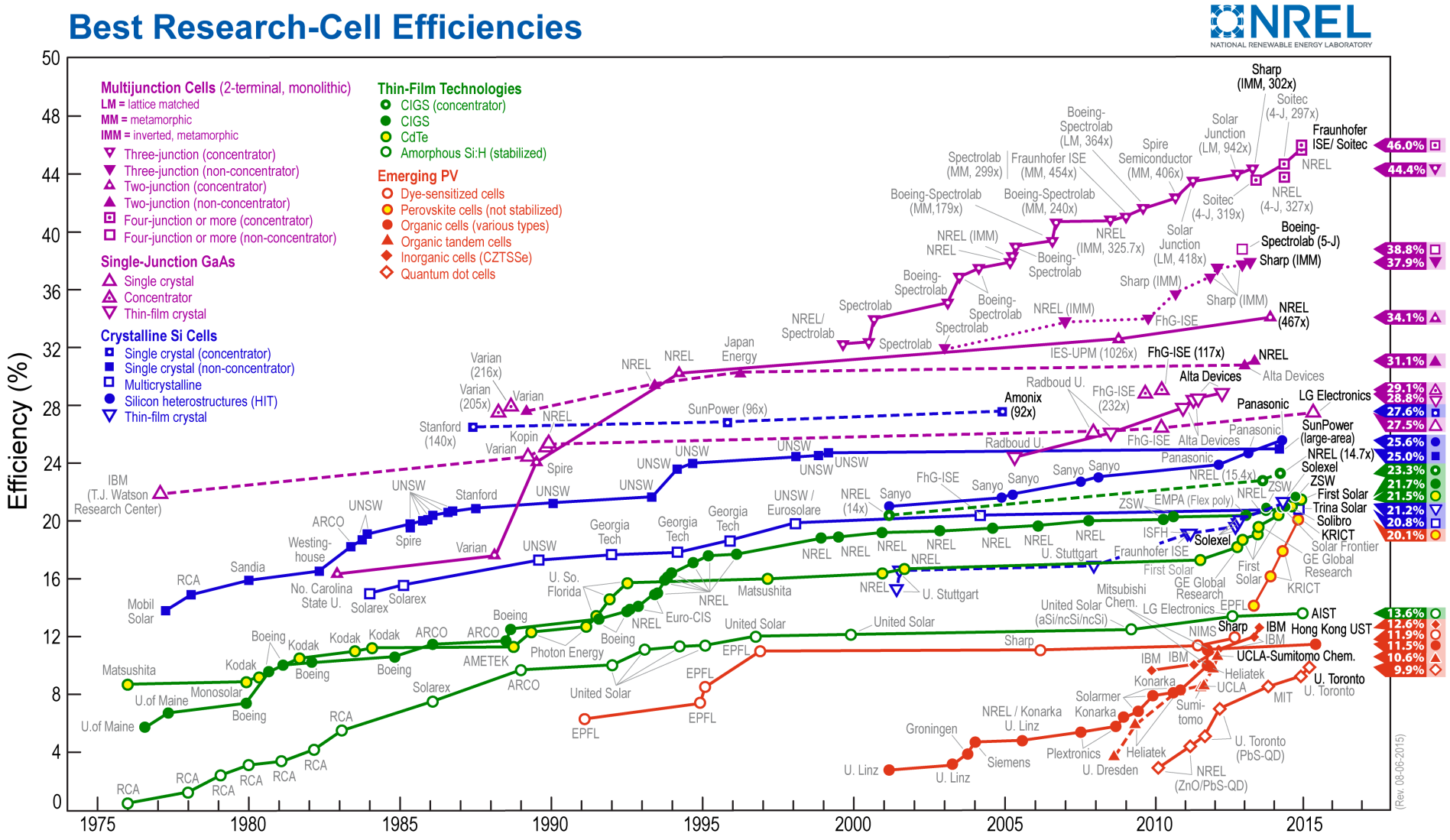
PV DEVELOPMENT CHALLENGES

- The efficiency of typical *PV* modules used in energy production is still rather low
- Solar energy is highly uncertain, variable and intermittent renewable resource and the *PV* system electricity production has limited controllability and dispachability

PV EFFICIENCY BY MATERIAL

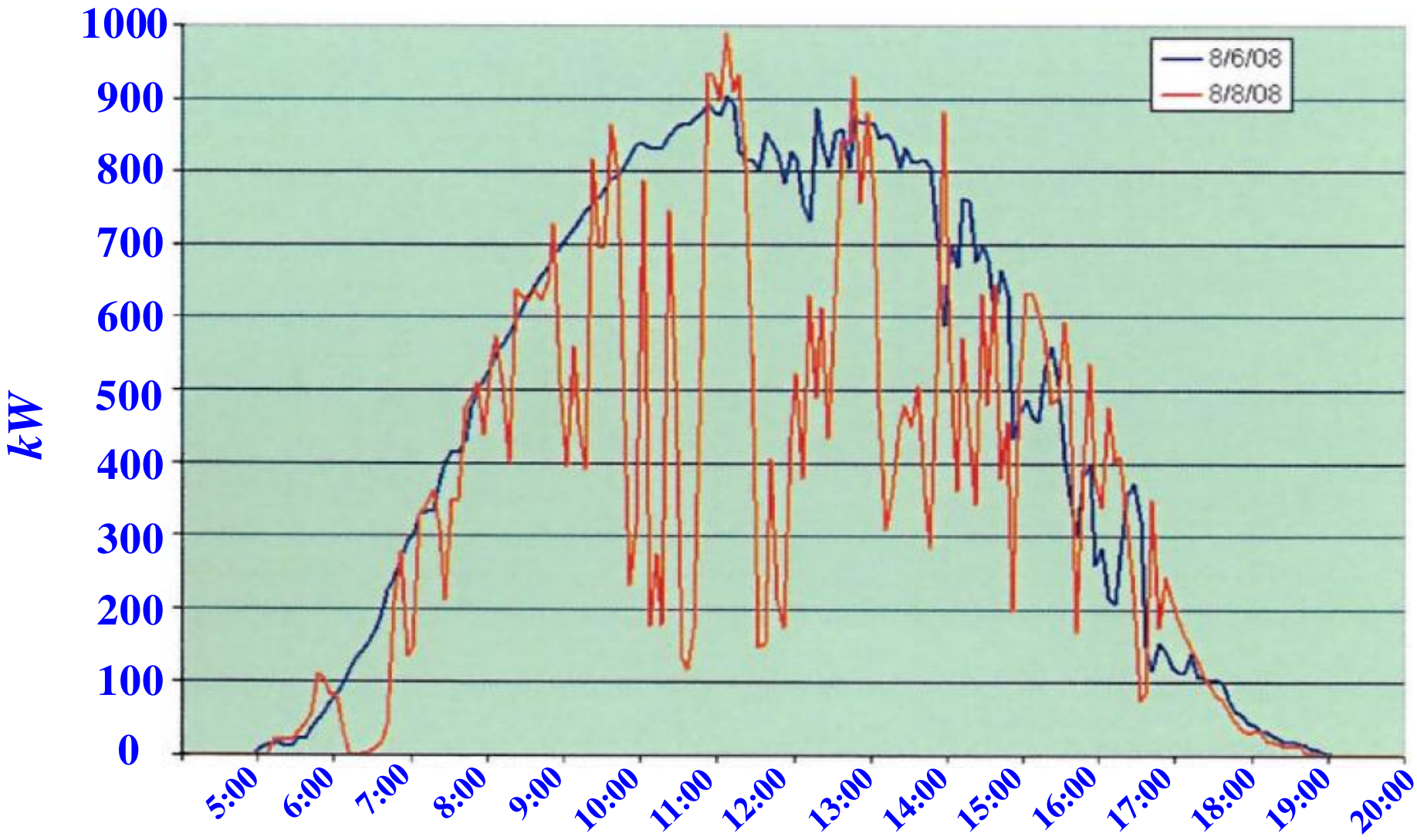


PV EFFICIENCY BY MATERIAL



Source: https://c1cleantechnicacom-wpengine.netdna-ssl.com/files/2014/02/efficiency_chart.png

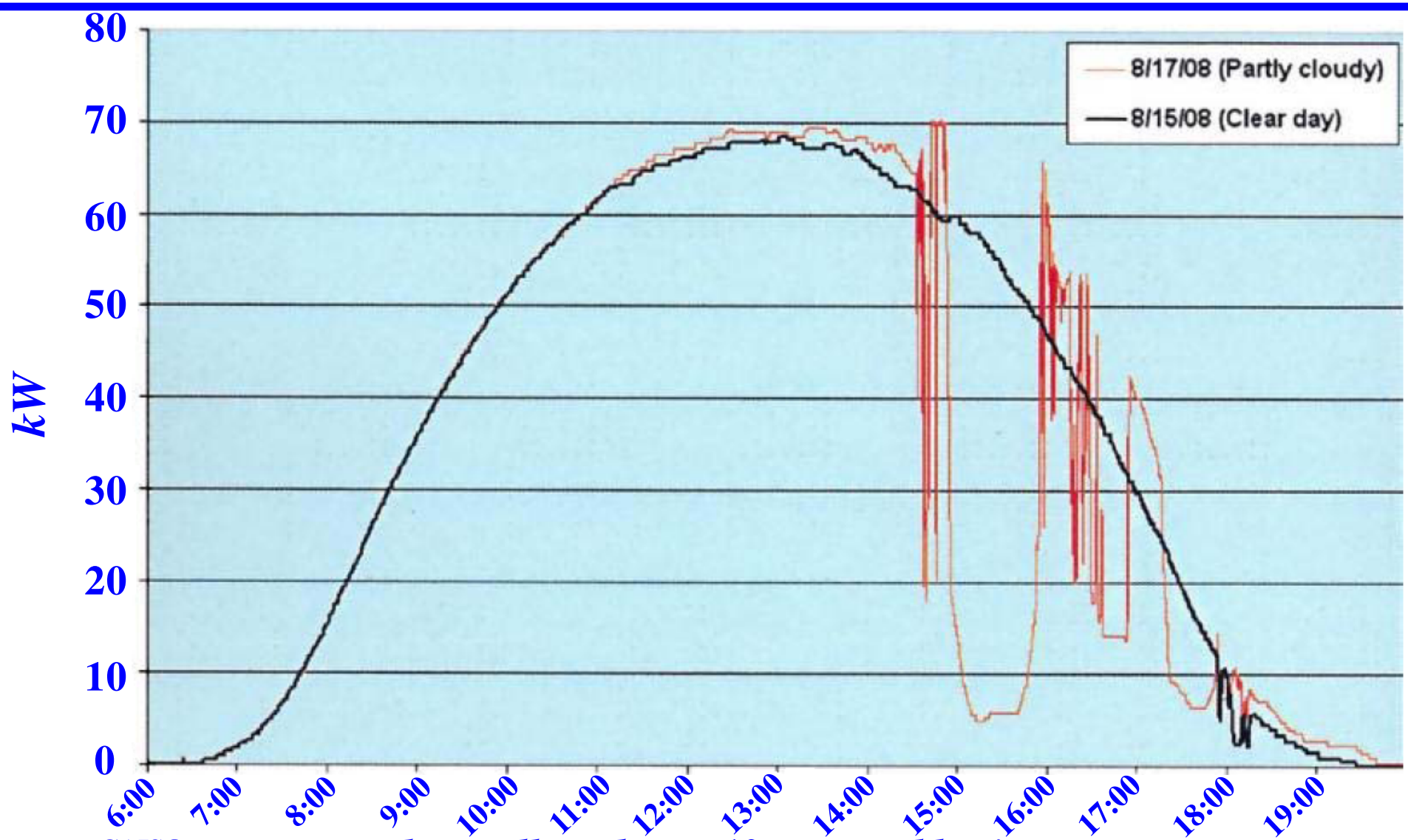
PV POWER OUTPUT OF 1 – *MW CdTe* ARRAY IN GERMANY



source: CAISO

samples collected on a 5 – minute basis

PV POWER OUTPUT AT THE NEVADA 70 *kW* POLYCRYSTALLINE ARRAY

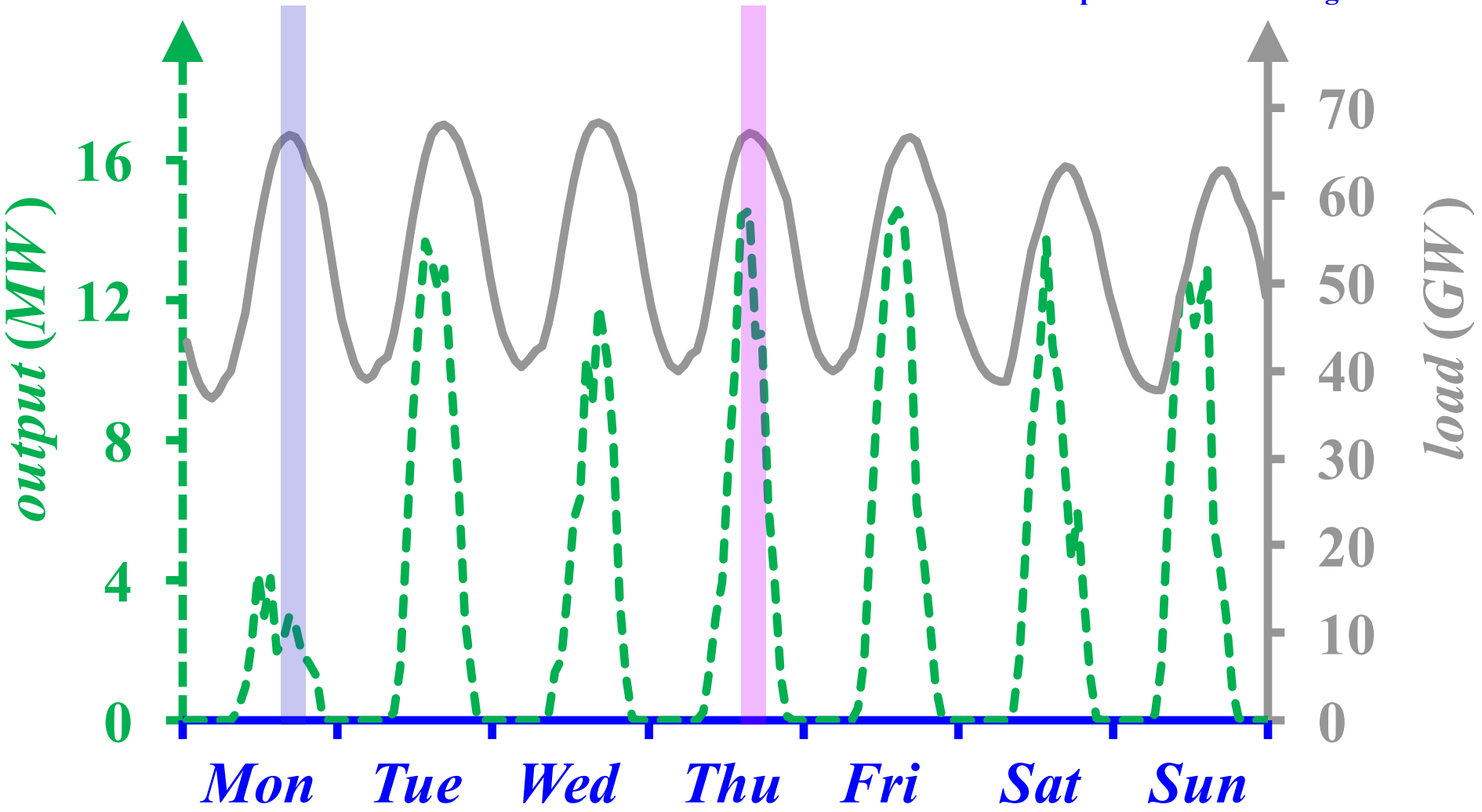


source: CAISO

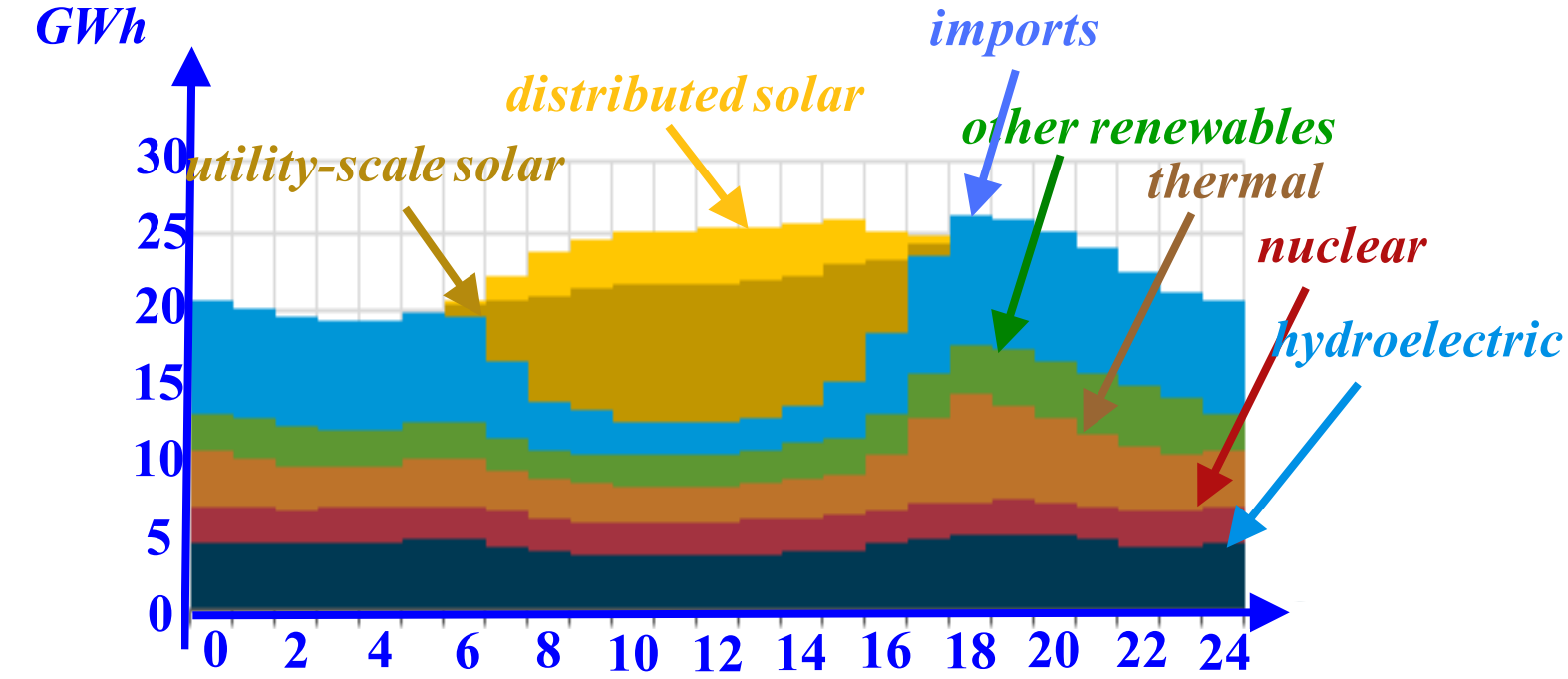
data collected on a 10 – second basis

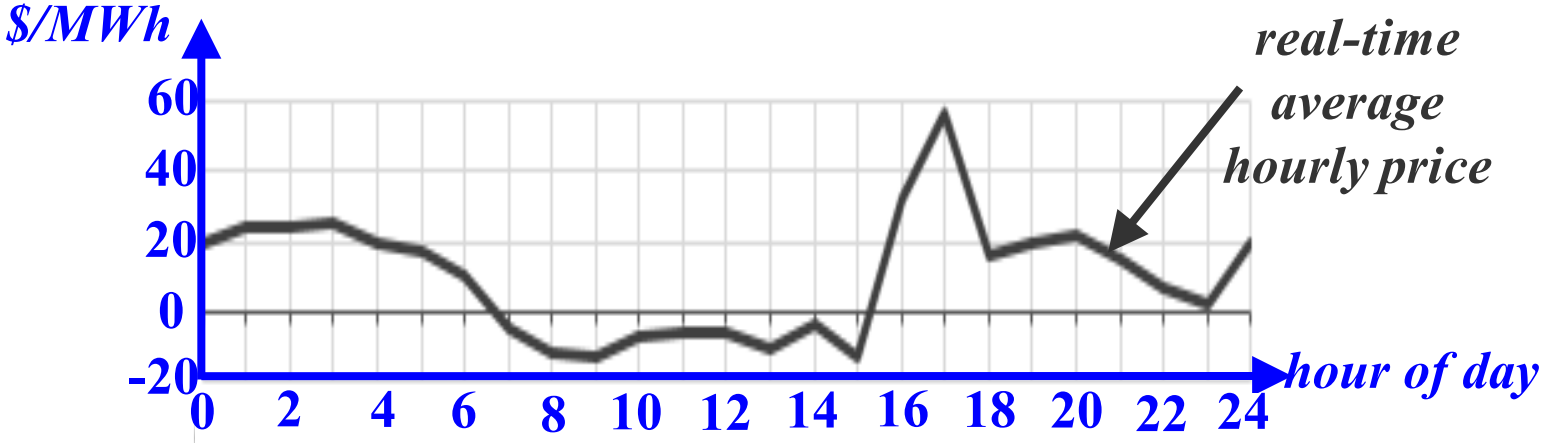
CHRONOLOGICAL *PV* OUTPUT AND *ERCOT* LOAD PATTERNS

source: ttp://www.ercot.com/gridinfo/



IMPACTS OF *CALIFORNIA* ROOFTOP SOLAR





Source: US EIA based on https://www.eia.gov/electricity/data/eia861m/index.html

