ECE 333

Green Electric Energy

Lecture 23

PV Status and Issues

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Slides Courtesy of Prof. George Gross

OUTLINE

- PV solar system status
- PV technology benefits
- Key drivers of the PV system growth
- PV system installation costs
- Major challenges in PV solar resource integration

2018 WORLD STATUS OF PV SOLAR RESOURCES

- More than $102\ GW$ of new capacity additions have increased the global cumulative PV capacity to over $509\ GW$
- The *Asia-Pacific* region with more than $295\ GW$ is now the world's leading region in terms of total installed capacity – about $58\ \%$ of the global PV capacity

2018 WORLD STATUS OF *PV* SOLAR RESOURCES: *EUROPE*

- European *PV* investment picked up in 2018 after a downward trend for the last few years – primarily due to Turkey's additions to *PV* capacity
- 11.3 *GW* of *PV* capacity were connected to the grid in Europe with Turkey leading with 1.6 *GW*
- The top 5 nations in compounded annual growth rate are *Ireland* (121 %), *Poland* and *Portugal* (tied at 47 %), *Russia* (40 %) and *Netherlands* (37 %)

2018 WORLD STATUS OF PV SYSTEMS

- $China$, US and $India$ were the top three nations in terms of PV capacity additions in 2018
- $China$ installed 44.4 GW of PV, a decrease of 16 $\%$ from the 52.8 GW installed in 2017
- The US solar power capacity additions remained stable at 10.6 GW in 2018 , same as in 2017
- In $India$, 8.3 GW of PV capacity was installed, a decrease of 16 $\%$ from 9.6 GW in 2017

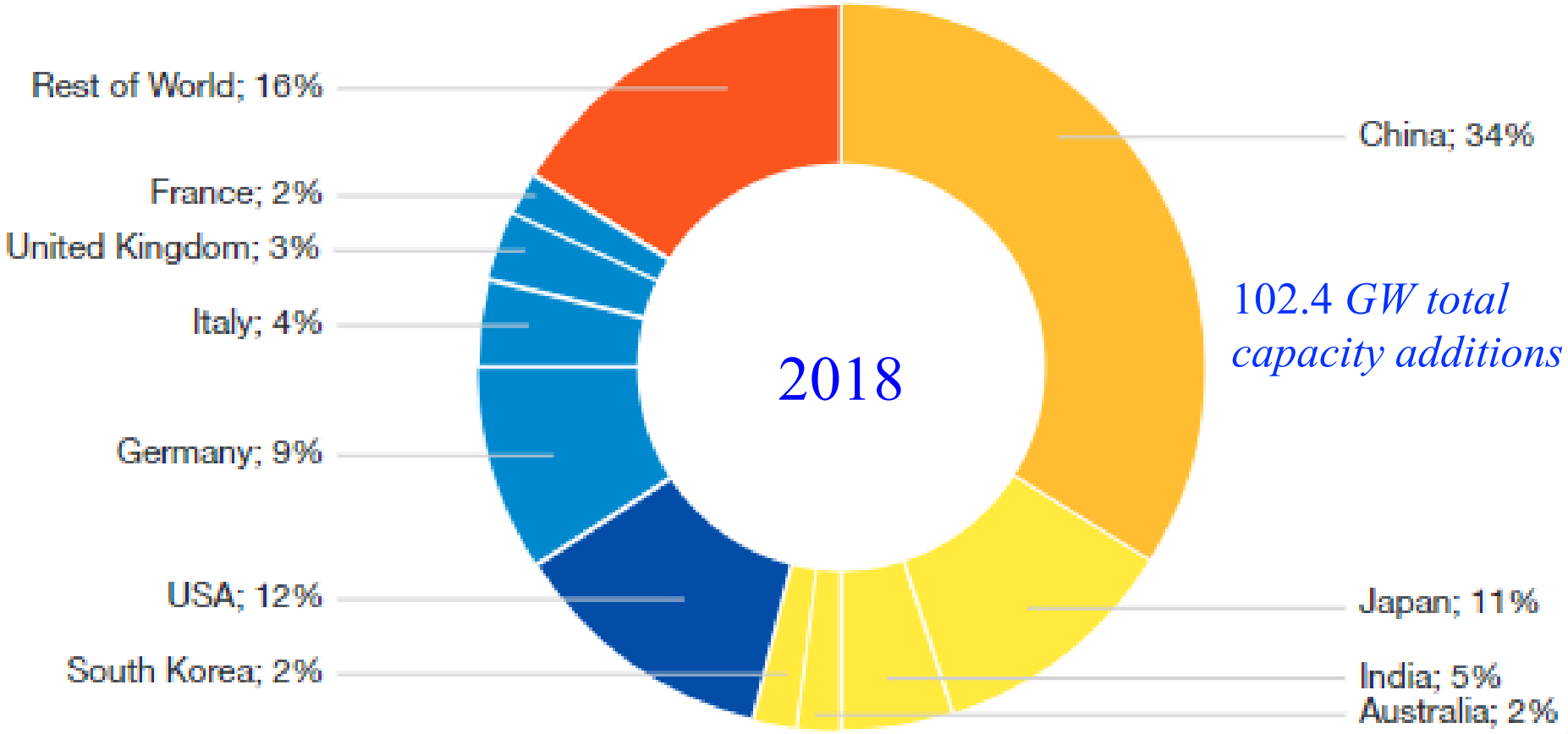
2018 SOLAR ENERGY STATUS

- The global PV cumulative capacity reached $509.3\ GW$ in 2018
- The addition of $102.4\ GW$ repre–sents a $25\ \%$ growth over the cumulative global capacity in 2017 and a 32 fold increase since 2008
- $China$ installed $44.4\ GW$ to continue as the largest solar capacity nation in the world
- $Europe$'s share at $25\ \%$ of the global PV capacity represents a cumulative total of $125.8\ GW$

Lakelands Park Middle School, MD hosts a $111\ kW$ rooftop system

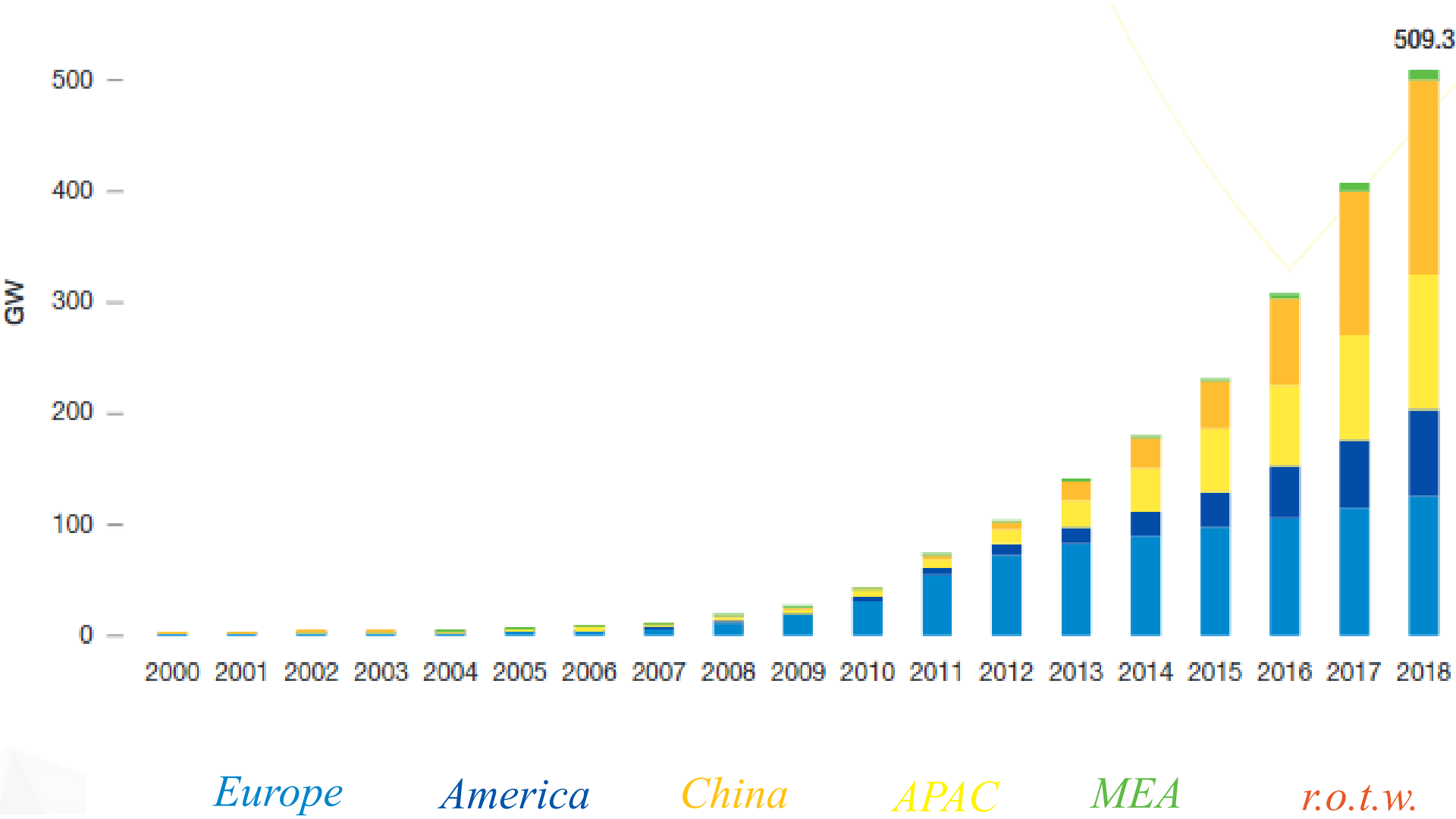
2018 *PV* SOLAR CAPACITY ADDITIONS: TOP 10 COUNTRIES

Source: *SolarPower Europe Global Market Outlook* 2019-2023

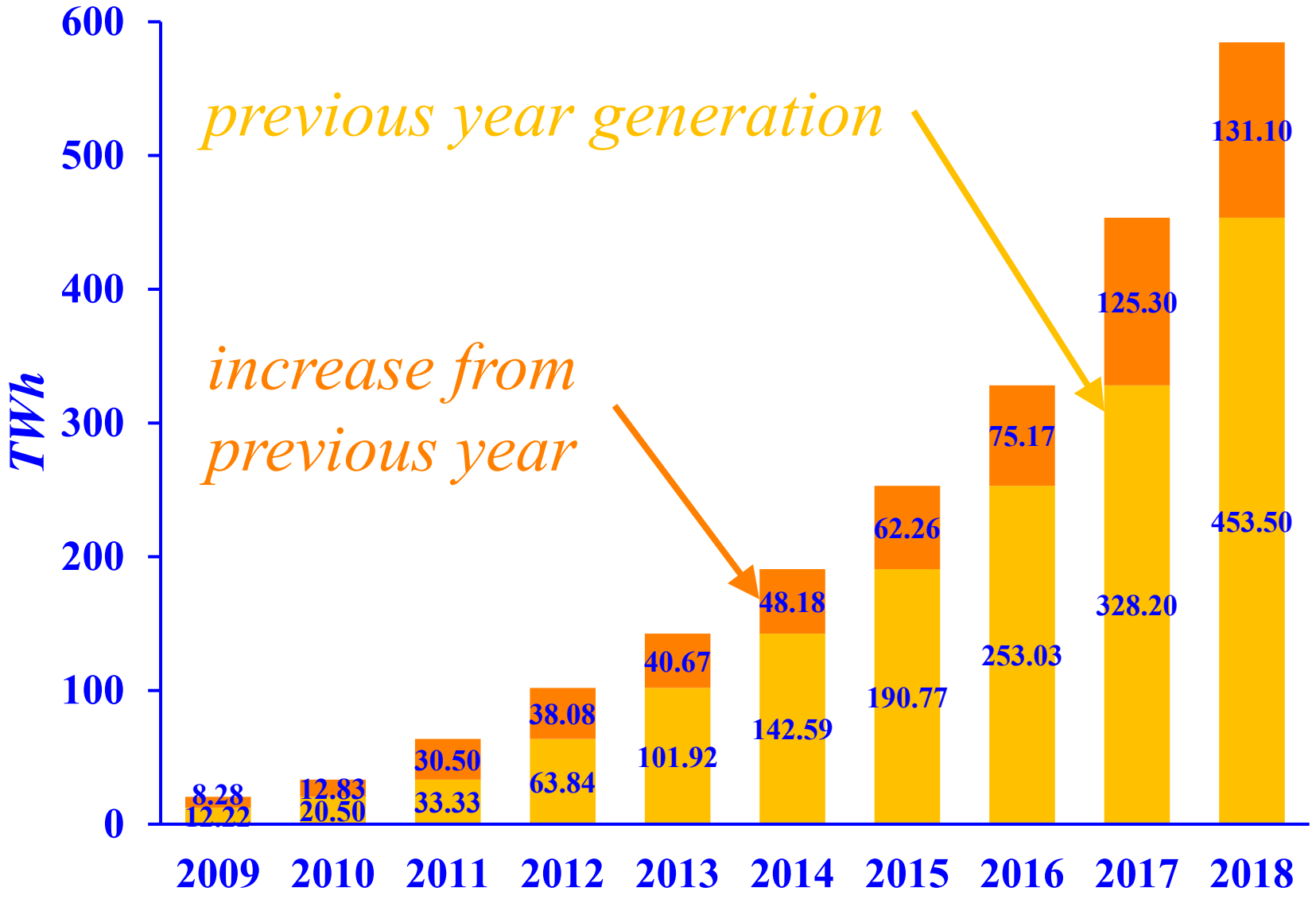


GLOBAL CUMULATIVE PV SOLAR CAPACITY BY REGION: 2000 – 2018

***Source*: *SolarPower Europe Global Market Outlook* 2019-2023**

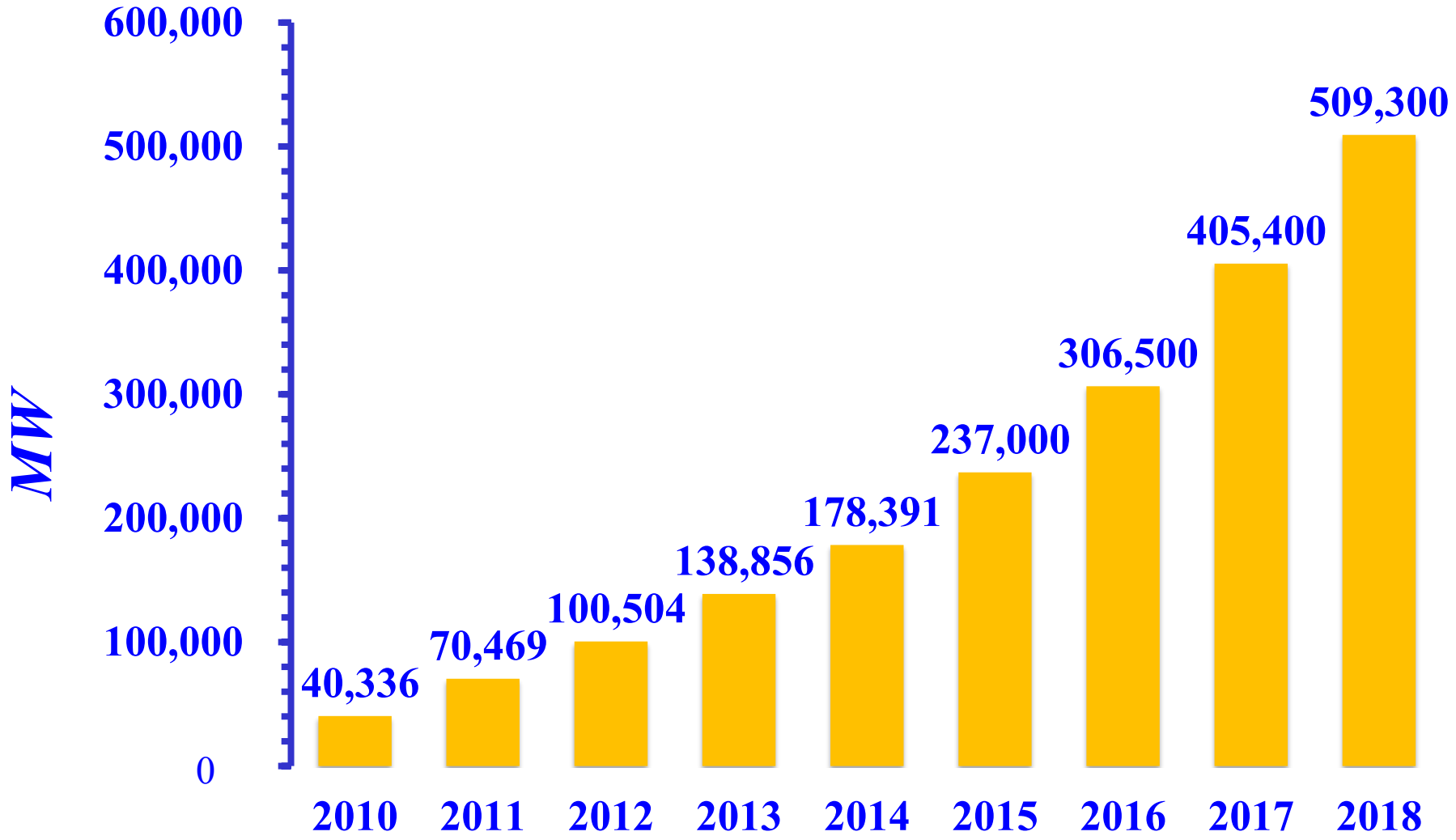


2009 – 2018: GLOBAL *PV* ELECTRICITY GENERATION

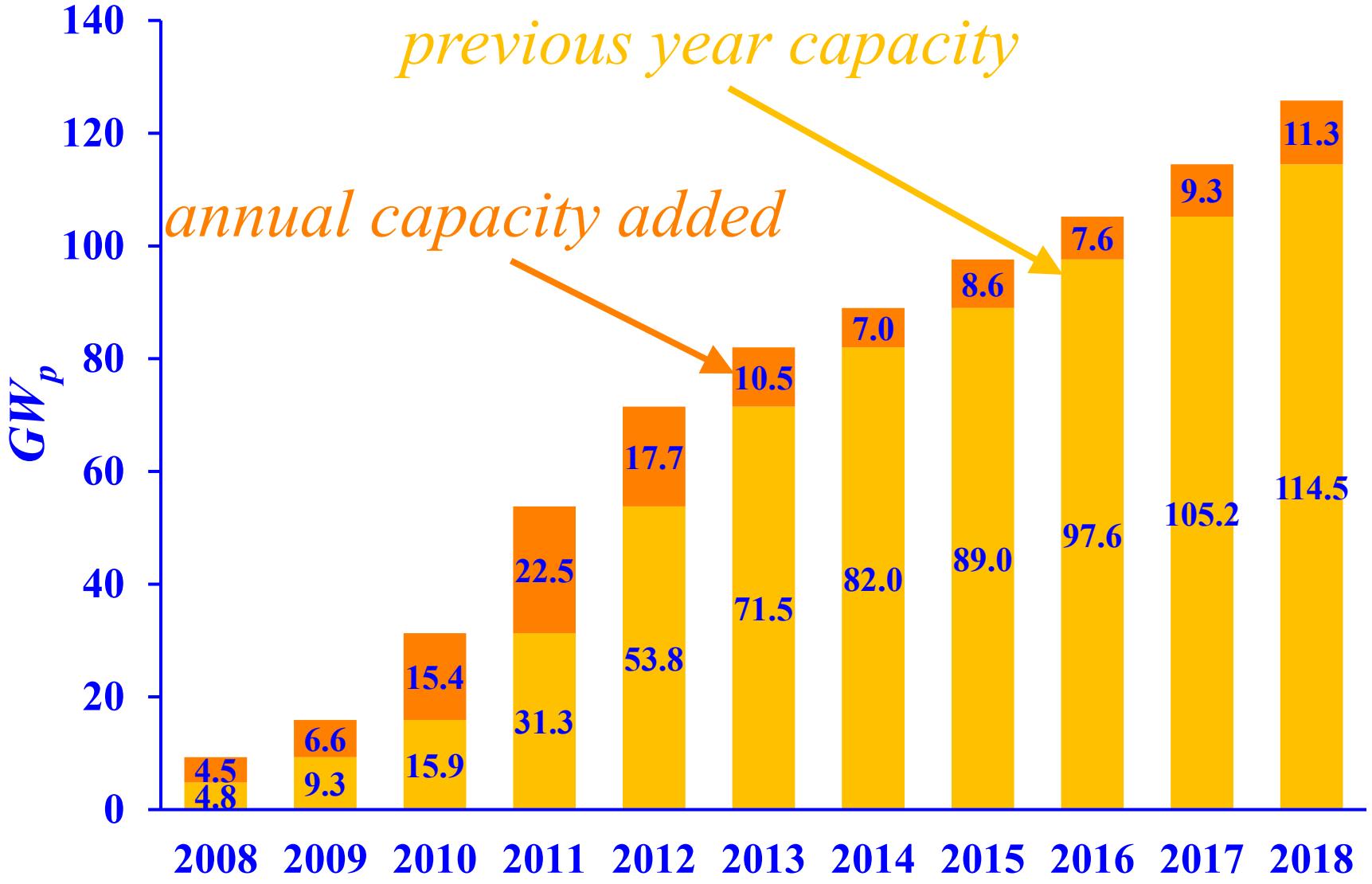


Source: BP Statistical Review of World Energy 2019, pg. 52; https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2019-full-report.pdf

2010 – 2018 GLOBAL CUMULATIVE *PV* CAPACITY

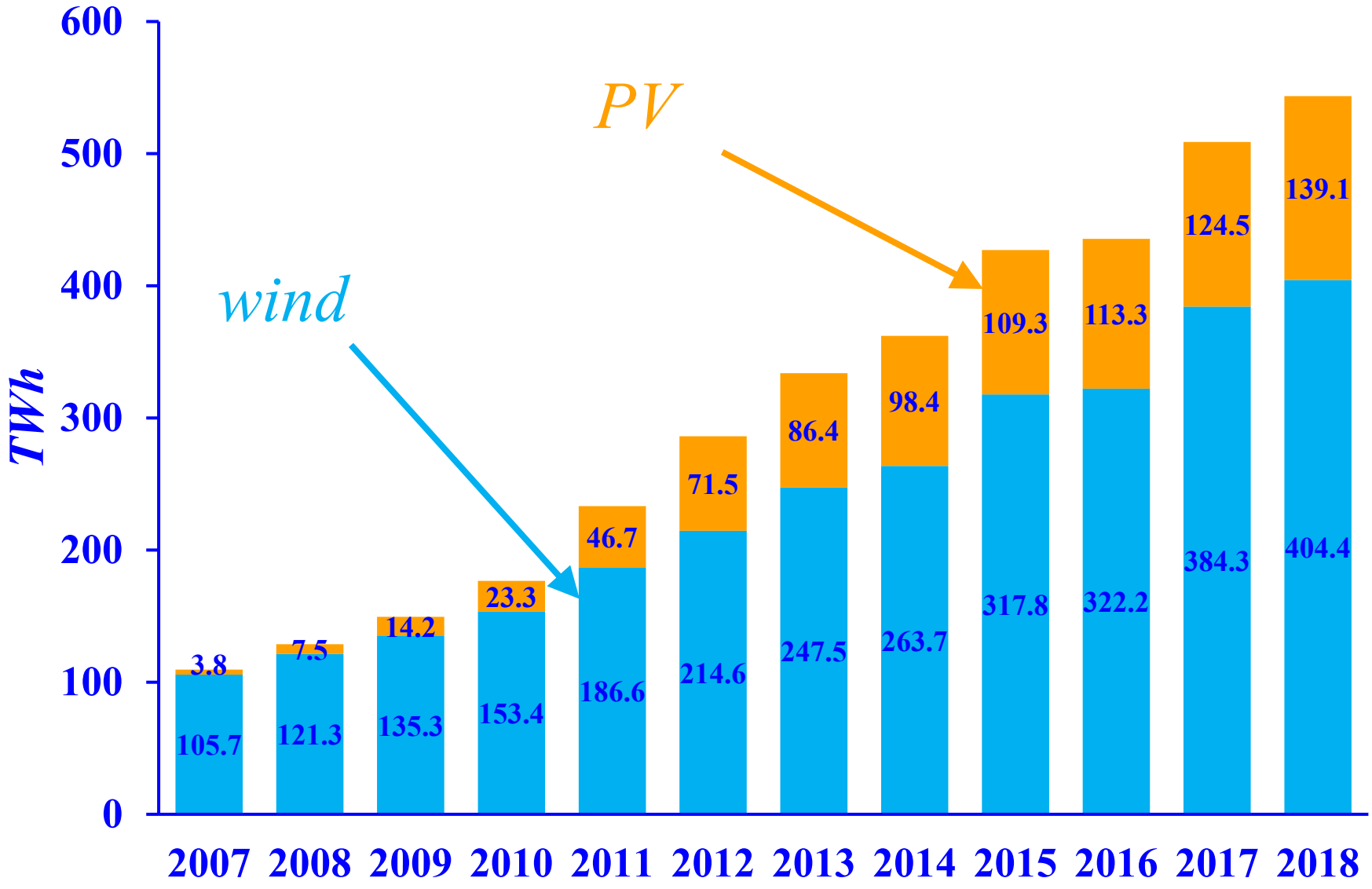


2008 – 2018 *EUROPEAN PV* ANNUAL CAPACITY ADDITIONS



Source: Global Market Outlook for Solar Power 2018-2023. pg. 80; http://www.solarpowereurope.org/wp-content/uploads/2019/05/SolarPower-Europe-Global-Market-Outlook-2019-2023.pdf

2007 – 2018 EUROPEAN ELECTRICITY GENERATION FROM WIND AND *PV*



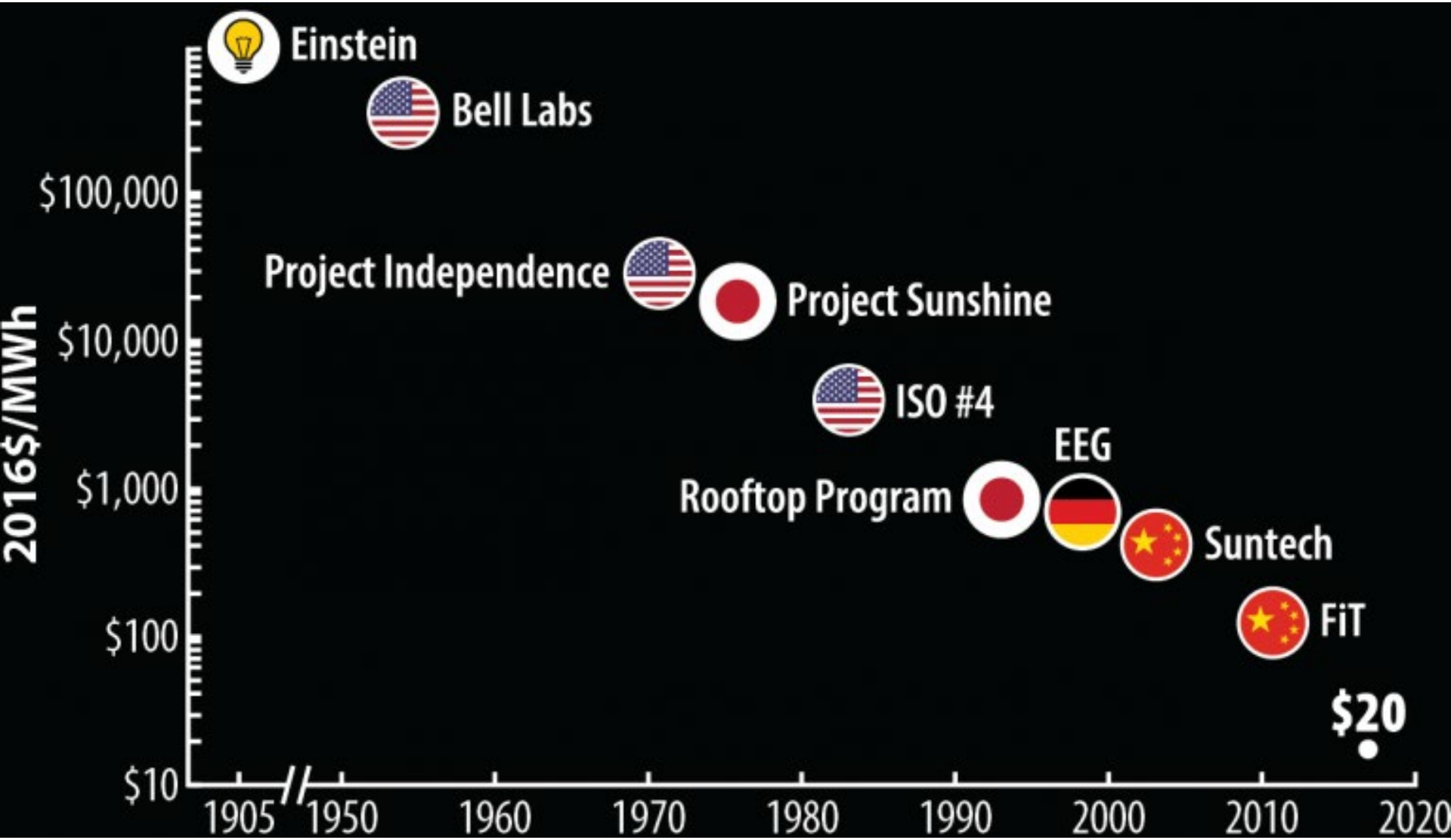
Source: BP Statistical Review of World Energy 2019, pg. 52; https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2019-full-report.pdf

ECEB SOLAR PANELS

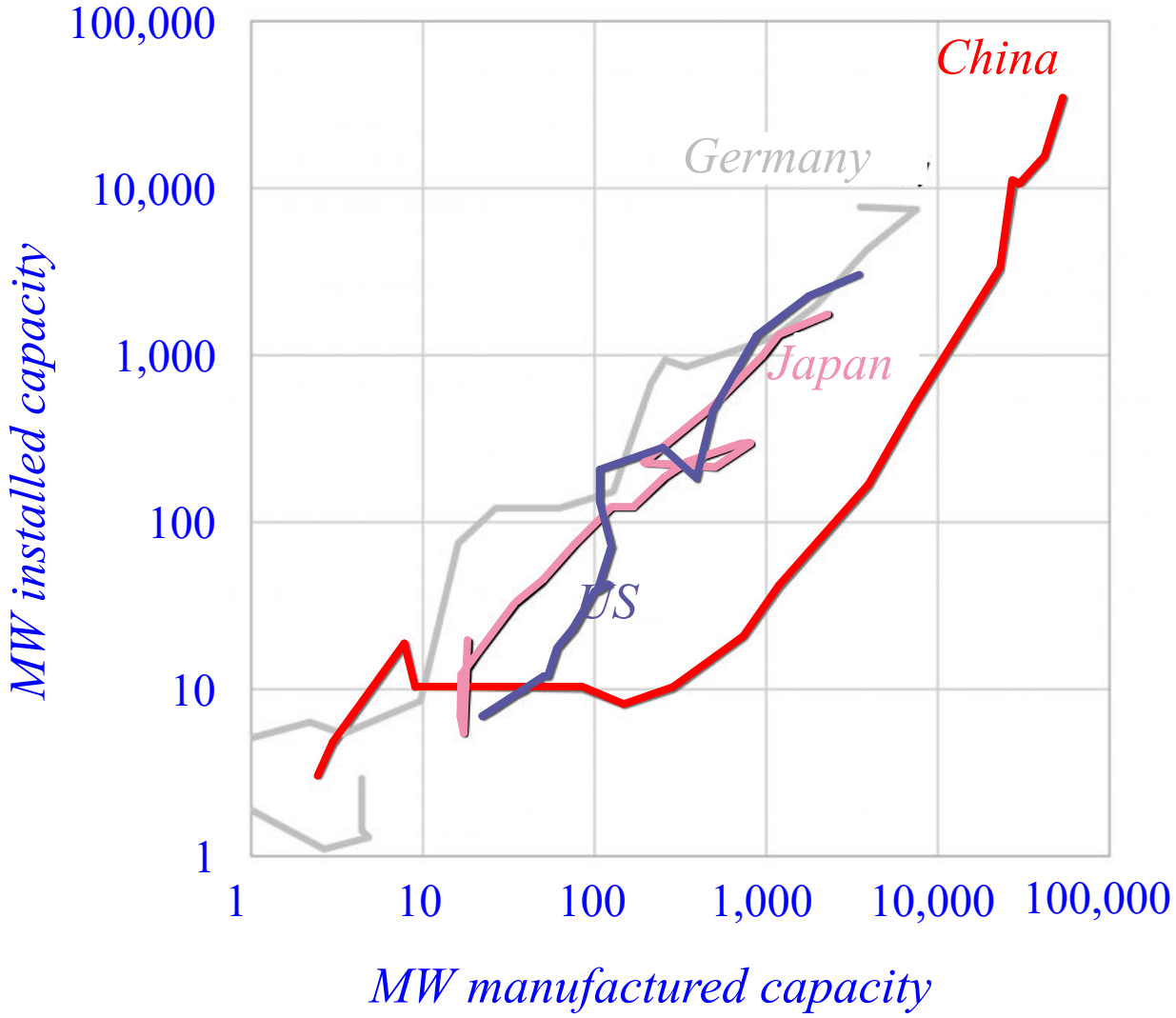
Source: *Stephen Haas/News-Gazette Archives, May 22, 2009*

THE WAY SOLAR BECAME SO CHEAP

Source: *Gregory F. Nemet, "How Solar Energy Became Cheap," Routledge,* 2018

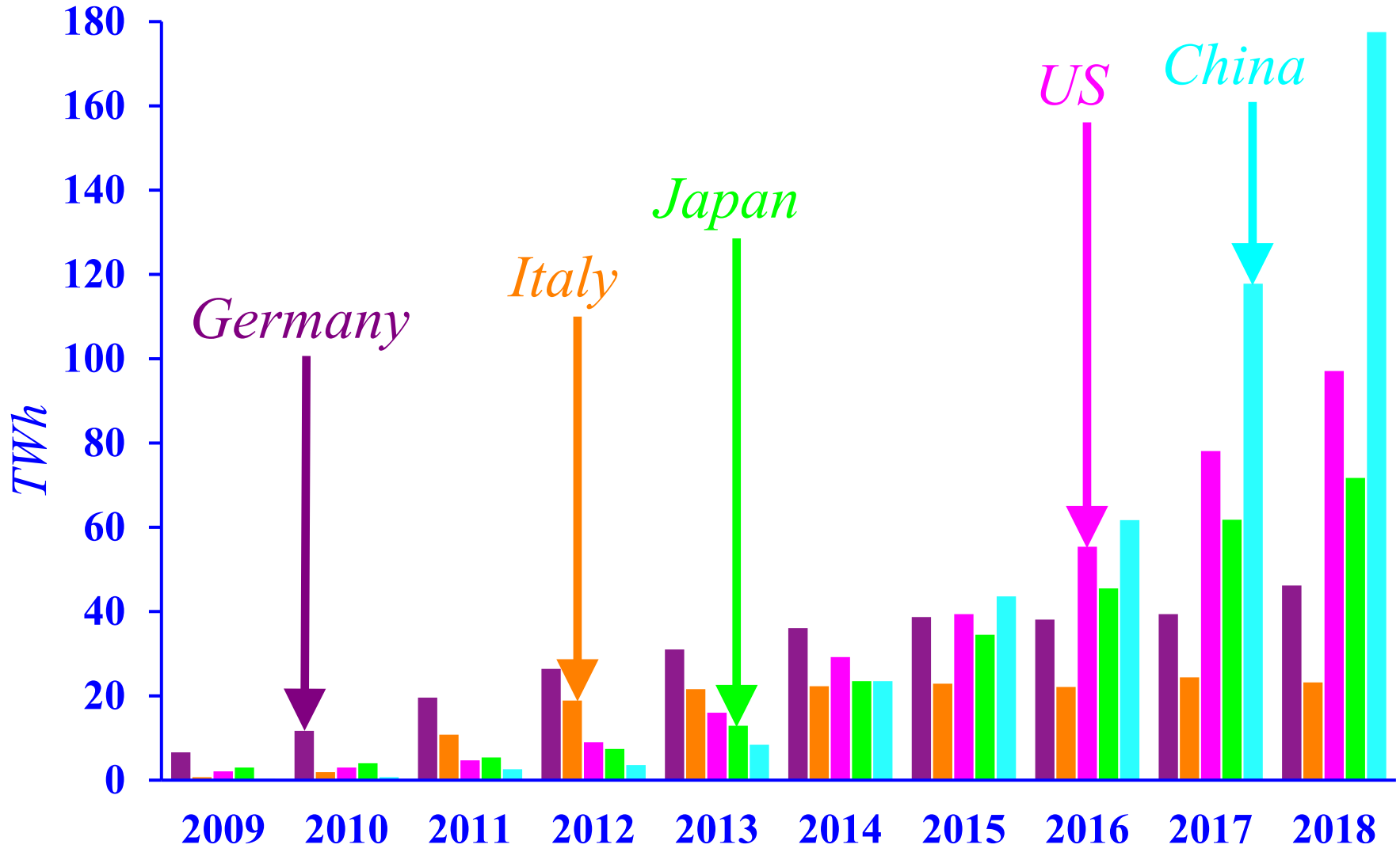


SOLAR PANEL PRODUCTION AND INSTALLATION IN 4 NATIONS



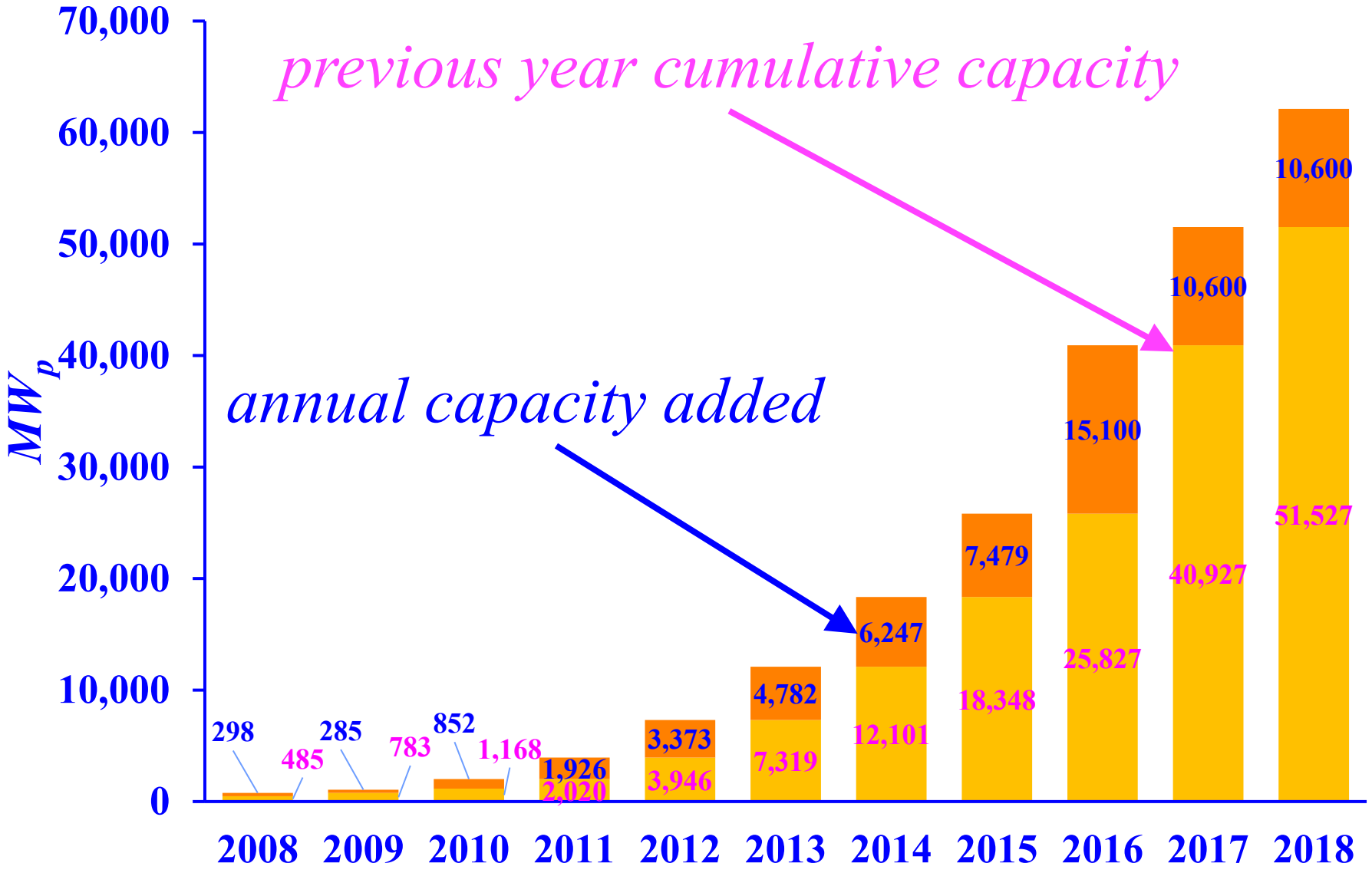
Source: *Gregory F. Nemet, "How Solar Energy Became Cheap," Routledge, 2018*

2009 – 2018: *PV* ELECTRICITY GENERATION BY LEADING NATIONS



Source: BP Statistical Review of World Energy 2019, pg. 52; https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2019-full-report.pdf

2008 – 2018 *US* CUMMULATIVE INSTALLED *PV* CAPACITY



Source: Global Market Outlook for Solar Power 2018-2023. pg. 11; http://www.solarpowereurope.org/wp-content/uploads/2019/05/SolarPower-Europe-Global-Market-Outlook-2019-2023.pdf

THE 2018 STATUS OF US PV SYSTEMS

- US is a small, but growing, player in the global solar capacity and energy arena
- The 2018 US cumulative PV capacity increased to roughly 62.1 GW, with 10.6 GW of new PV capacity added in 2018
- The 10.6 GW PV capacity installed in 2018 was over 14 times the 2009 amount of installed PV capacity

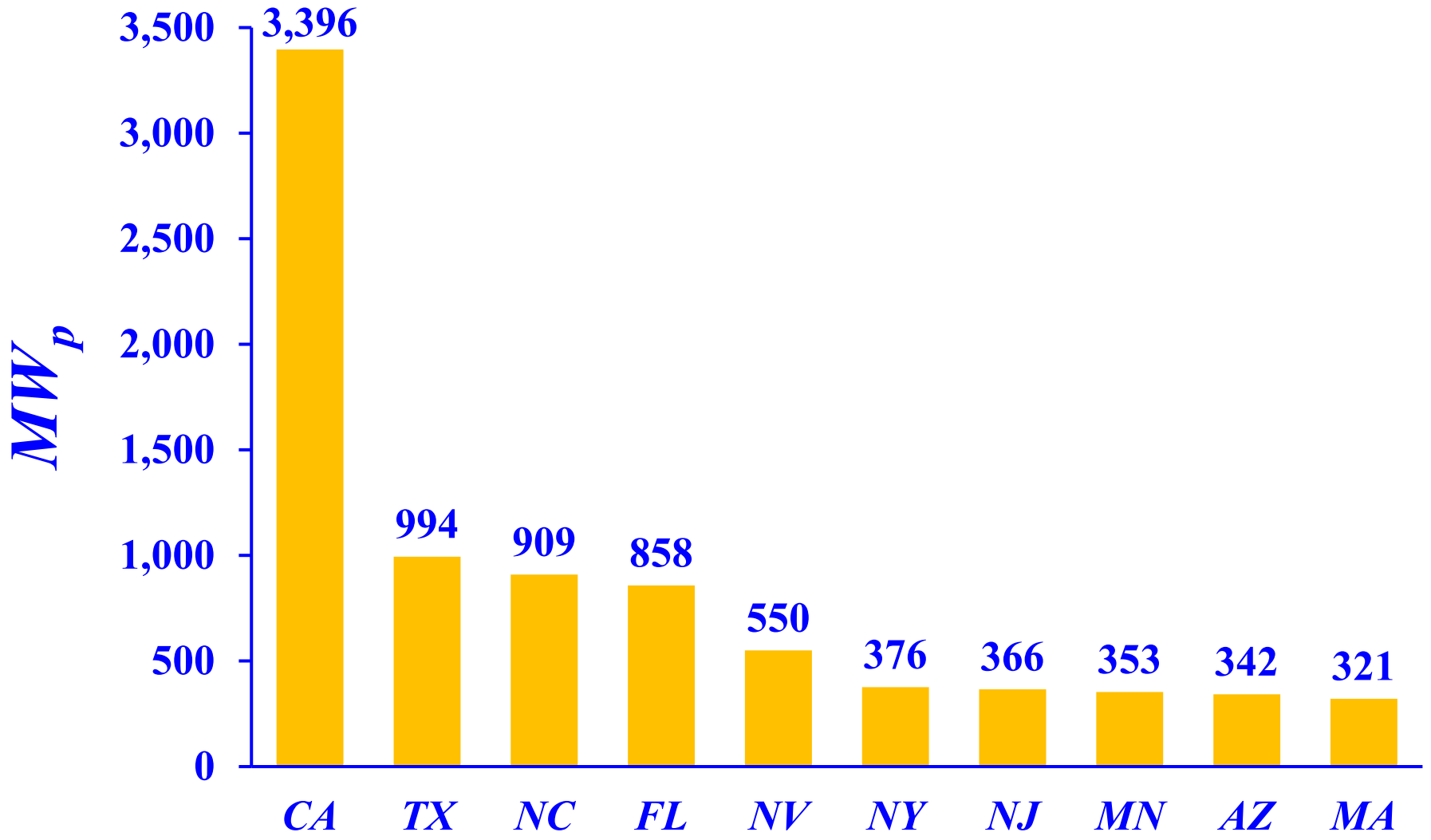
US SOLAR ENERGY IS BOOMING

- *PV* solar installation costs fell $70\ \%$ since 2010
- The community solar grew $107\ \%$ from $734\ MW$ in 2017 to $1{,}523\ MW$ in 2018
- Conformance with state *RPS* requirements is no longer as key a driver, as many new projects are corporate procurements of off–site solar projects, typically, via various *PPA* mechanisms

2018 *US* STATUS OF *PV* SYSTEMS BY STATES

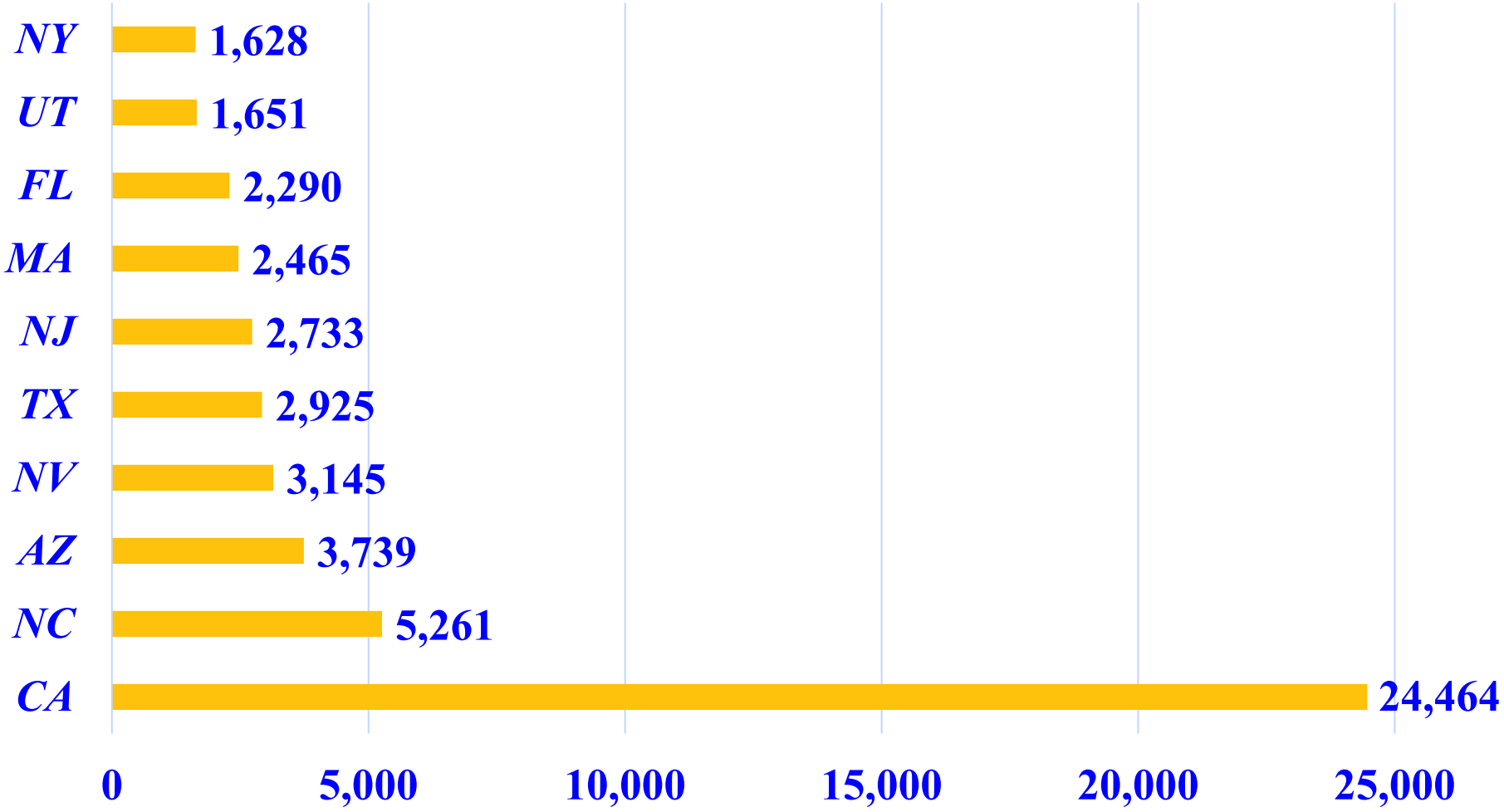
- Nearly 1/3 of the *US PV* capacity installations were in *CA*
- *CA, NC* and *AZ* account for nearly 54 % of the cumulative *PV* capacity in the *U.S.*
- The solar industry in *NC* is growing rapidly, due, in part, to the state's *Renewable Energy and Energy Efficiency Portfolio Standard (REPS)*

US TOP 10 STATES WITH LARGEST *PV* CAPACITY ADDITIONS IN 2018



Source: https://www.seia.org/states-map

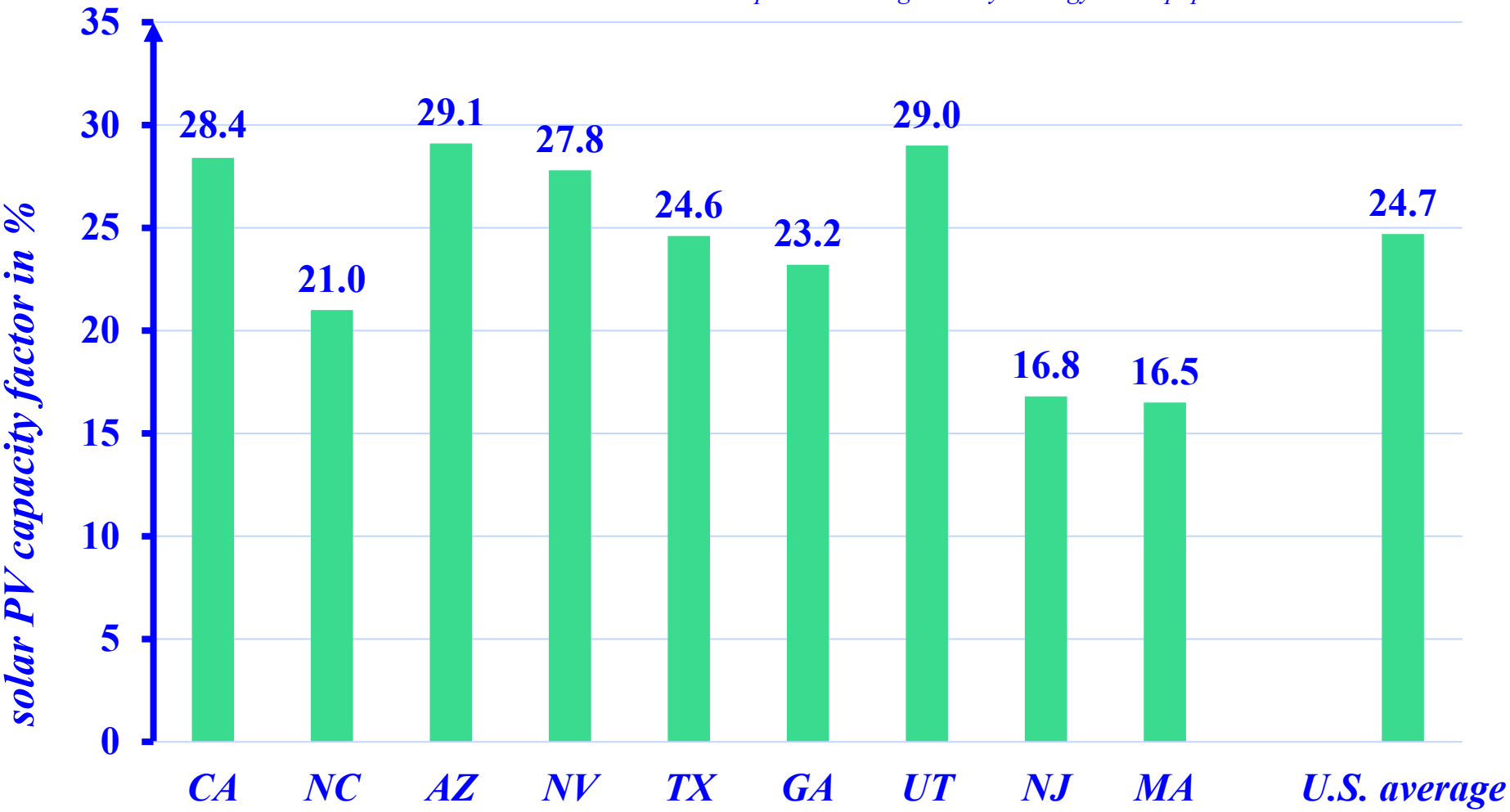
TOP 10 STATES WITH INSTALLED SOLAR *PV* CAPACITY IN 2018



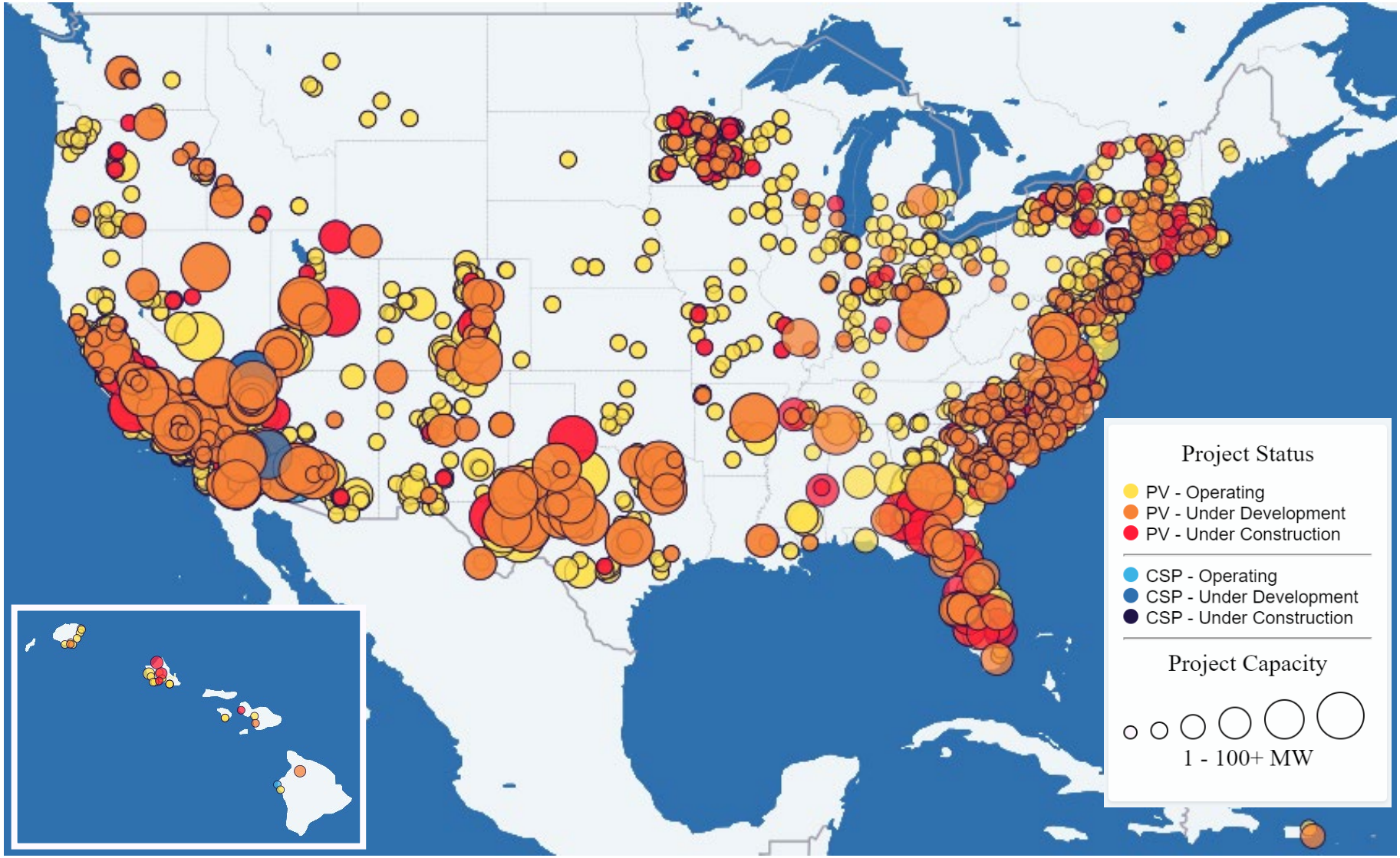
Source: 2018 data, available at https://www.seia.org/solar-industry-research-data

US UTILITY–SCALE *PV* SOLAR CAPACITY FACTORS : 2014 – 2017

Source: *EIA, Annual Electric Generator Inventory and Annual Electric Utility Data, available at https://www.eia.gov/todayinenergy/detail.php?id=39832*



2019 *US* UTILITY – SCALE SOLAR PROJECTS



Source: 2019 data; https://www.seia.org/research-resources/major-solar-projects-list

THE 2019 FIVE LARGEST *US PV* INSTALLATIONS

plant	*location*	*capacity (MW)*	*year built*	*owner*	*electricity purchaser*
Solar Star	*Rosamond, CA*	579	2015	*BHE Renewables*	*SCE*
Copper Mountain Solar Facility	*Boulder City, NV*	552	2016	*Sempra Generation*	*PG&E & SC Public Power Authority*
Desert Sunlight Solar Farm	*Riverside County, CA*	550	2015	*NextEra, Sumitomo*	*PG&E & SCE*
Topaz Solar Farm	*San Luis Obispo, CA*	550	2014	*Berkshire Hathaway Energy*	*PG&E*
Mount Signal Solar	*Calexico, CA*	460	2018	*8minutenergy Renewables*	*SCE & SD Gas & Electric*

Source: https://en.wikipedia.org/wiki/List_of_photovoltaic_power_stations

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* became the world's largest solar farm in terms of capacity from the 1.7 *million* solar panels installed 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
- 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

LONGYANGXIA DAM SOLAR PARK

Source: //http://www.chinadaily.com.cn/m/powerchina/2014-01/02/content_17210451.htm

LONGYANGXIA DAM SOLAR PARK

- The world's largest *PV* plant is the 850-*MW* *Longyangxia Dam Solar Park*, which is located in, *Qinghai* Province, *China*
- Construction began in March 2013 and the first phase of the project (530 *MW*) was commissioned on December 4, 2013
- The second phase of the project was completed in 2015
- The expected annual generation is 824 *GWh*

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 *PV* SOLAR

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

ROOFTOP PV SOLAR IN US

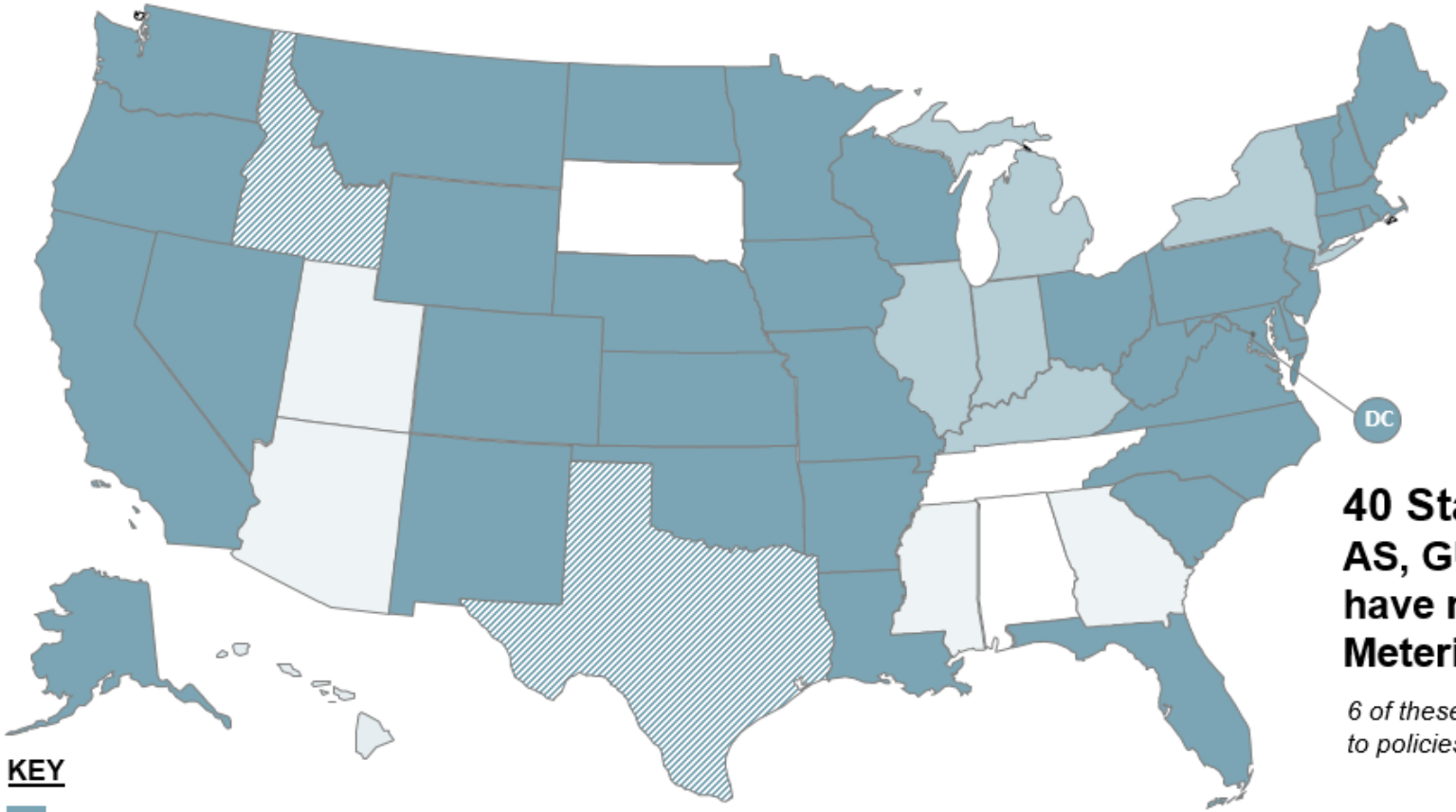
- Rooftop solar electricity still represents a small portion of US electricity generation
- Residential solar continues its rebound, growing $3\ \%$ *quarter-over-quarter* and $8\ \%$ *year-over-year*; $Q2$ 2019 was the fourth consecutive quarter of more than $600\ MWdc$ of installed residential capacity
- Government incentives to promote solar energy have led to widespread rooftop solar in the Western states – CA, AZ, CO and NV

ROOFTOP *PV* SOLAR IN *US*

- Location–dependent incentives for utility customers to install rooftop solar panels vary from state to state and include tax credits, installation cost rebates and *net metering*
- At present 43 states, the *District of Columbia* and 3 territories offer net metering

US NET METERING STATUS

Source: DSIRE 2019, available at https://s3.amazonaws.com/ncsolarcen-prod/wp-content/uploads/2019/07/DSIRE_Net_Metering_April2019.pdf



40 States + DC, AS, GU, PR, & USVI have mandatory Net Metering rules

6 of these states are in transition to policies other than net metering

KEY

- State-developed mandatory rules for certain utilities (40 states + DC+ 4 territories)
- In transition to statewide distributed generation compensation rules other than net metering (6 states)
- Statewide distributed generation compensation rules other than net metering (5 states)
- No statewide mandatory rules, but some utilities allow net metering (2 states)

U.S. Territories:

AS PR VI GU

NET METERING

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

KEY PV BENEFITS

- Residential and commercial PV system installations reduce the amount of electricity these 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 and use of the expensive and polluting fossil generation units

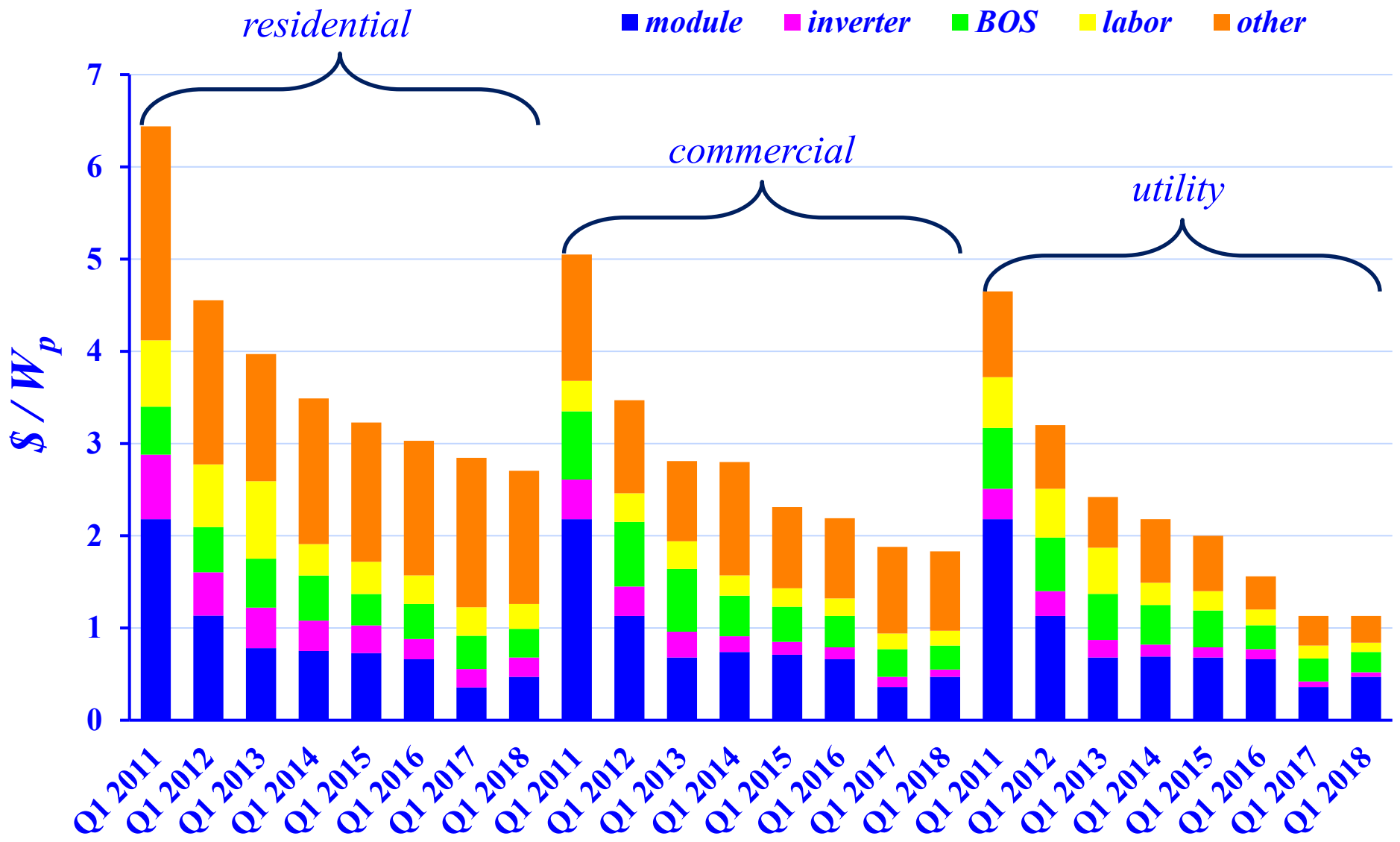
KEY PV BENEFITS

- PV systems are important supply resources that lessen the nation's dependence on fossil fuels
- The clean PV–generated electricity helps reduce the amount of GHG – a major contributor to global climate change
- The growing PV industry provides local jobs and economic development opportunities to states and regions to create sustainable paths to meet the nation's energy needs

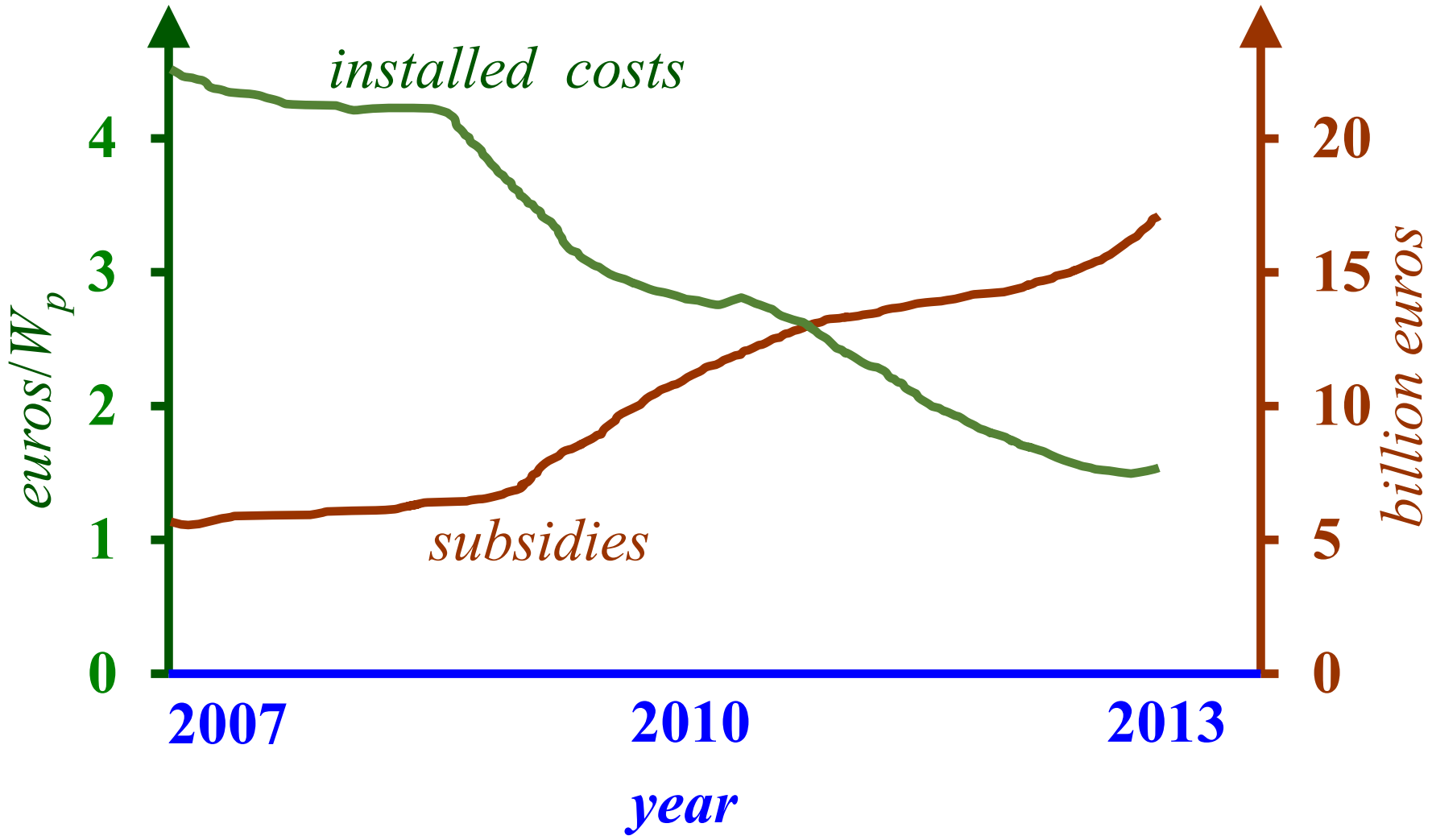
THE KEY DRIVERS OF *US PV* GROWTH

- 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 investment into *PV* installations;
  - *loan guarantees* provided by the 2009 *American Recovery and Reinvestment Act* (*ARRA*), allowed the *US* Department of Energy to provide preferential financing support to qualifying renewable energy projects;
  - *cash grants* that provides commercial projects an alternative to the tax credit in the form of a cash grant

PV INSTALLATION COSTS BY SECTORS: *Q*1 2011 – 2018



GERMANY *PV* INSTALLATION COSTS AND SUBSIDIES



2018 INSTALLED COST TREND

- The total installed costs for PV systems dropped by $38\ \%$ from those in 2013
- The inflation–adjusted system cost reductions from 2017 to 2018 are $\$\ 0.14/W$, $\$\ 0.05/W$ and $\$\ 0.02/W$ for residential, commercial and fixed–tilt utility–scale, respectively
- The module and inverter pricing, in general, has been decreasing since 2011

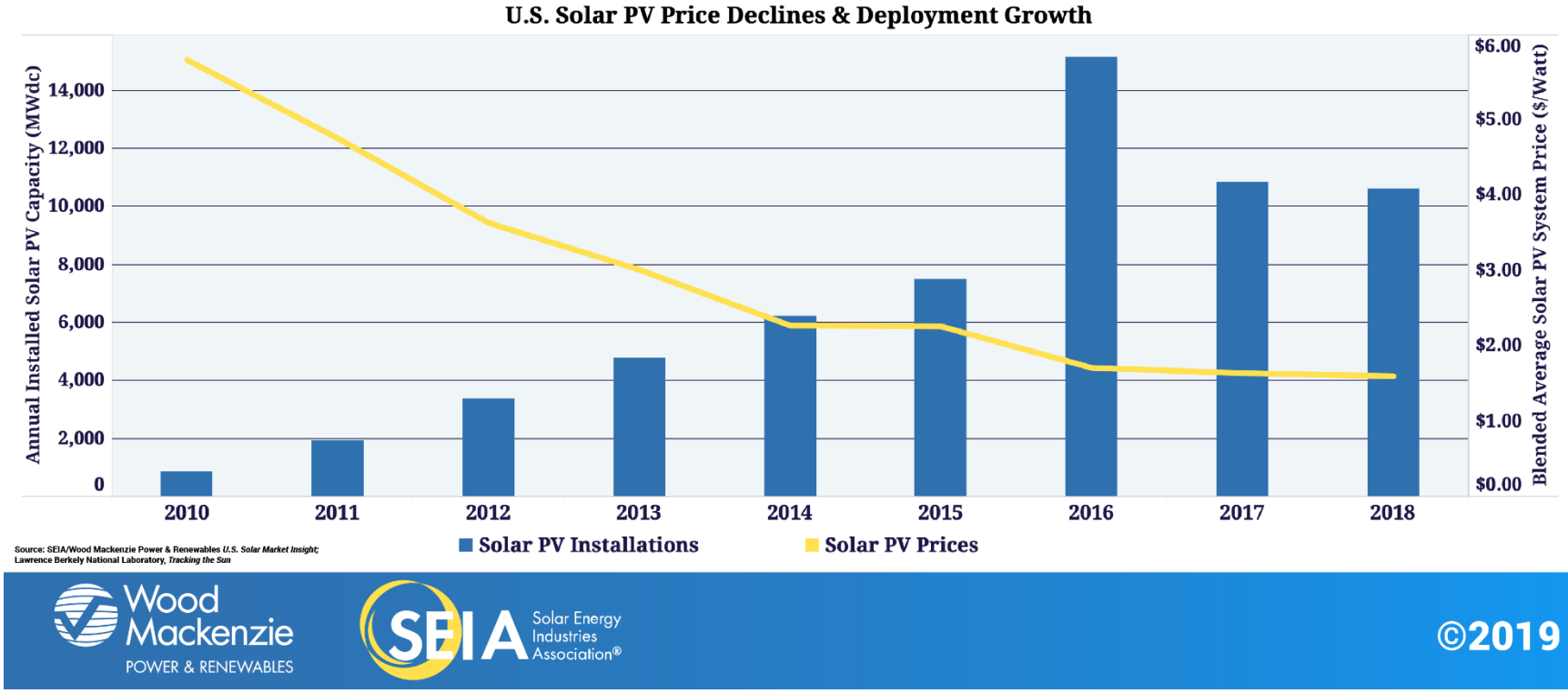
US SOLAR *PV* COMPONENT PRICES

Source: GTM Research US Solar Market Insight

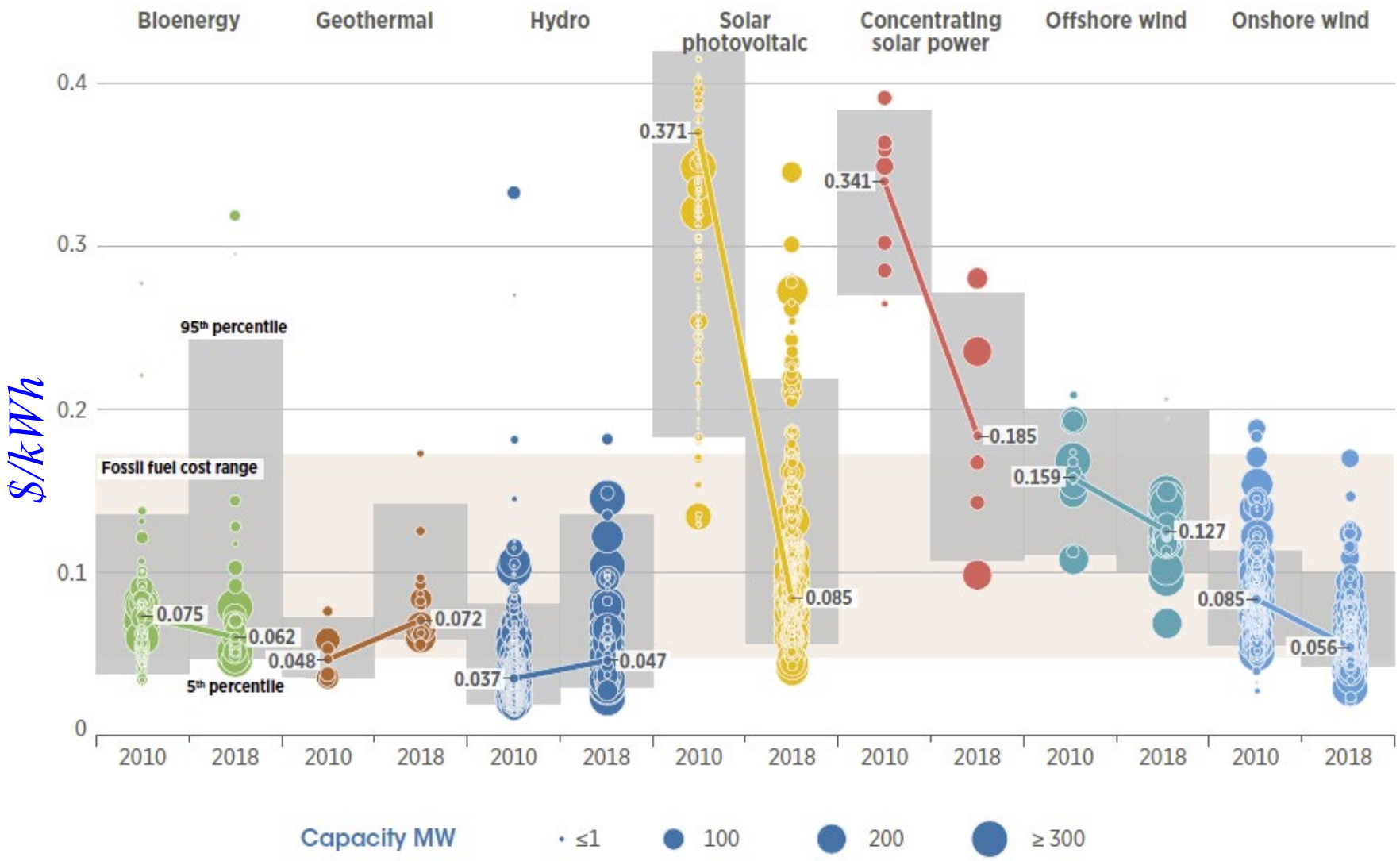
	Q2 2018	Q3 2018	Q4 2018	Q1 2019	Q2 2019
Polysilicon ($/kg) *	$15.3	$11.7	$ 9.9	$ 9.3	$8.9
Multi wafer ($/W) *	$ 0.12	$ 0.07	$ 0.06	$ 0.06	$ 0.06
Mono wafer ($/W) *	$ 0.13	$ 0.09	$ 0.08	$ 0.08	$ 0.09
Multi cell ($/W) *	$ 0.17	$ 0.13	$ 0.11	$ 0.11	$ 0.12
Mono cell ($/W) *	$ 0.19	$ 0.14	$ 0.13	$ 0.14	$ 0.12
Multi module ($/W) *	$ 0.33	$ 0.26	$ 0.23	$ 0.23	$ 0.23
Mono module ($/W) *	$ 0.38	$ 0.30	$ 0.27	$ 0.28	$ 0.28
U.S. multi module ($/W)	$ 0.42	$ 0.38	$ 0.36	$ 0.36	$0.35
U.S. mono PERC module ($/W)	$ 0.47	$ 0.44	$ 0.41	$ 0.40	$0.43

US ANNUAL *PV* SOLAR CAPACITY ADDITIONS AND PRICES

Source: *Wood Mackenzie and SEIA*; *available online at https://www.seia.org/solar-industry-research-data*

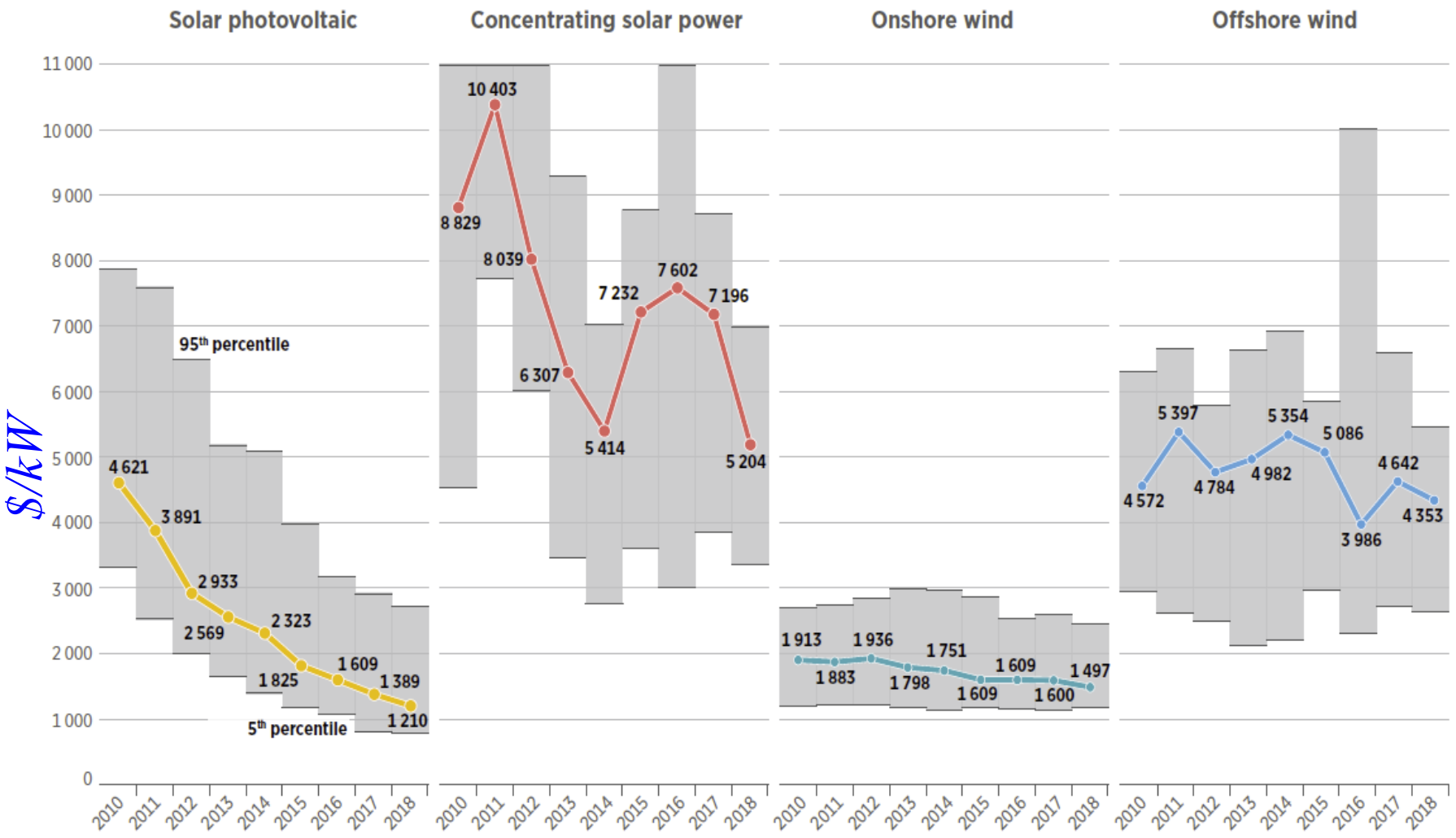


LCOE OF UTILITY–SCALE RENEWABLE POWER GENERATION



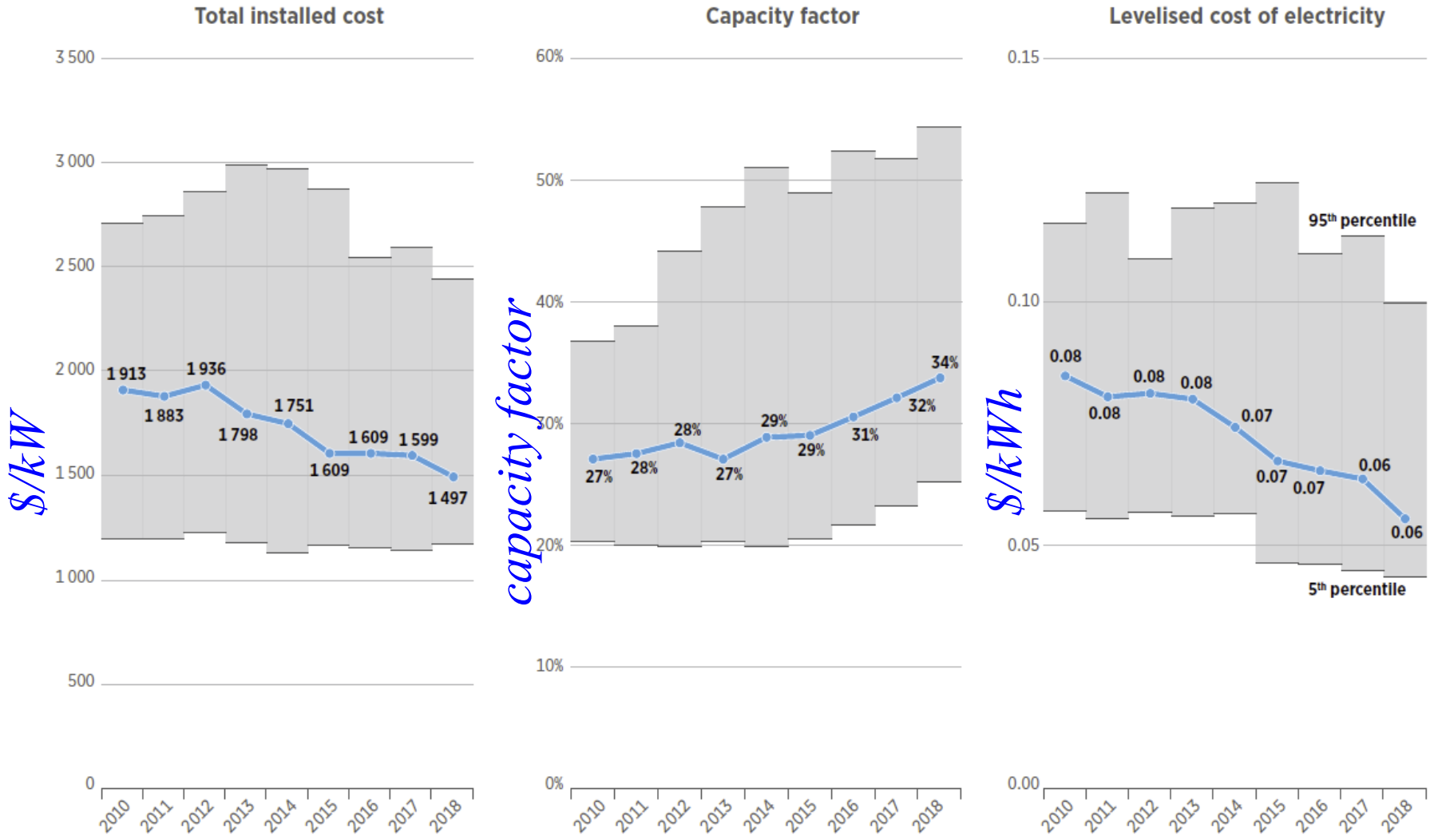
Source: IRENA Renewable Power Generation Costs in 2018, p. 12; available online at https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/IRENA_Renewable-Power-Generations-Costs-in-2018.pdf

GLOBAL WEIGHTED AVERAGE TOTAL INSTALLED COSTS



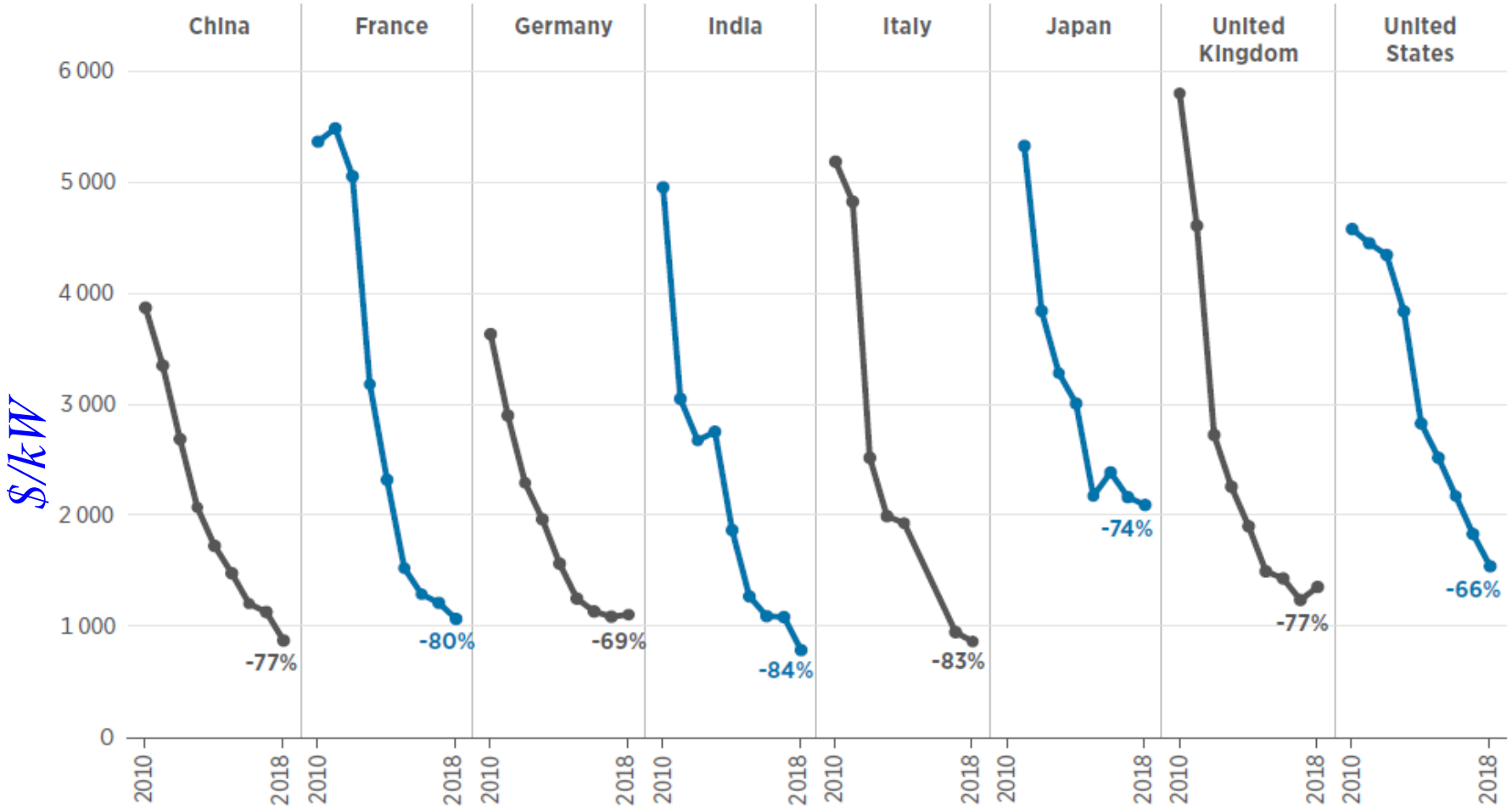
Source: IRENA Renewable Power Generation Costs in 2018, p. 14; available online at https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/IRENA_Renewable-Power-Generations-Costs-in-2018.pdf

GLOBAL CAPACITY FACTORS AND *LCOE* FOR ONSHORE WIND



Source: IRENA Renewable Power Generation Costs in 2018, p. 19; available online at https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/IRENA_Renewable-Power-Generations-Costs-in-2018.pdf

UTILITY–SCALE SOLAR *PV* TOTAL INSTALLED COST TRENDS



Source: IRENA Renewable Power Generation Costs in 2018, p. 45; available online at https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/IRENA_Renewable-Power-Generations-Costs-in-2018.pdf

2017 PV MODULE MANUFACTURING STATUS

- The top–10 manufacturing companies supplied 50 GW of PV modules in 2017, an increase of $45\ \%$ over the 2016 production output
- Five of the top ten companies are publicly–listed, vertically–integrated, $China$–based crystalline silicon $(c\text{-}Si)$ solar panel manufacturers

2017 *PV* MODULE MANUFACTURING STATUS

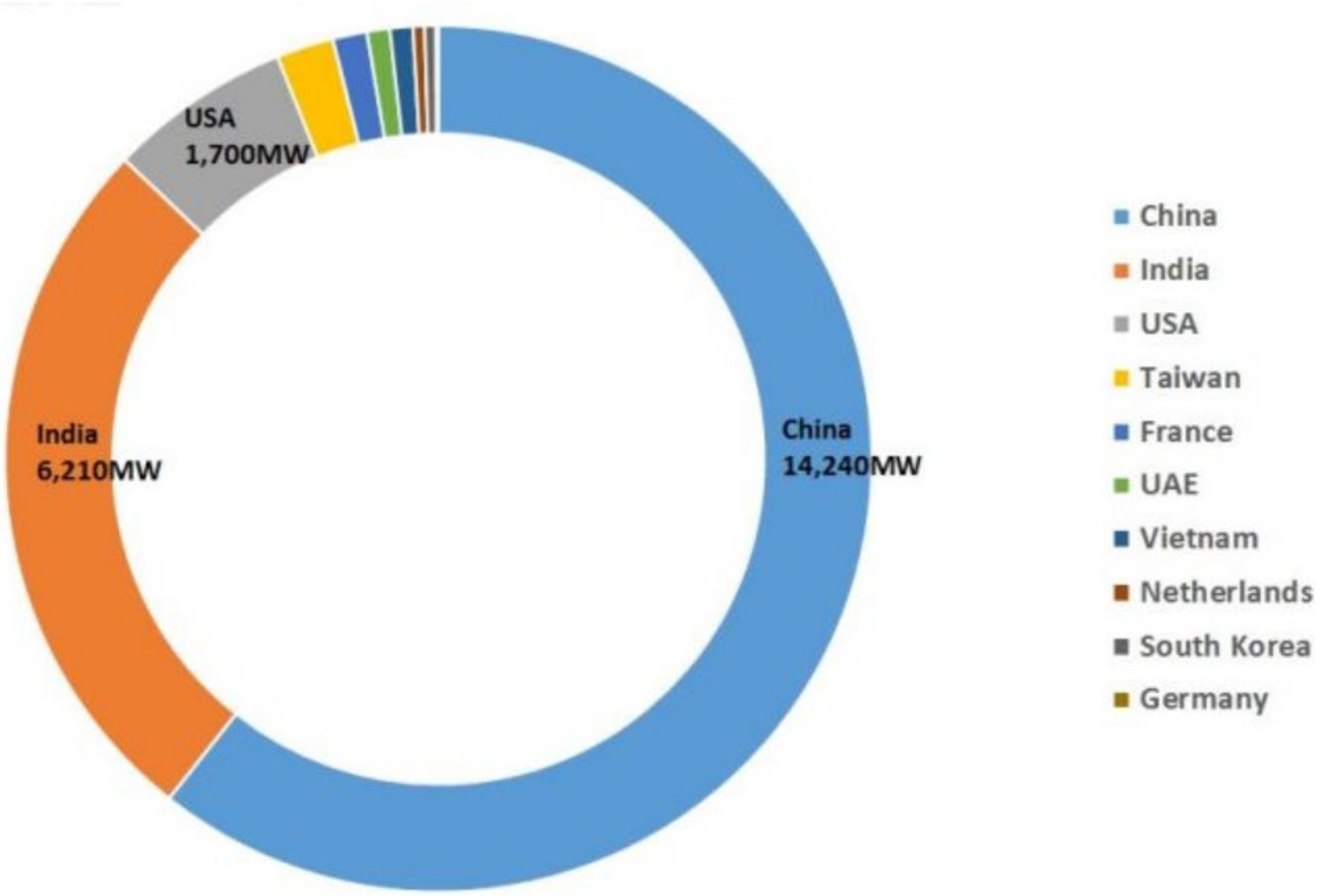
- *Trina Solar, Canadian Solar* and *JA Solar Holdings* are the leaders in module shipments to meet *US* market needs
- In Japan, the leading domestic *PV* module suppliers are *Sharp, Kyocera* and *Panasonic*
- The top two suppliers in European *PV* module market are *Schott Solar* and *SolarWorld*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

TOP 10 *PV* MODULE MANUFACTURERS IN 2018

company	country
Jinko Solar Holding Co. Ltd.	China
JA Solar Holding Co. Ltd.	China
Trina Solar Ltd.	China
LONGi Green Energy Technology	China
Canadian Solar	Canada
Hanwha Q CELLS	South Korea
Risen Energy	China
GCLSI	China
Talesun Solar	China
First Solar Inc	USA

Source: http://news.energysage.com/best-solar-panel-manufacturers-usa/

Q1 2018 *PV* MODULE EXPANSION ANNOUNCEMENTS



Source: https://www.pv-tech.org/editors-blog/solar-manufacturing-capacity-expansion-announcements-in-q1-2018-reached-24

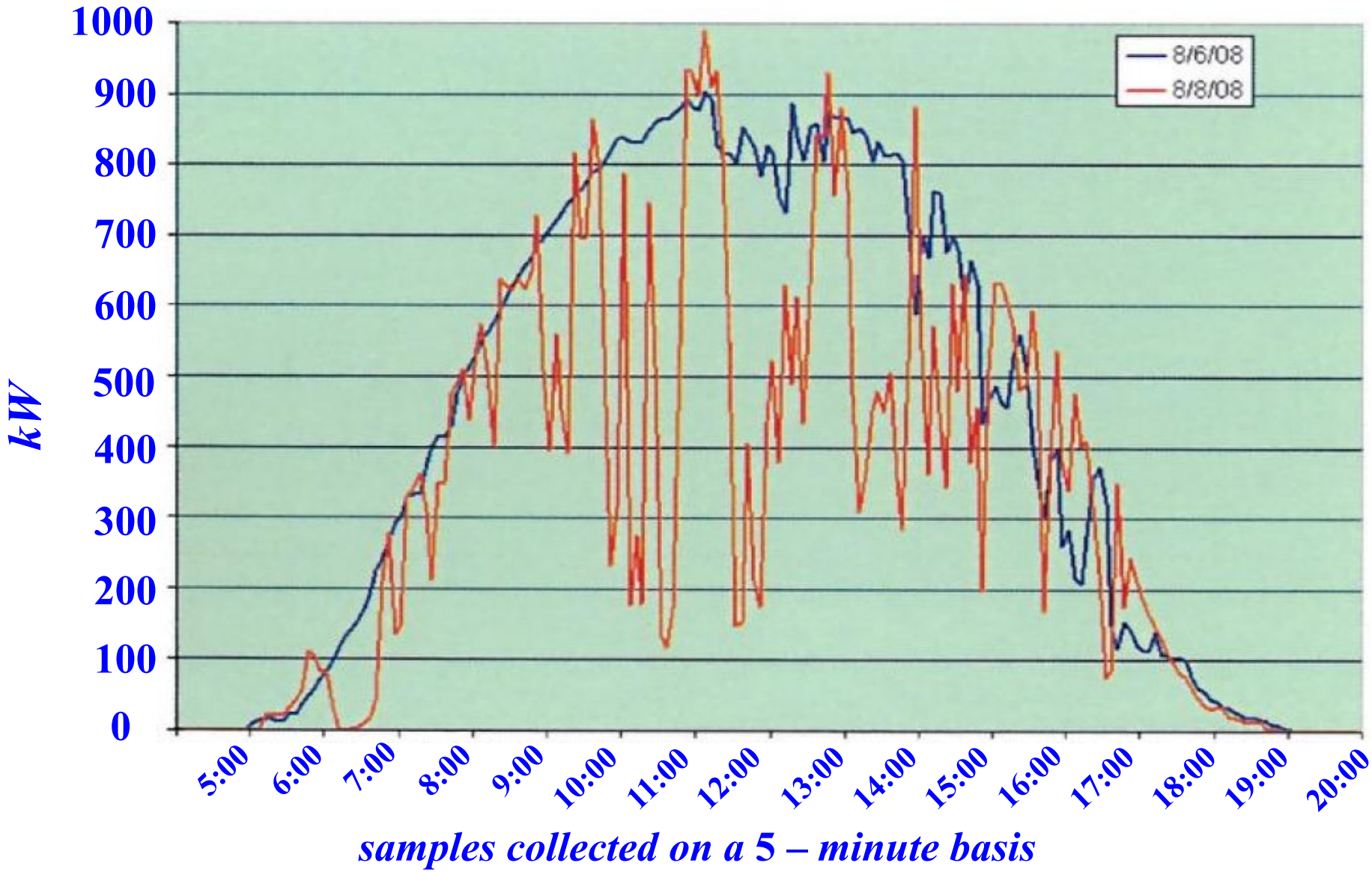
DOE SOLAR PROGRAM GOALS

- 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

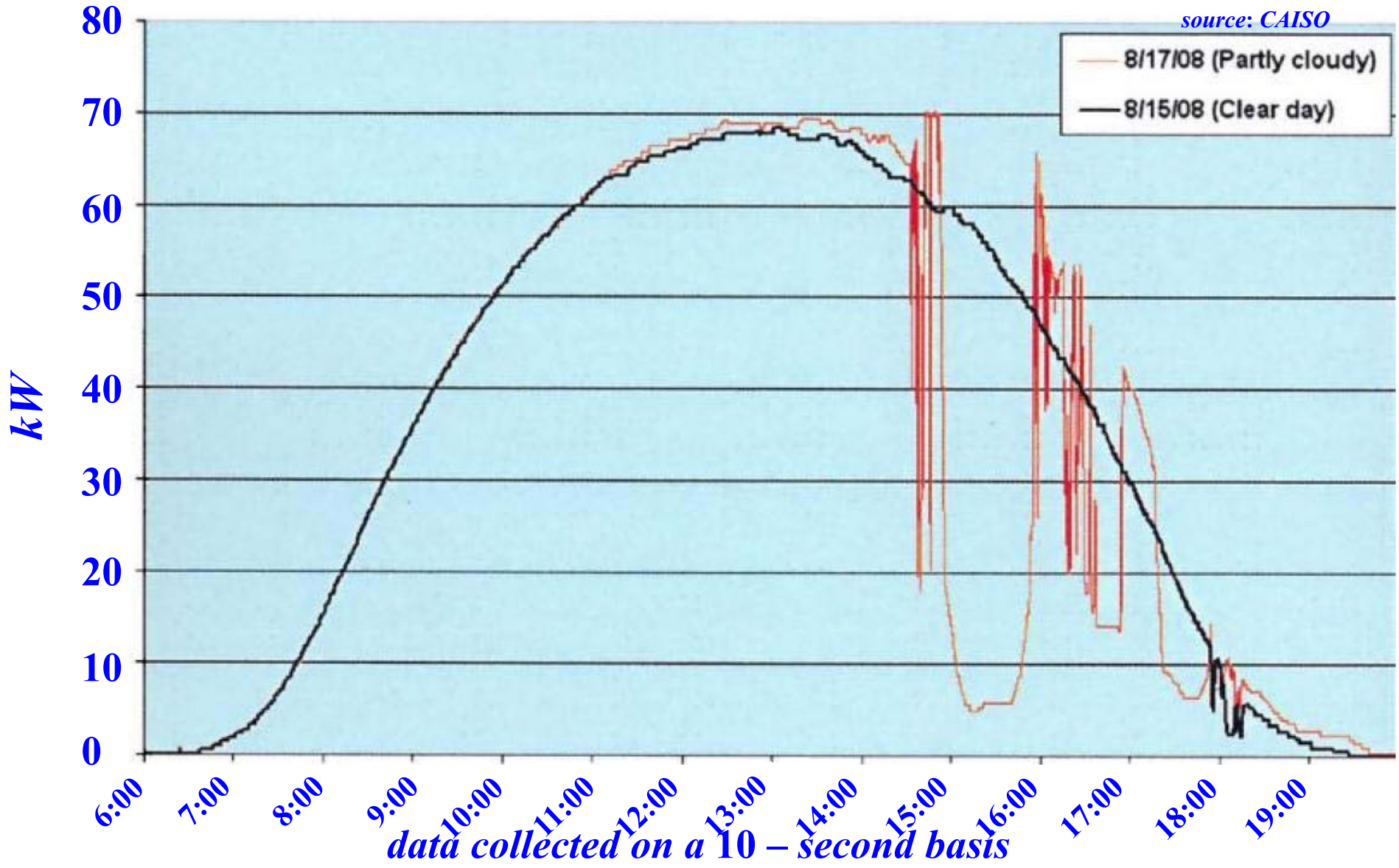
- The efficiency of typical PV modules used in energy production is still rather low
- Solar energy is highly uncertain, variable and intermittent renewable resource and the PV system electricity production has limited controllability and dispachability

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



source: CAISO

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



CHRONOLOGICAL *PV* OUTPUT AND *ERCOT* LOAD PATTERNS

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