ECE 333 – GREEN ELECTRIC ENERGY

1. Introduction and Overview

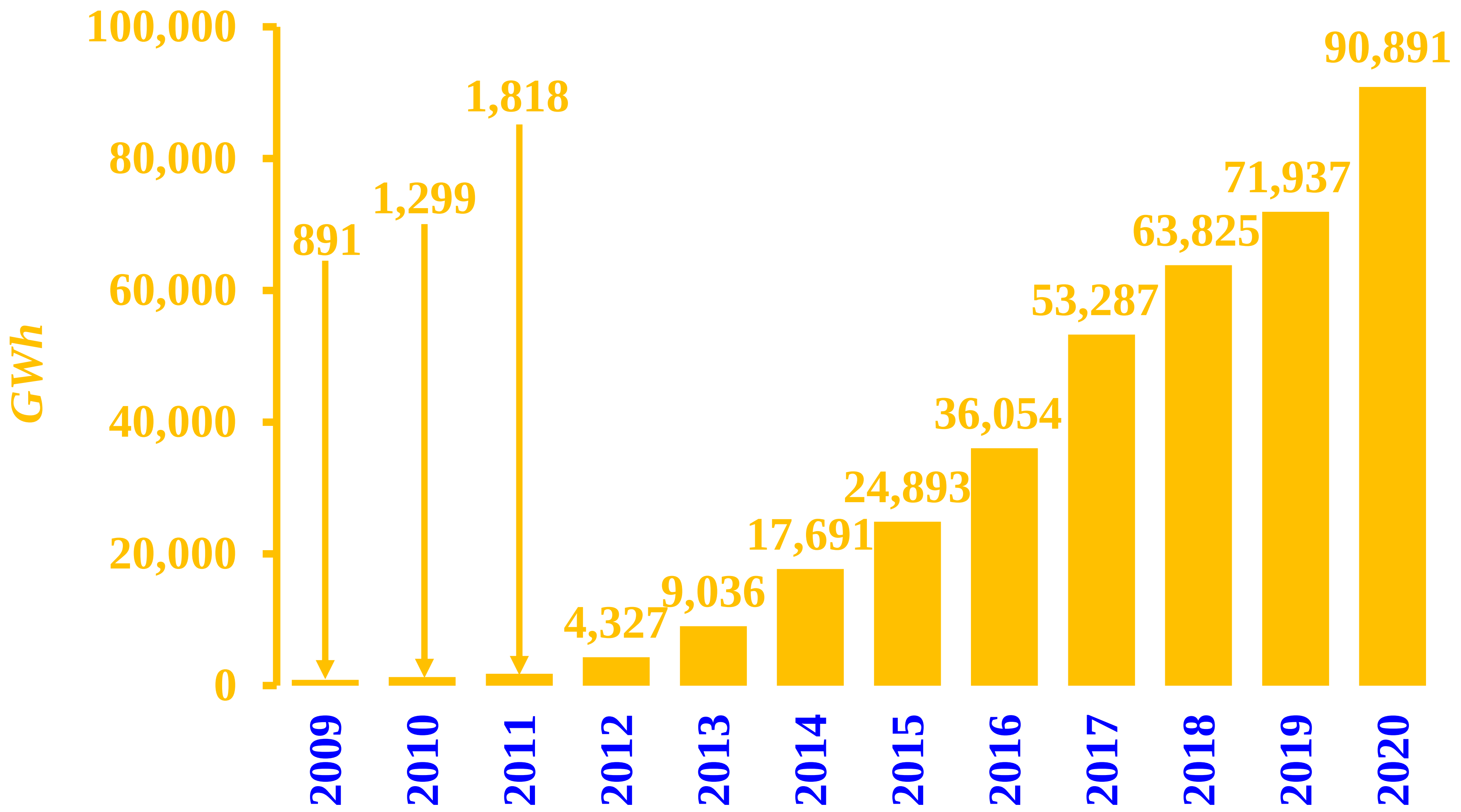
George Gross

Department of Electrical and Computer Engineering

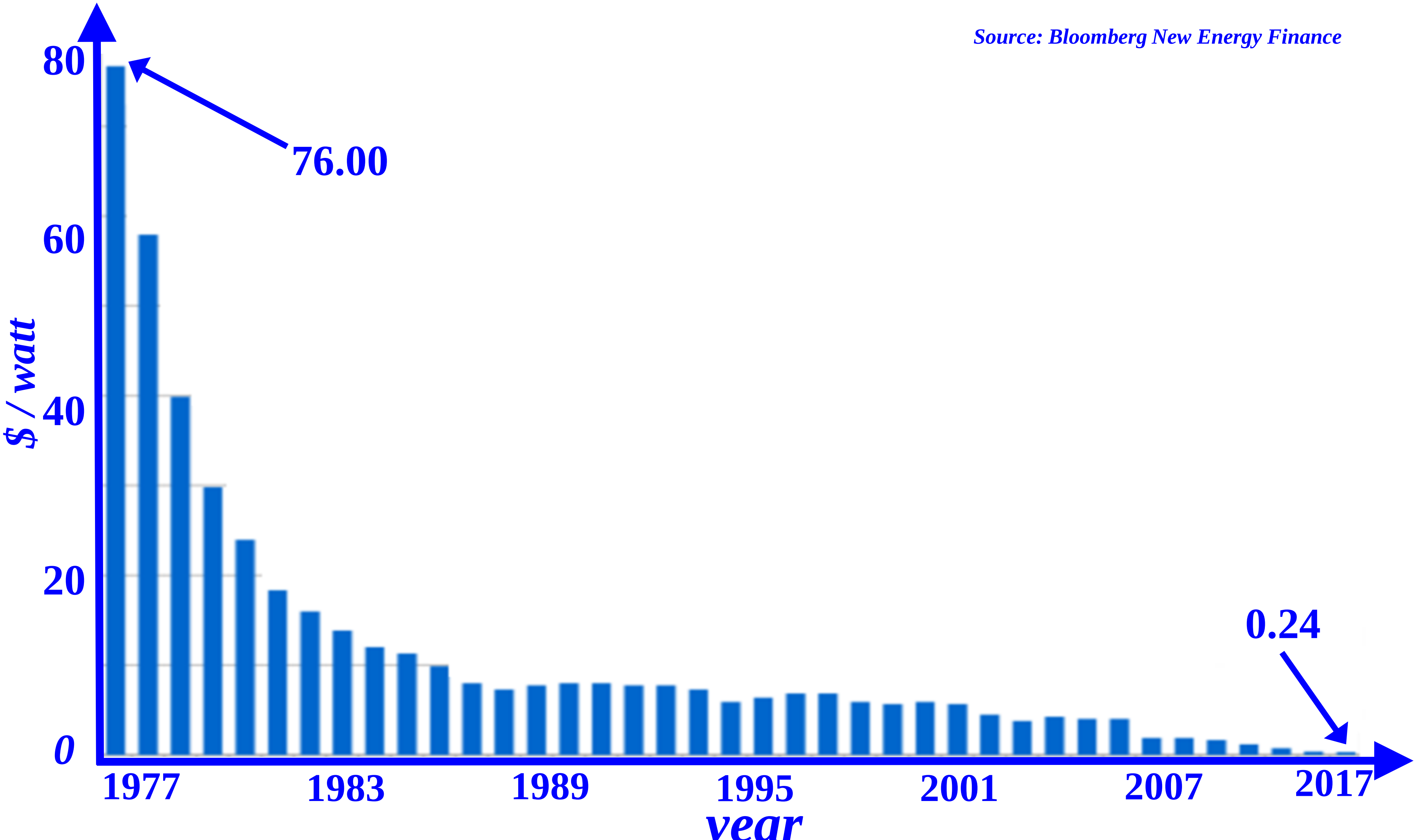
University of Illinois at Urbana–Champaign

US SOLAR UTILITY – SCALE GENERATION: 2009 – 2020

Source*: *https://www.eia.gov/electricity/data/browser/#/topic/0?agg=2,0,1&fuel=0045u&geo=vvvvvvvvvvvvo&sec=g&linechart=ELEC.GEN.SUN-US-99.A&columnchart=ELEC.GEN.SUN-US-99.A&map=ELEC.GEN.SUN-US-99.A&freq=A&ctype=linechart&ltype=pin&rtype=s&pin=&rse=0&maptype=0



PV SOLAR CAPACITY PRICE DECLINE



2020 *US* SOLAR *PV* STATUS

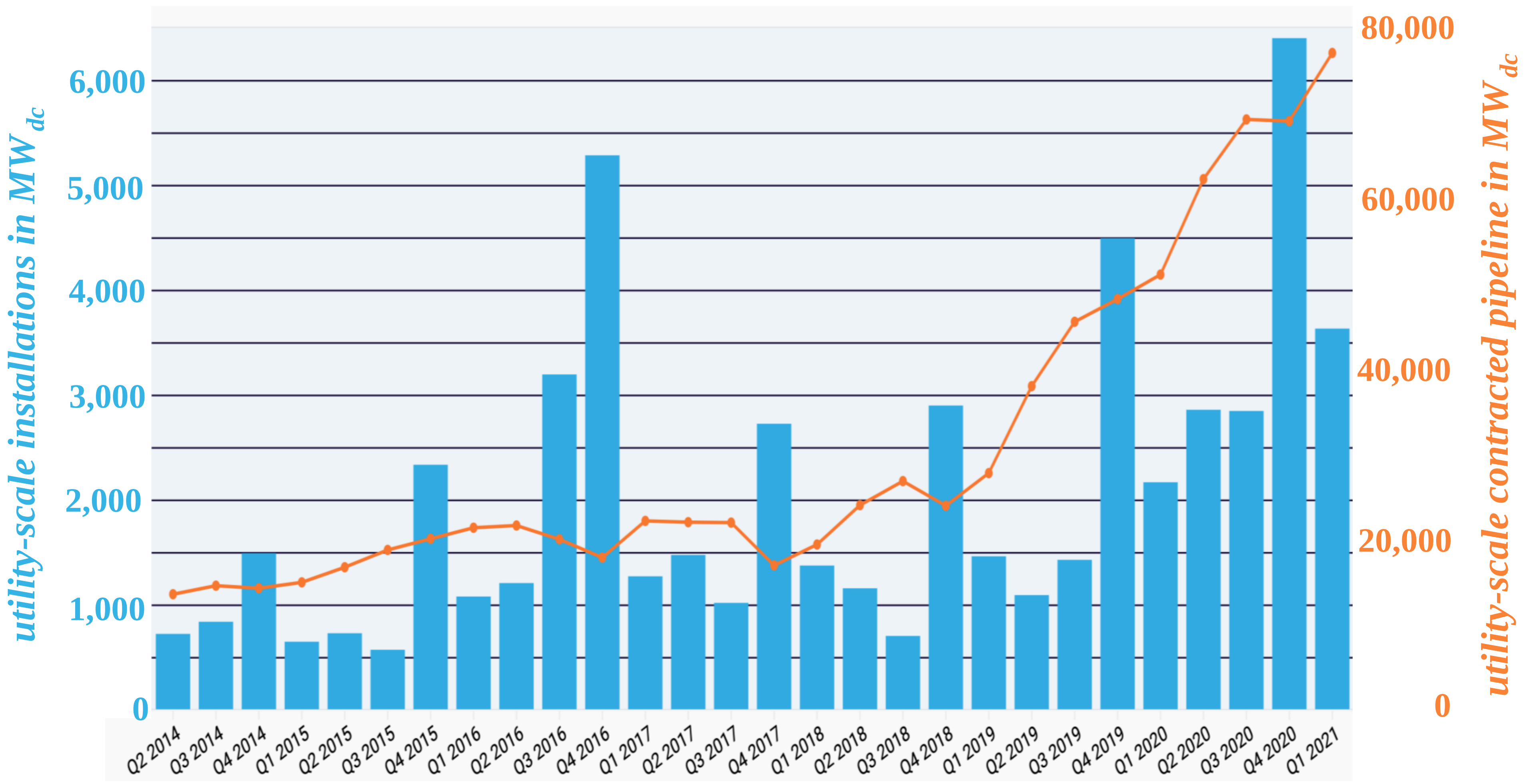
- *US* installed 19.2 GW_{dc} of solar *PV* capacity in 2020, a 43 % increase over the amount installed in 2019
- The *PV* capacity represents almost 43 % of the 2020 added *US* electricity generation capacity
- The *US* cumulative operational solar *PV* capacity exceeds 100 GW_{dc}
- The implementation of *concentrated solar power* (*CSP*) – often referred to as solar thermal – plants is growing considerably more slowly both in the *US* and the rest of the world

2020 *US* SOLAR *PV* STATUS

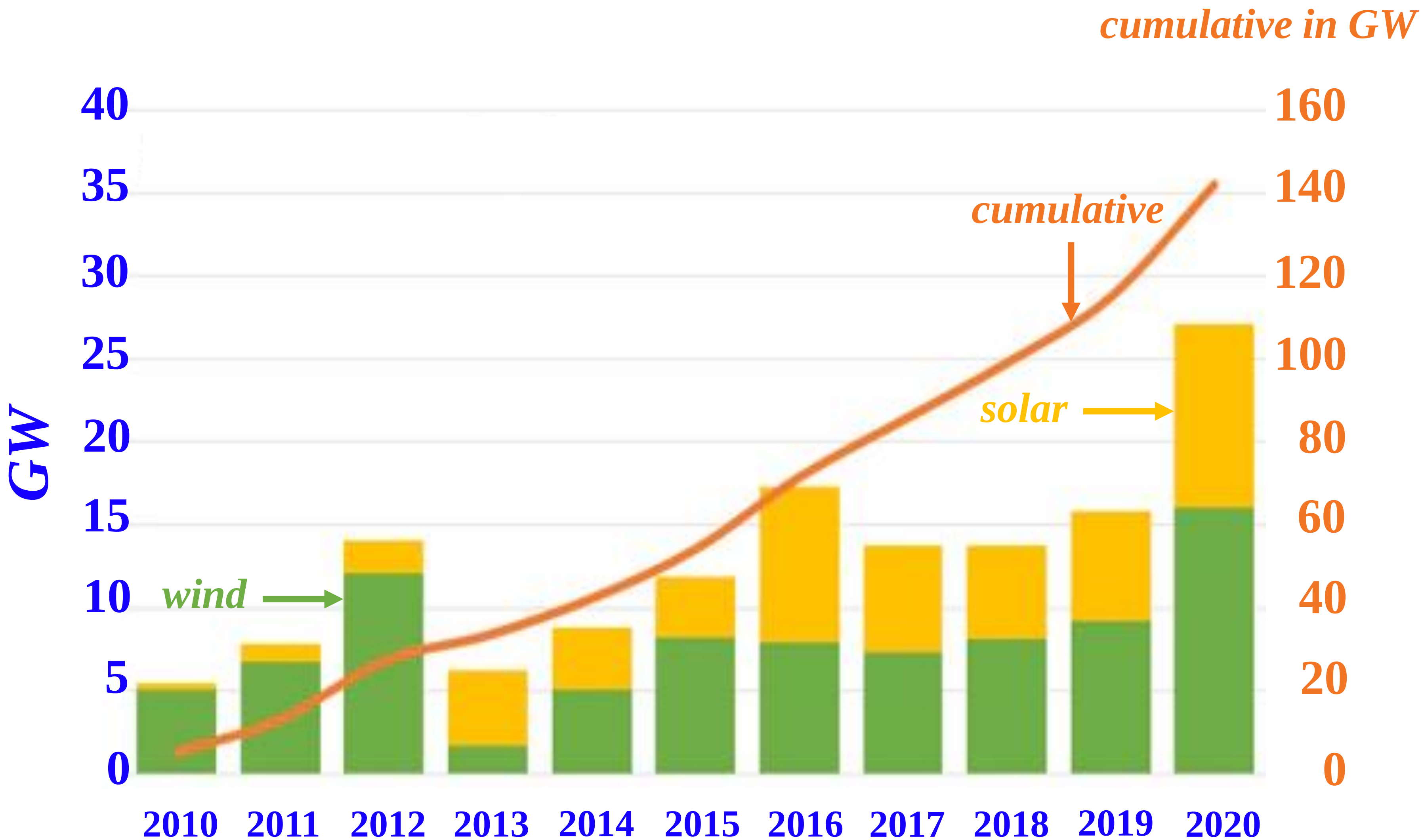
- The 2021 *Q*1 was the *US* solar industry's largest *Q*1 ever with over 5 GW_{dc} new solar *PV* capacity
- Potential headwinds loom on the horizon for the foreseeable future as the *COVID*-19 pandemic fallout threatens project schedules due to labor shortage/supply chain problems that lead to construction delays, work stoppages, permitting delays, reduced customer demand and a more challenging financing access environment; as a result, solar growth may slow

UTILITY *PV* INSTALLATIONS VS. CONTRACTED PIPELINE

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

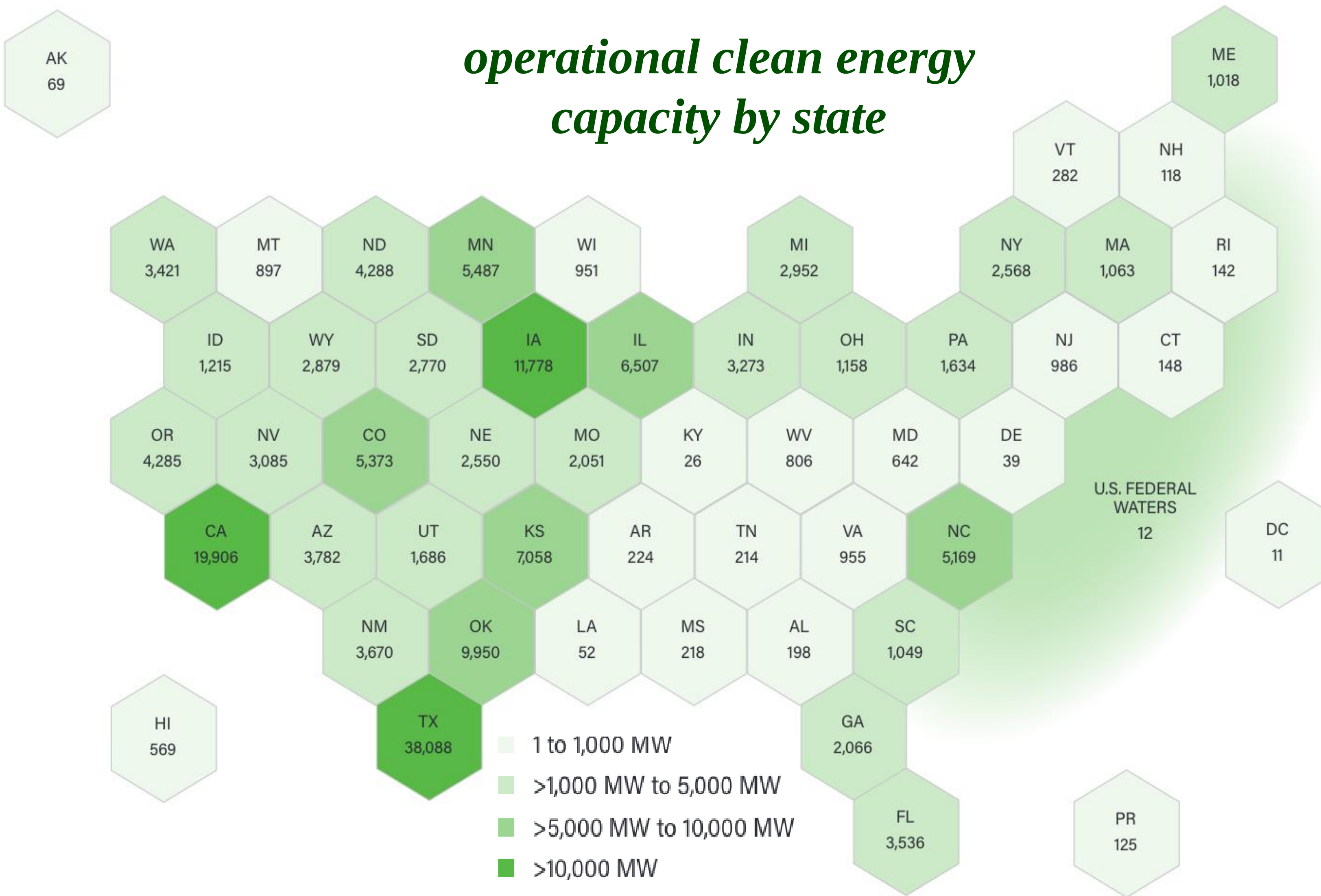


ANNUAL *US* UTILITY RENEWABLE CAPACITY ADDITIONS: 2010 – 2020



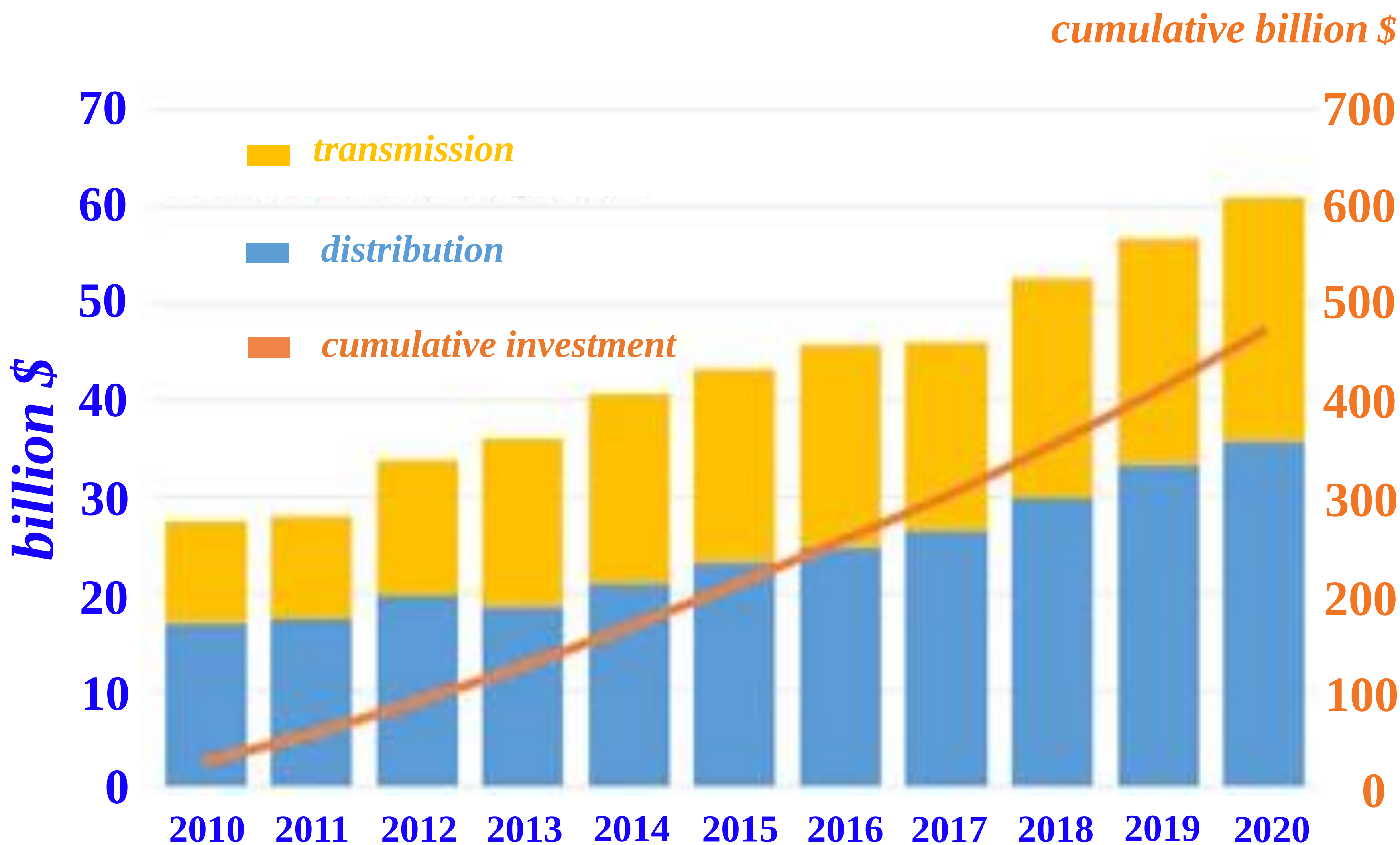
Source: Hitachi ABB Power Grids Velocity Suite available at: https://www.tdworld.com/transmission-reliability/article/21171011/a-stronger-more-resilient-electric-grid-requires-more-transmission-investments0

CLEAN POWER CAPACITY GROWTH BY STATE



Source: American clean power 2021, q1; available at https://cleanpower.org/wp-content/uploads/2021/05/CPQ-2021Q1_public.pdf; p. 6

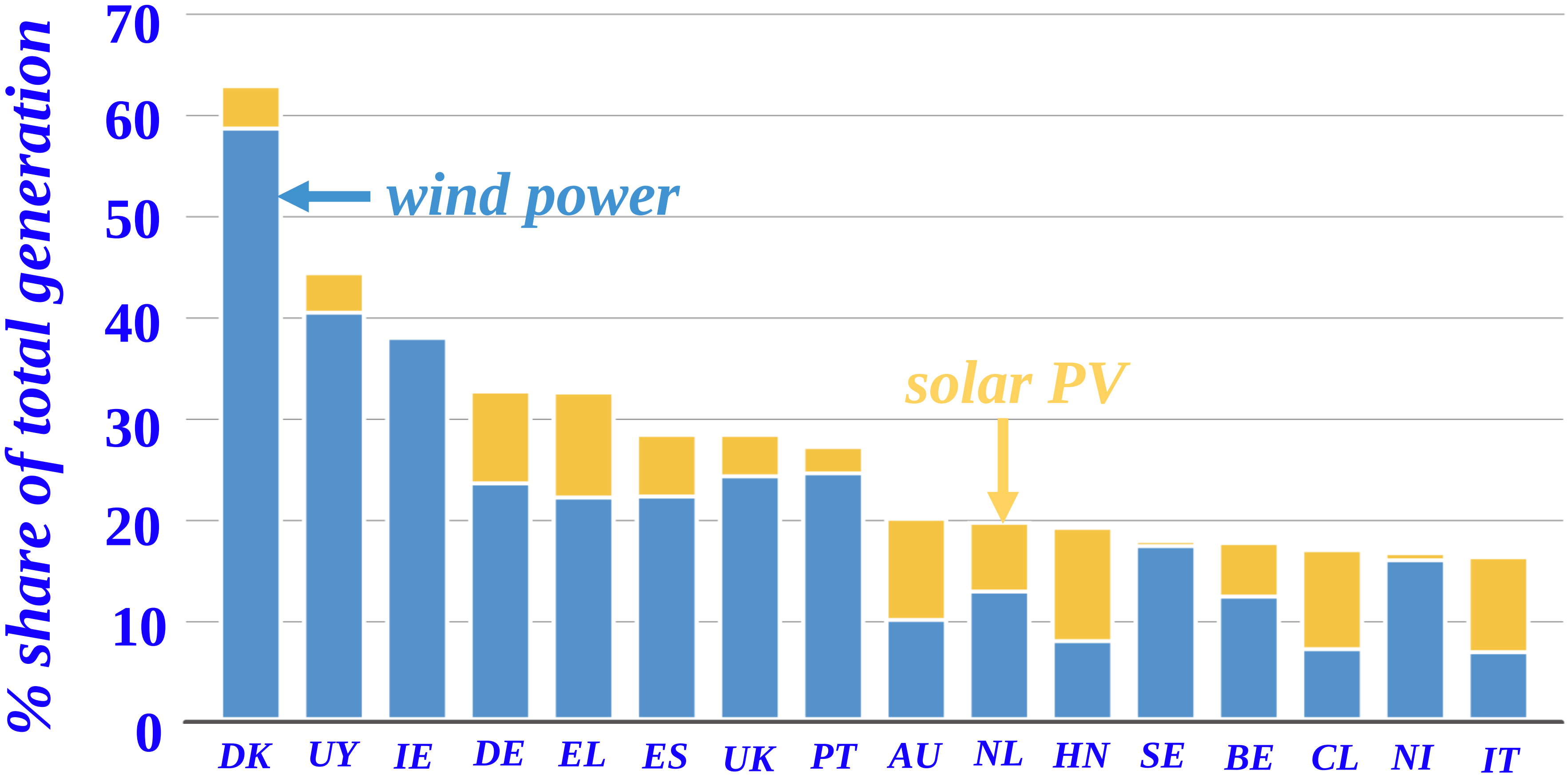
ANNUAL *NORTH AMERICAN* *T & D* INVESTMENTS: 2010 – 2020



Source: Hitachi ABB Power Grids Velocity Suite available at: https://www.tdworld.com/transmission-reliability/article/21171011/a-stronger-more-resilient-electric-grid-requires-more-transmission-investments0

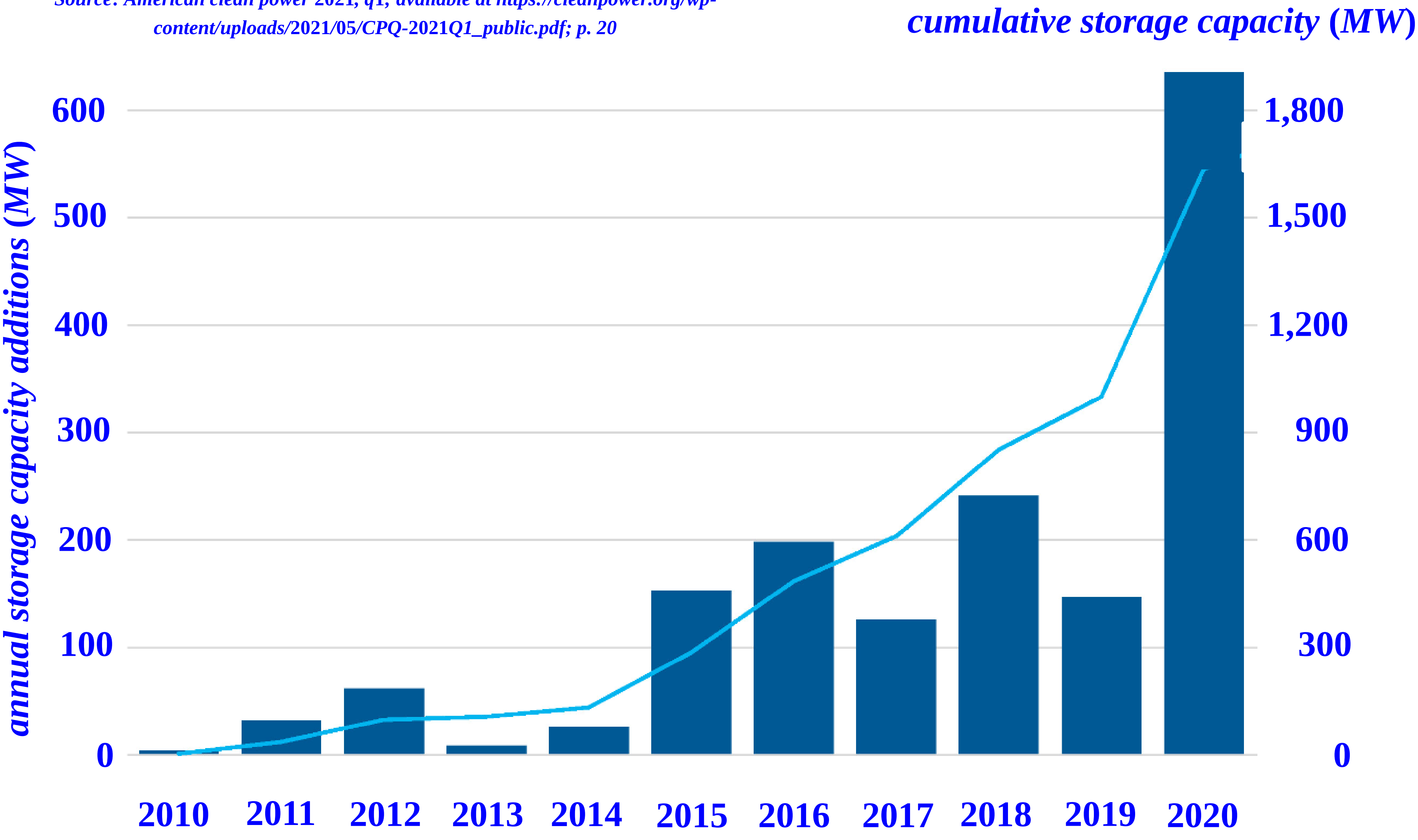
LEADING NATIONS' RENEWABLE ENERGY GENERATION 2020

***Source*: REN 21 at https://www.ren21.net/wp-content/uploads/2019/05/GSR2021_Full_Report.pdf; p. 199**

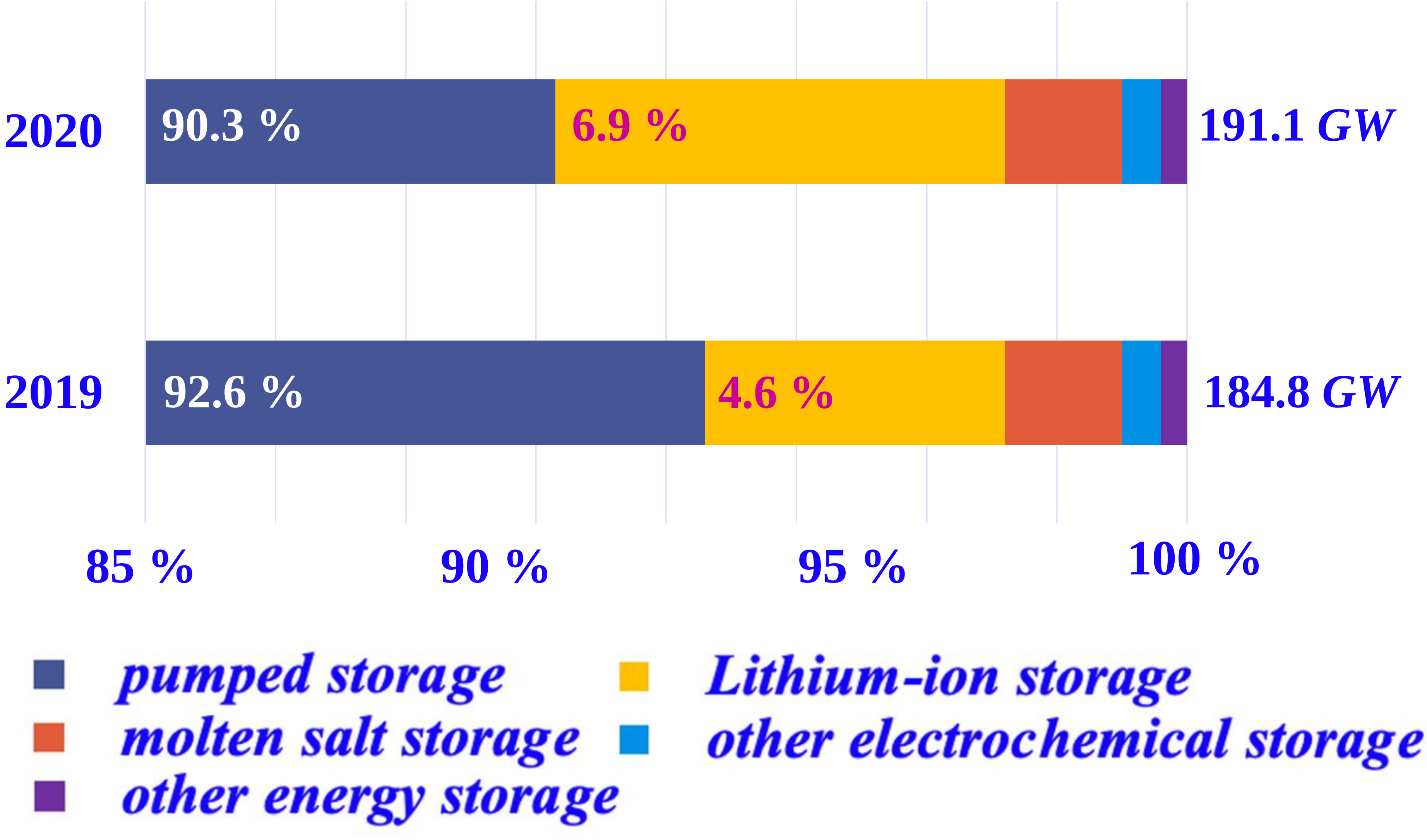


US ANNUAL AND CUMULATIVE UTILITY BATTERY STORAGE CAPACITY GROWTH

***Source**: American clean power 2021, q1; available at https://cleanpower.org/wp-content/uploads/2021/05/CPQ-2021Q1_public.pdf; p. 20*



GLOBAL ENERGY STORAGE INSTALLED CAPACITY TECHNOLOGIES: 2019 – 2020



Source: REN 21 p.211, at https://www.ren21.net/wp-content/uploads/2019/05/GSR2021_Full_Report.pdf

NATIONAL SOLAR DATABASE

Source: http://www.seia.org/research-resources/national-solar-database; Issued 2016

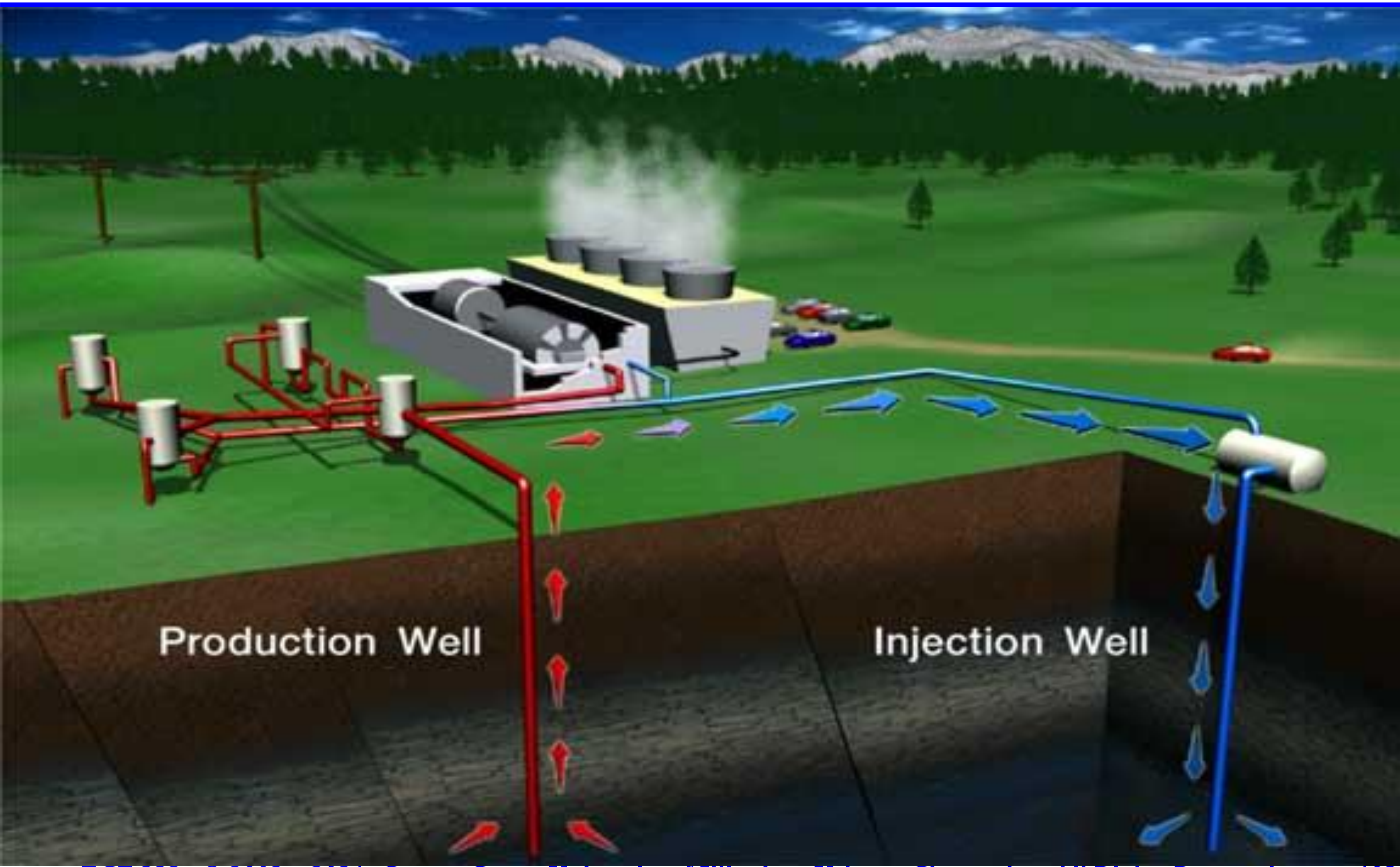
2020 *US* GEOTHERMAL ENERGY STATUS

U.S.'s first geothermal power plant, Mayacama Mountains, California, turned 60 in 2019

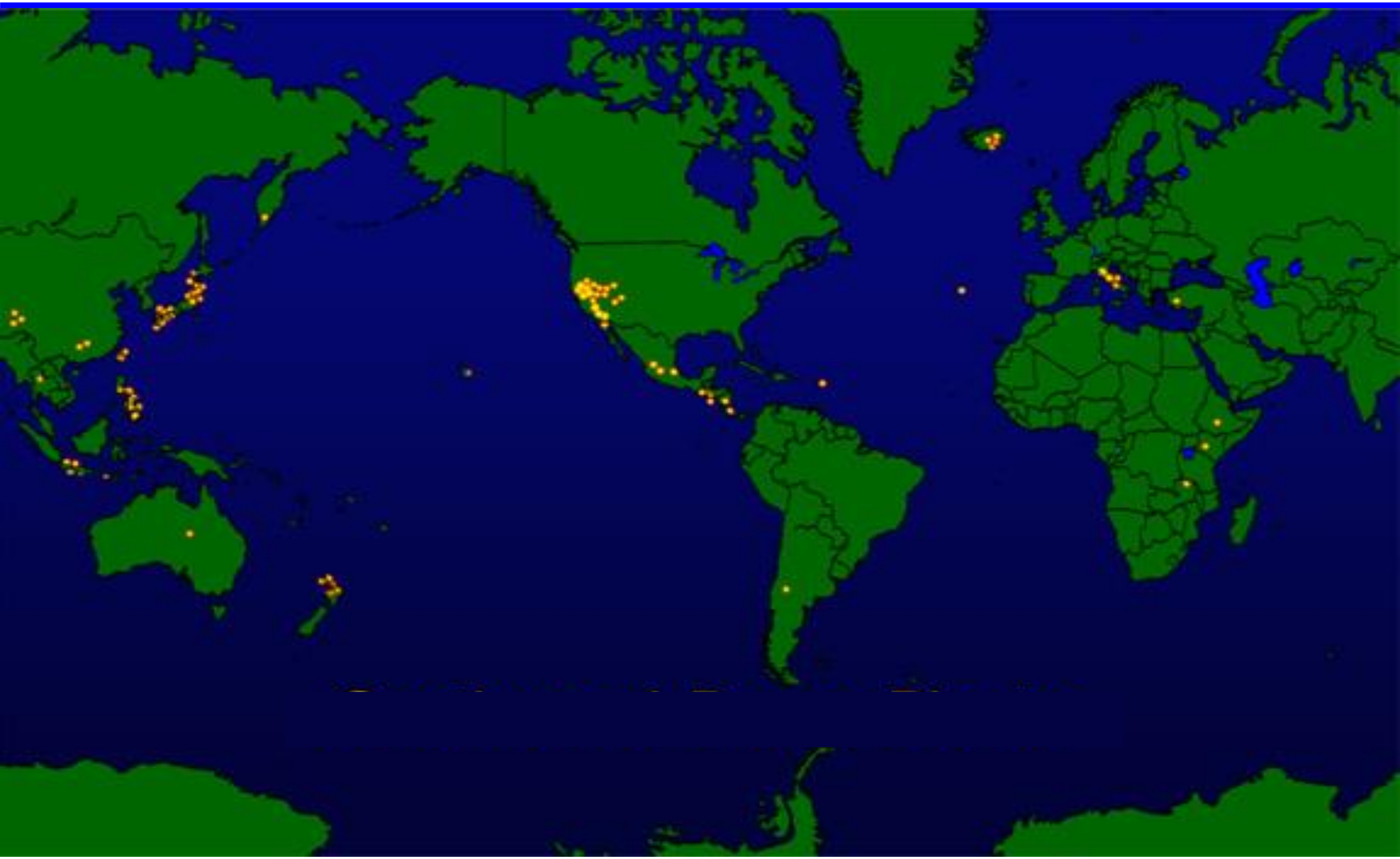
- **In 2020, *US* geothermal units produced about 0.5 % of the total *US* electricity generation**
- **Total 2020 installed *US* geothermal capacity was 3,673 *MW*; generation in 2020 was 16,930 *GWh***
- **Geothermal generation has experienced slow growth in recent years**
- **Geothermal prices exceed wind/solar prices**

Source: NREL, http://www.nrel.gov/docs/fy10osti/48178.pdf

GEOTHERMAL PRODUCTION

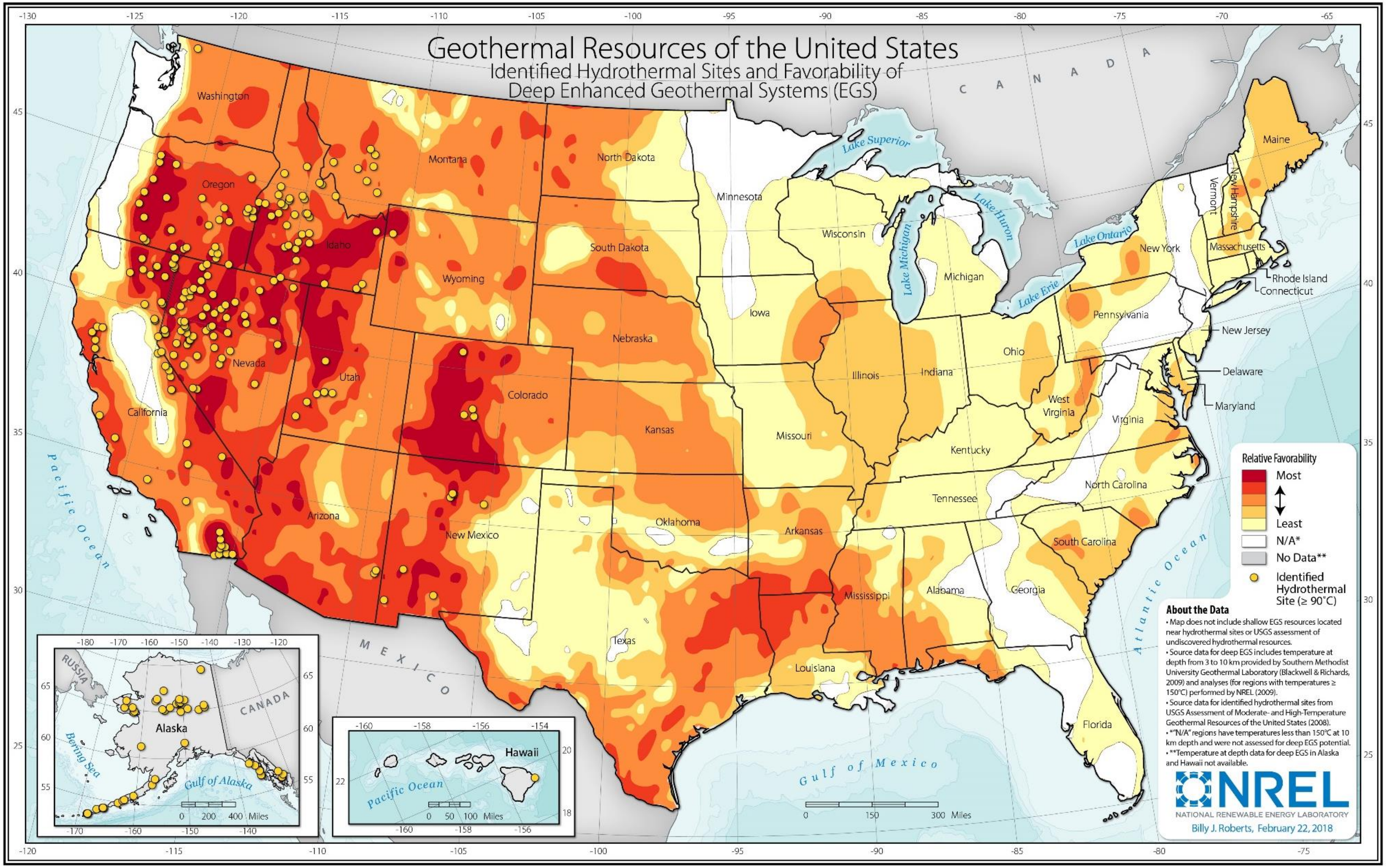


GEOTHERMAL PLANTS

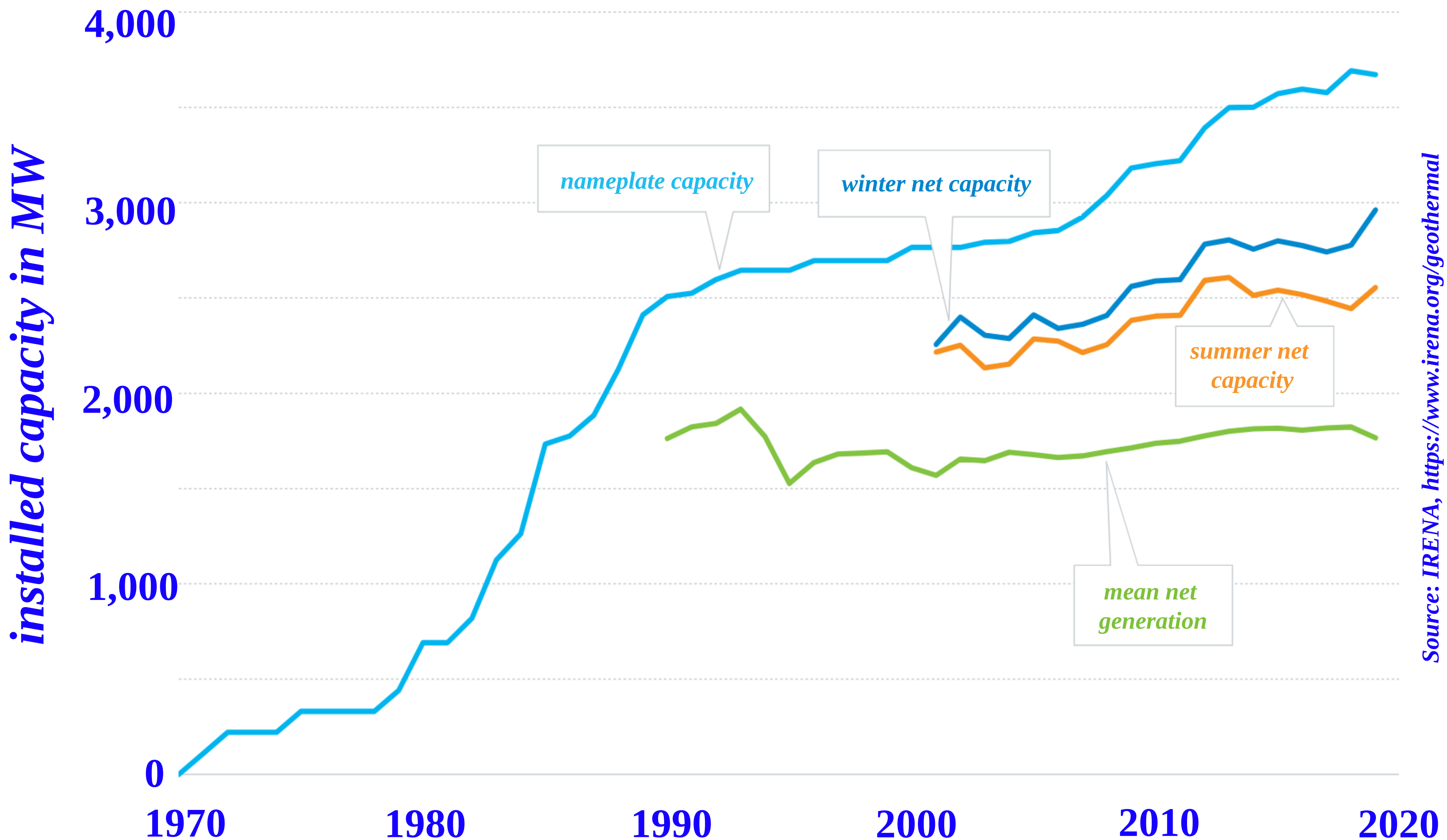


US GEOTHERMAL RESOURCES

Source*: *NREL; available at https://www.nrel.gov/gis/assets/images/geothermal-identified-hydrothermal-and-egs.jpg

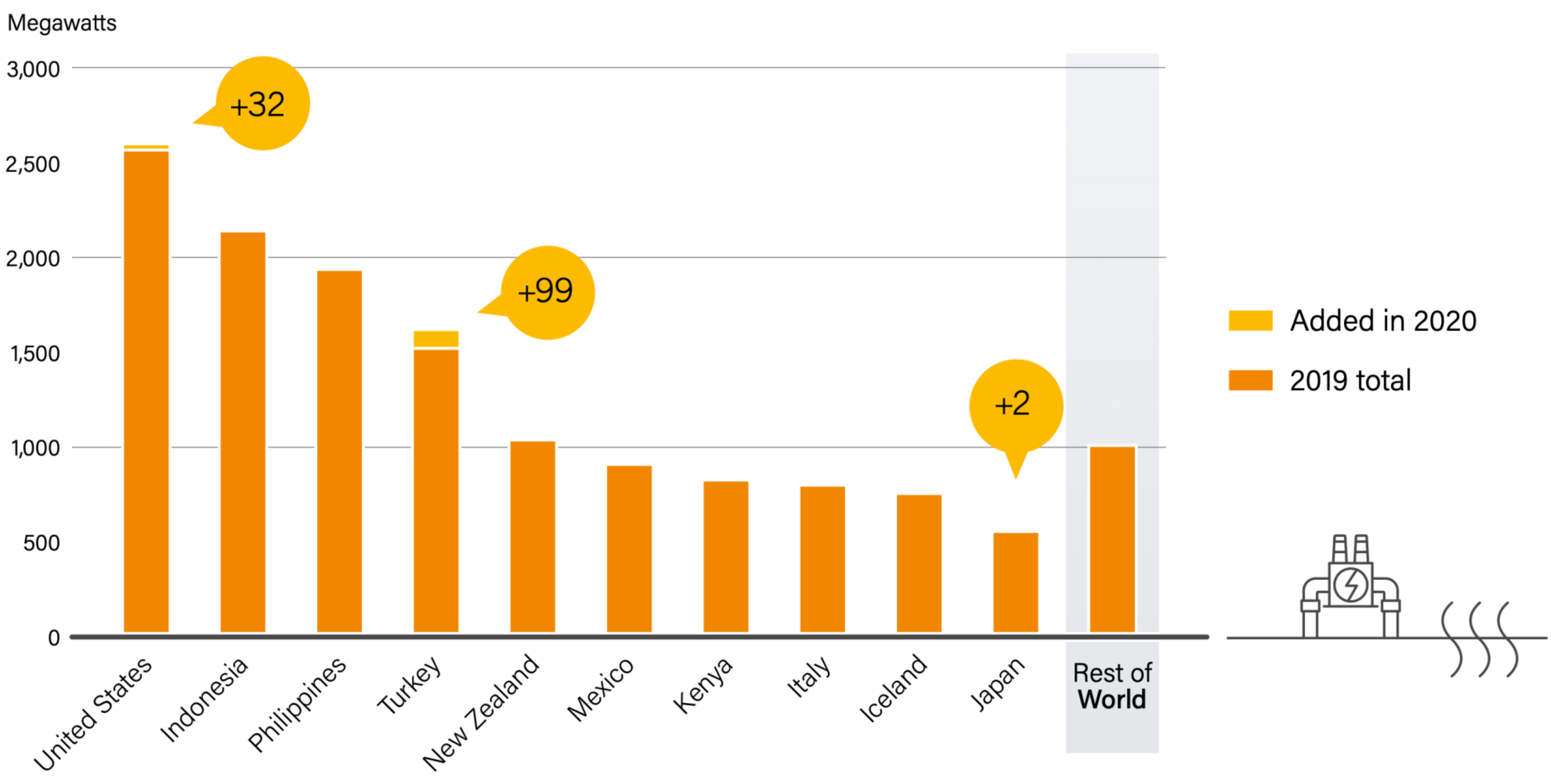


US GEOTHERMAL ENERGY STATUS

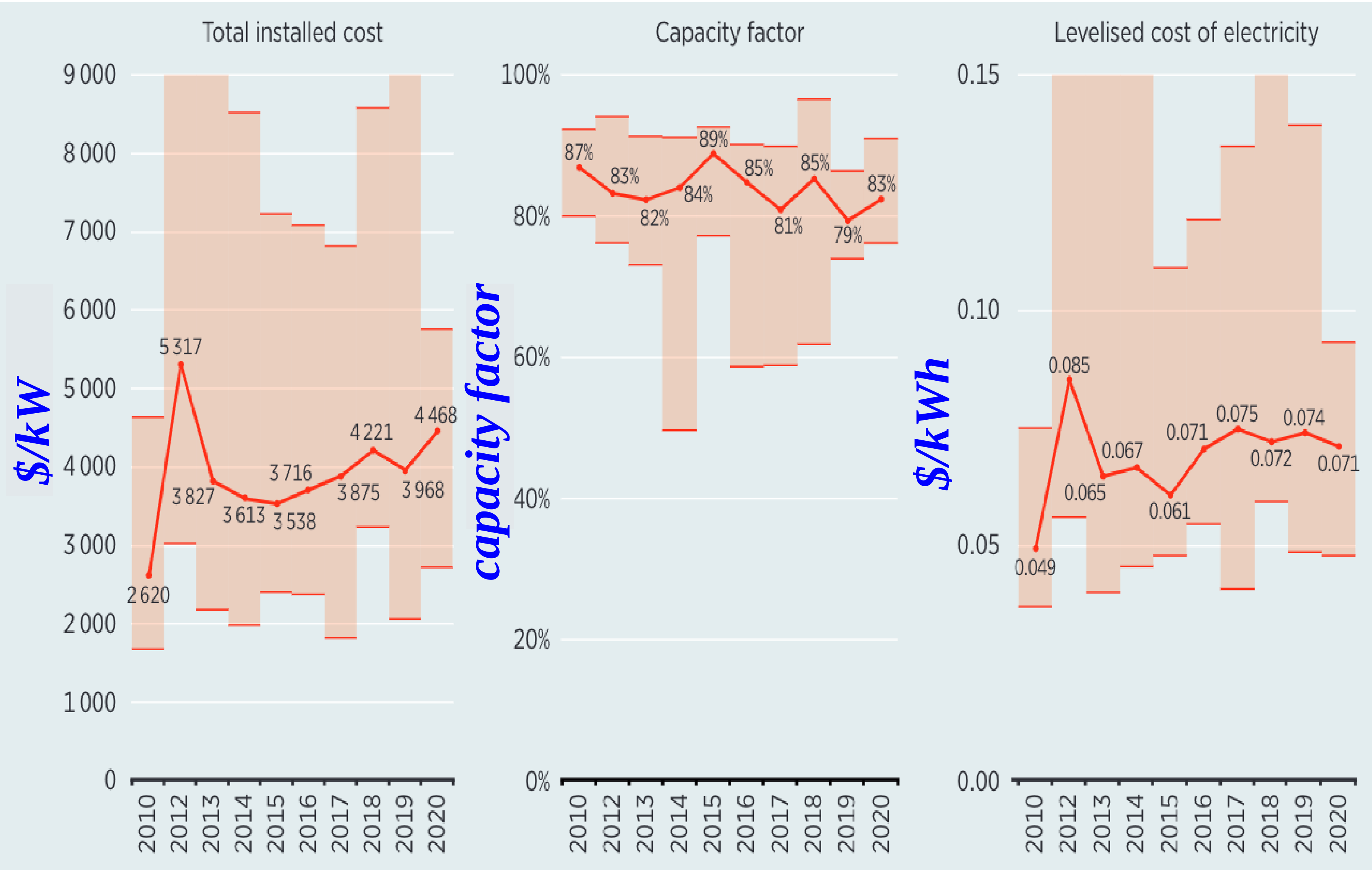


TOP TEN GEOTHERMAL CAPACITY COUNTRIES IN 2020

Source: REN 21 GSR 2021, available at https://www.ren21.net/wp-content/uploads/2019/05/GSR2021_Full_Report.pdf; p.100

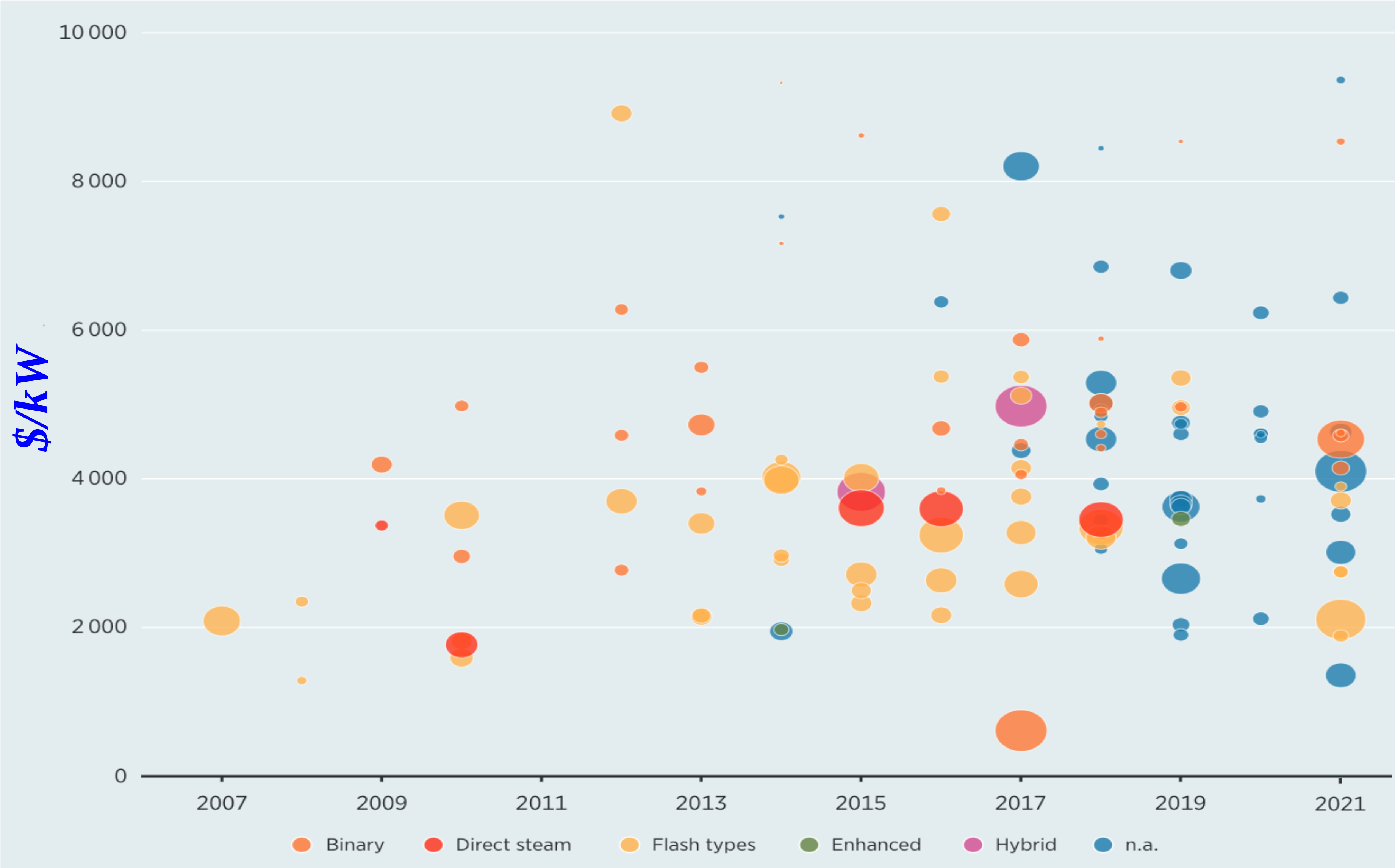


GEOTHERMAL POWER INSTALLED COSTS, *c.f.*s AND *LCOE*: 2010 – 2020



Source: IRENA Renewable Power Generation Costs in 2020, p.133; available online at https://www.irena.org/publications/2021/Jun/Renewable-Power-Costs-in-2020

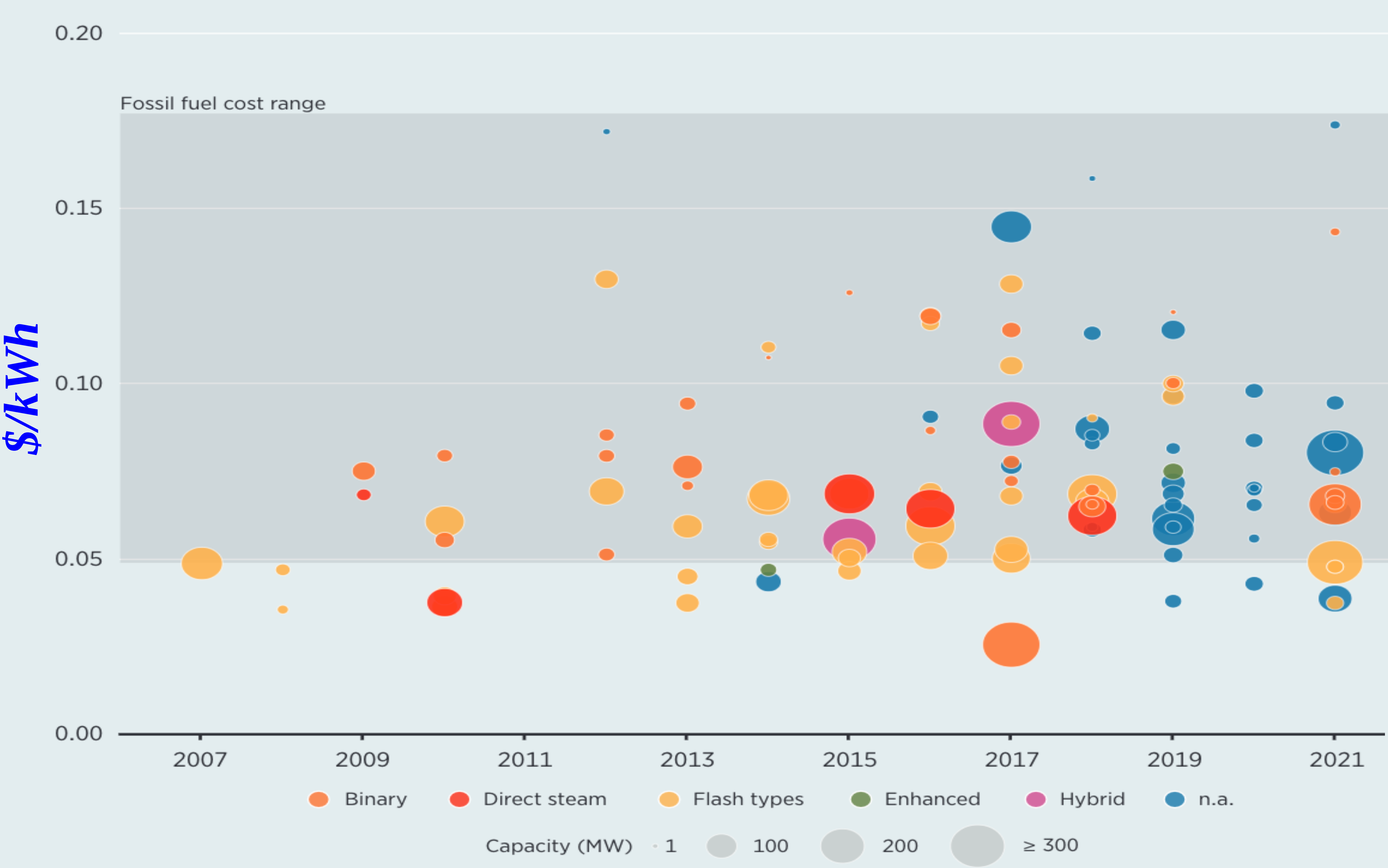
GEOTHERMAL POWER TOTAL INSTALLED COSTS: 2007–2021



Source: IRENA Renewable Power Generation Costs in 2020, p.137; available online at https://www.irena.org/publications/2021/Jun/Renewable-Power-Costs-in-2020

CAPACITY FACTORS OF GEOTHERMAL POWER PLANTS: 2007–2021

LCOE OF GEOTHERMAL POWER PROJECTS: 2007–2021



Source: IRENA Renewable Power Generation Costs in 2020, p.139; available online at https://www.irena.org/publications/2021/Jun/Renewable-Power-Costs-in-2020

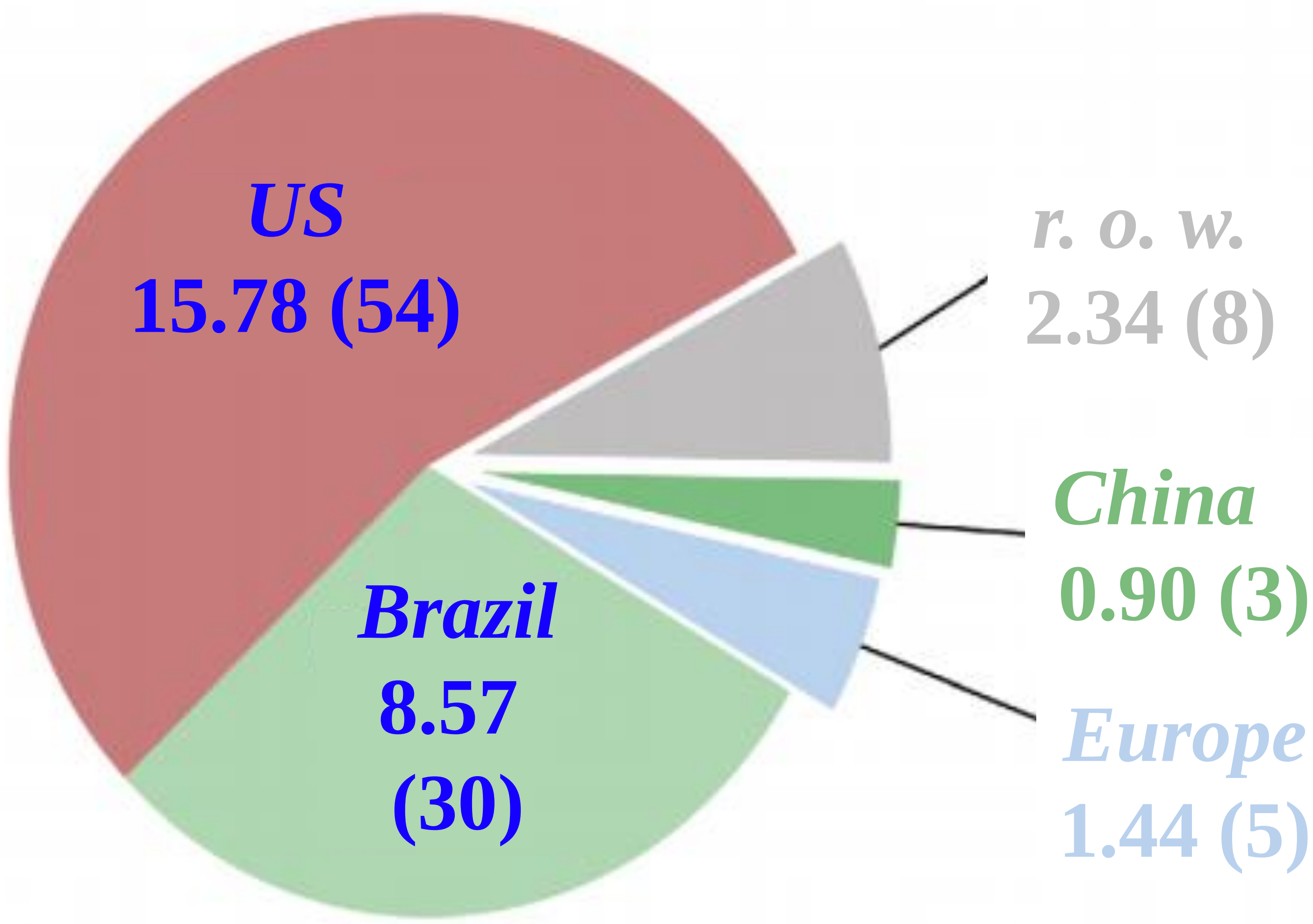
2019 BIOMASS / BIOFUELS STATUS

- **World biomass installed capacity is 146 *GW* and the 2016 generation was 504 *TWh***

21 *MW* Tracy Biomass Plant

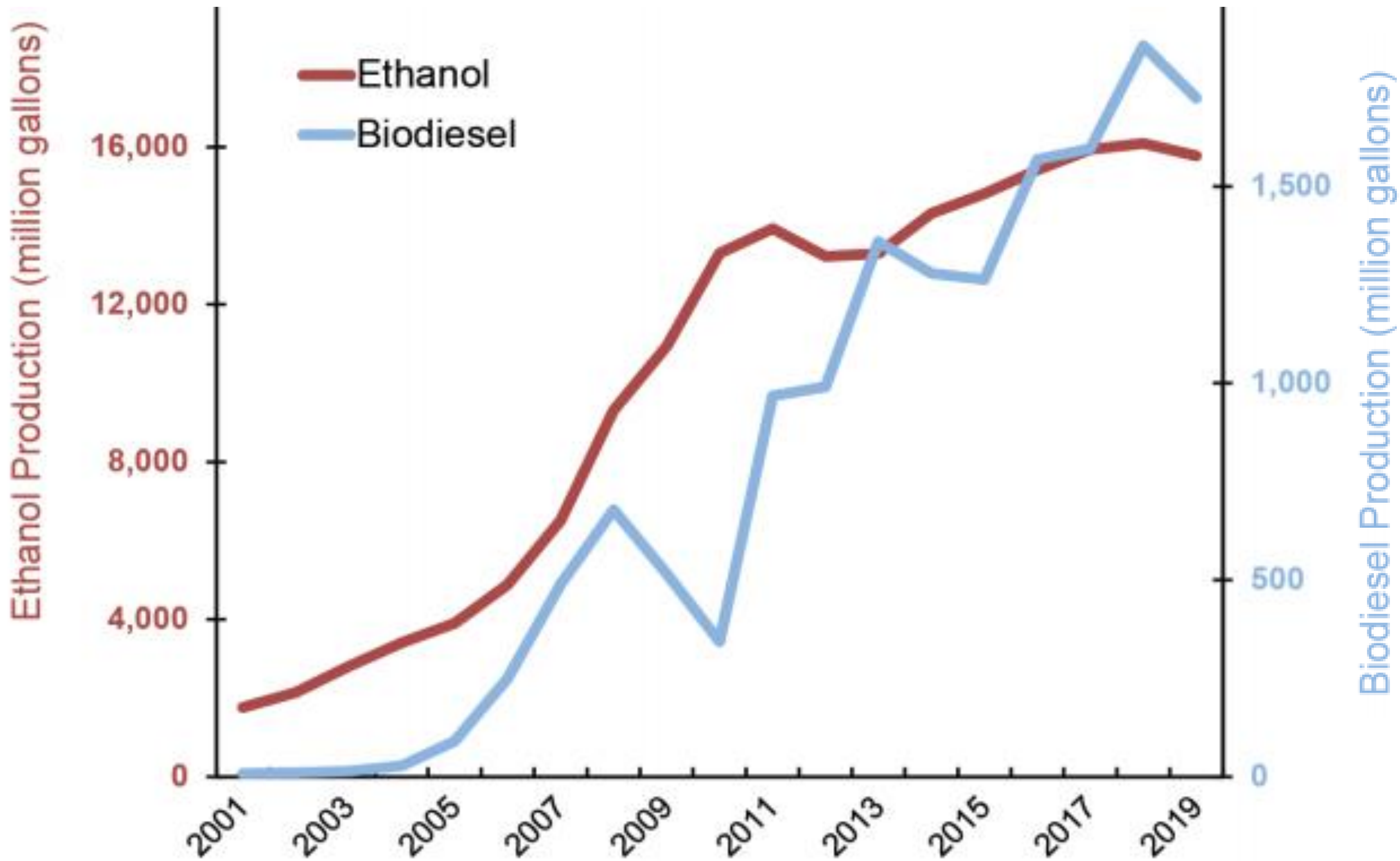
- **The *US* grid-connected installed biomass capacity is 16.0 *GW***
- ***China, US* and *Brazil* are the three largest biofuel producers in the world**
- **World biofuels production capacity is 144 *billion l/y***

GLOBAL FUEL ETHANOL PRODUCTION: 2020



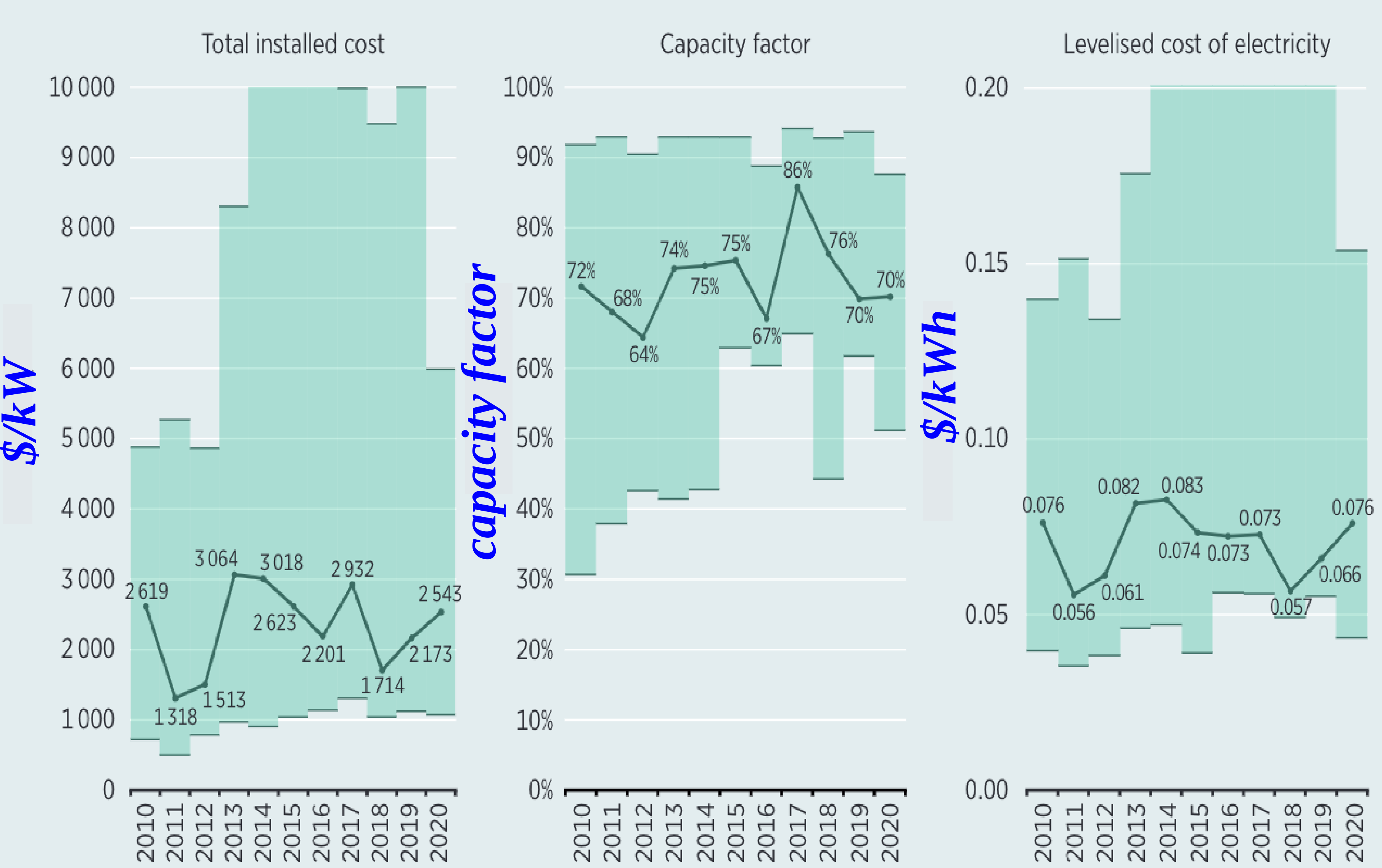
Source: Center for Sustainable Systems University of Michigan, available at http://css.umich.edu/factsheets/biofuels-factsheet

YEARLY ETHANOL AND BIODIESEL PRODUCTION: 2001–2019



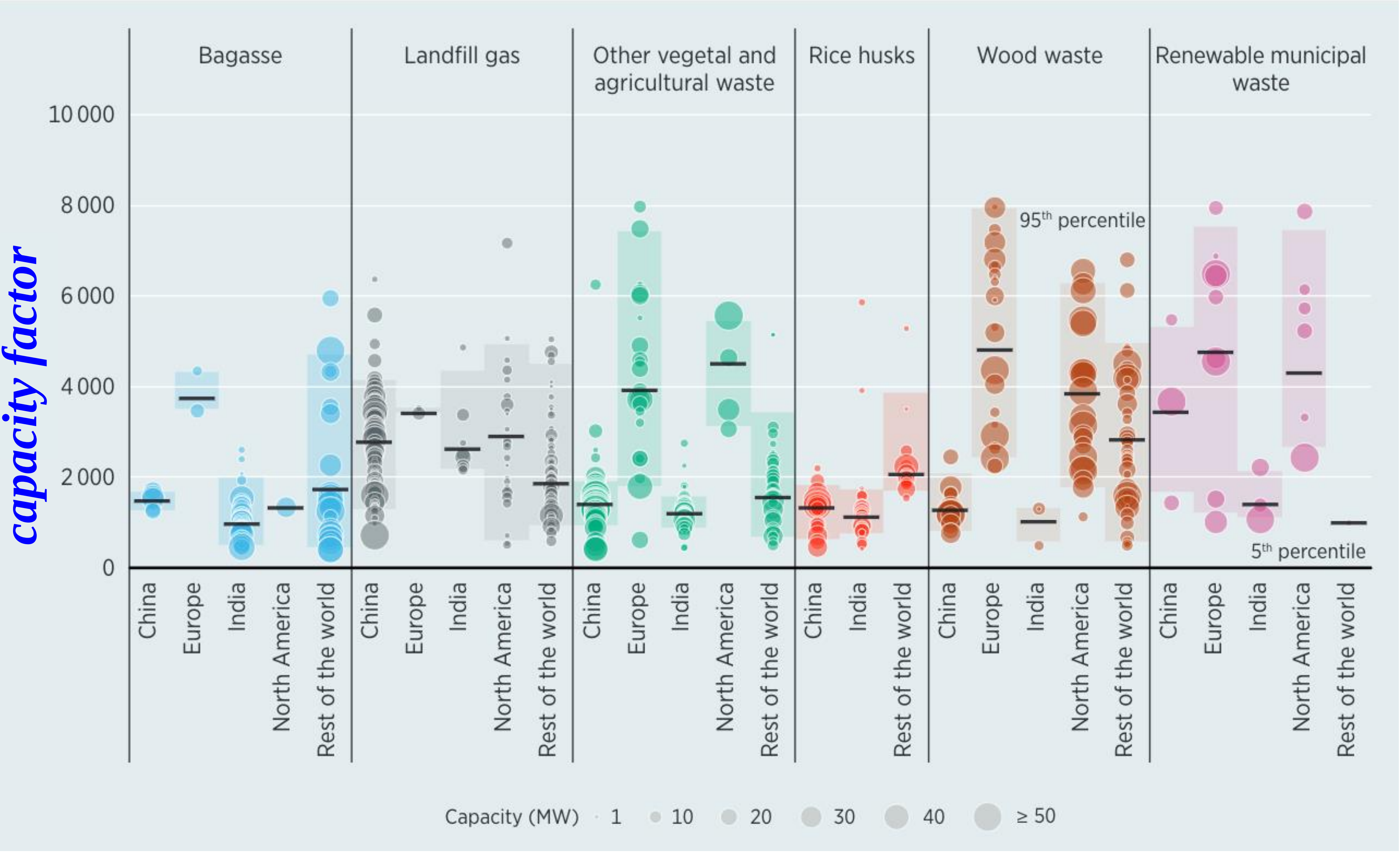
Source: Center for Sustainable Systems University of Michigan, available at http://css.umich.edu/factsheets/biofuels-factsheet

BIOENERGY INSTALLED COSTS, *c.f.*s AND *LCOE*: 2010 – 2020



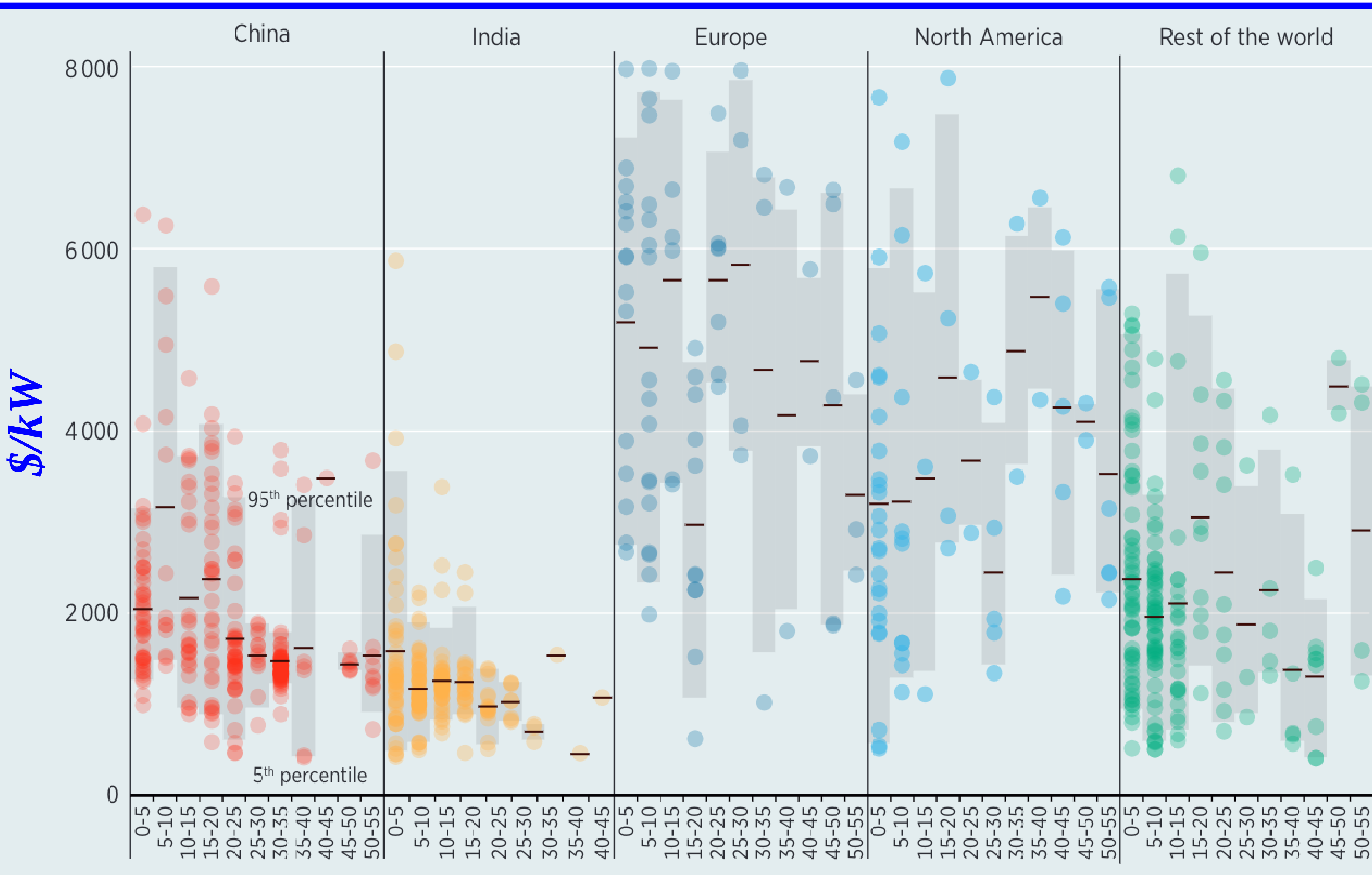
Source: IRENA Renewable Power Generation Costs in 2020, p.141; available online at https://www.irena.org/publications/2021/Jun/Renewable-Power-Costs-in-2020

BIOENERGY PROJECTS *c.f.*s. IN 2020



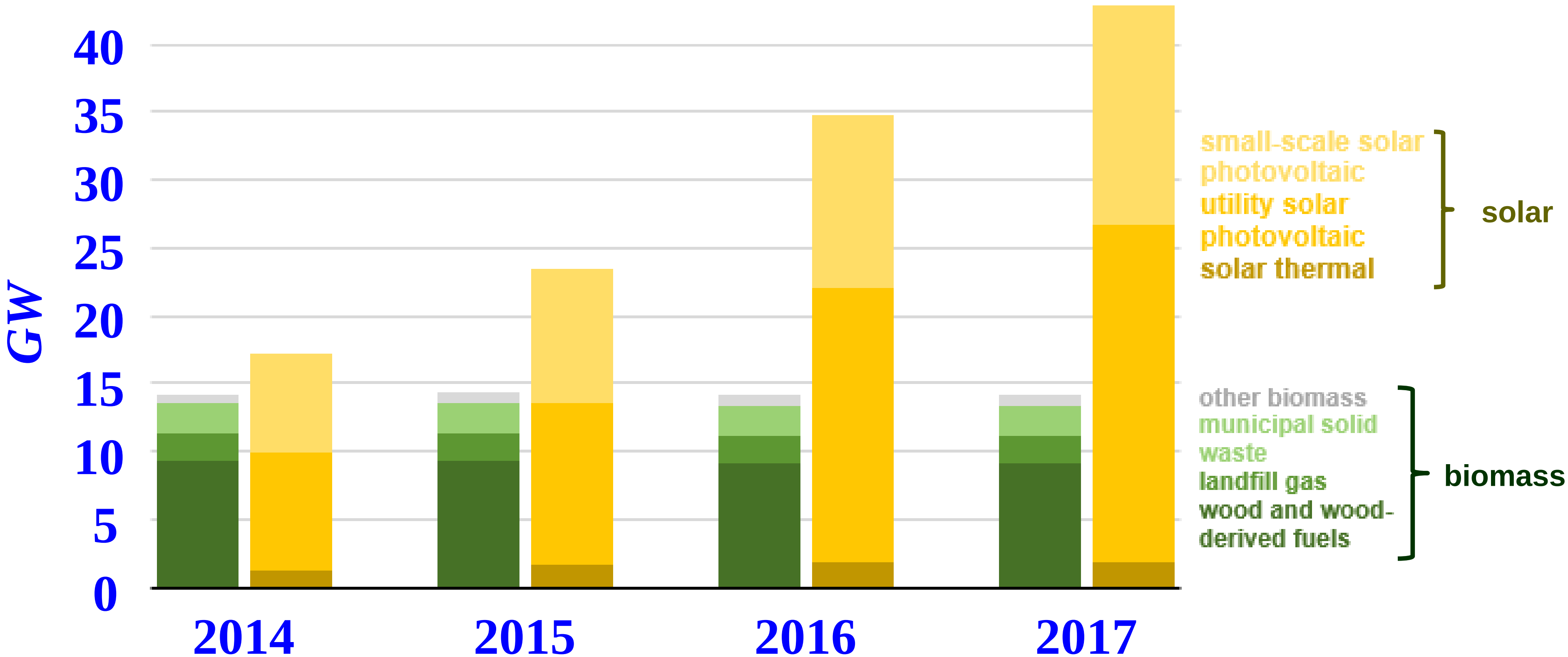
Source: IRENA Renewable Power Generation Costs in 2020, p.145; available online at file:///C:/Users/Azr/Downloads/IRENA_Power_Generation_Costs_2020%20(1).pdf

TOTAL INSTALLED COSTS OF BIOENERGY PROJECTS IN 2020



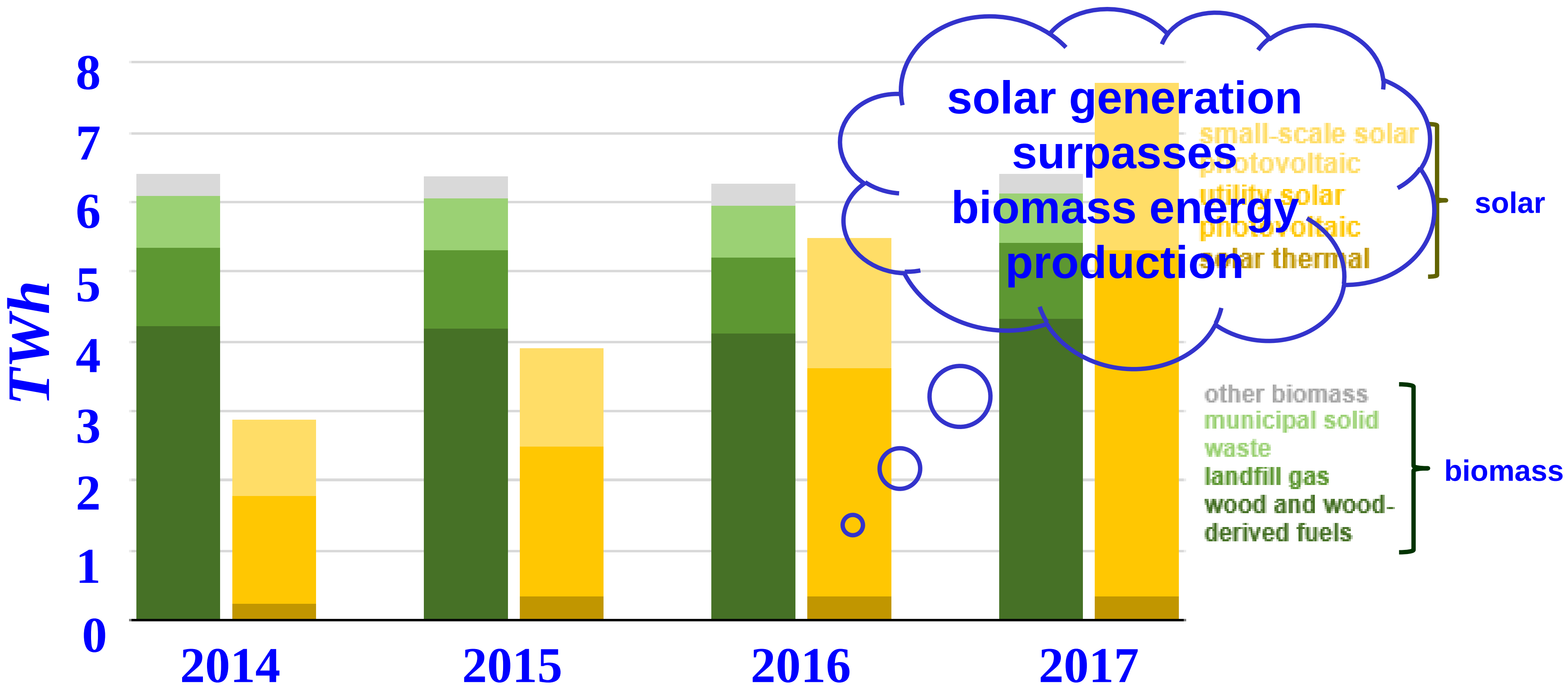
Source: IRENA Renewable Power Generation Costs in 2020, p.145; available online at file:///C:/Users/Azr/Downloads/IRENA_Power_Generation_Costs_2020%20(1).pdf

ANNUAL SOLAR AND BIOMASS CAPACITY: 2014 – 2017



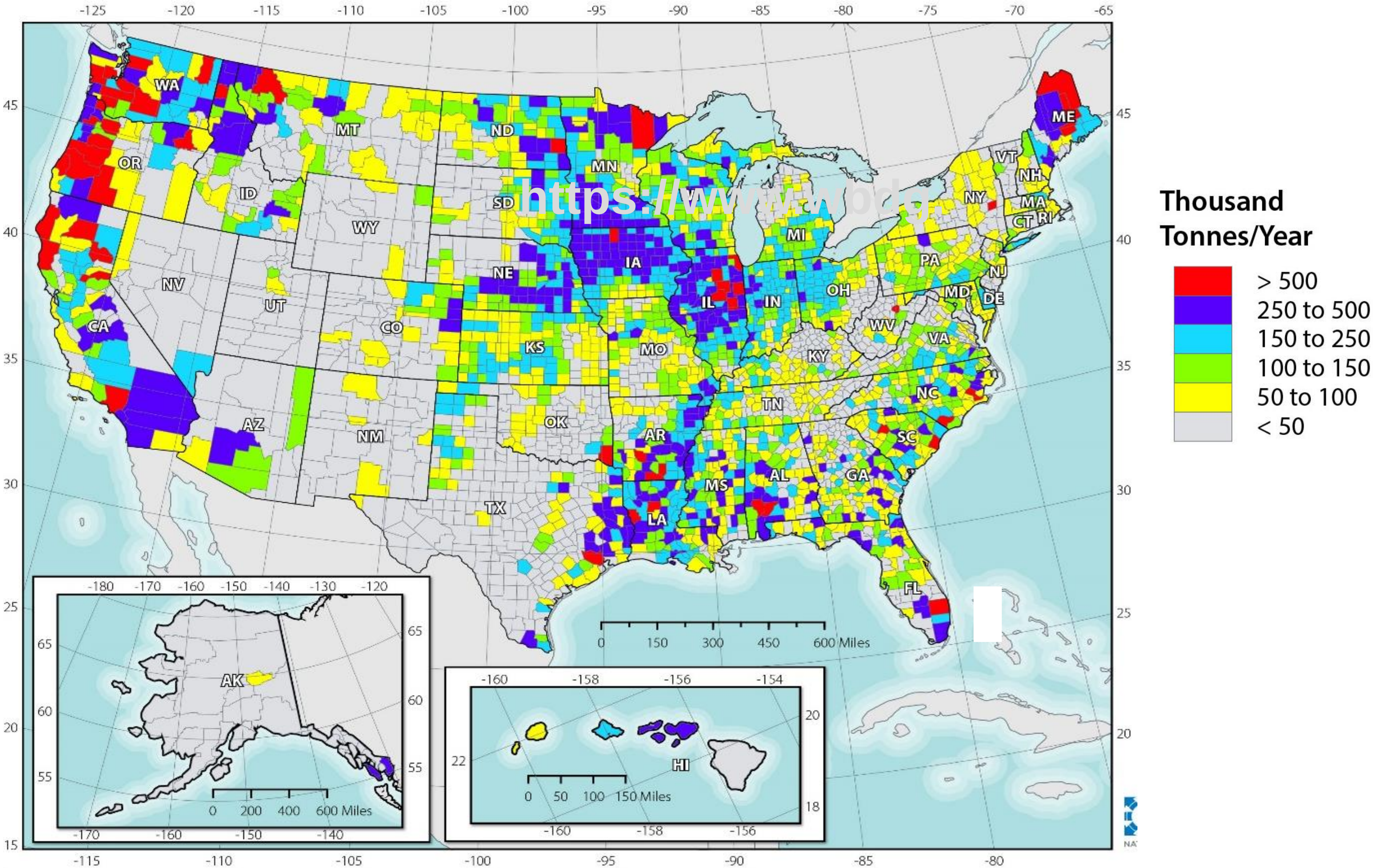
Source: *EIA, Electric Power Monthly, data published in May* 9, 2018, *Today in Energy*; *available online at https://www.eia.gov/todayinenergy/detail.php?id=36132*

ANNUAL SOLAR & BIOMASS ENERGY PRODUCTION: 2014 – 2017



Source: EIA, Electric Power Monthly, data published in May 9, 2018, Today in Energy; available online at https://www.eia.gov/todayinenergy/detail.php?id=36132

US BIOMASS RESOURCE MAP



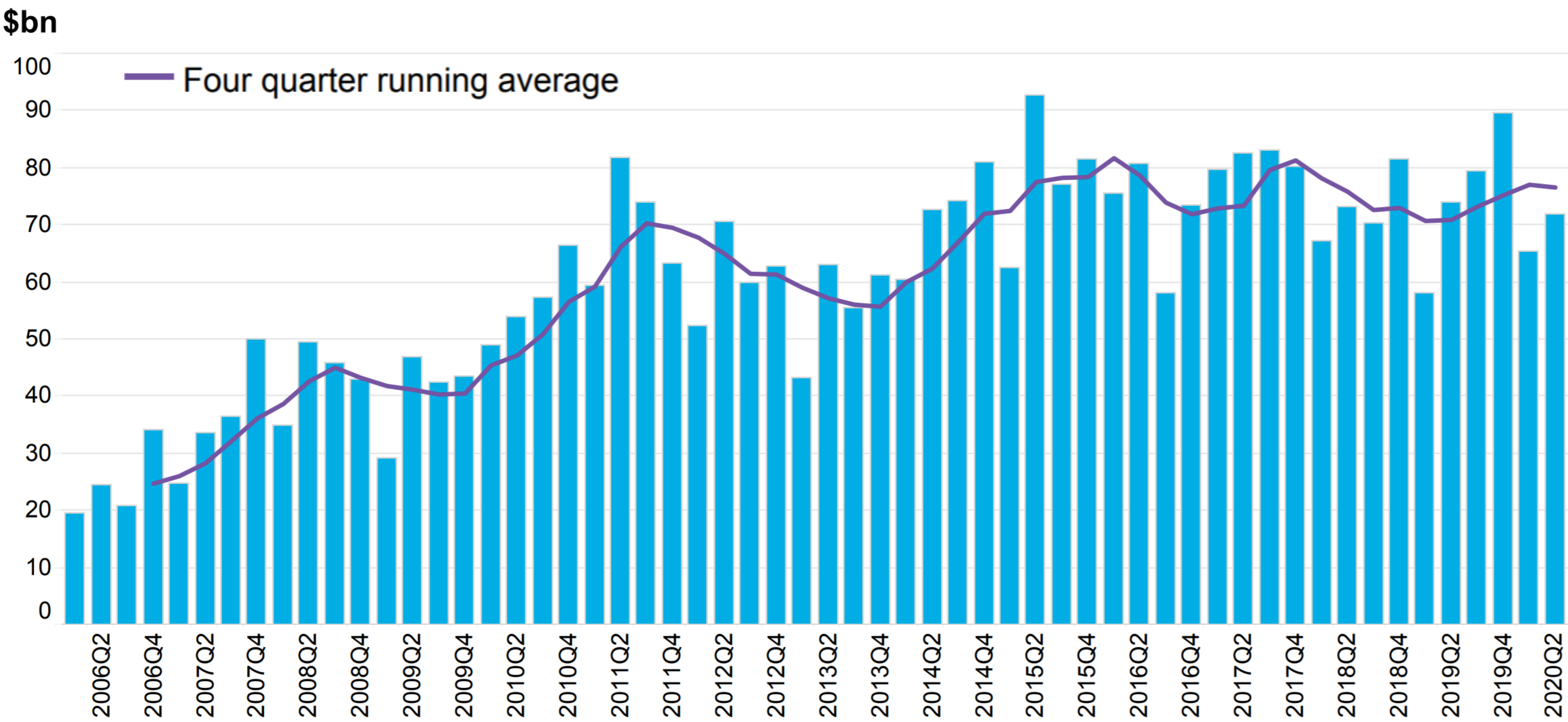
Source: NREL, available at https://www.nrel.gov/gis/biomass.html

BIOMASS RESOURCES

- **The major capital cost items for a biomass power system include the fuel storage and fuel handling equipment, the combustor, boiler, prime mover, generator, controls, stack, and emissions control equipment**
- ***US* biomass resources deploy direct combustion as the most common method of heat production**
- **Small-scale biomass electric plants installed cost range is 3,000 – 4,000 *$/kW* and levelized costs of energy of 80 – 150 *$/MWh***

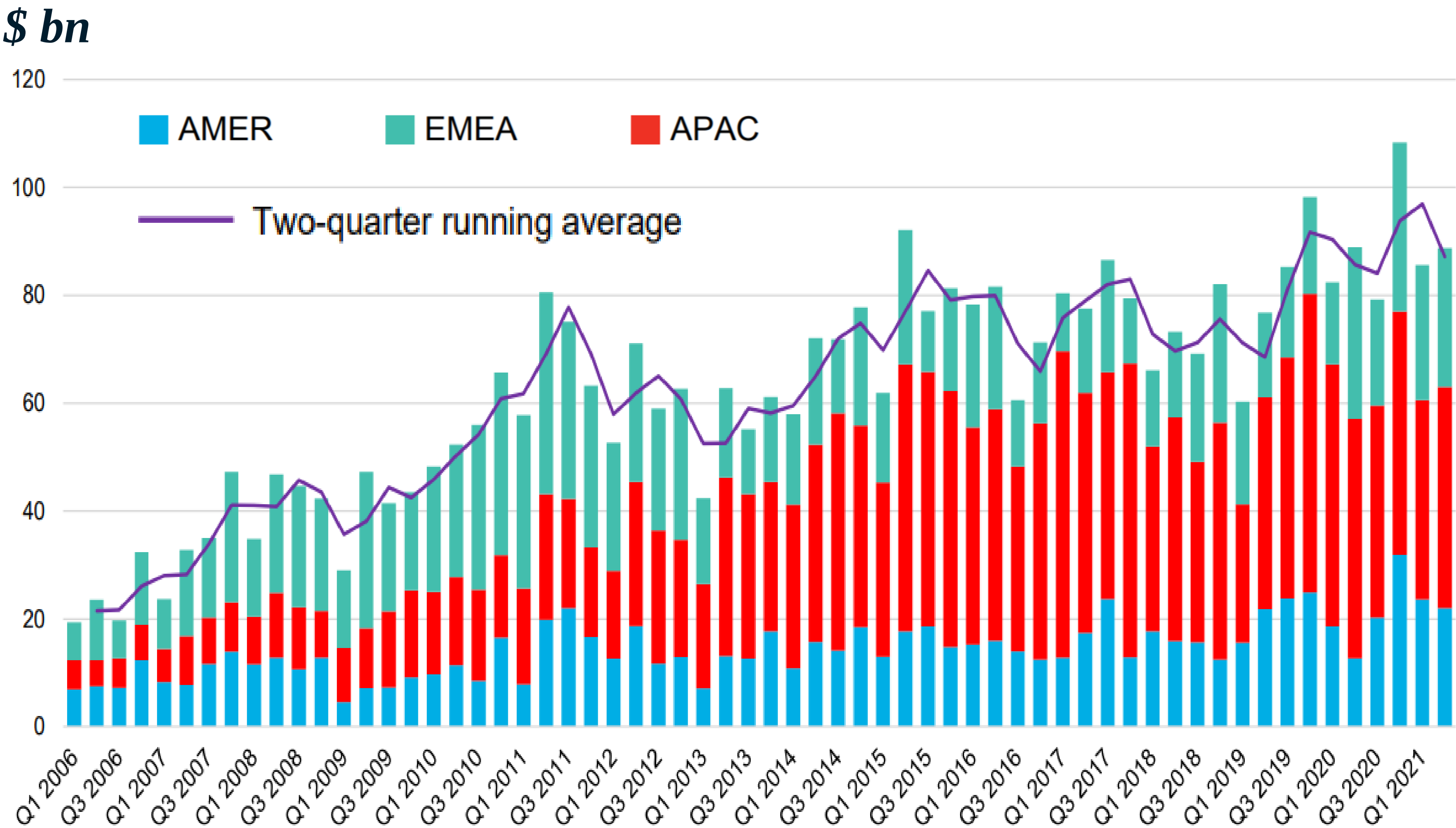
NEW WORLDWIDE CLEAN ENERGY INVESTMENT: *Q*1/2006 – *Q*2/2020

Source: Bloomberg New Energy Finance; available at https://about.bnef.com/clean-energy-investment/



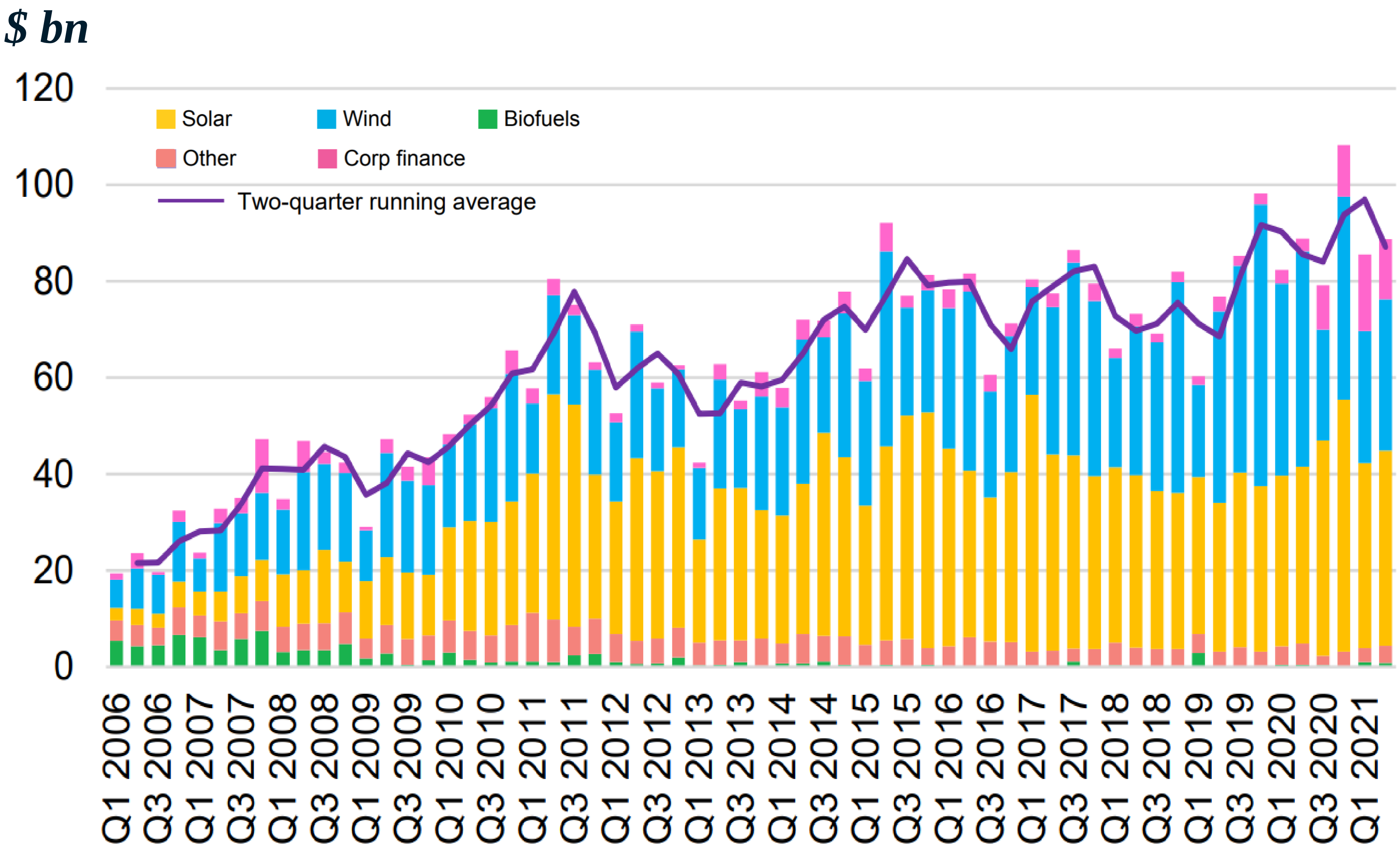
NEW WORLDWIDE CLEAN ENERGY INVESTMENT BY REGION: *Q*1/2006 – *Q*2/2021

Source*: *Bloomberg New Energy Finance; available at https://assets.bbhub.io/professional/sites/24/BNEF-Renewable-Energy-Investment-Tracker-1H-2021_FINAL_abridged.pdf; p.17



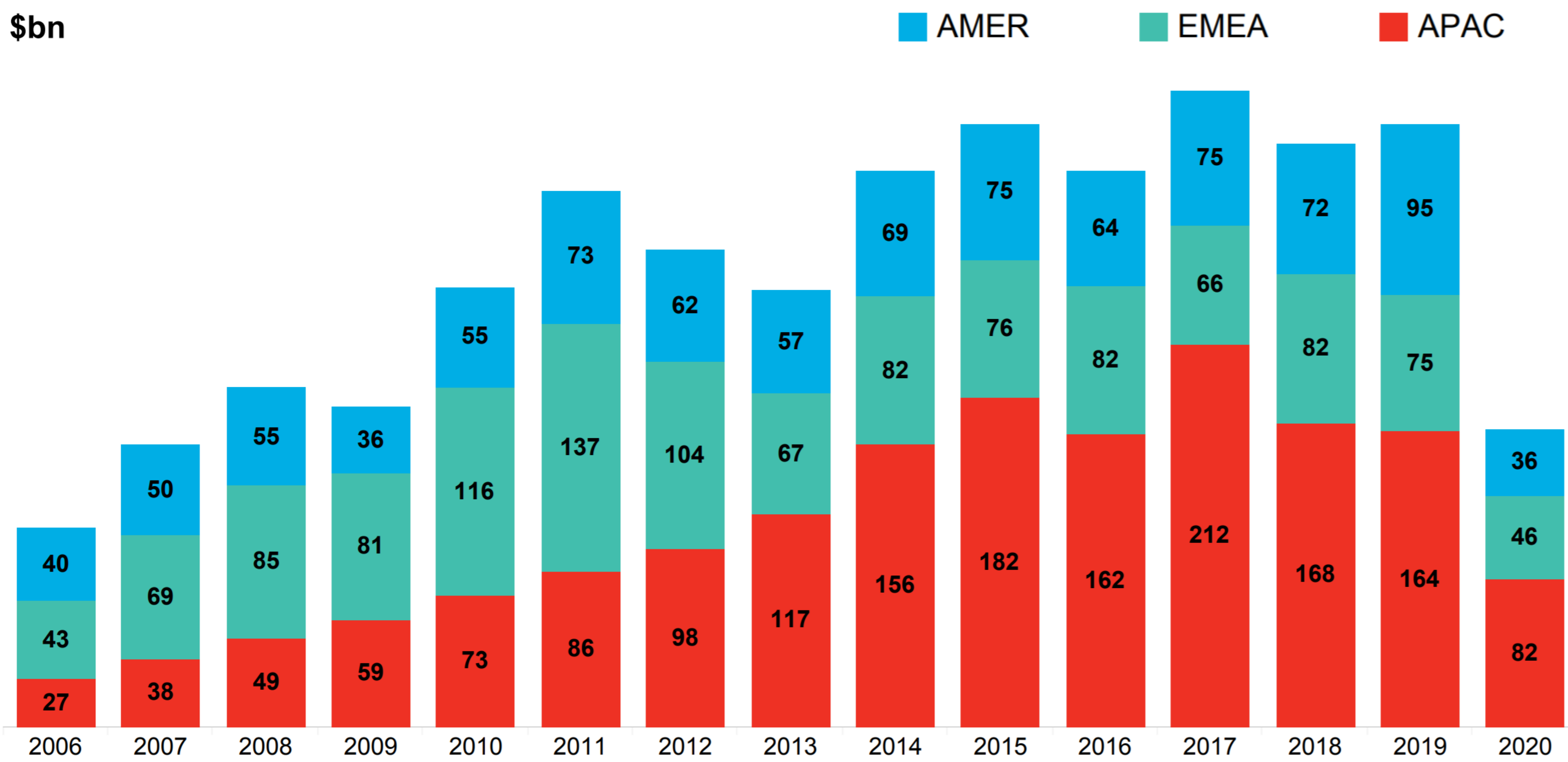
NEW WORLDWIDE CLEAN ENERGY INVESTMENT BY SECTOR: *Q1/2006 – Q2/2021*

Source: *Bloomberg New Energy Finance; available at https://assets.bbhub.io/professional/sites/24/BNEF-Renewable-Energy-Investment-Tracker-1H-2021_FINAL_abridged.pdf; p.1*



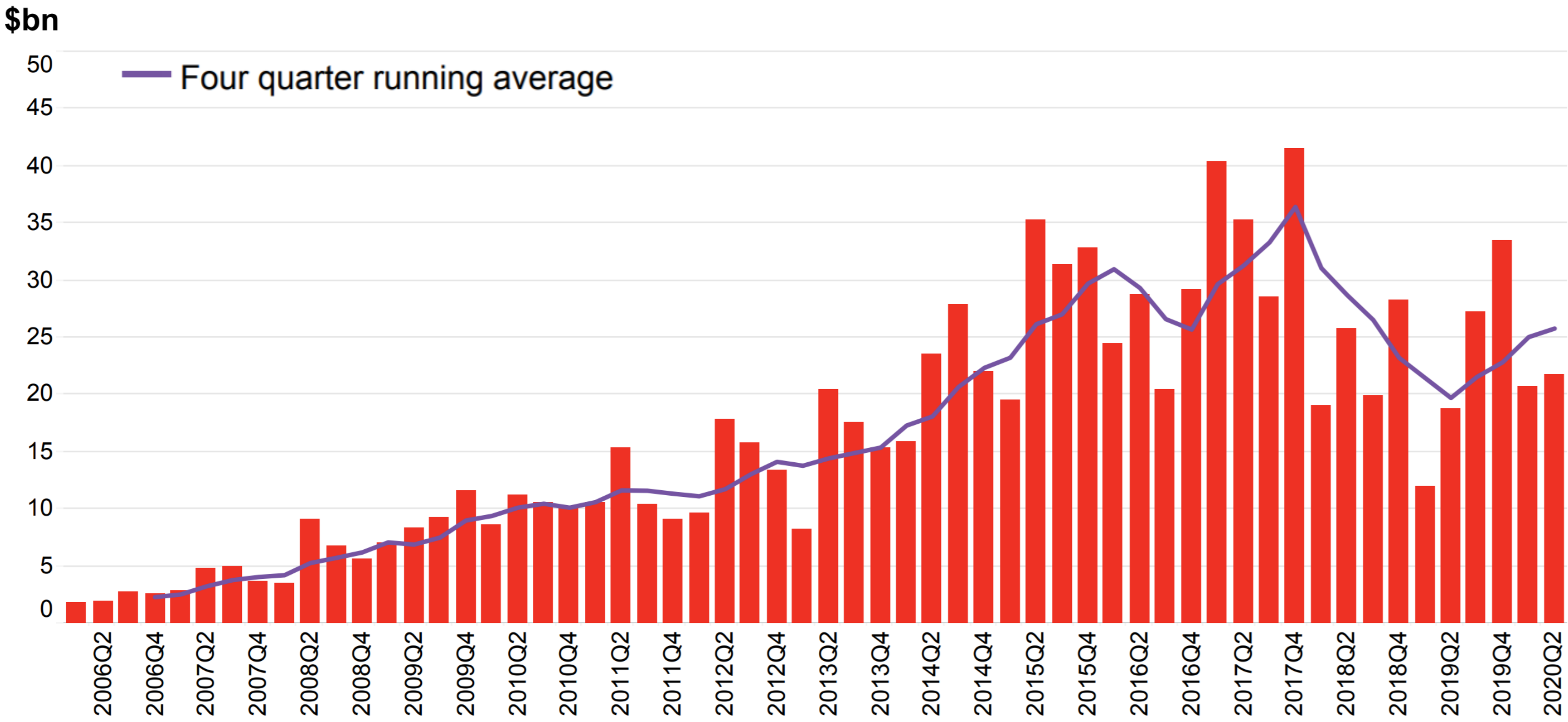
NEW ANNUAL GLOBAL CLEAN ENERGY INVESTMENT BY REGION: 2006 – 2020

Source: Bloomberg New Energy Finance; available at https://about.bnef.com/clean-energy-investment/



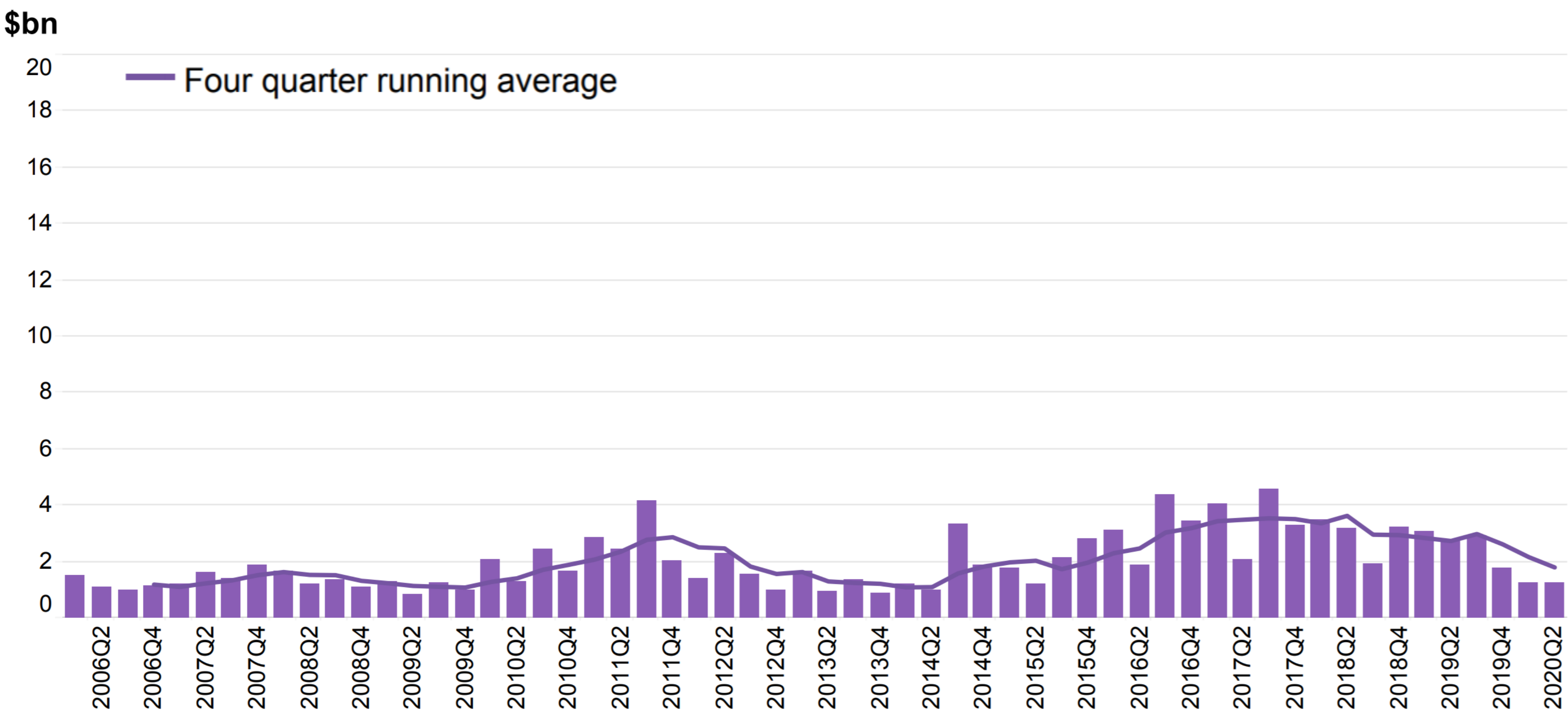
NEW CLEAN ENERGY INVESTMENT BY *CHINA*: *Q1/2006 – Q2/2020*

Source*: *Bloomberg New Energy Finance; available at https://about.bnef.com/clean-energy-investment/

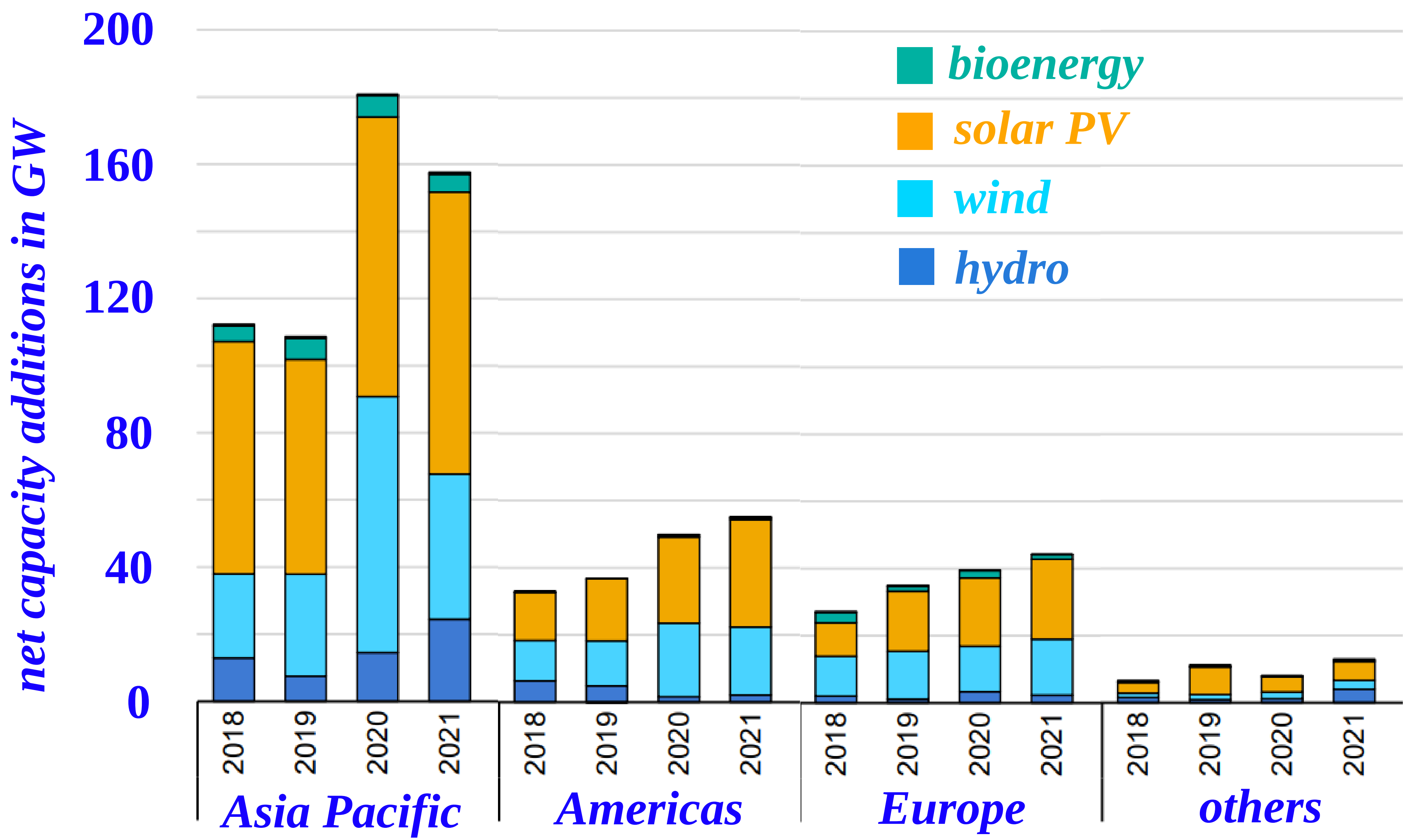


NEW CLEAN ENERGY INVESTMENT BY *INDIA*: *Q1/2006 – Q2/2020*

Source*: *Bloomberg New Energy Finance; available at https://about.bnef.com/clean-energy-investment/

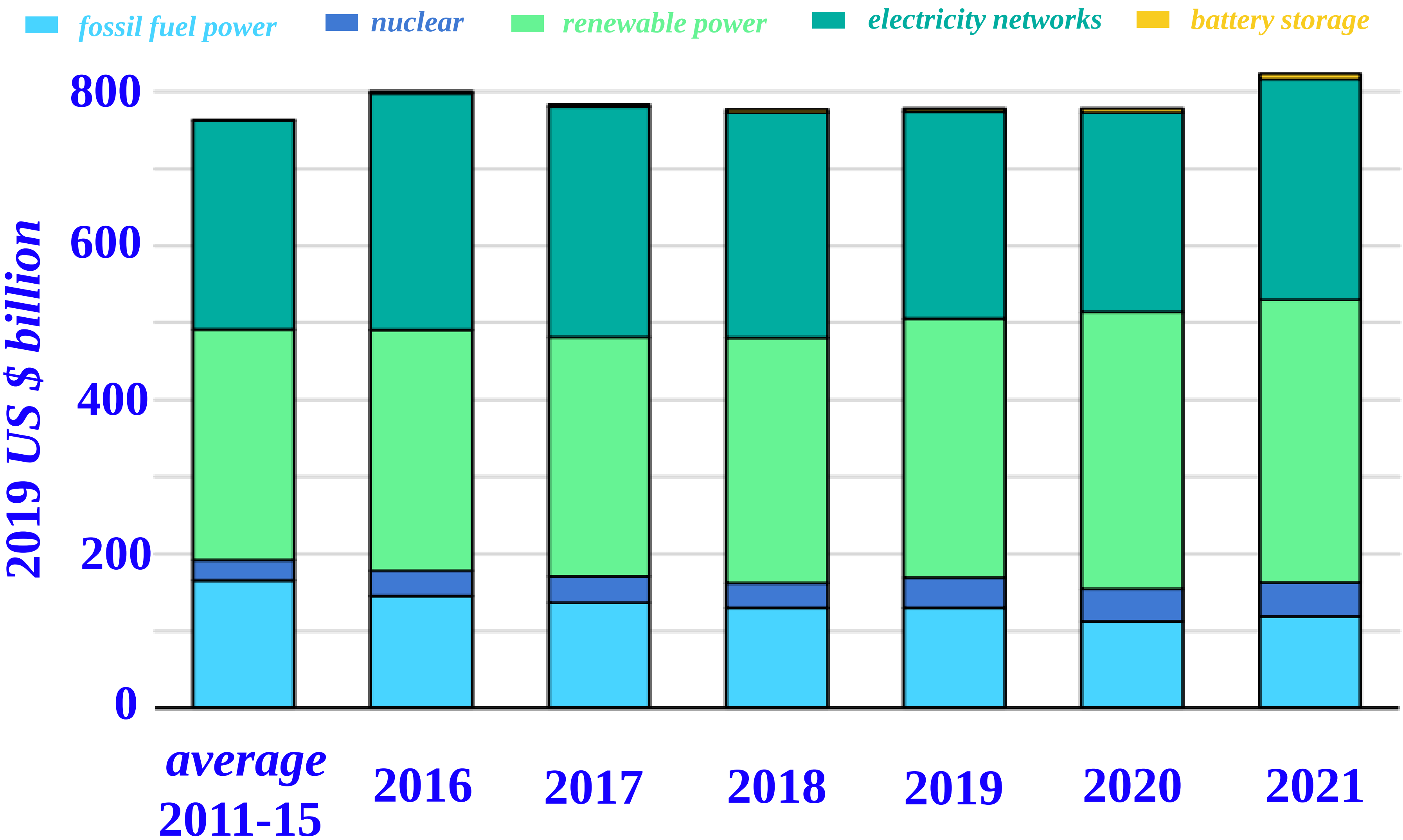


NET ANNUAL RENEWABLE CAPACITY ADDITION: 2018 – 2021



Source: IEA analysis based on EIA 2021, available at https://iea.blob.core.windows.net/assets/01e1e998-8611-45d7-acab-5564bc22575a/ElectricityMarketReportJuly2021.pdf; p. 33

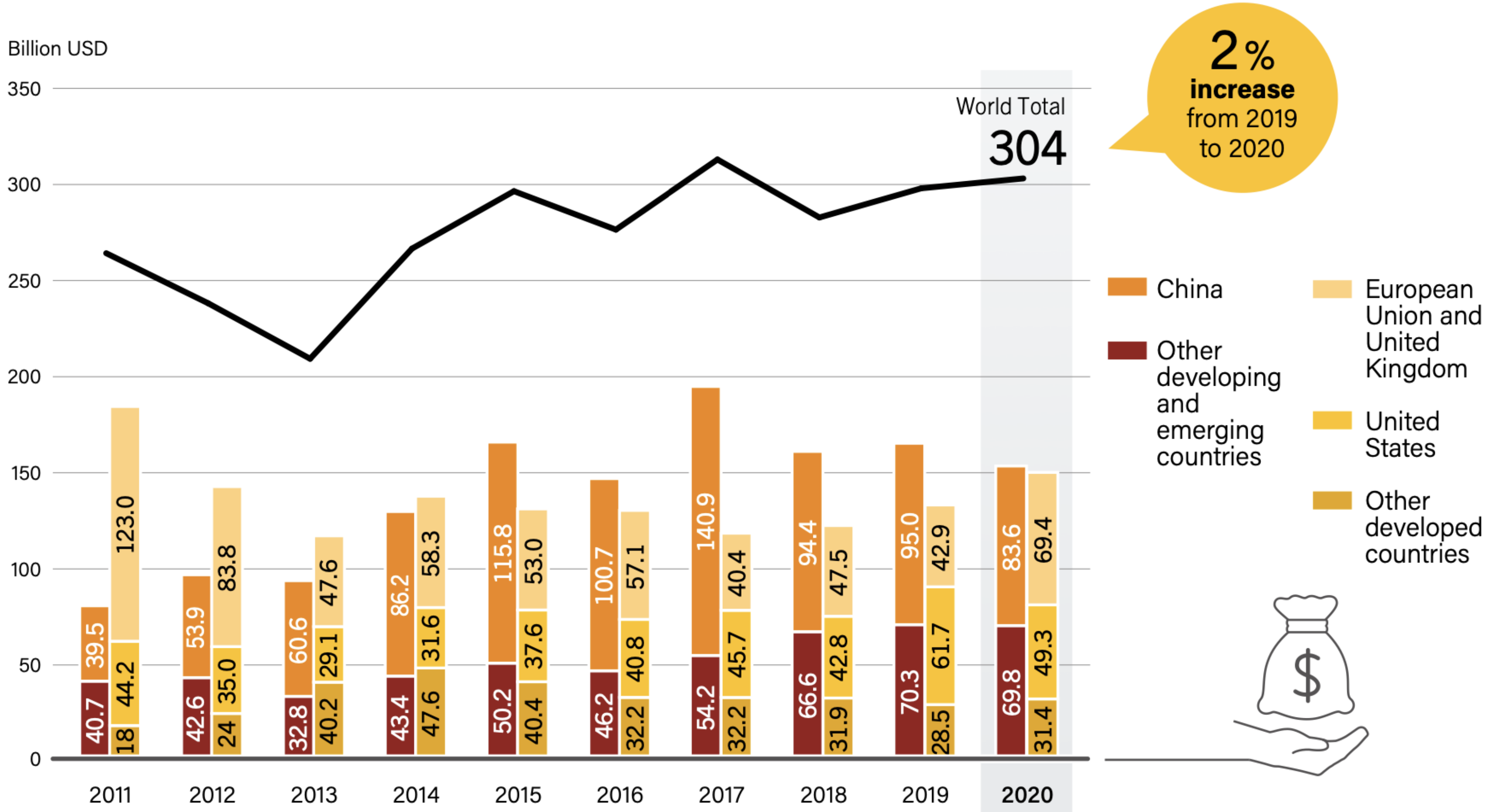
ANNUAL GLOBAL POWER SECTOR INVESTMENT: 2011 – 2021



Source: IEA analysis based on EIA 2021, available at https://iea.blob.core.windows.net/assets/01e1e998-8611-45d7-acab-5564bc22575a/ElectricityMarketReportJuly2021.pdf; p. 31

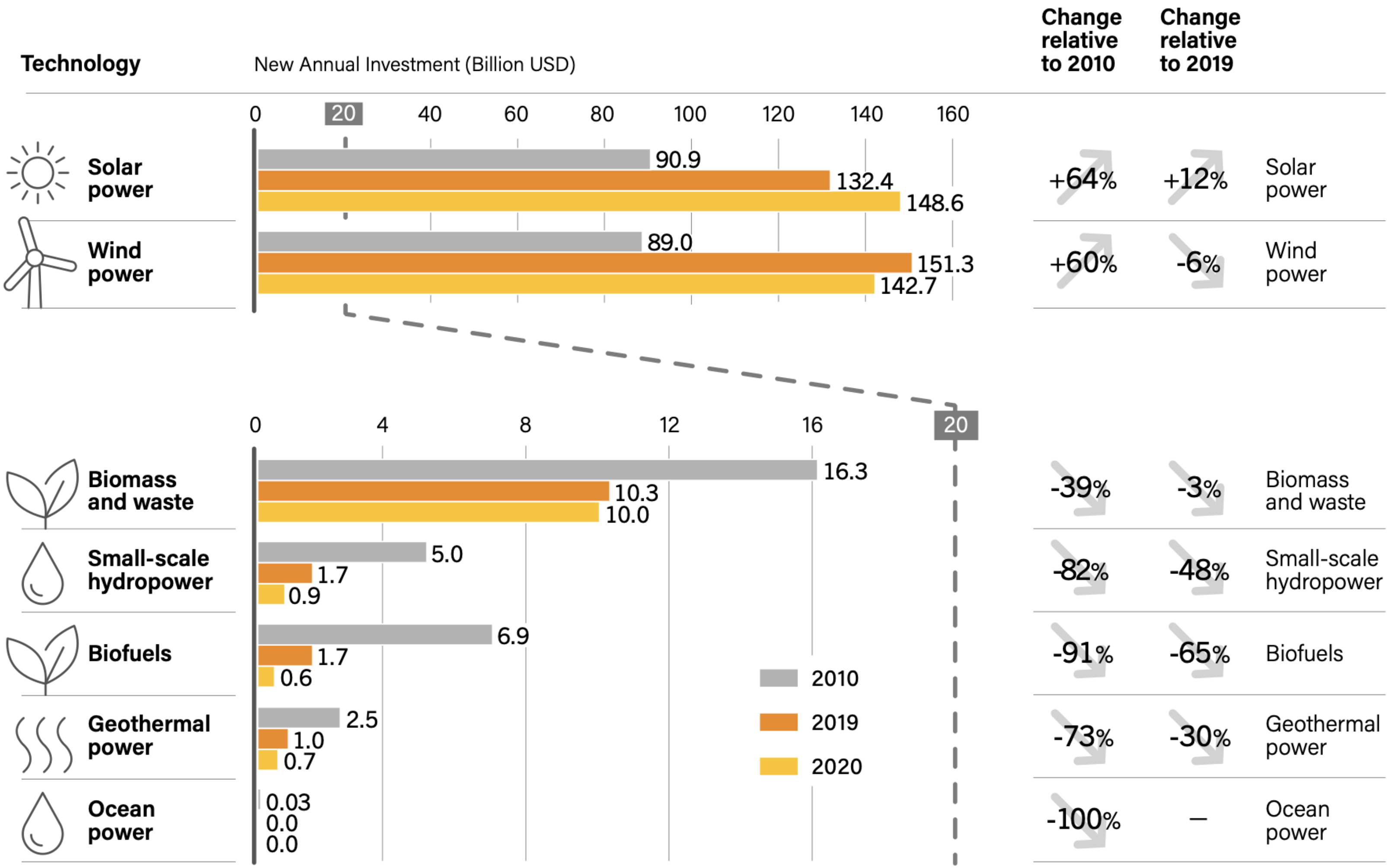
GLOBAL RENEWABLE INVESTMENT: 2011 – 2020

***Source*: REN 21 at https://www.ren21.net/wp-content/uploads/2019/05/GSR2021_Full_Report.pdf; p.184**

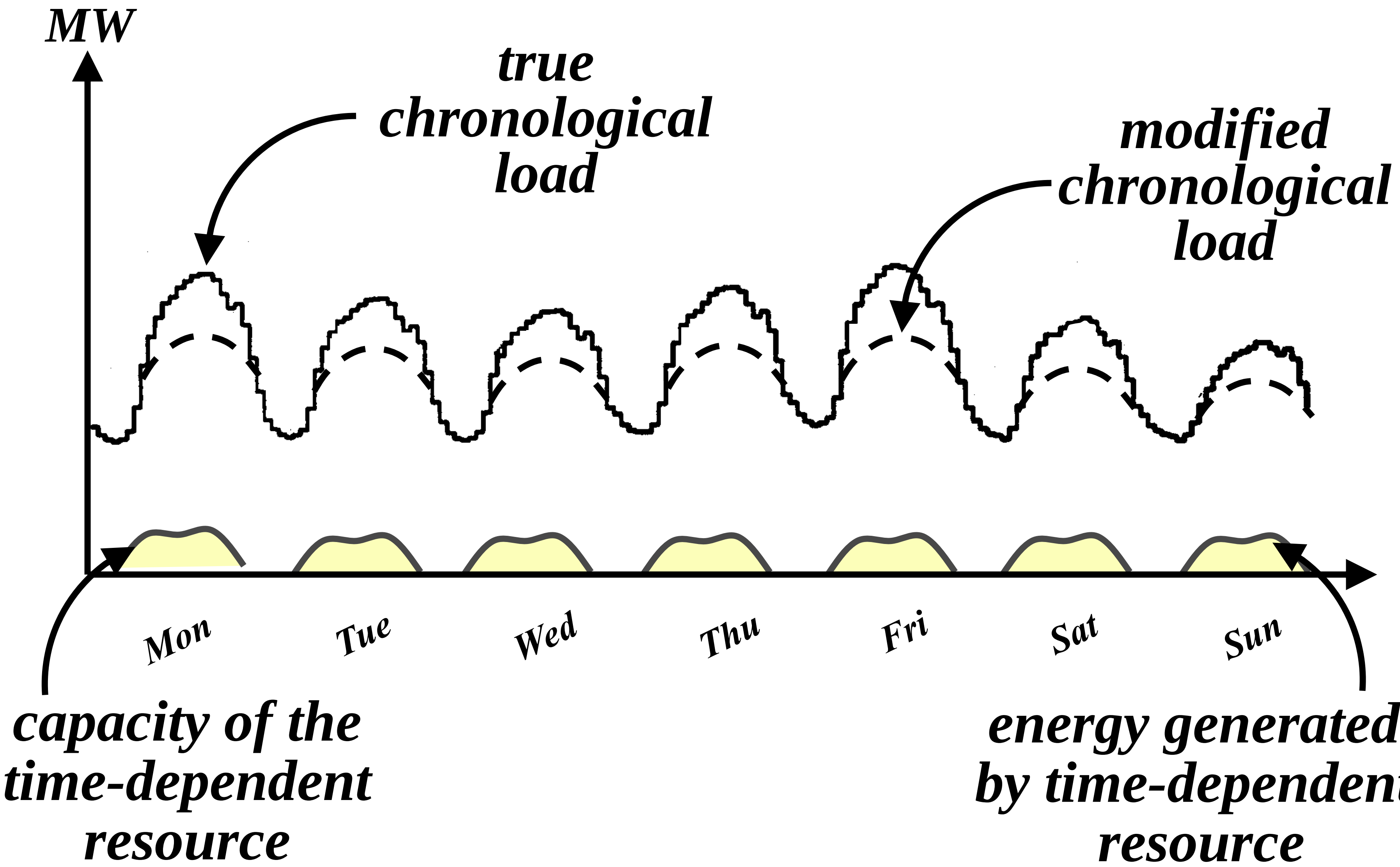


TRENDS IN GLOBAL RENEWABLE INVESTMENT: A COMPARISON

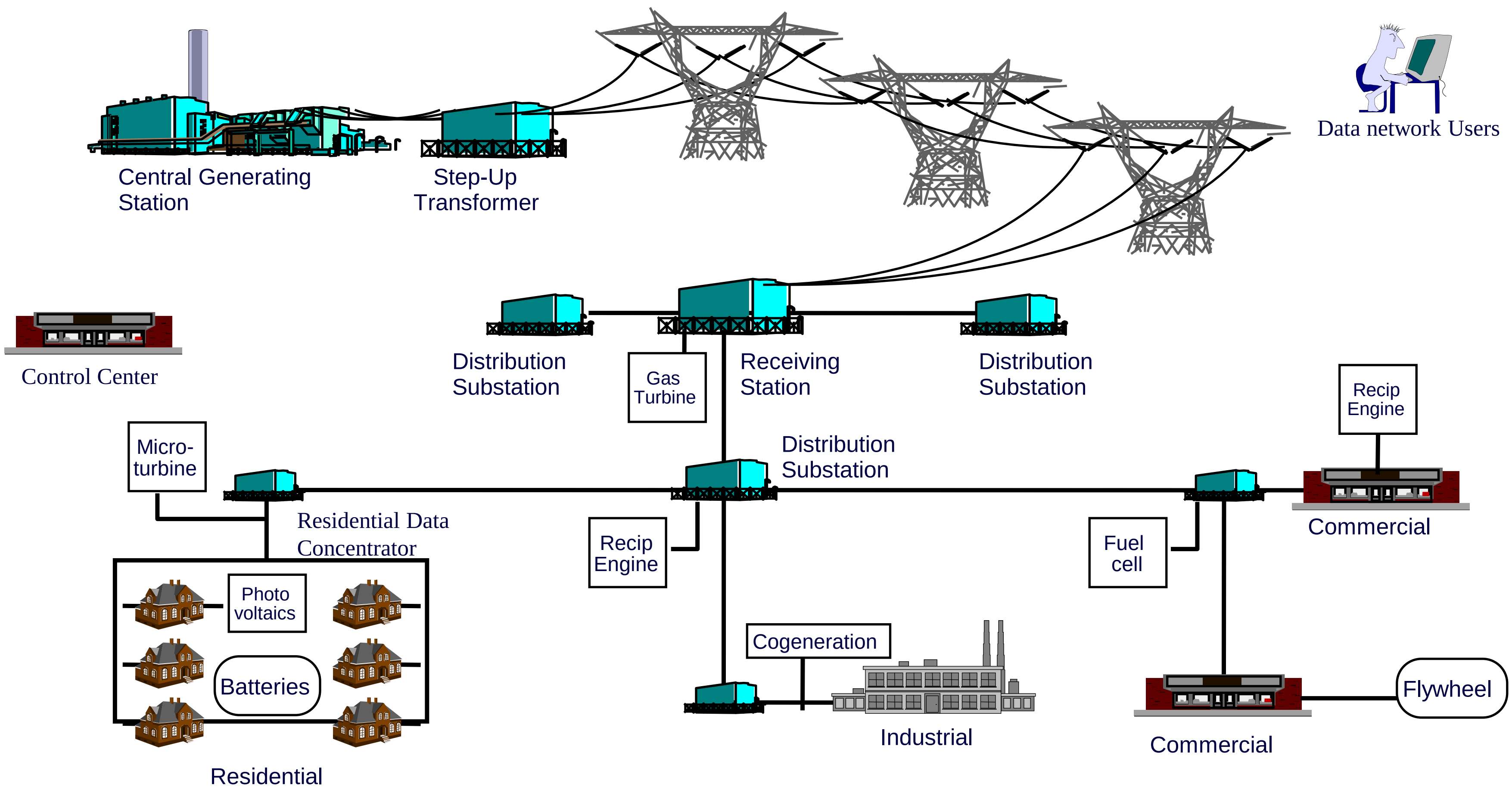
Source: REN 21 at https://www.ren21.net/wp-content/uploads/2019/05/GSR2021_Full_Report.pdf; p.188



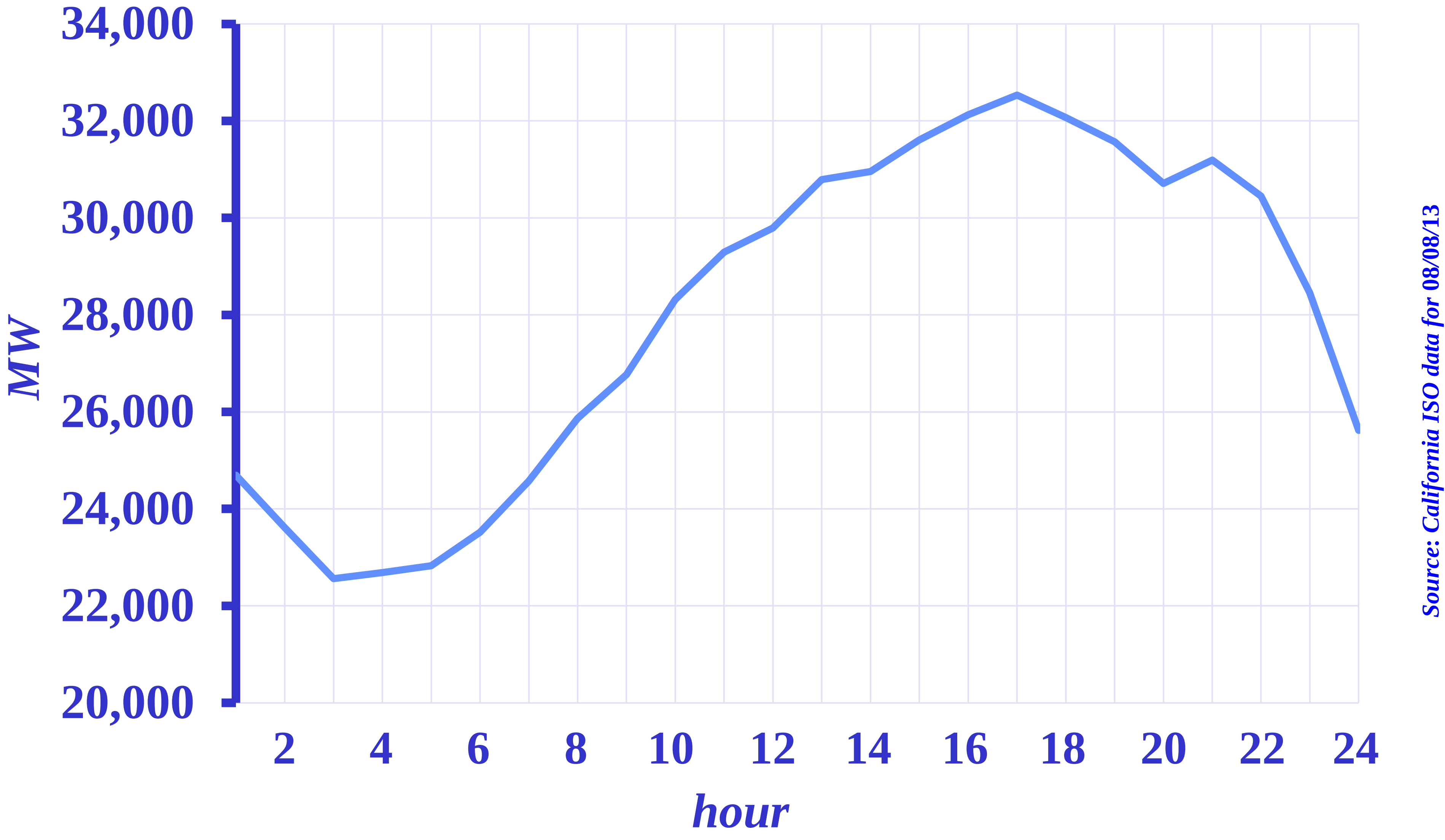
IMPACTS OF RENEWABLES



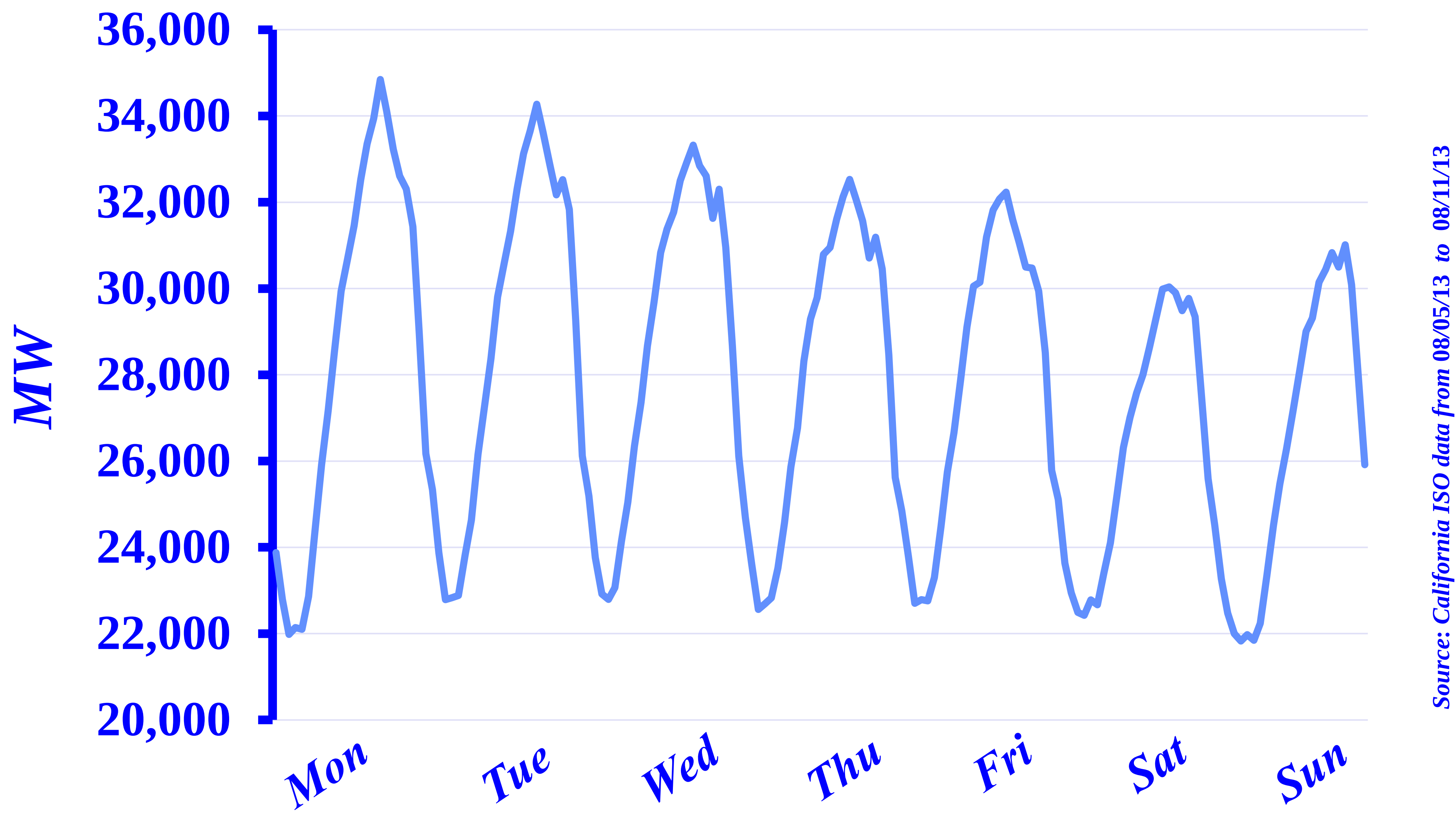
ELECTRIC SYSTEM INFRASTRUCTURE



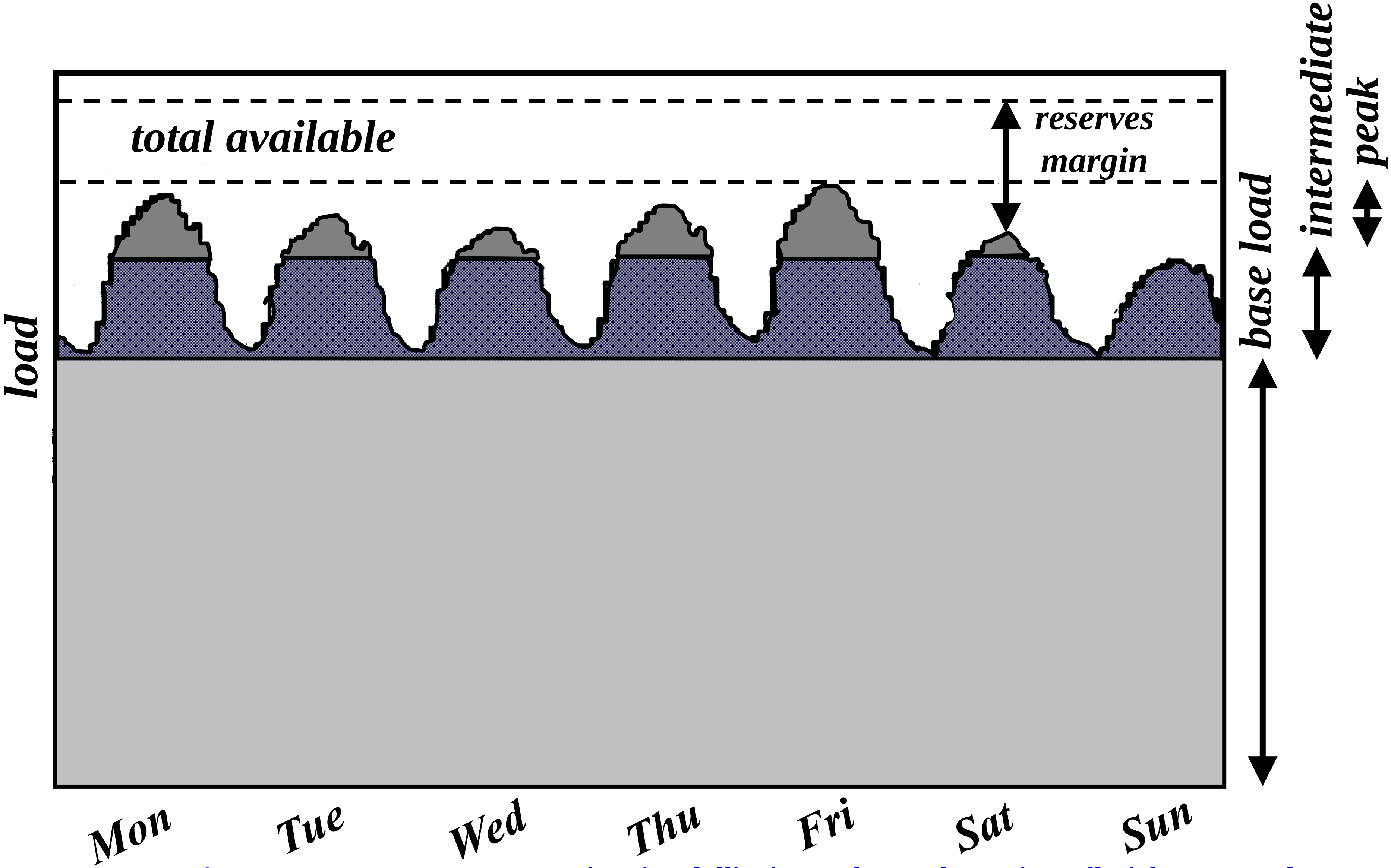
TWENTY–FOUR HOUR PROFILE



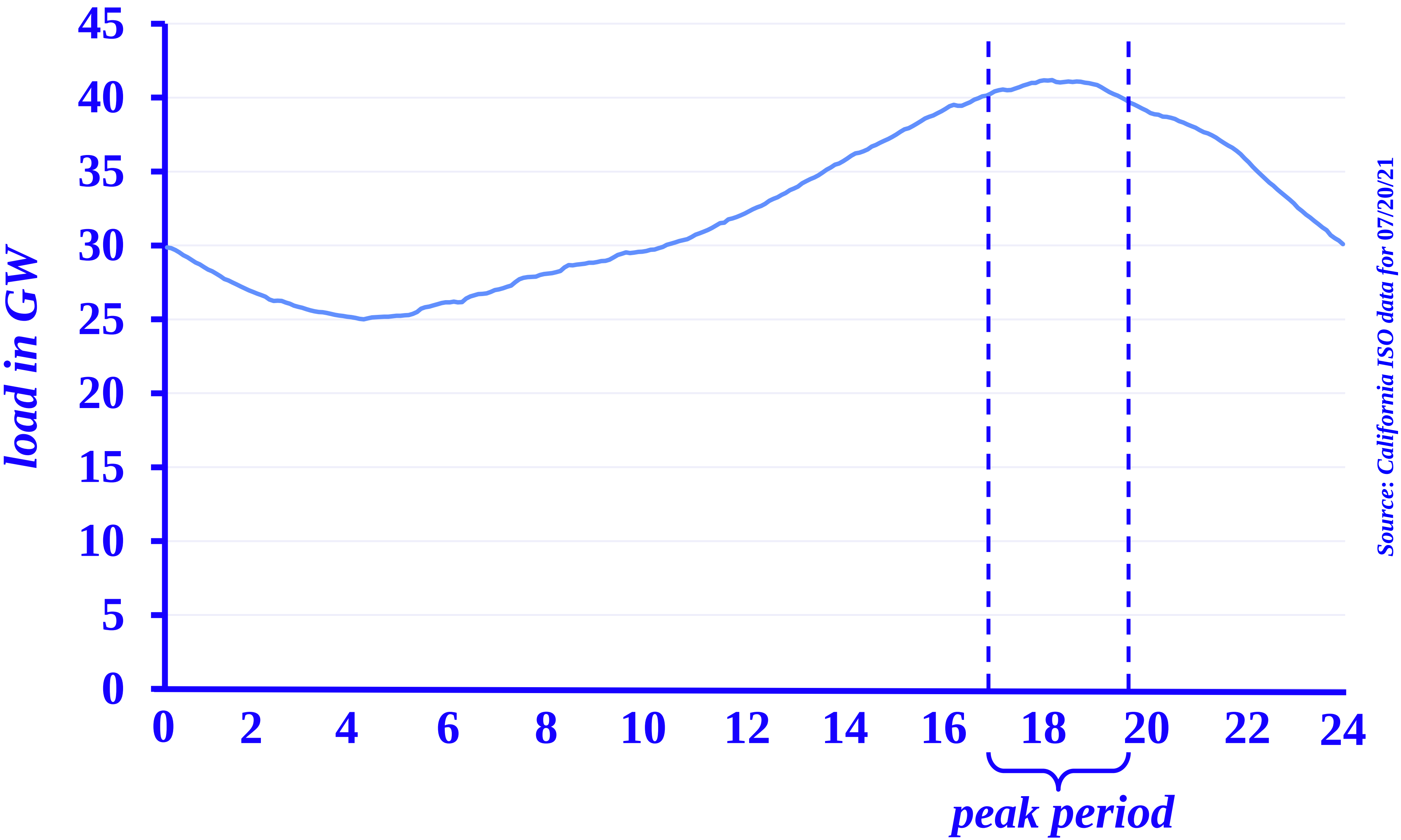
WEEKLY LOAD CYCLE



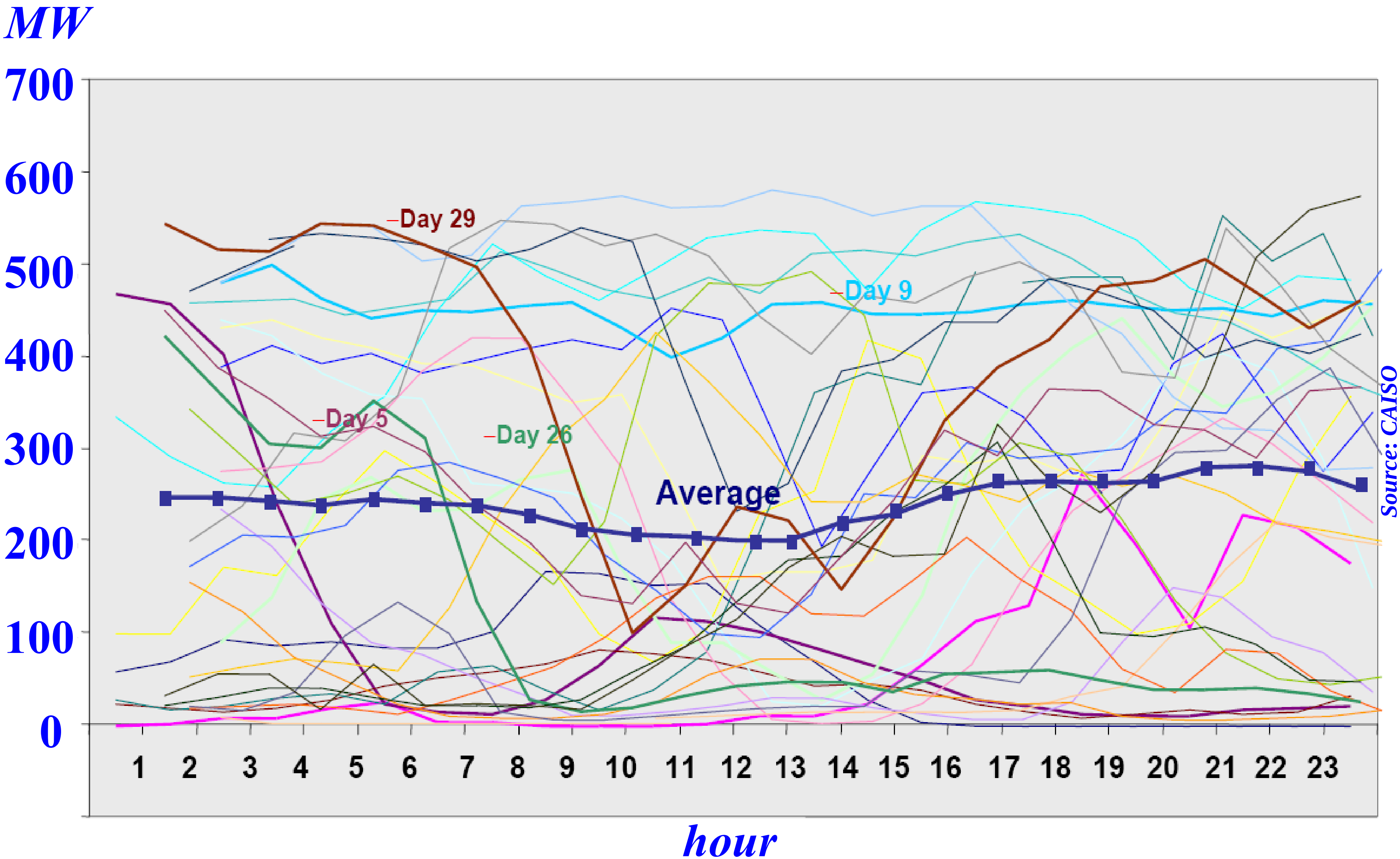
THE WEEKLY LOAD SHAPE



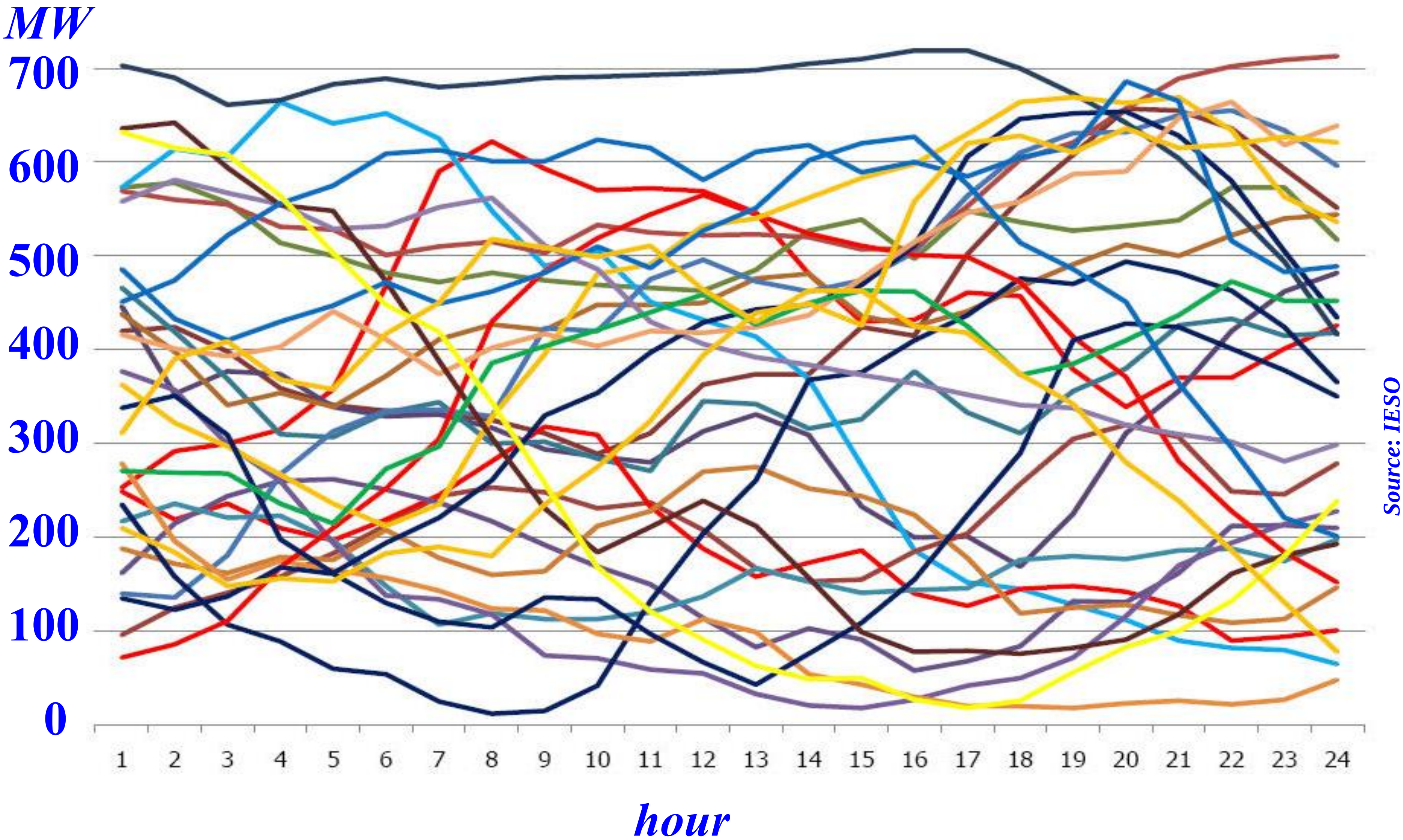
CALIFORNIA SUMMER LOAD: TYPICAL DAILY SHAPE



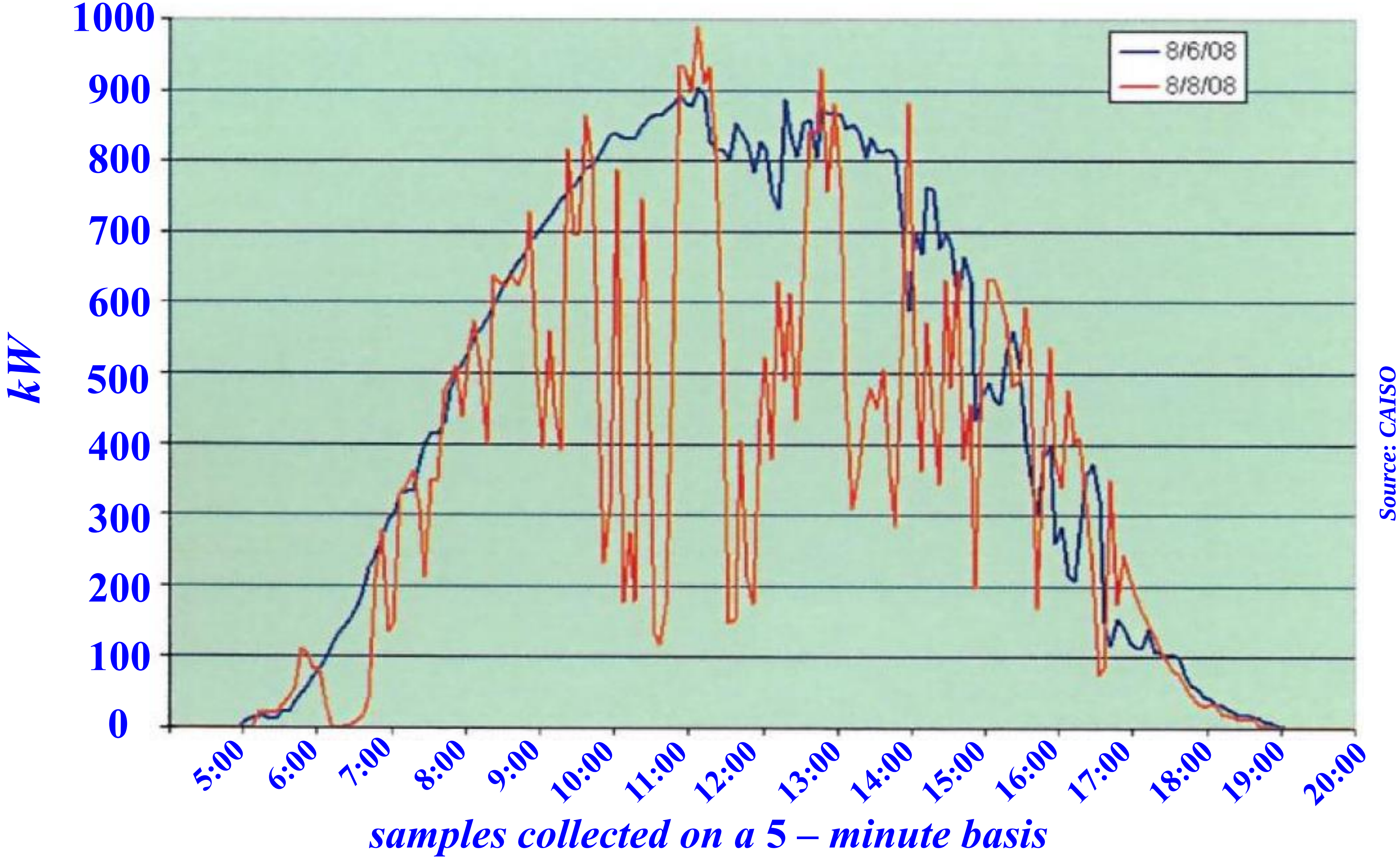
CAISO APRIL 2005 DAILY WIND PATTERNS



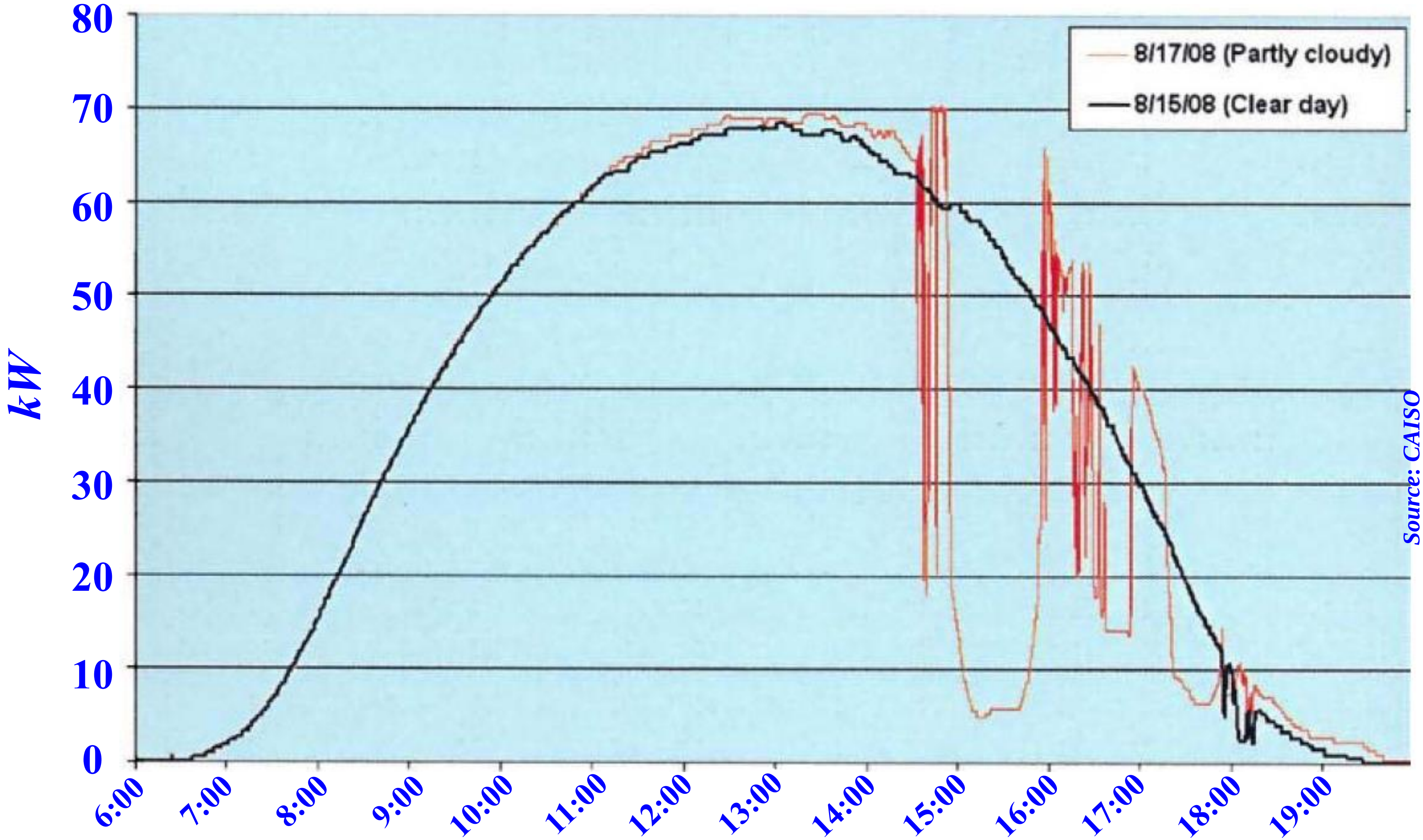
ONTARIO DAILY WIND POWER OUTPUT



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

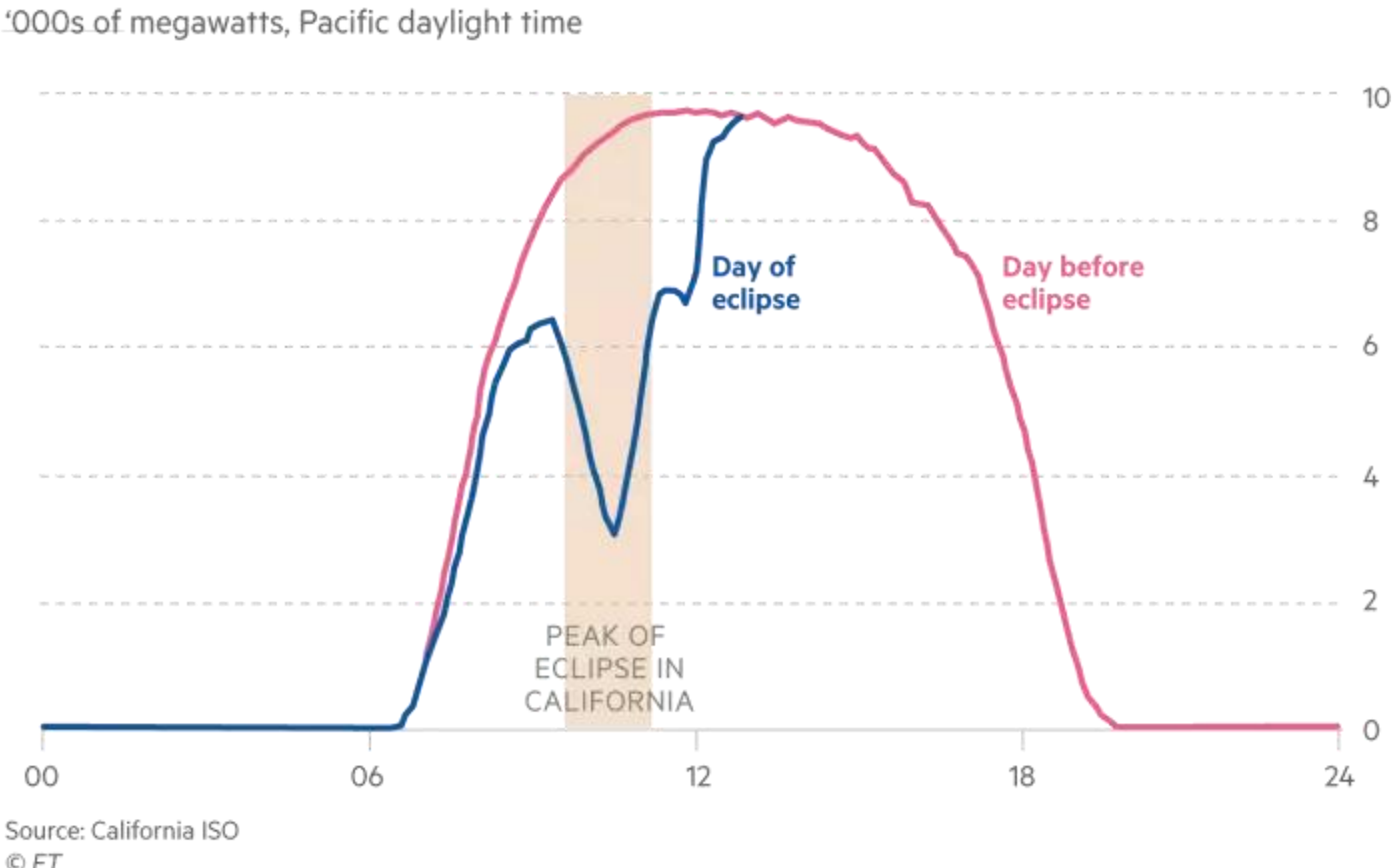


PV POWER OUTPUT AT THE NEVADA 70 – *kW* POLYCRYSTALLINE ARRAY



data collected on a 10 – *second basis*

AUGUST 21, 2017 SOLAR ECLIPSE



KEY CHALLENGES IN RENEWABLE EXPANSION

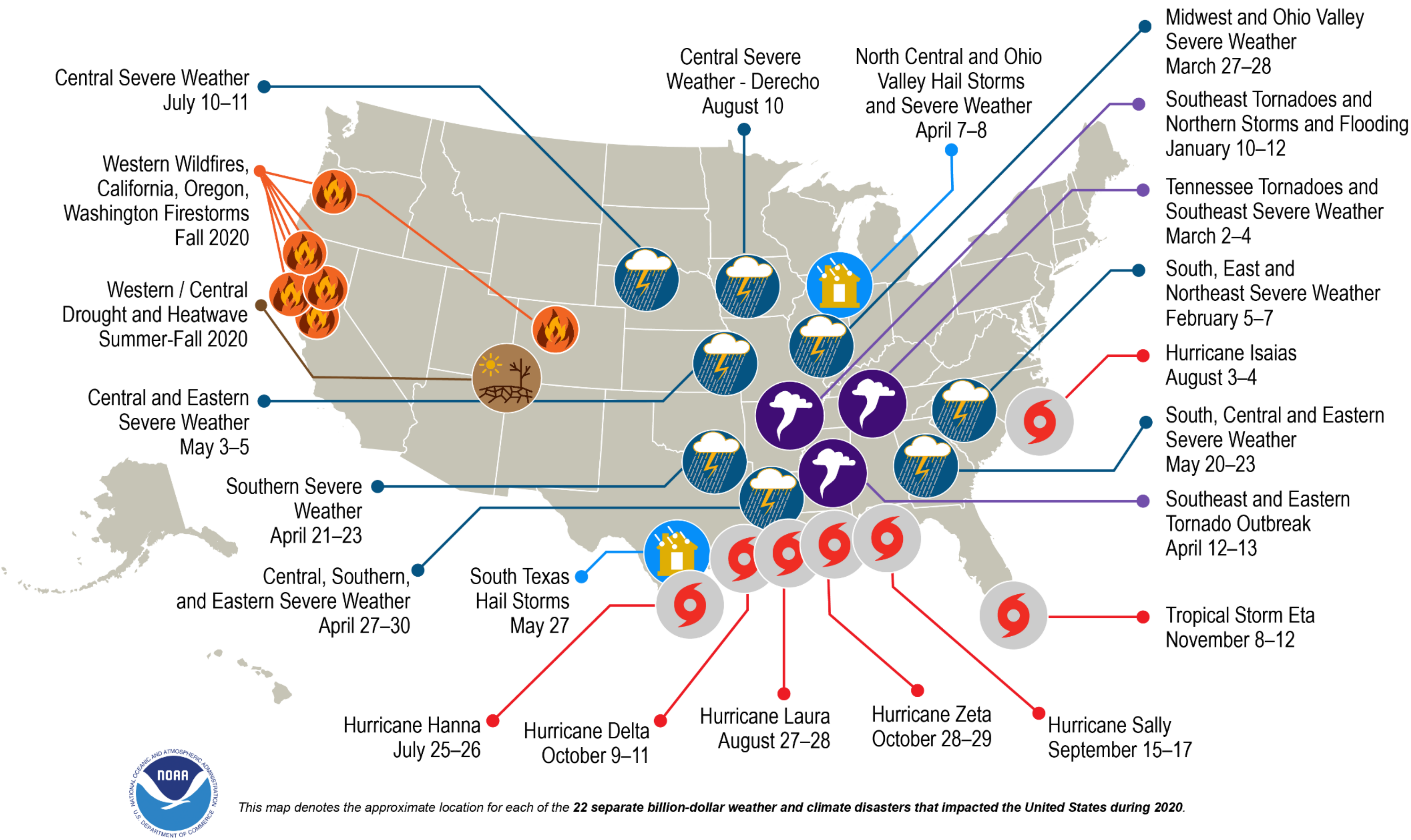
- Integration into the grid
  - interconnection
  - grid capability
  - reliability issues
  - power quality
- Competitiveness of technology costs
- Environmental issues, e.g., recycling
- Development of lower-cost storage technology

KEY CHALLENGES IN RENEWABLE EXPANSION

- Formulation of appropriate policies at the
  - federal;
  - state; and
  - local

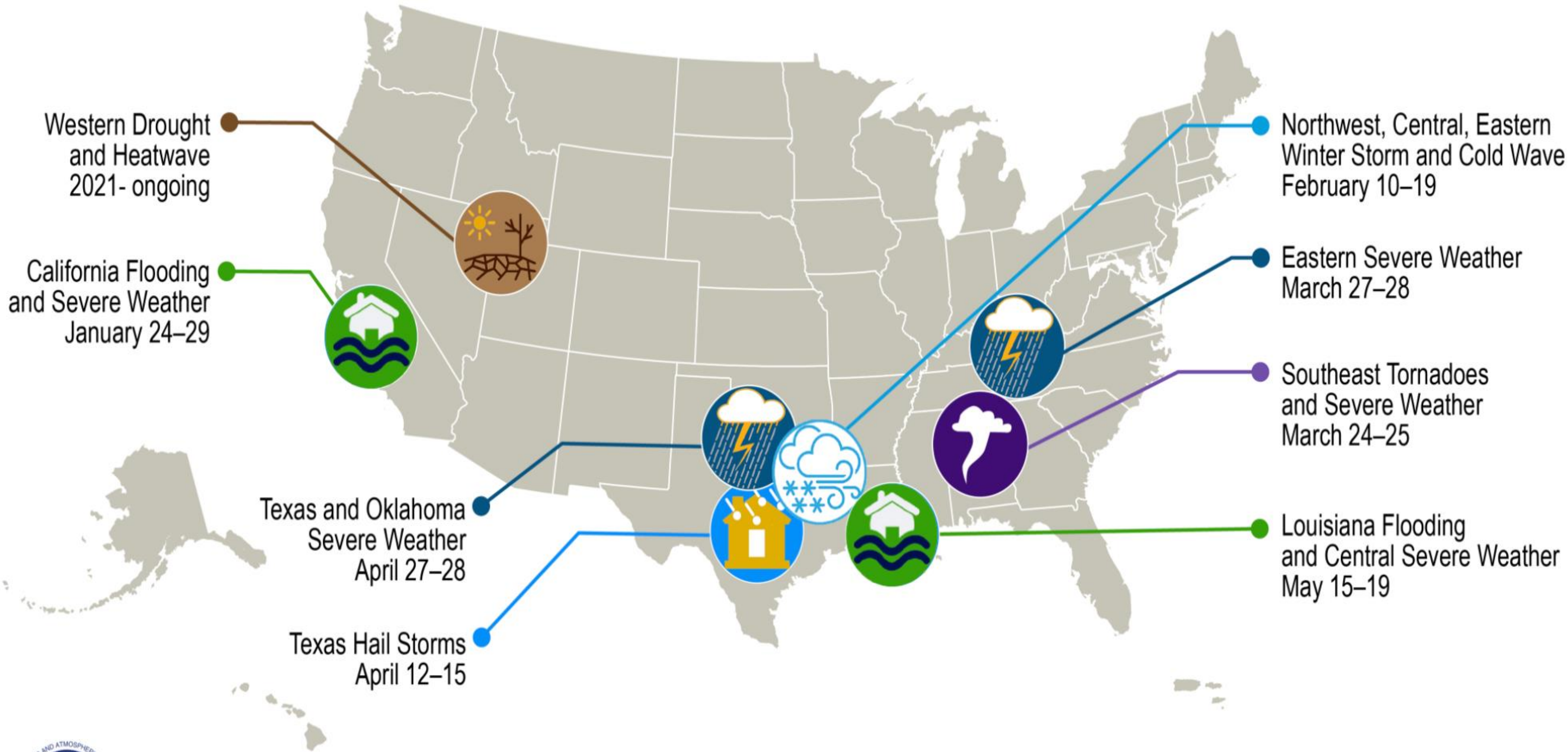
  levels
- Regulatory accommodation via
  - smoother permitting processes
  - assurances of back up power provision
  - implementation of “green power” differential

US 2020 BILLION – DOLLAR WEATHER AND CLIMATE DISASTERS



Source: NOAA; available at https://www.ncdc.noaa.gov/billions/

US 2021 BILLION – DOLLAR WEATHER AND CLIMATE DISASTERS



This map denotes the approximate location for each of the ***8 separate billion-dollar weather and climate disasters that impacted the United States January–June 2021****.*

Source: NOAA; available at https://www.ncdc.noaa.gov/billions/

THE *US* VANISHING COAL PLANTS

- From 2011 to 2019, 121 coal–fired power plants were repurposed to use other type of fuels: 49.2 *GW* of coal from the total 316.8 *GW* coal capacity at the start of 2011 was retired
- Of the 121 plants, 103 were converted to or replaced by natural-gas-fired plant:
  - 14.3 *GW* capacity converted the boiler to burn natural gas

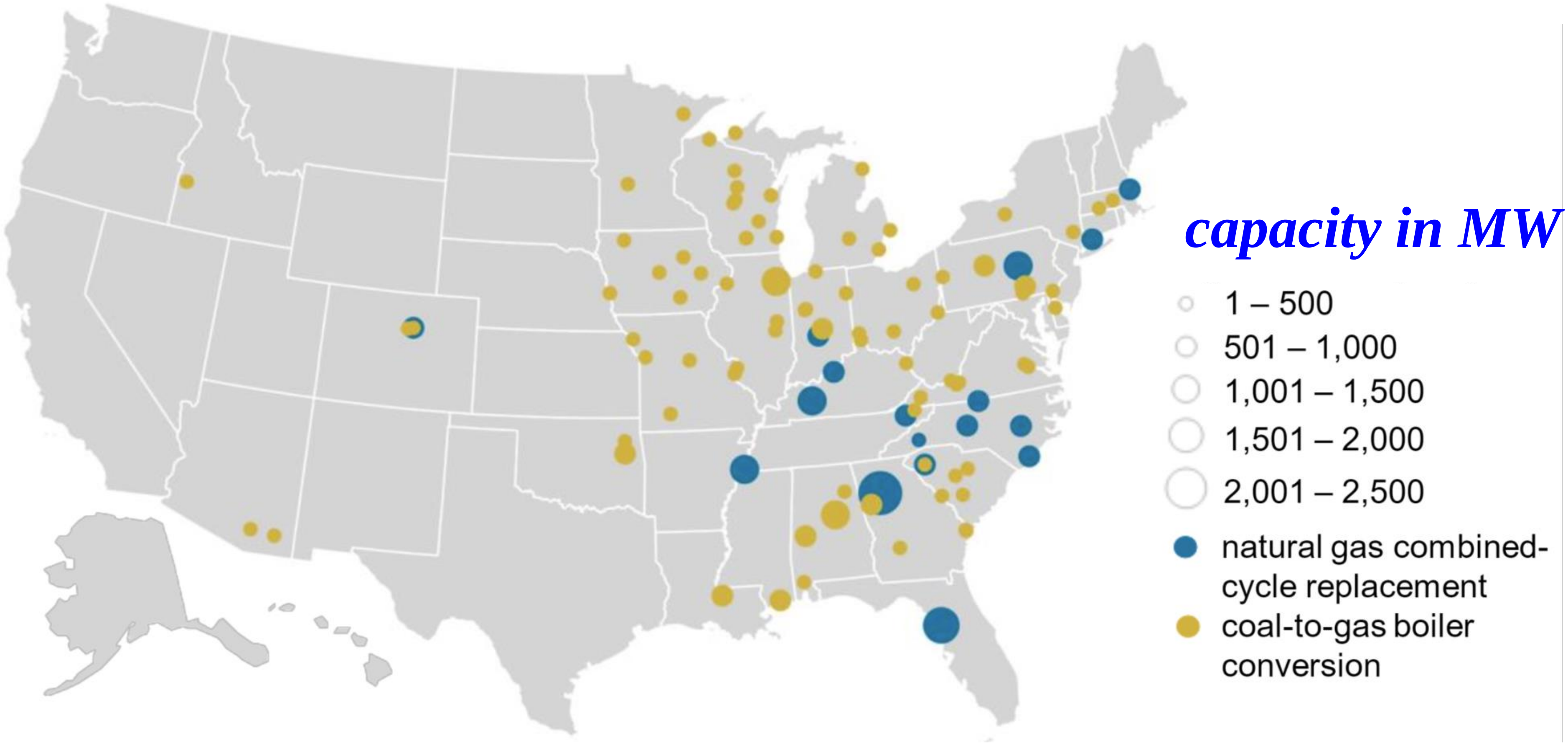
THE *US* VANISHING COAL PLANTS

- 15.3 *GW* capacity of natural gas combined cycle (*NGCC*) replaced 7.9 *GW* coal capacity

- The switch from coal to natural gas was driven by
  - stricter emission standards;
  - low natural gas prices; and,
  - more efficient gas turbine technology

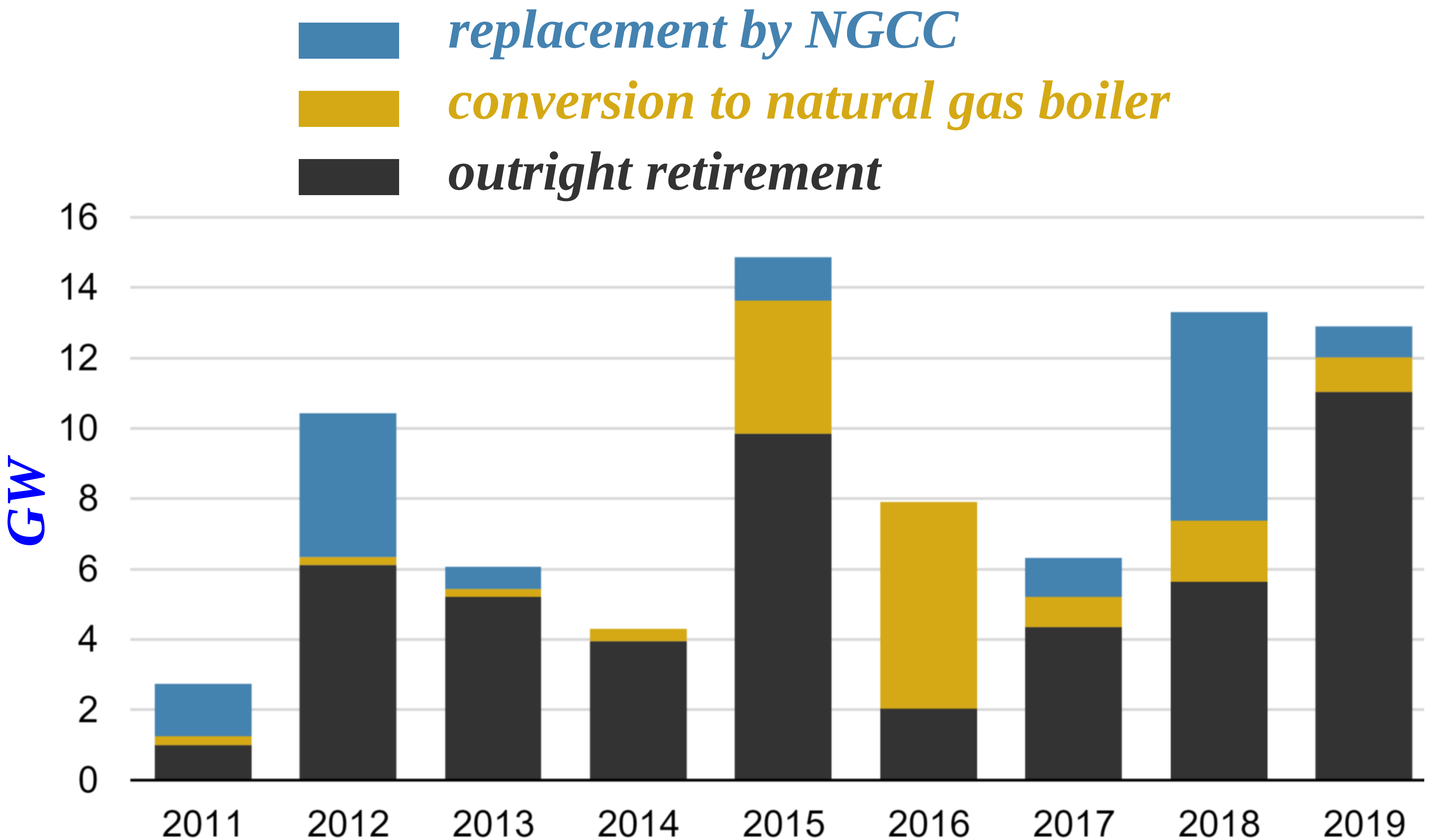
US COAL TO NATURAL GAS CONVERSION : 2011 – 2019

***Source*: *EIA August* 5, 2020; *available at https://www.eia.gov/todayinenergy/detail.php?id=*44636**



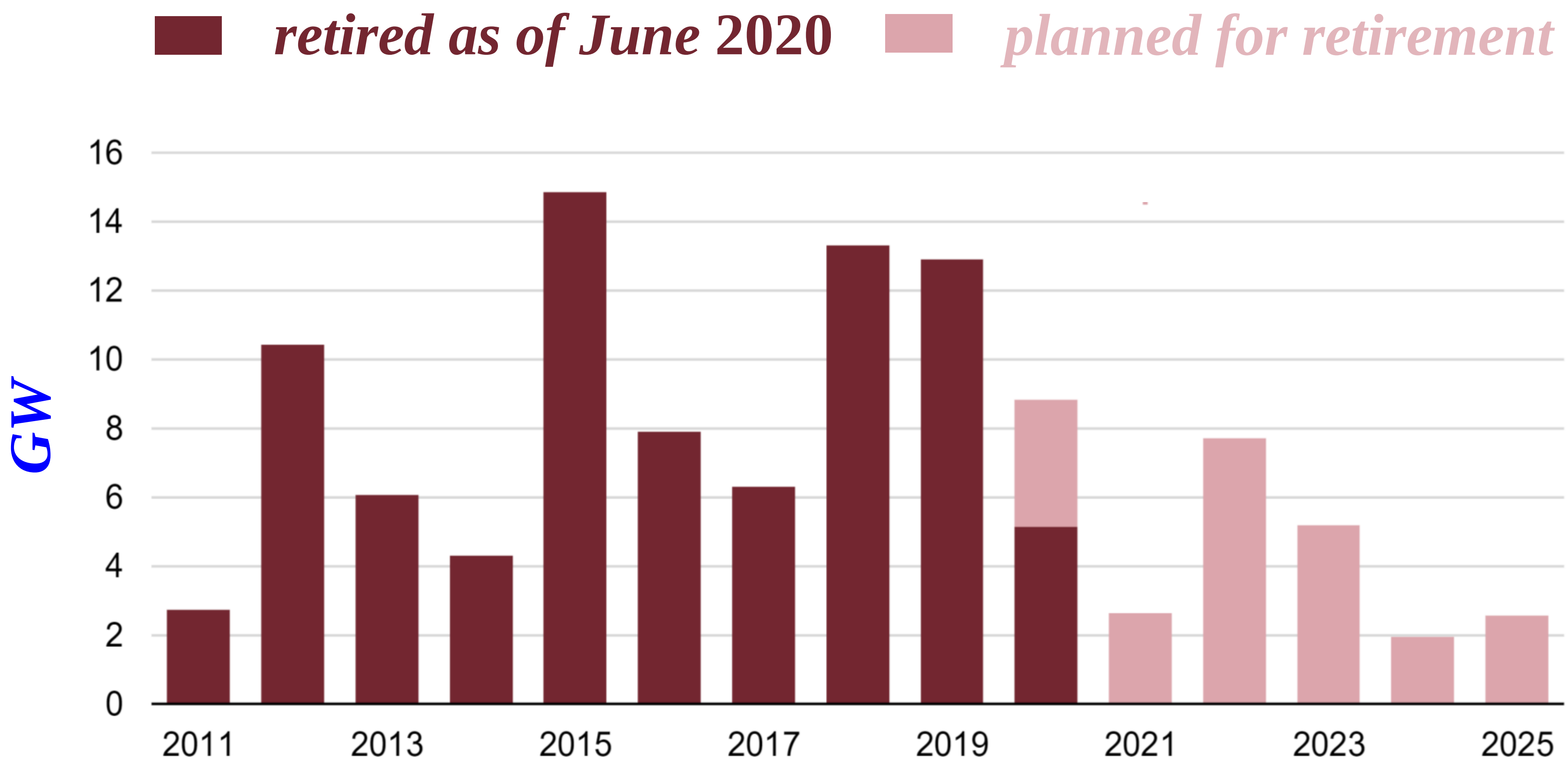
US COAL–FIRED CAPACITY RETIREMENTS / REPLACEMENTS : 2011 – 2019

Source: EIA August 5, 2020; available at https://www.eia.gov/todayinenergy/detail.php?id=44636

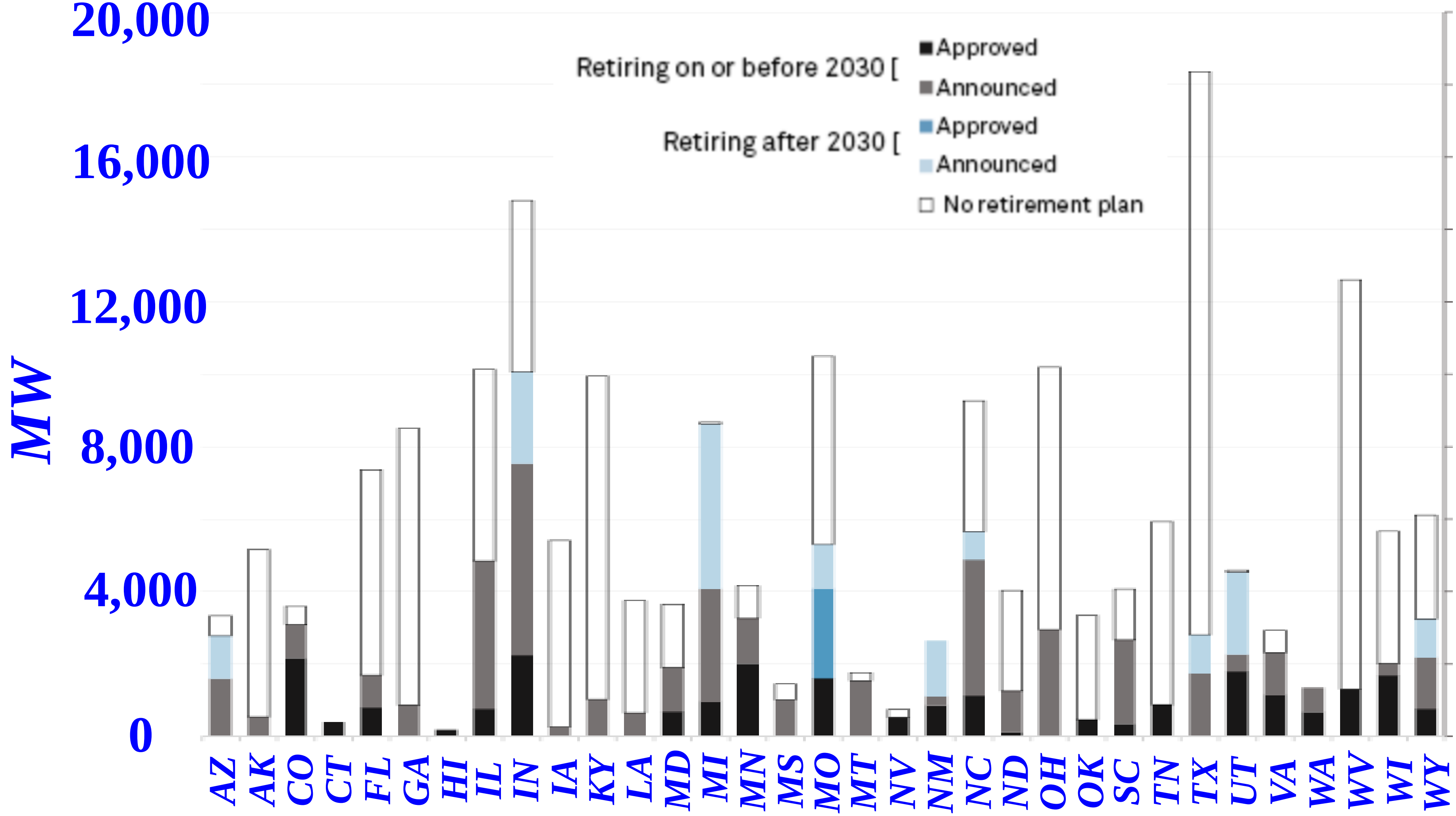


COAL PLANT RETIREMENTS CONTINUE

Source: EIA, Today in Energy, September 1, 2020; available online at https://www.eia.gov/todayinenergy/detail.php?id=44976



COAL PLANT RETIREMENTS



Source: S&P Global Market Inteligence; available on-line at https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/2030-is-the-new-2050-utilities-pressured-to-hasten-decarbonization-goals-62432337

TRUMP " DIGS COAL "

- **While the *US* remains the world's premier oil and gas producer, Trump has tried to stop the coal decline but without much success:**
  - **retirements of mostly 50+ years-old plants continued**
  - **thousands of miners lost jobs**
  - **integration of renewable resources – principally solar – at deeper penetrations**

TRUMP " DIGS COAL "

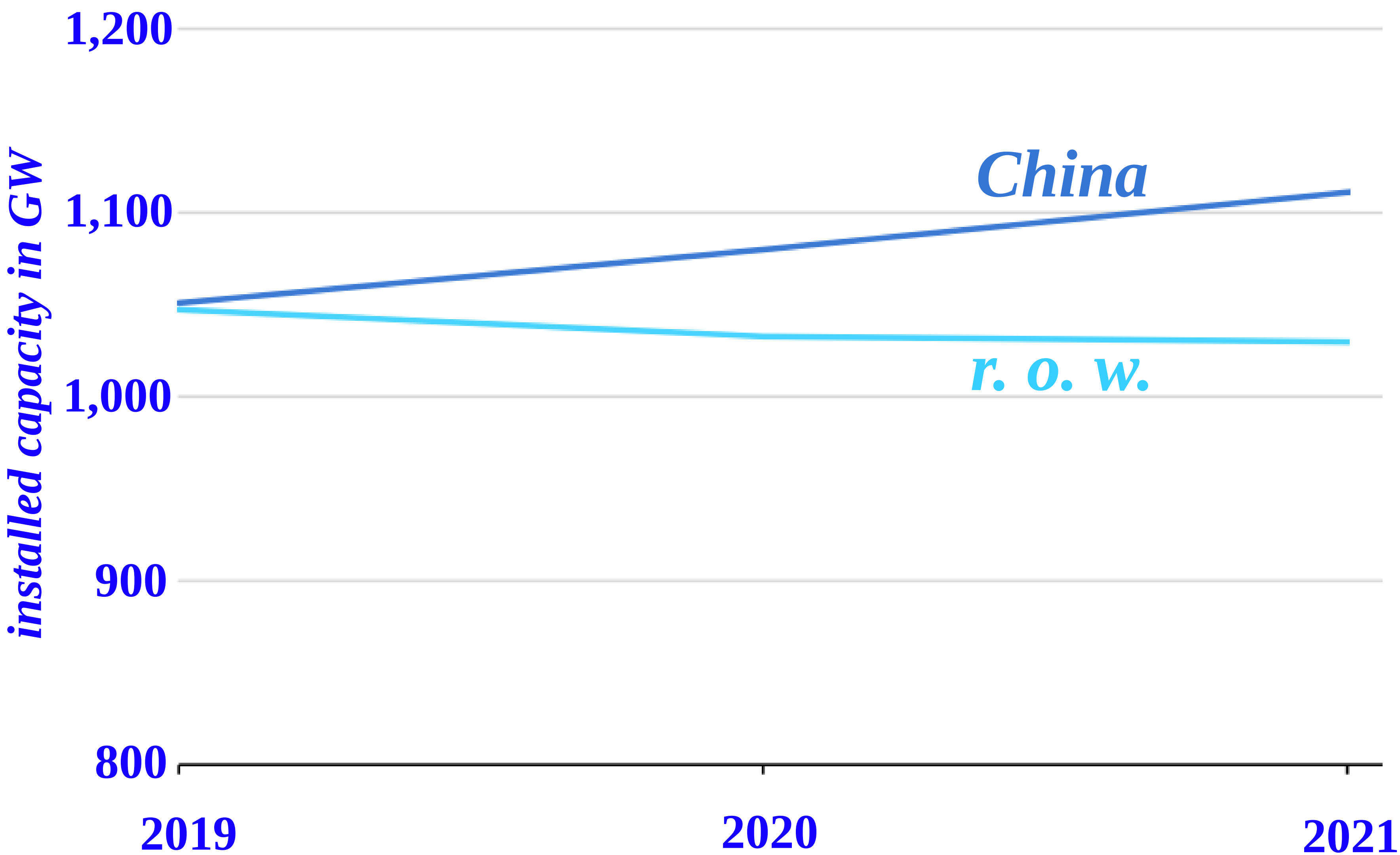
- **Today, coal powers less than 20 % of *US* electricity consumption**
- **Climate change concerns, the movement away from coal by many advanced economies and the push by states and cities to limit future fossil resource reliance are key drivers and so is the improved economics of solar and wind power**

The Washington Post

Kentucky Coal Mining Museum in Harlan County switches to solar power

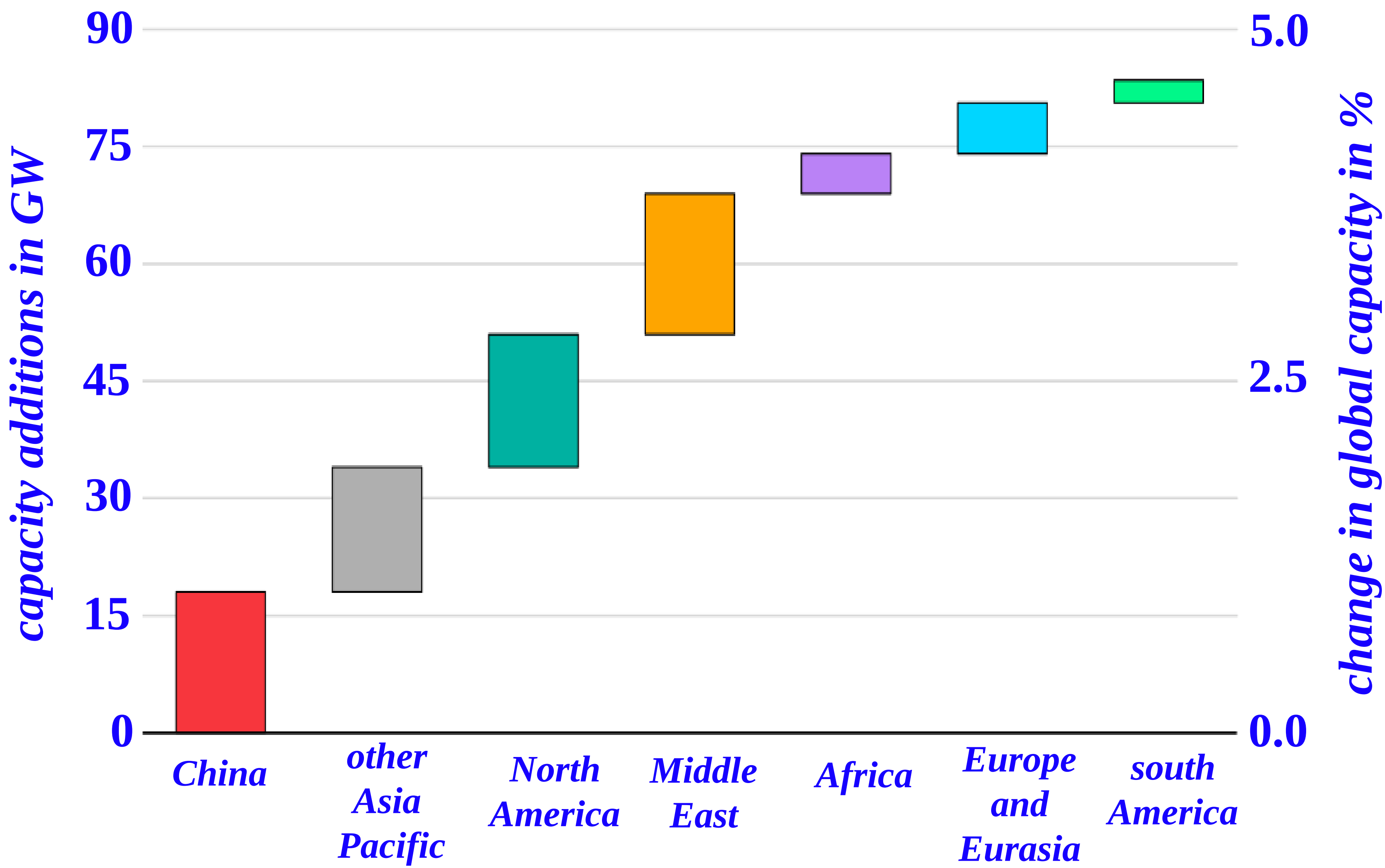
(Washington Post, April 6 2017)

GLOBAL COAL-FIRED GENERATION CAPACITY: 2019 – 2021



Source: IEA analysis based on EIA 2021, available at https://iea.blob.core.windows.net/assets/01e998-8611-45d7-acab-5564bc22575a/ElectricityMarketReportJuly2021.pdf; p. 39

GAS-FIRED POWER GENERATION CAPACITY ADDITION: 2020 – 2022



Source: IEA analysis based on EIA 2021, available at https://iea.blob.core.windows.net/assets/01e1e998-8611-45d7-acab-5564bc22575a/ElectricityMarketReportJuly2021.pdf; p. 35

COURSE OBJECTIVES

- Acquaint students with key basic physical principles used in renewable energy generation
- Stress the importance of *economics* − including the role of incentives − and *environmental* aspects in electricity developments; also, the role in job creation by the renewable sector is critical
- Provide a good understanding of impacts of market forces on shaping the electricity business

COURSE OBJECTIVES

- Expose students to some major national and international developments in renewable energy systems and their effective integration into today's power grids
- Explain the exciting developments in the energy sector and the role electricity plays in addressing global warming issues

ECE 333 : KEY ASPECTS

- Understanding of the basic scientific principles underlying renewable resources is essential
- Awareness of the role that renewables can play in effective climate change activities is important
- Challenges in the integration of renewables are huge in nearly every dimension

TOPICAL OUTLINE

- **General overview of electricity demand, supply, industry structure, interconnected system operations and state of technology**
- **Nature/role of** ***renewable generation resources***
- **Review of concepts in electric circuit analysis**
- **Engineering aspects of** ***renewable resource*** **genera-tion technologies: wind energy conversion**

TOPICAL OUTLINE

systems; thermodynamics considerations; solar resource and solar array systems; economics of renewable technologies; environmental issues

- The roles of energy storage resources and their deployment in grids with integrated renewable
- The demand picture: the nature of electrical loads; time dependence and periodicity; price impacts

TOPICAL OUTLINE

- **Demand management and energy conservation; efficiency improvements; price–responsive demand; load management; and the role of new technologies**
- **Electricity market basics**
- **Integration of renewable generation into the grid**
- **The policy and regulatory dimensions**

GRADING POLICY

- The course grade is based on the performance of the student in the quizzes, the midterm exams and the final exam
- Students will be assigned homework but will not need to hand them in as they are not graded
- The problems in the short quizzes in class will be based on the homework assignment problems

PROPOSED GRADING POLICY TABLE

component	*percentage*
homework	**0**
quizzes	**15**
two midterm exams	**40**
final	**45**
total	**100**

Suddenly, knowing a lot about the U.S. power grid became sexy at cocktail parties.