ECE 333 – GREEN ELECTRIC ENERGY

19. Energy Storage Resources

George Gross

Department of Electrical and Computer Engineering

University of Illinois at Urbana–Champaign

*ESR*s IN THE NEWS

"Big Oil well placed to accelerate transition to electric vehicles"

Financial Times (*October* 26, 2020)

Tesla Project to Install Another Giant Battery in Australia

Bloomberg (*November* 4, 2020)

Battery energy storage systems integrated in solar facilities to receive tax incentives

PV magazine (*September* 15, 2020)

Duke Energy to spend $500M on battery storage in next 15 years

Utility Dive (*October* 11, 2018)

Global storage heading to 741 GWh by 2030, WoodMac projects

Utility Dive (*October* 5, 2020)

California Community Choice groups seek up to 500MW of long-duration energy storage

Energy Storage News (*October* 19, 2020)

UK's largest battery energy storage system goes live

Power Engineering Intl. (*November* 6, 2020)

LS Power Energizes World's Biggest Battery, Just in Time for California's Heat Wave

Greentech Media (*August* 19, 2020)

OUTLINE

- The critical importance of energy storage
- *ESR* roles and applications to power systems
- The role of battery energy storage systems
- The current status of storage
- The California mandate for storage deployment

THE *DIRE NEED* FOR STORAGE

- **The *electricity business* is the only industry sector that sells a commodity *without sizeable inventory***
- **The lack of utility–scale storage in today's power system drives electricity to be a highly *perishable* commodity**
- **The deepening renewable resource penetrations exacerbate the challenges to maintain the *demand–supply equilibrium* at all points in time**
- **Storage is a major flexibility source to maintain demand–supply balance *around the clock***

CHANGING REALITY IN POWER SYSTEMS

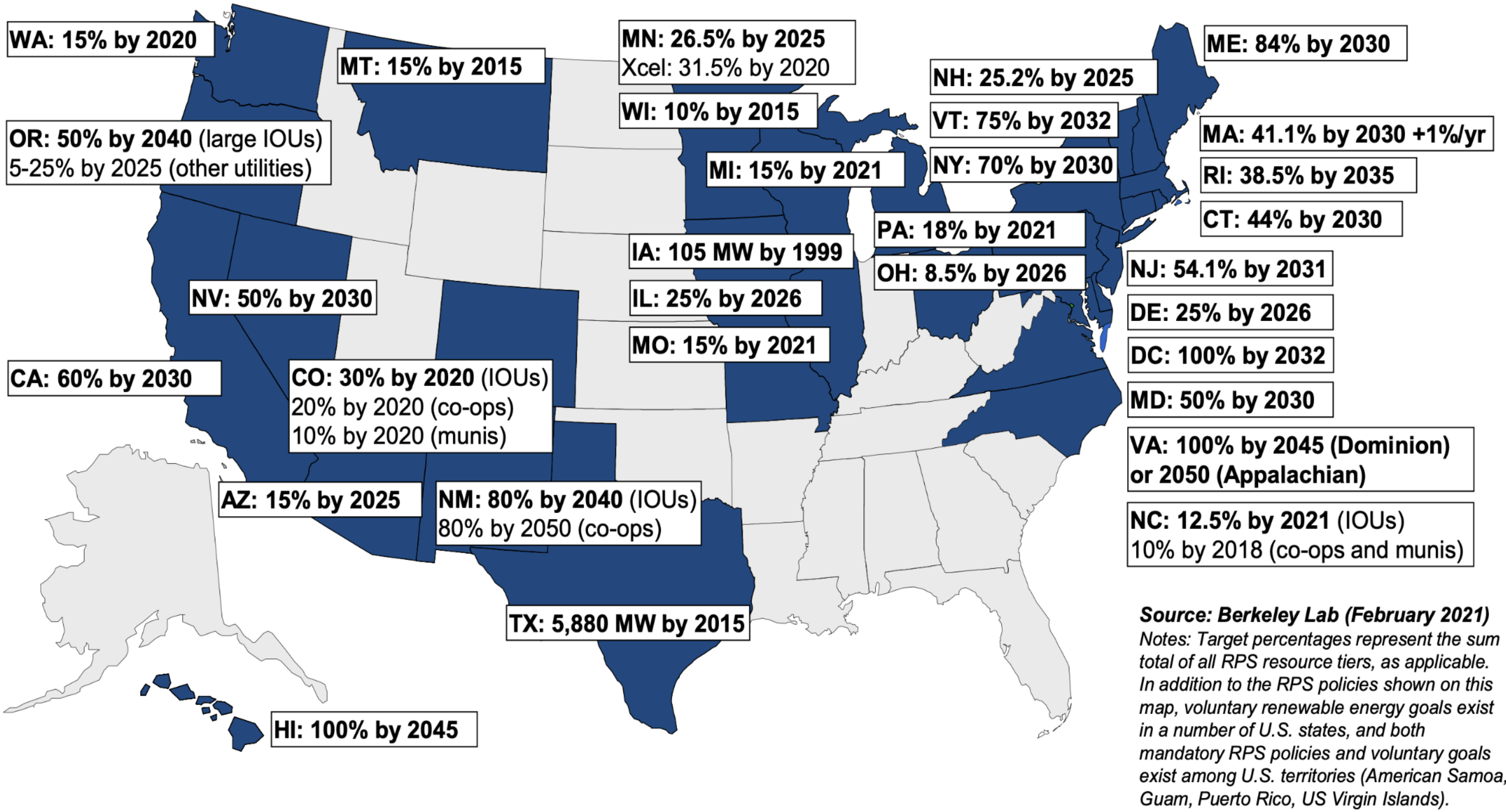
- Climate change impacts are the key drivers of the growing deployment of renewable resources to bring about CO_2 emission reductions
- Various jurisdictions's legislative/regulatory initiatives stipulate specific reduction targets with the dates by which they must be met to create a greener, healthier and sustainable environment

RENEWABLE PORTFOLIO STANDARDS

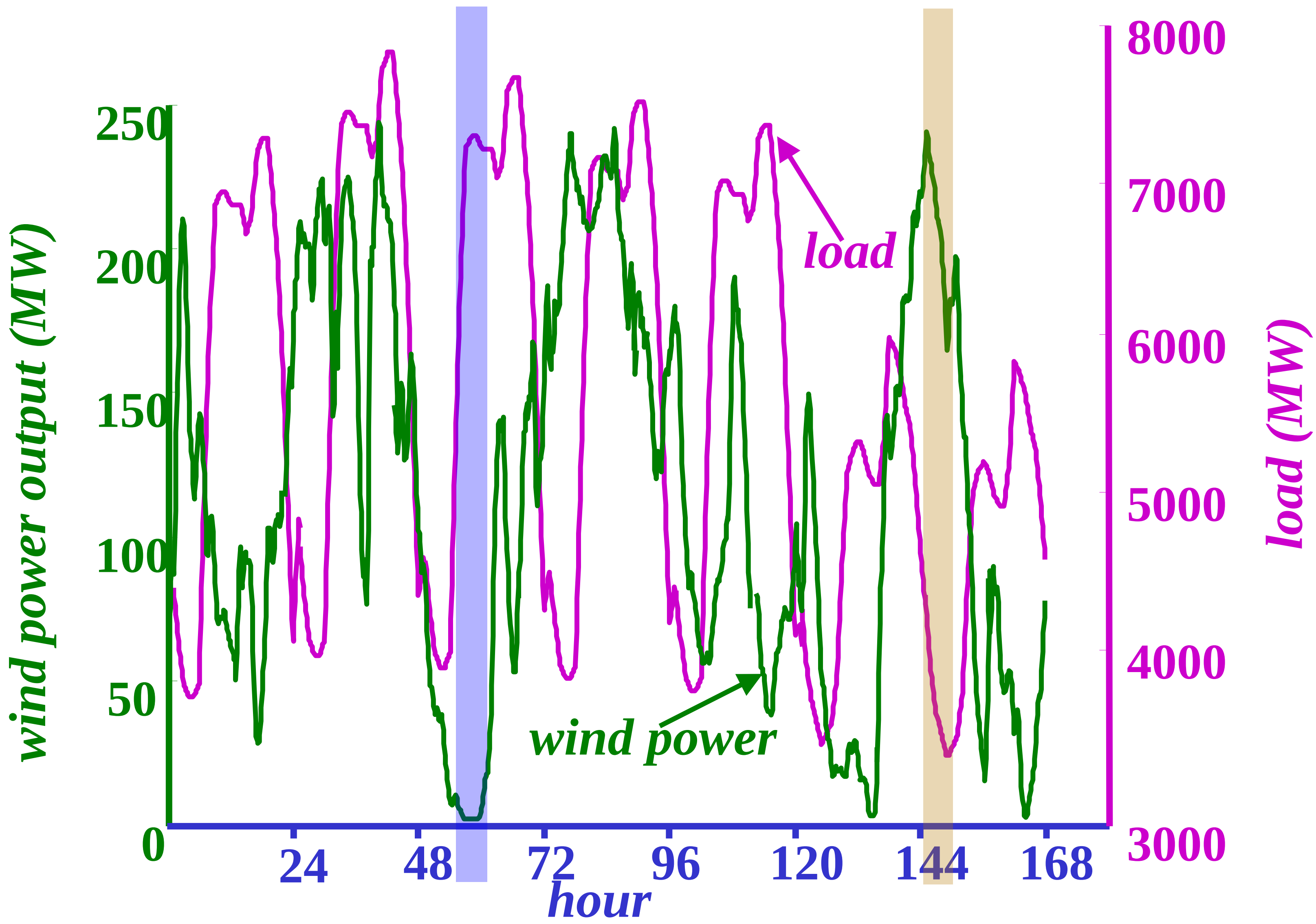
- ❑ **Many states have been active in the adoption of *renewable portfolio standards* (*RPS*) – 29 states, *DC*, and 3 *US territories* have adopted such standards**
- ❑ ***RPS* require a specified percentage or amount of renewable electricity – typically in terms of *MWh* – by the specified date that must be met to bring about a cleaner environment**
- ❑ **In addition, 8 states and a territory have *voluntary* goals for renewable generation implementation**

RENEWABLE PORTFOLIO STANDARDS

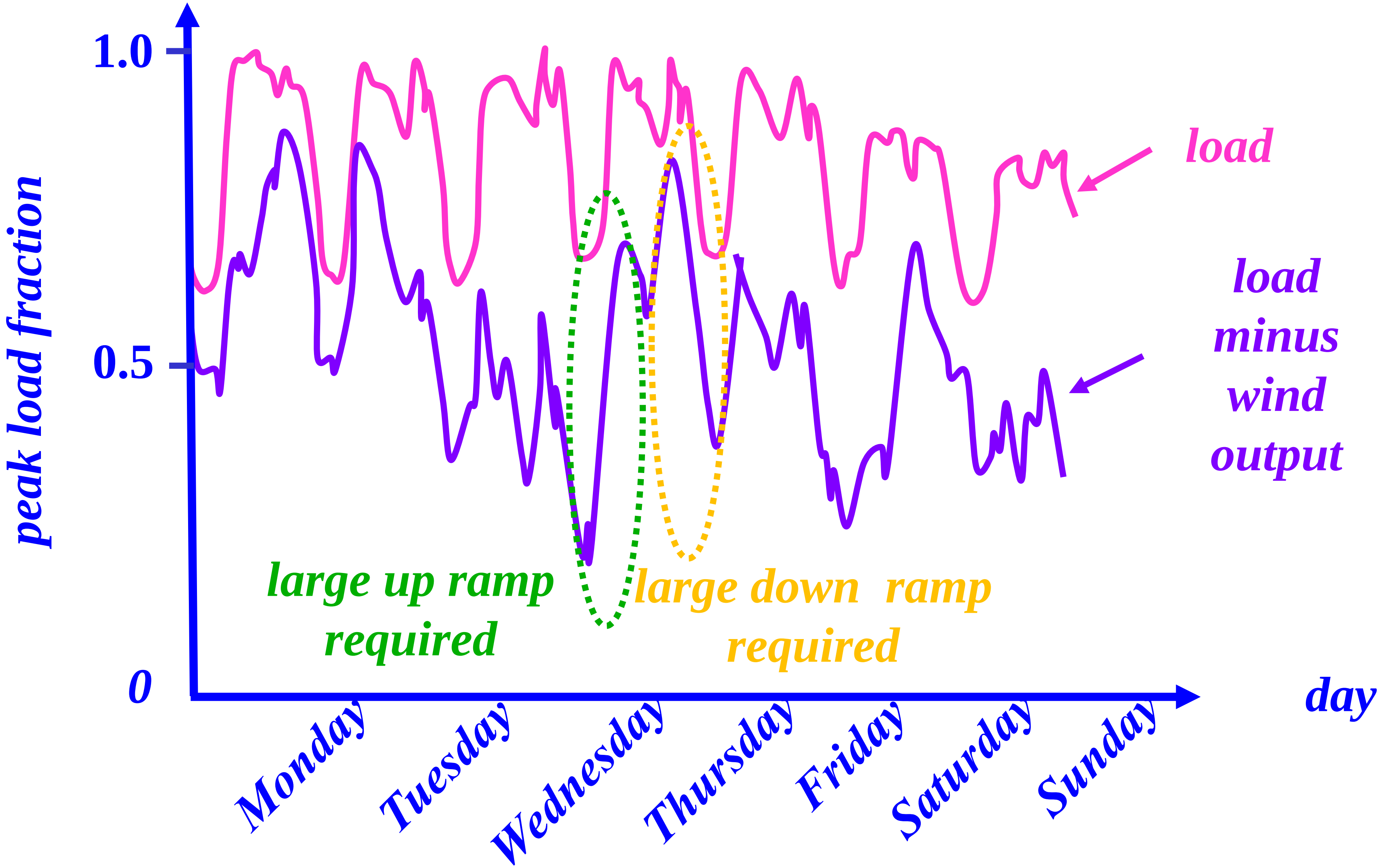
***Source*: *Berkeley Lab* (*Feb 2021*), *available online at https://eta-publications.lbl.gov/sites/default/files/rps_status_update-2021_early_release.pdf; p.* 9**



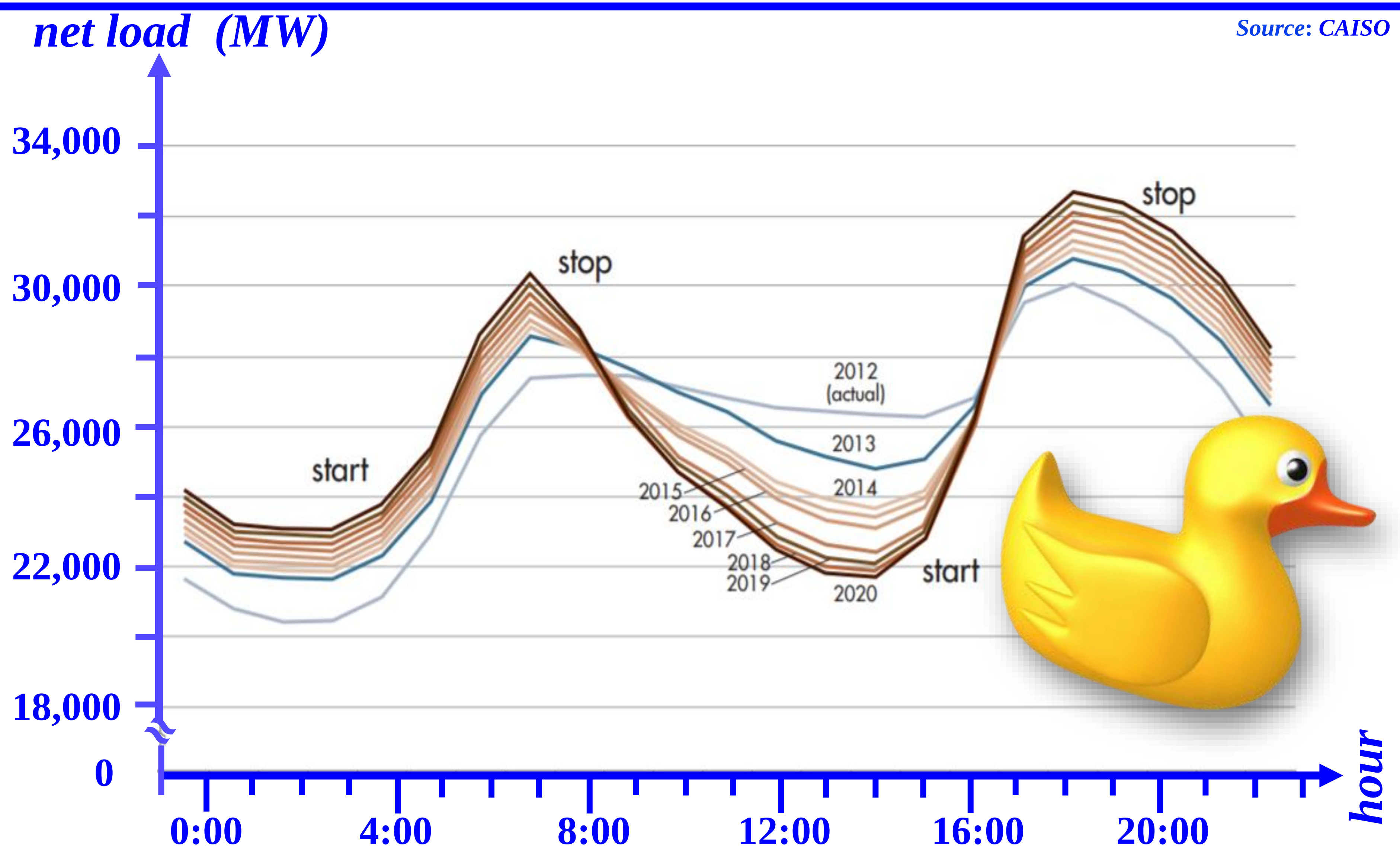
MISALIGNMENT OF WIND POWER OUTPUT AND LOAD



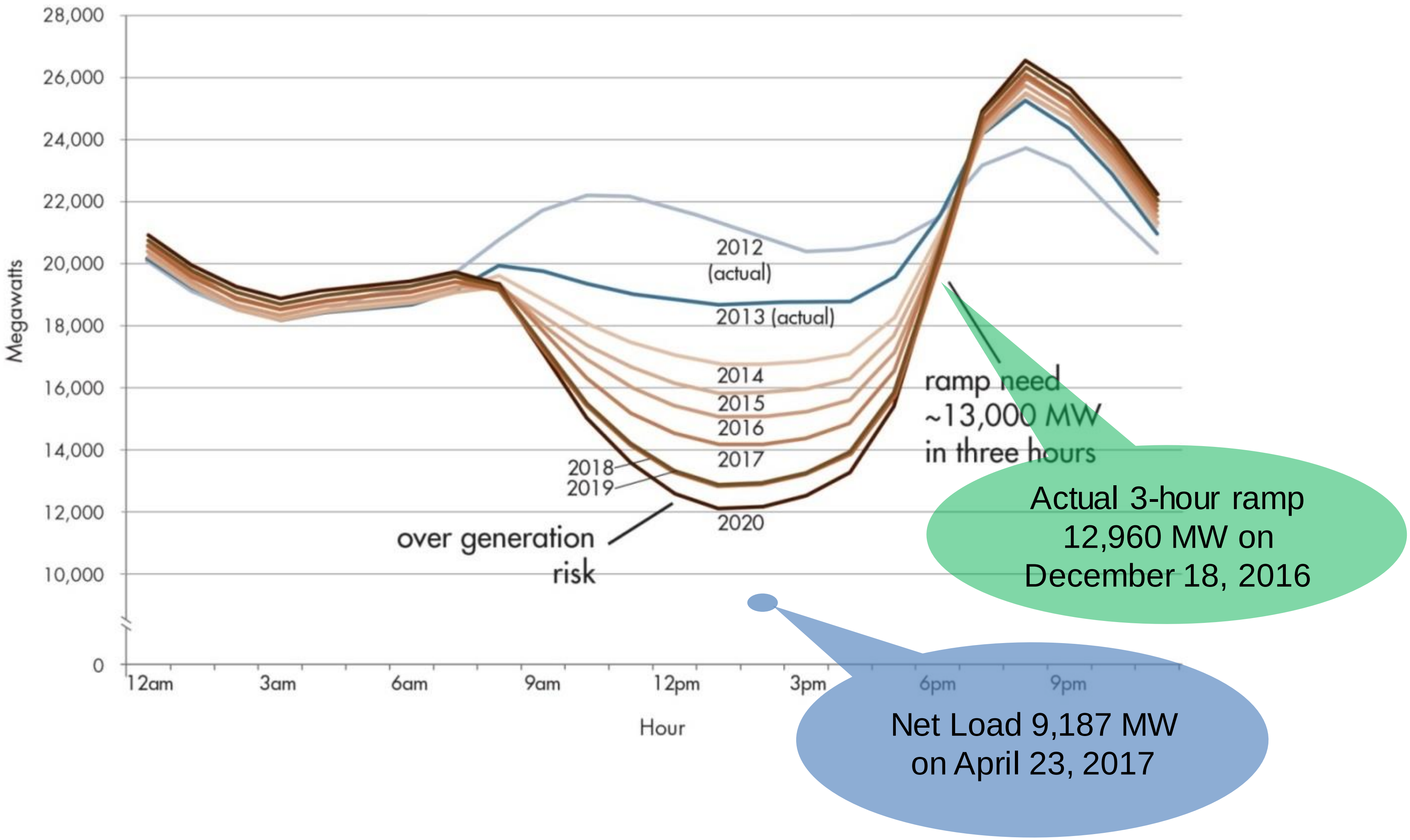
NEED FOR LARGER AND FASTER RAMPING RESERVES



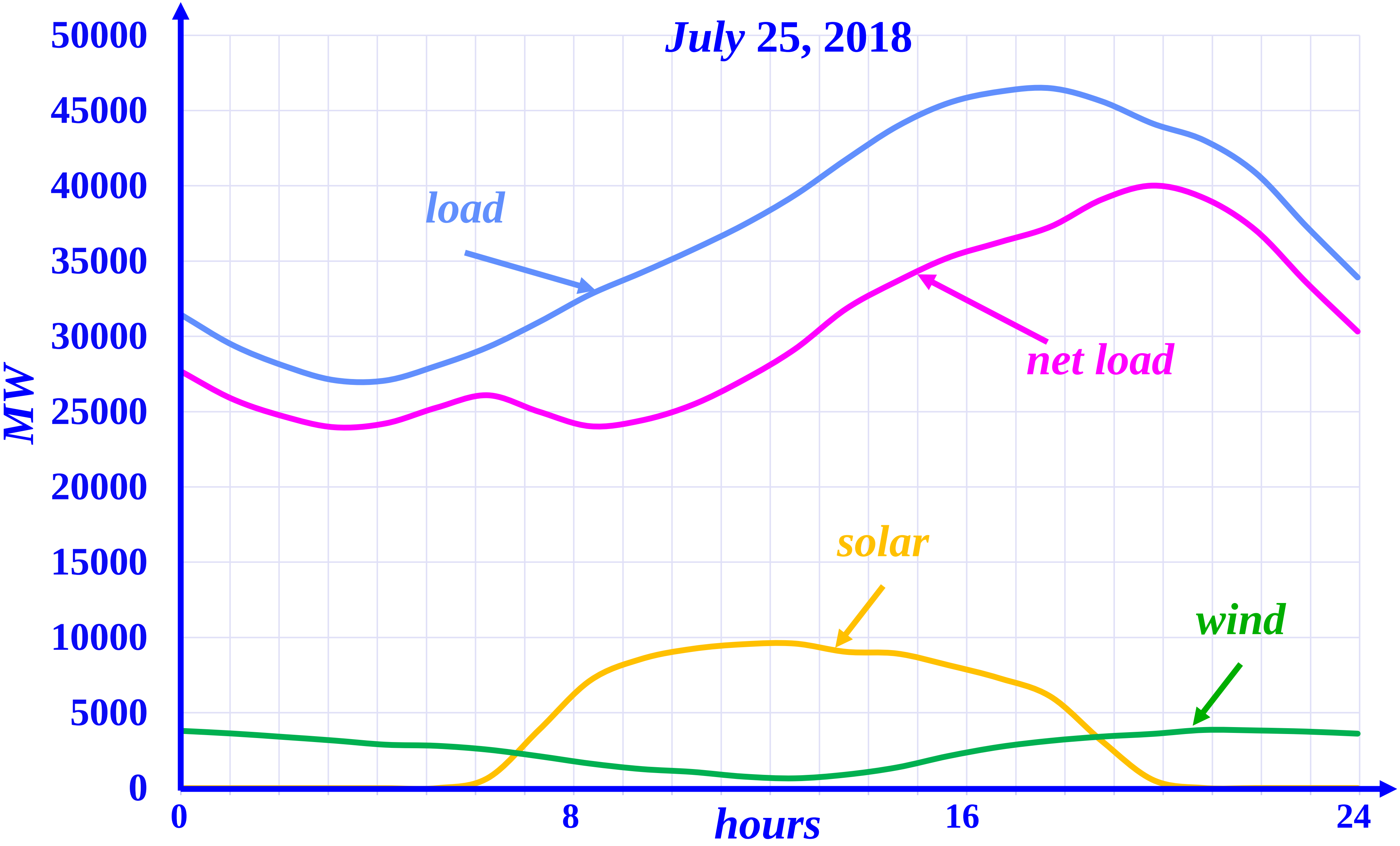
CAISO DAILY NET LOAD CURVE UNDER DEEPENING *RER* PENETRATIONS



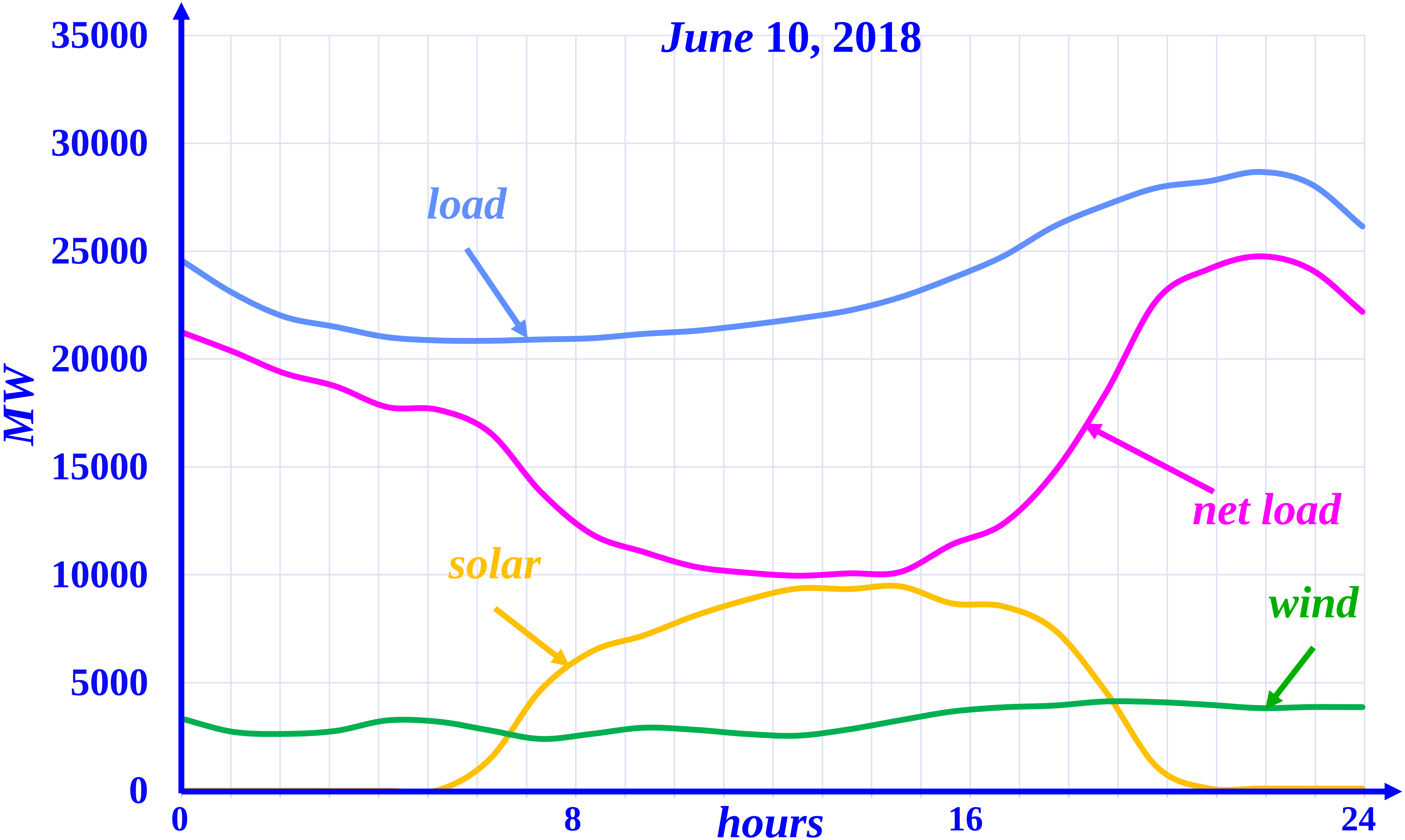
CAISO DAILY *NET LOAD* CURVE UNDER DEEPENING PENETRATIONS



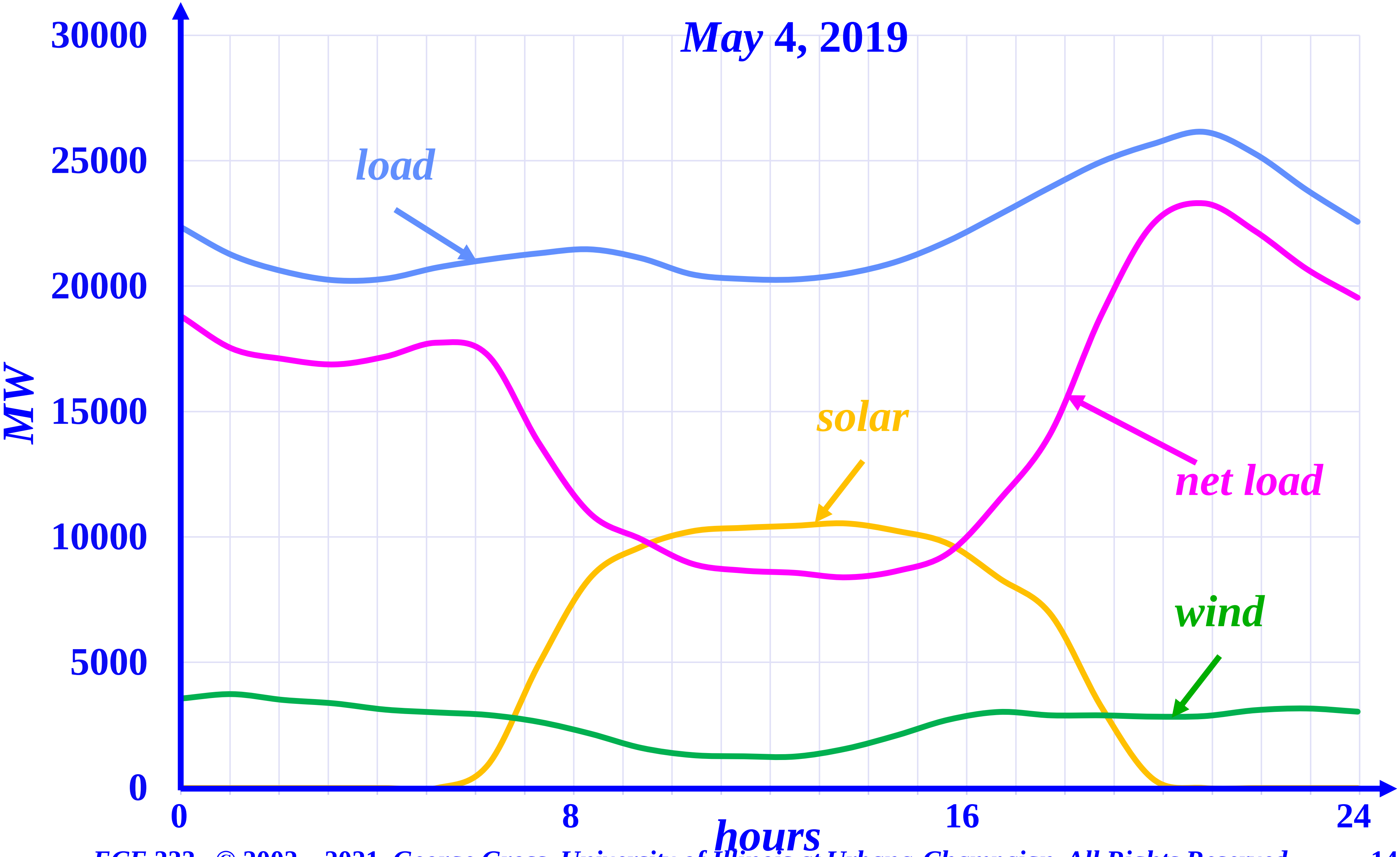
CAISO DAILY NET LOAD CURVE UNDER DEEPER *PV* PENETRATION



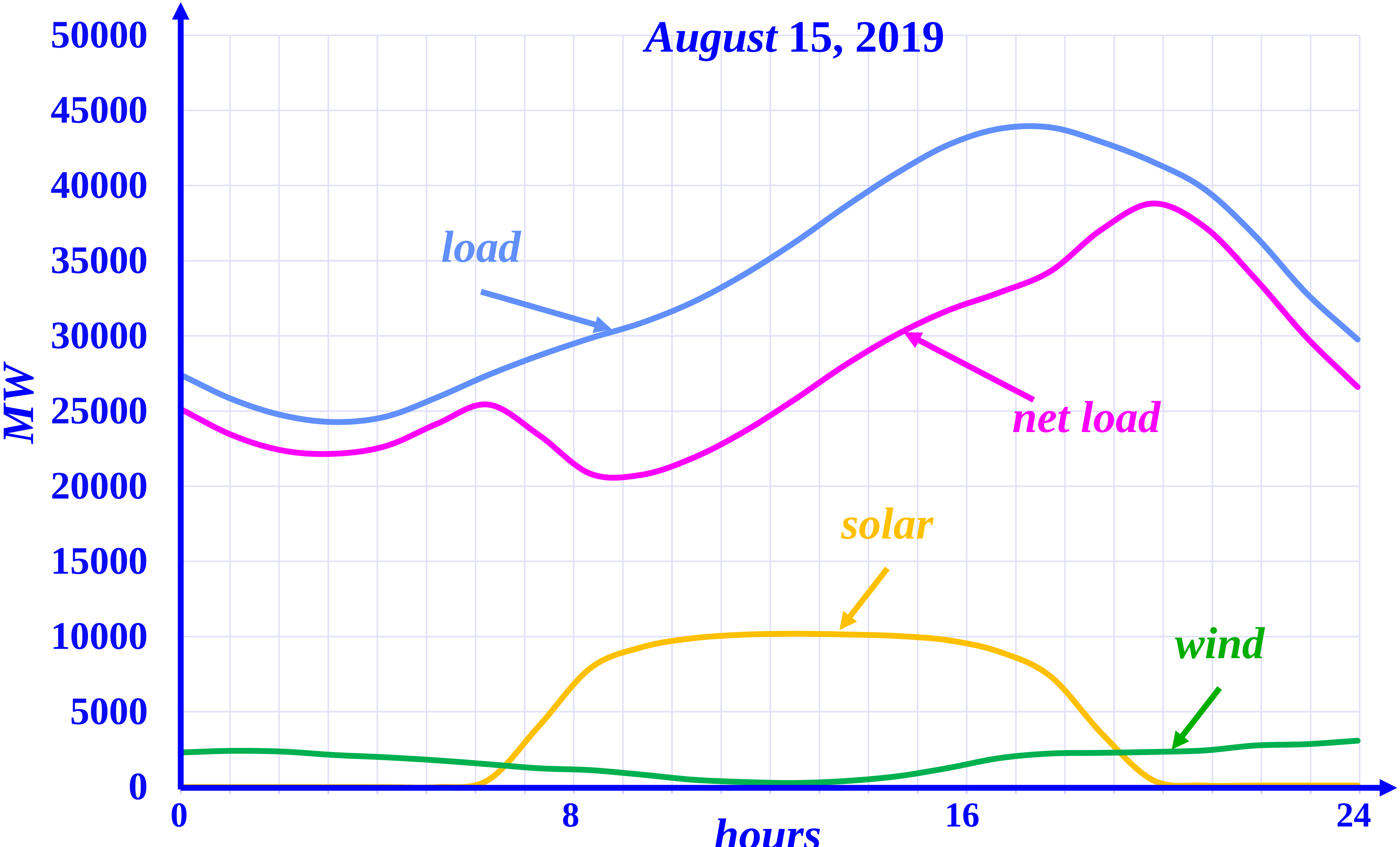
CAISO DAILY NET LOAD CURVE UNDER DEEPER *PV* PENETRATION



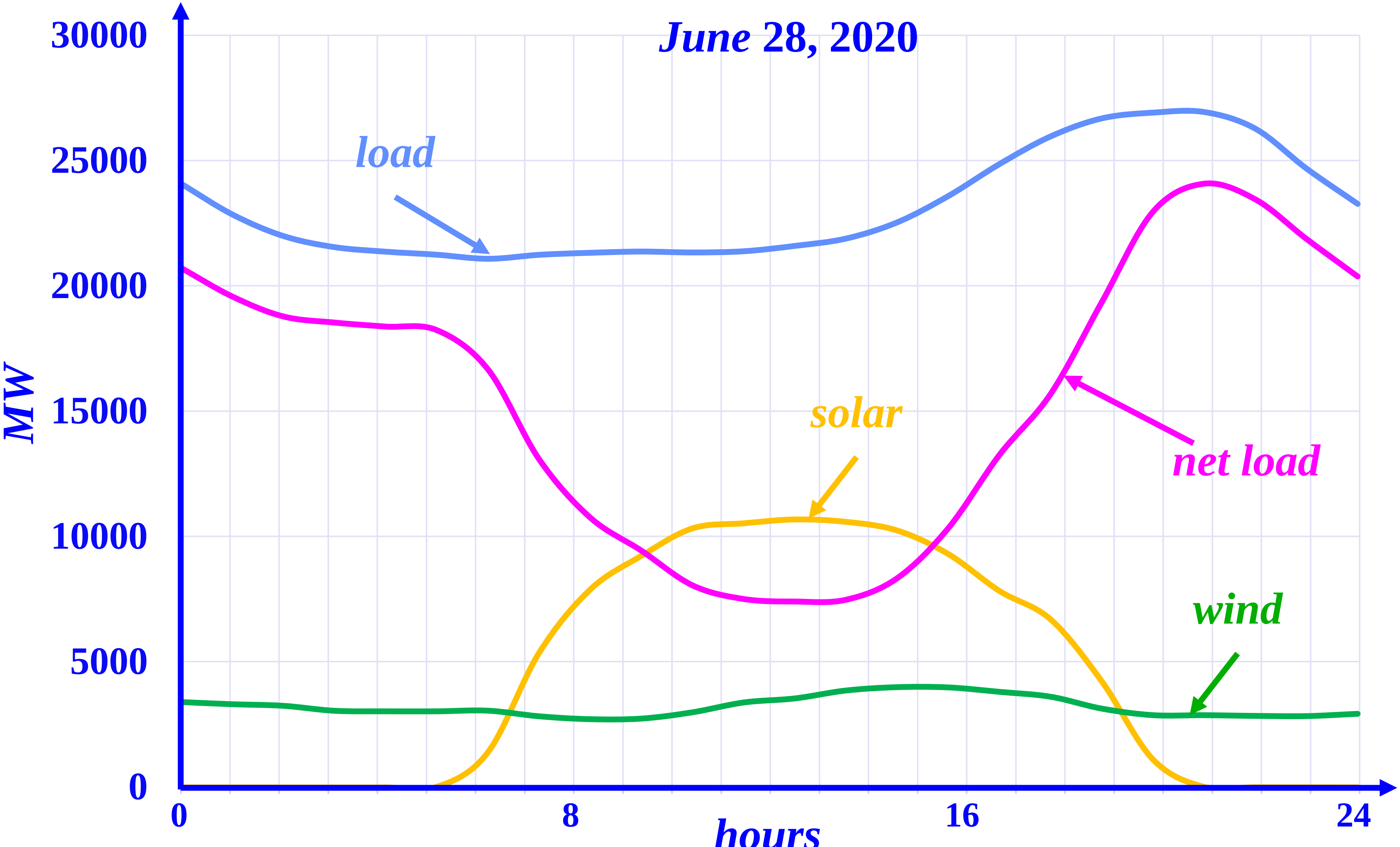
CAISO DAILY NET LOAD CURVE UNDER DEEPER *PV* PENETRATION



CAISO DAILY NET LOAD CURVE UNDER DEEPER *PV* PENETRATION

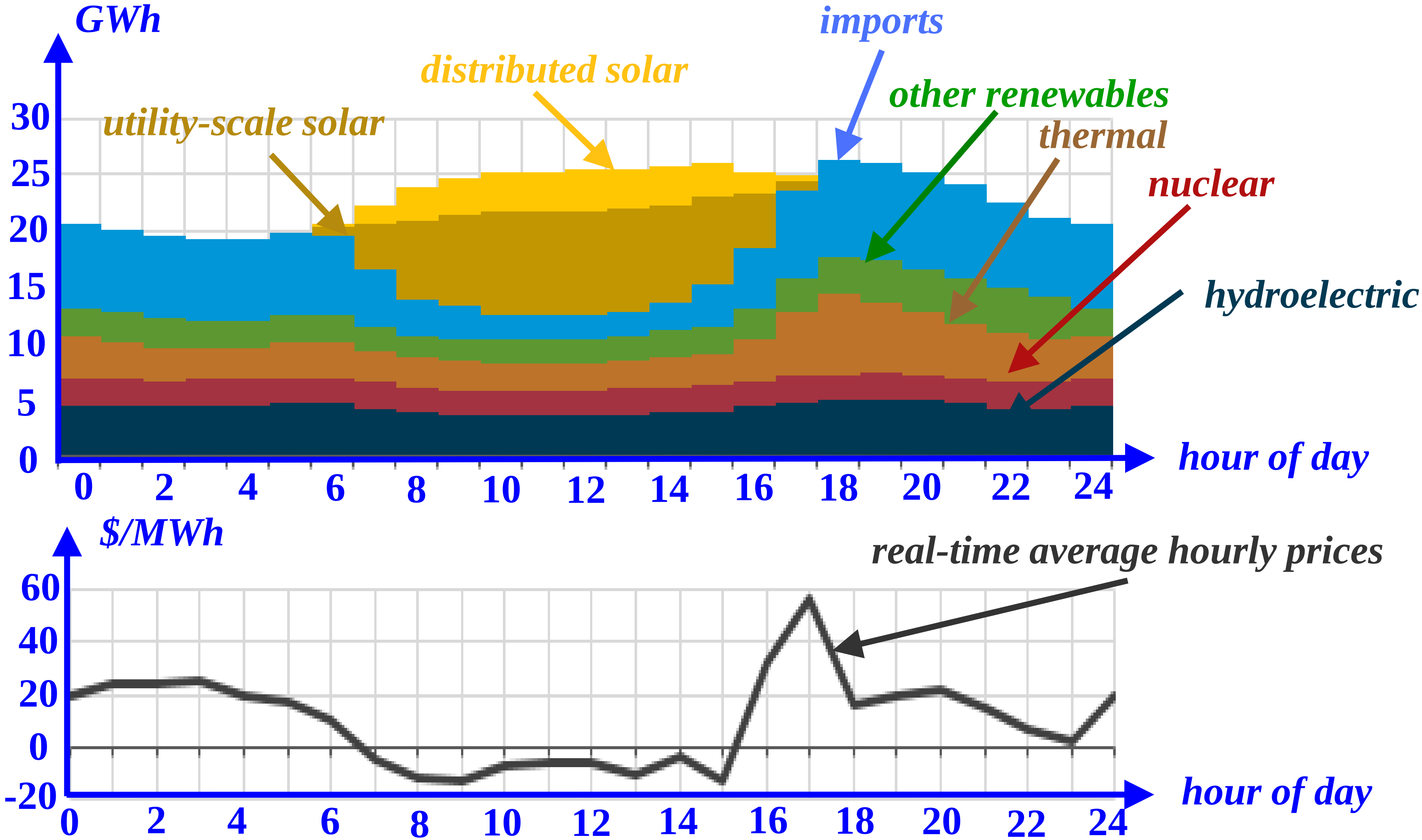


CAISO DAILY NET LOAD CURVE UNDER DEEPER *PV* PENETRATION

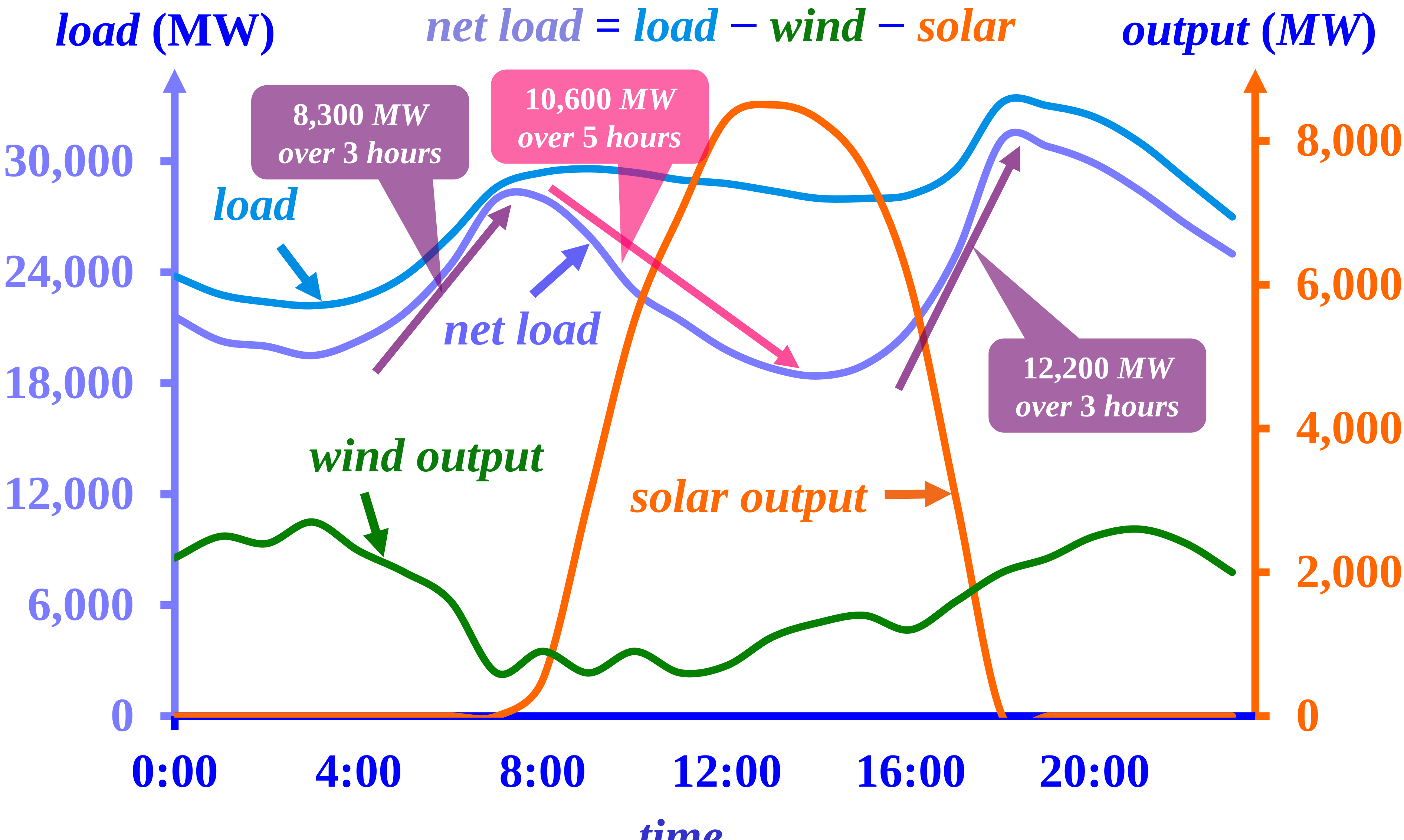


CALIFORNIA ROOFTOP SOLAR IMPACTS: MARCH 11, 2017

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



INCREASED FLEXIBILITY NEEDS

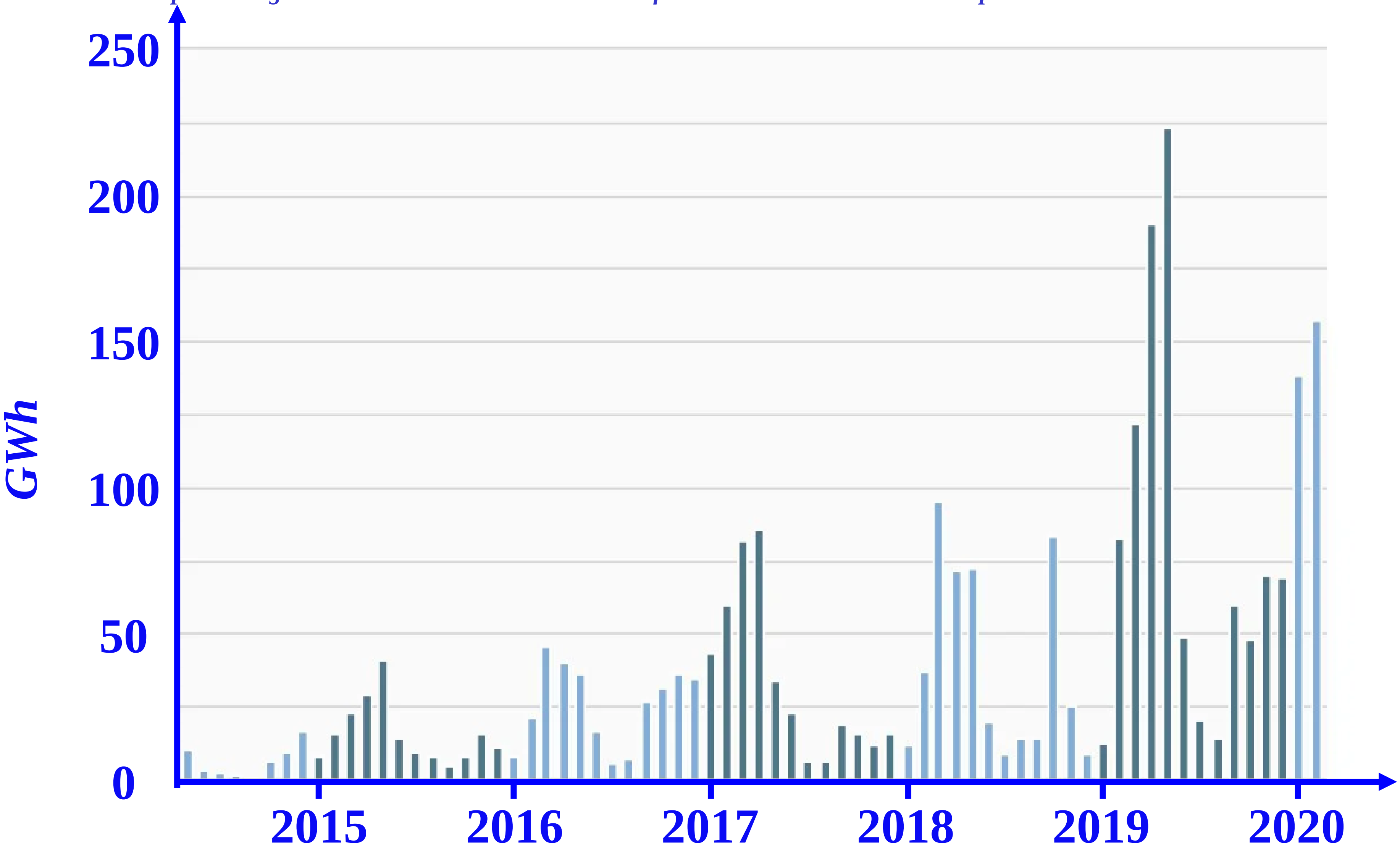


NET LOAD **IN** ***CALIFORNIA*** **IN SPRING**

- **Renewable energy curtailment in *CAISO* has increased markedly since 2017**
- ***CAISO* mostly curtails renewable energy during the Spring, when the duck curve becomes more pronounced**
- ***CAISO* needs to curtail the output of renewable resources to preclude overly steep net load ramps and ensure secure grid operations**

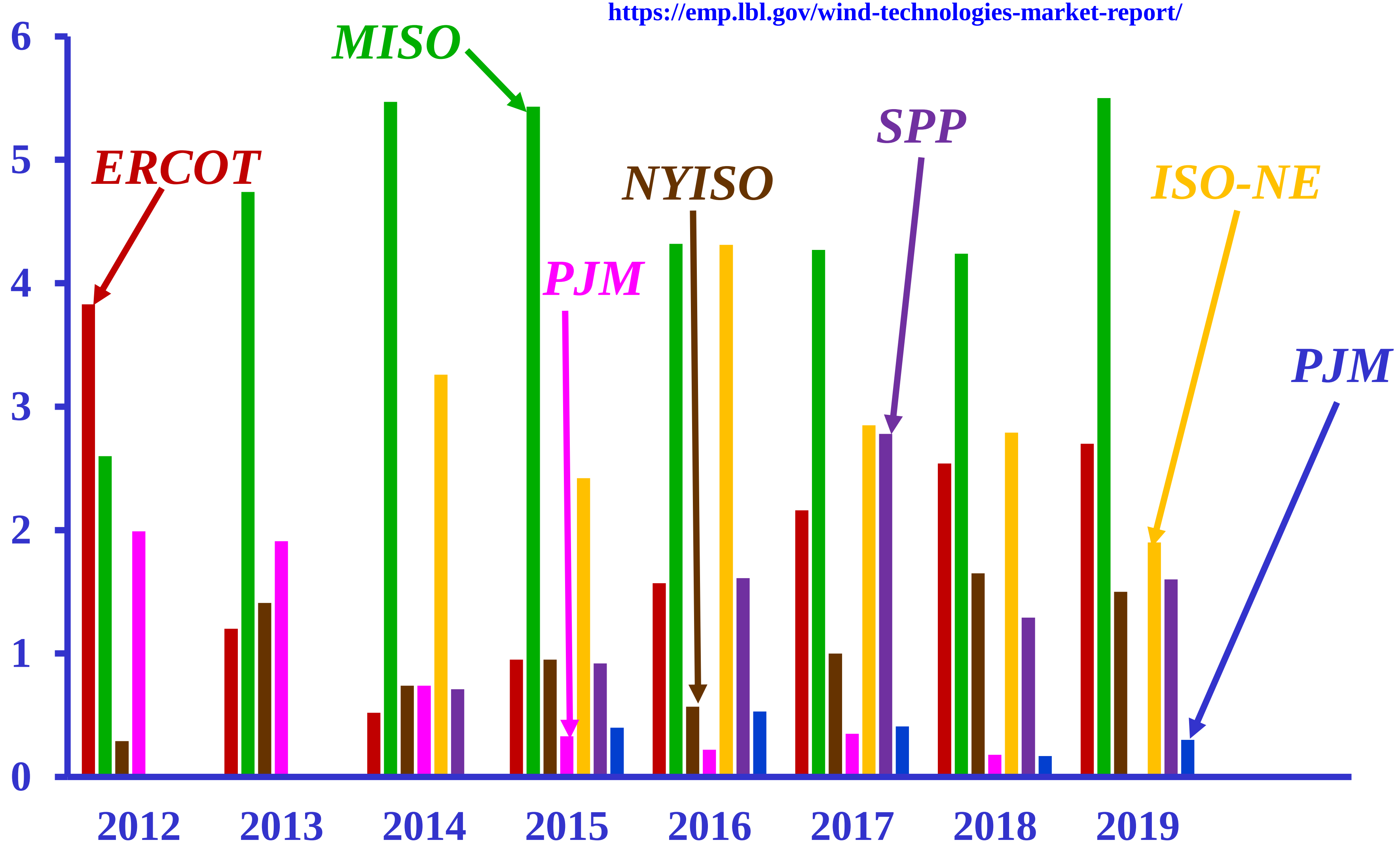
MONTHLY *CAISO* RENEWABLE ENERGY CURTAILMENTS

Source: ***https://www.greentechmedia.com/articles/read/california-renewable-curtailments-spike-as-coronavirus-reduces-demand***



CURTAILMENT PERCENTAGES OF WIND GENERATION : 2012 – 2019

Source: Lawrence Berkeley National Laboratory, available online at https://emp.lbl.gov/wind-technologies-market-report/



PRINCIPAL ROLES *ESR*s CAN PLAY

- Storage enables deferral of investments in:
  - new, conventional generation resources
  - new transmission lines
  - distribution circuit upgrades
- Storage is key to the development of microgrids – in either grid–connected or autonomous systems

MORE ROLES *ESR*s CAN PLAY

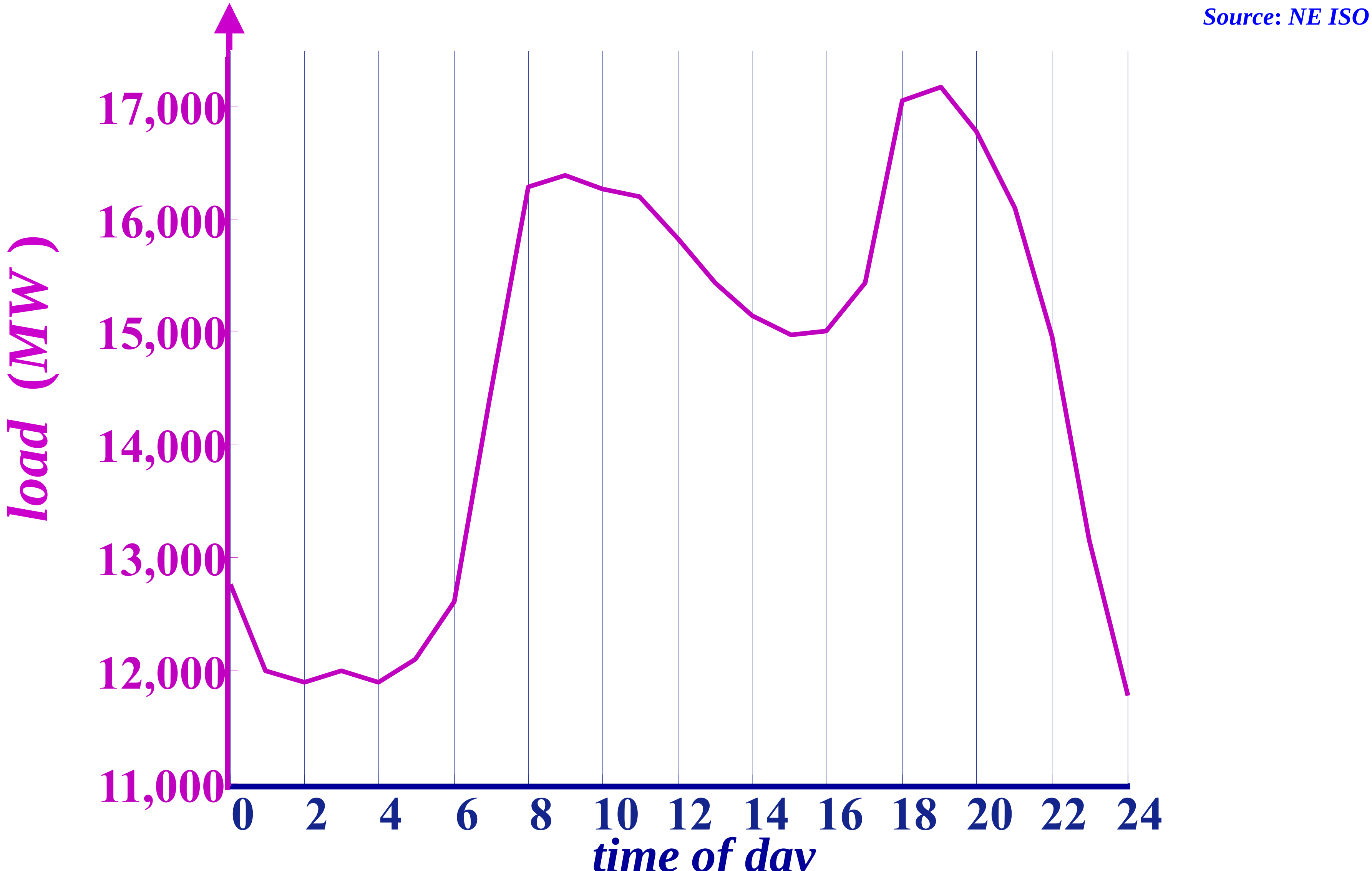
- **For short–term operations, storage provides:**
  - **flexibility in time of energy consumption via demand shift and peak–load shaving**
  - **ability to delay the start up of cycling units**
  - **levelization of substation load**
  - **reserves and frequency regulation services**

MORE ROLES *ESR*s CAN PLAY

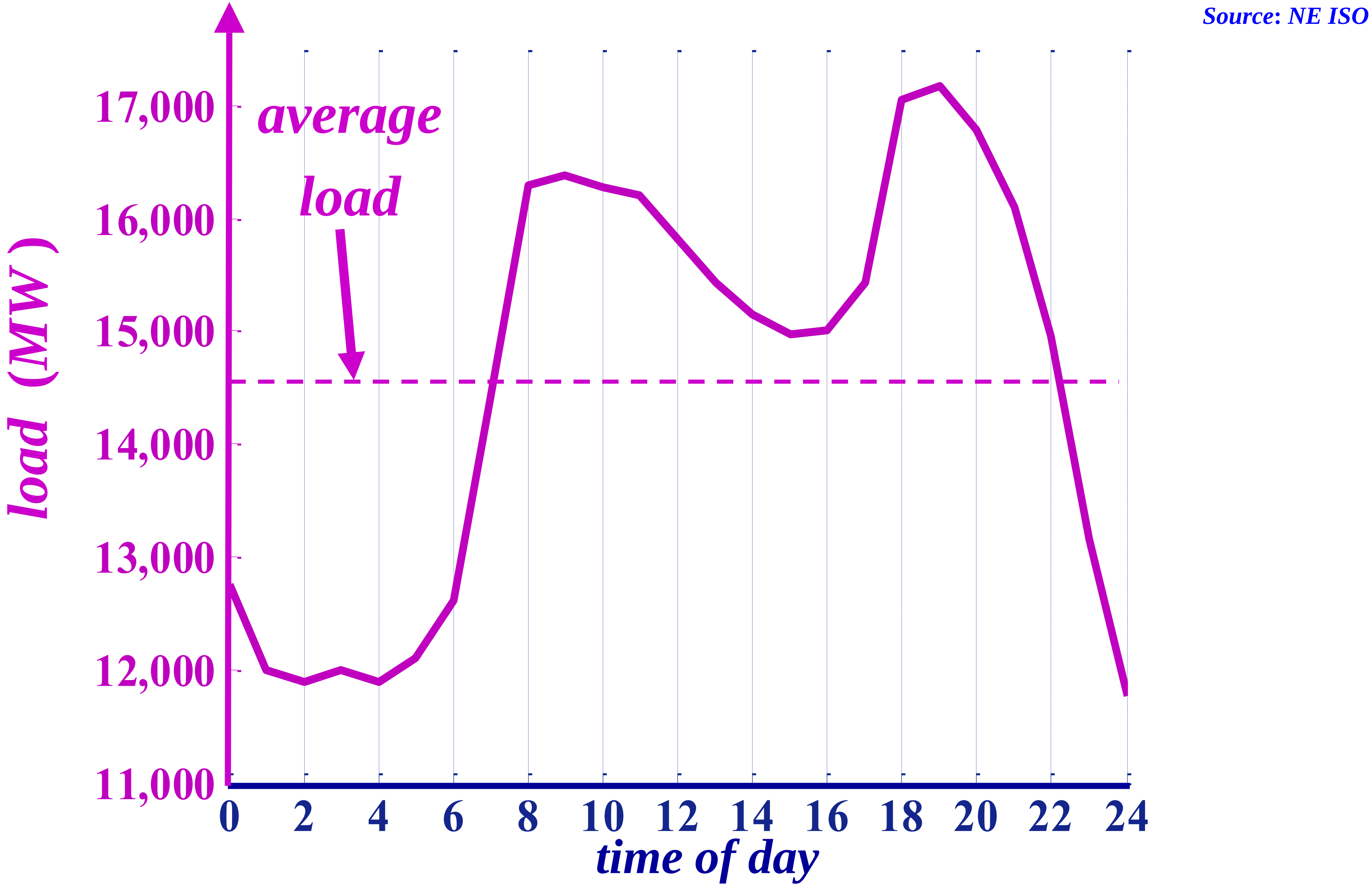
- demand response action
- capability to provide voltage support

- Storage can also provide ***virtual inertia service*** to replace part of the missing inertia in grids with integrated renewable resources – a major issue in grids with deeper levels of integrated renewable energy resources

LOADS AND LOCATIONAL MARGINAL PRICES (*LMP*s)

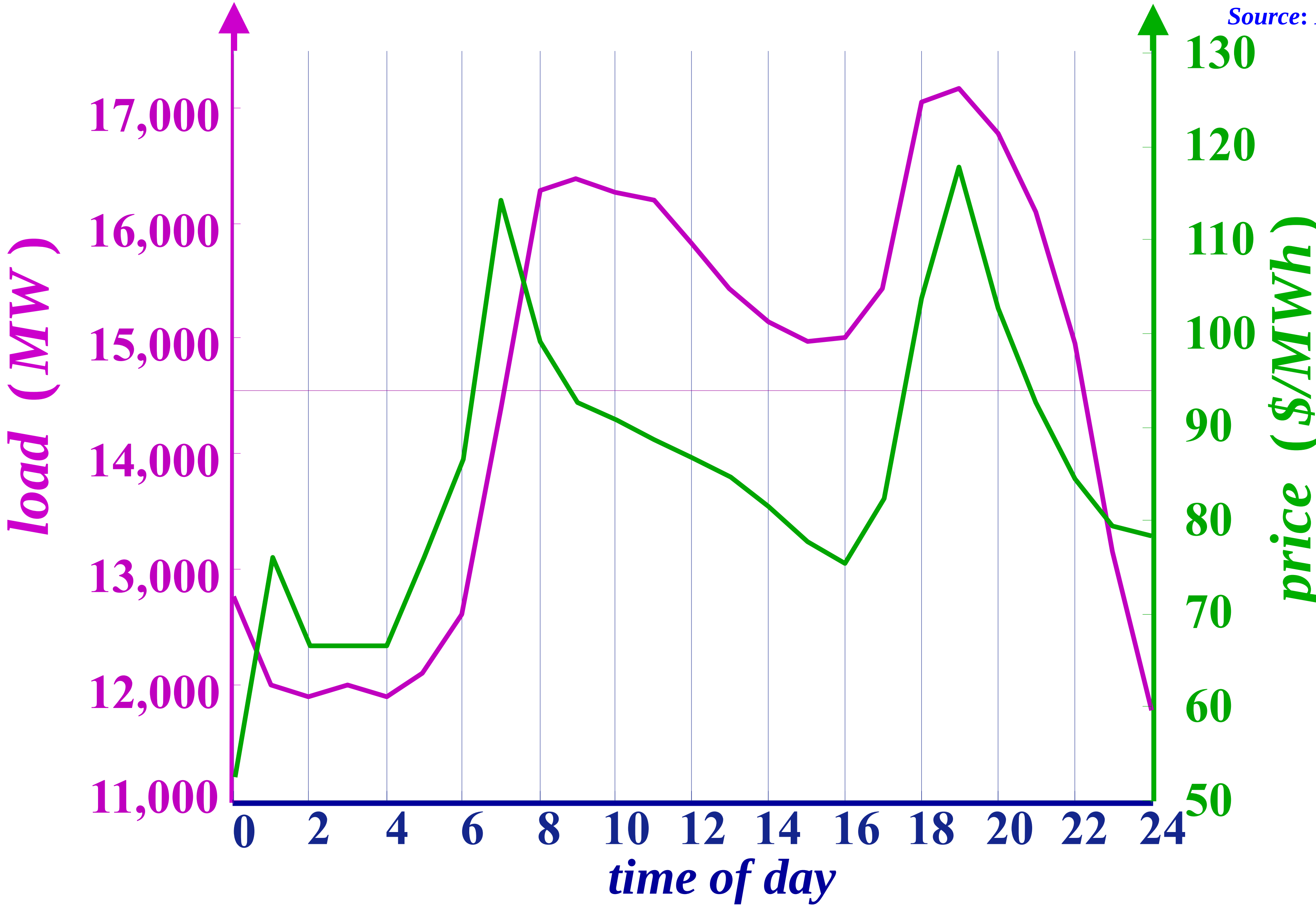


LOADS AND *LMPs*

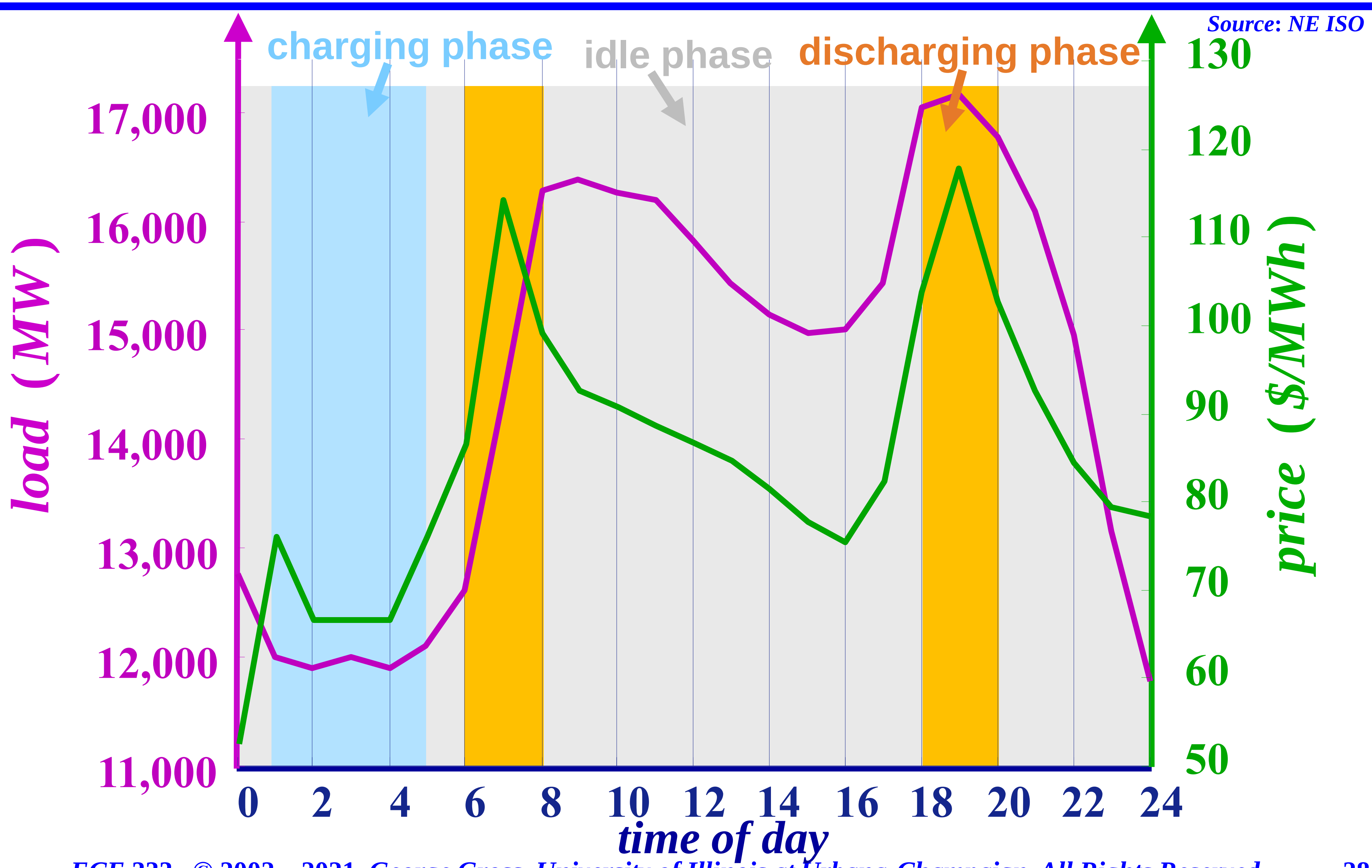


LOADS AND *LMPs*

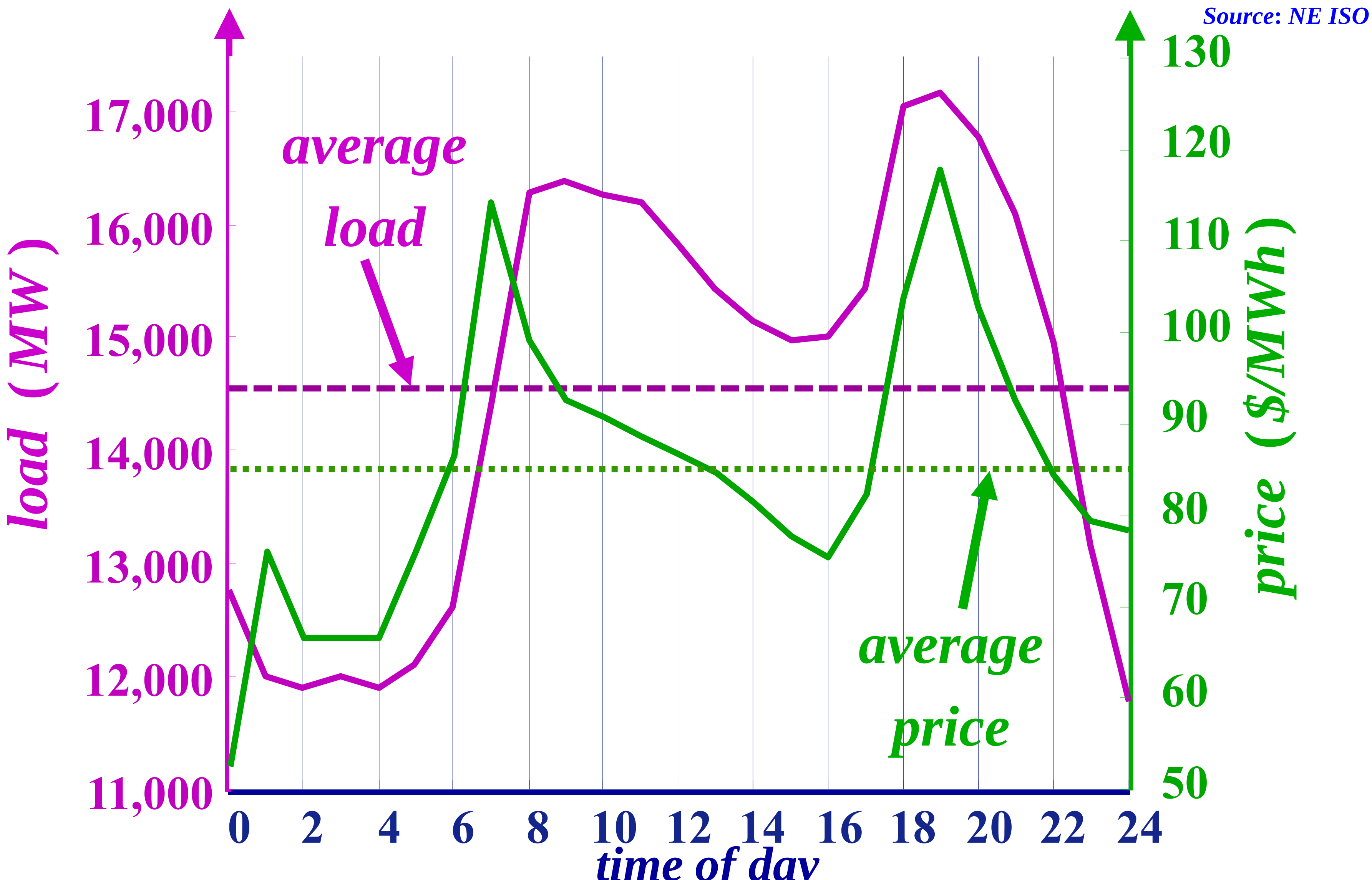
Source: *NE ISO*



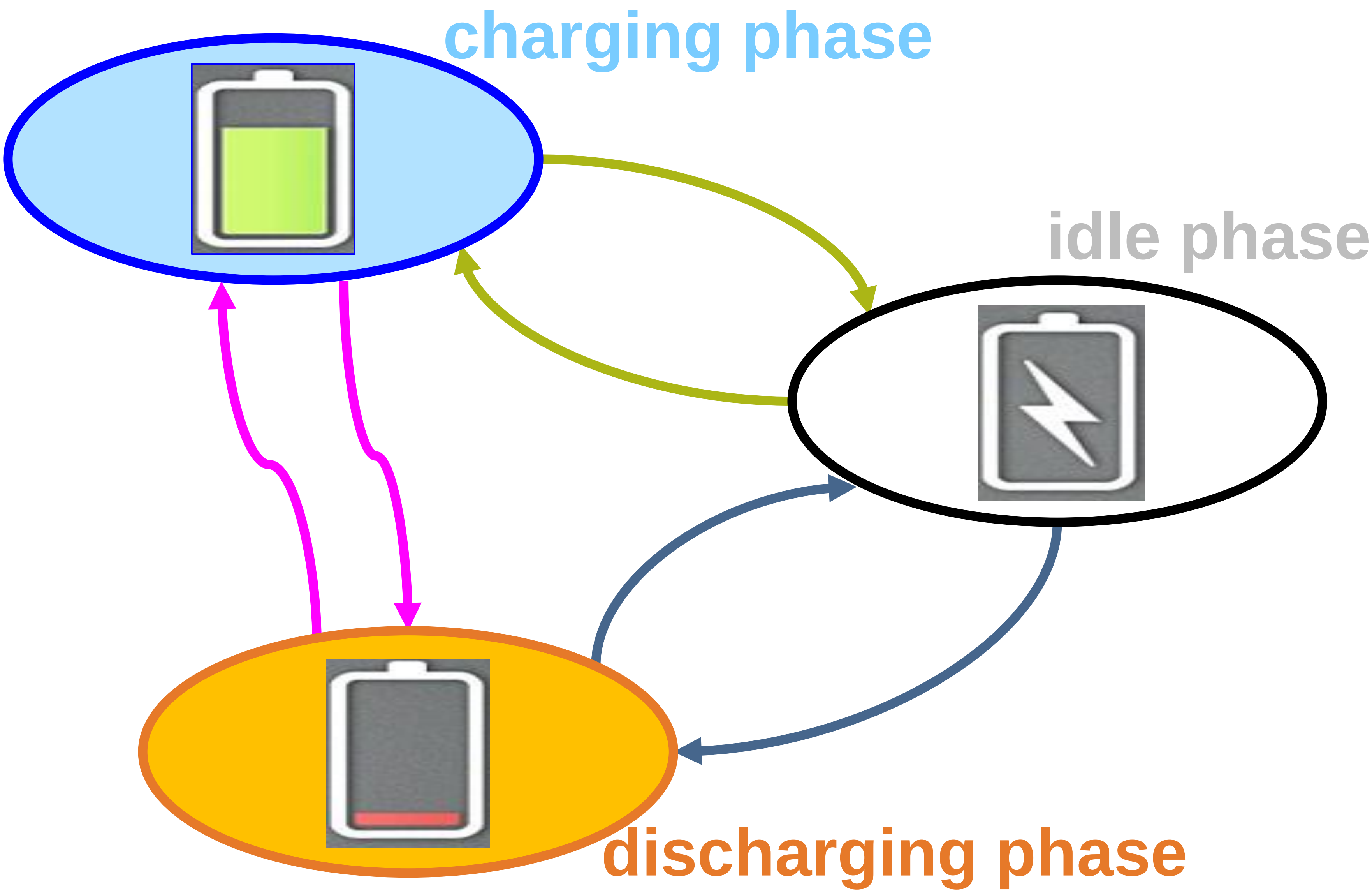
STORAGE UTILIZATION



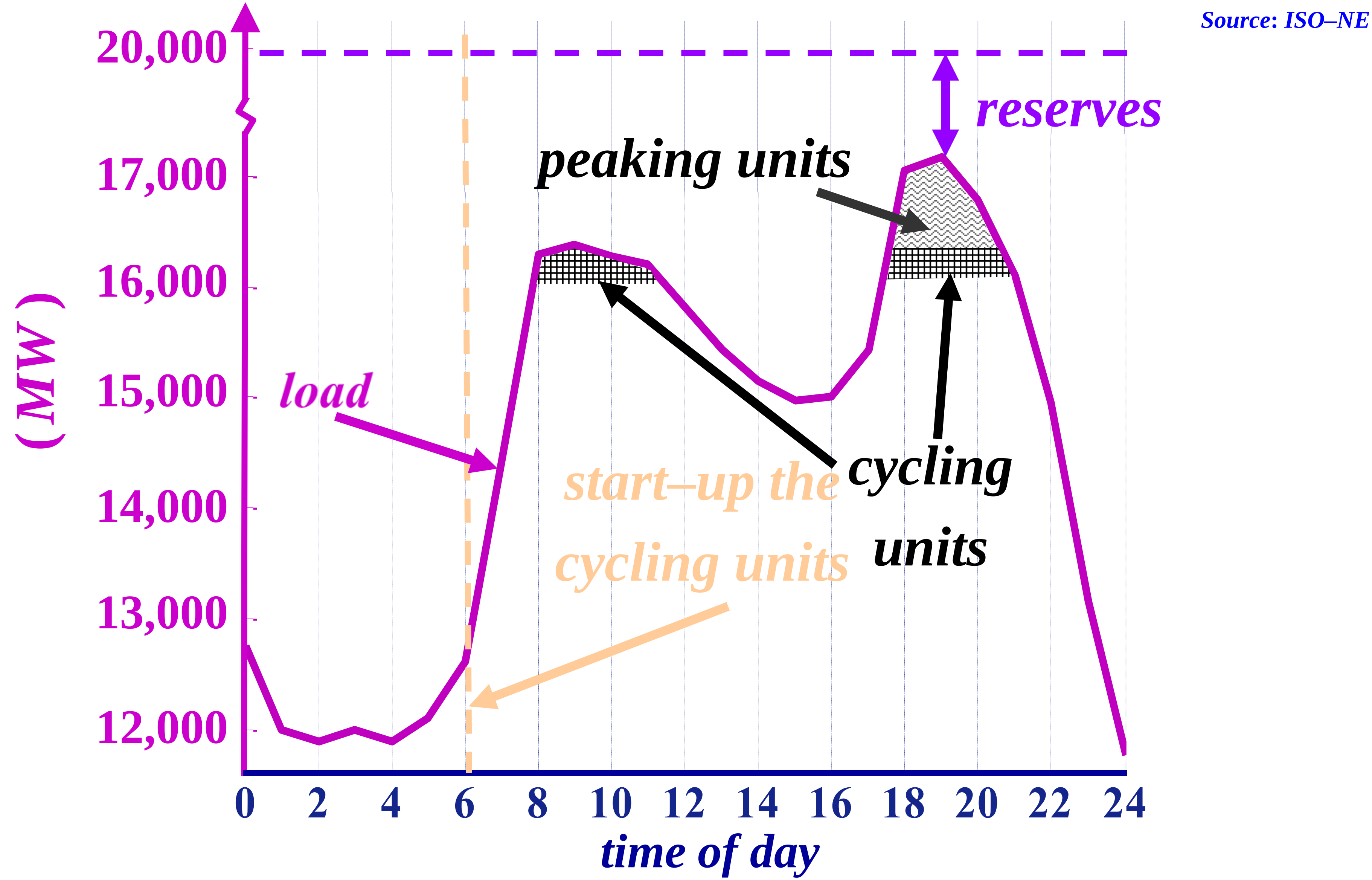
LOADS AND *LMPs*



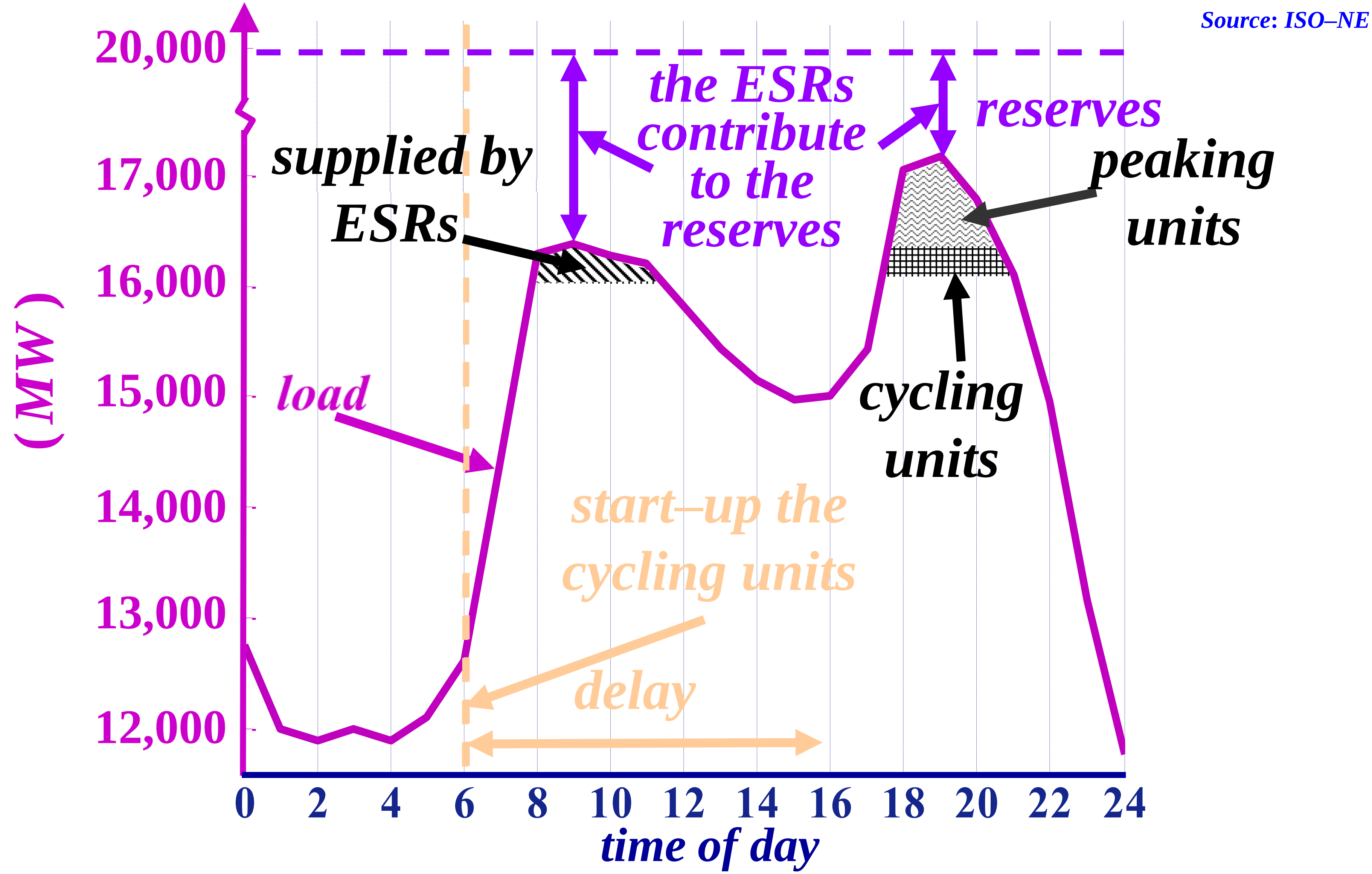
THE STORAGE RESOURCE PHASES



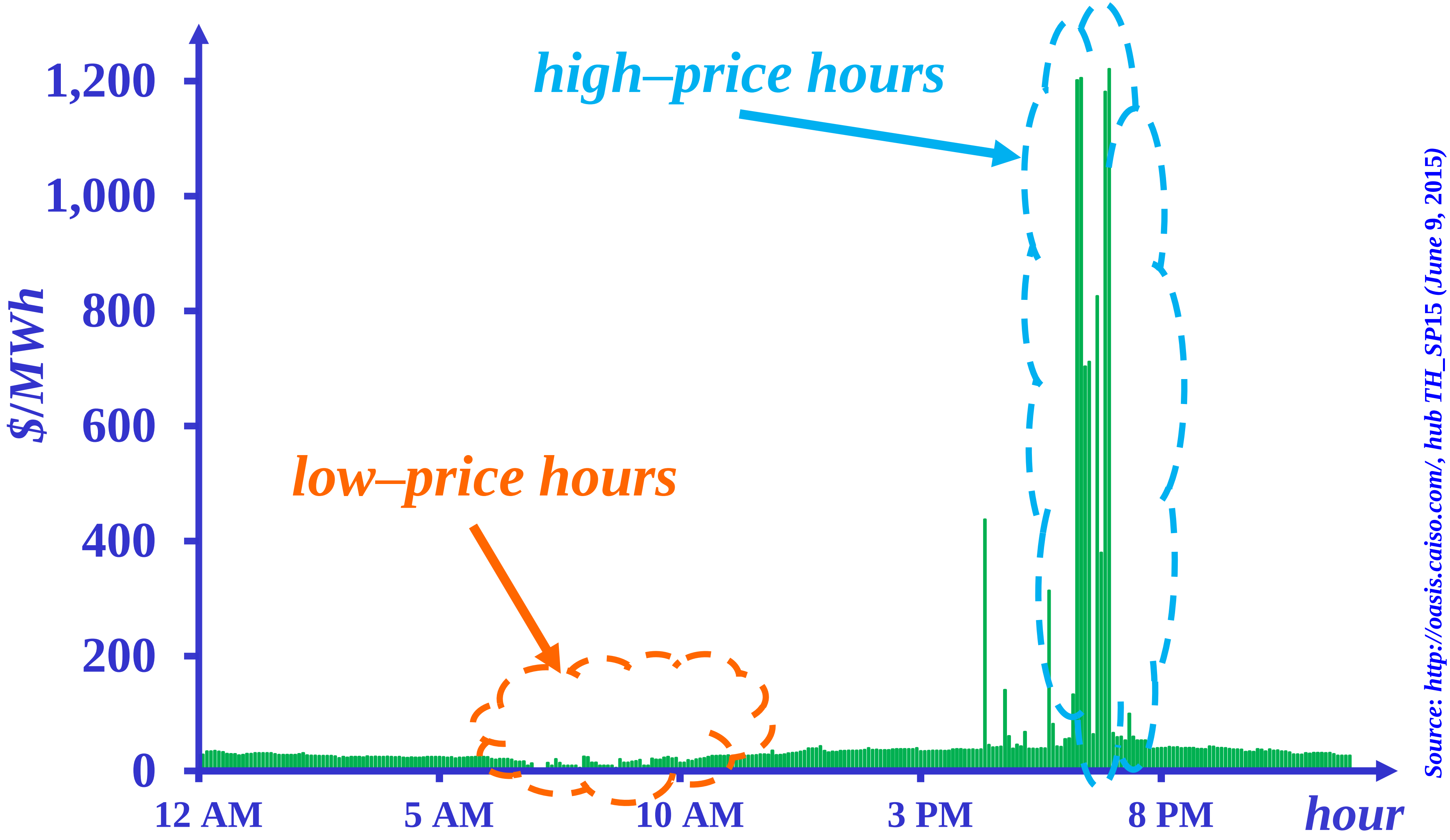
CYCLING UNITS WITHOUT *ESRs*



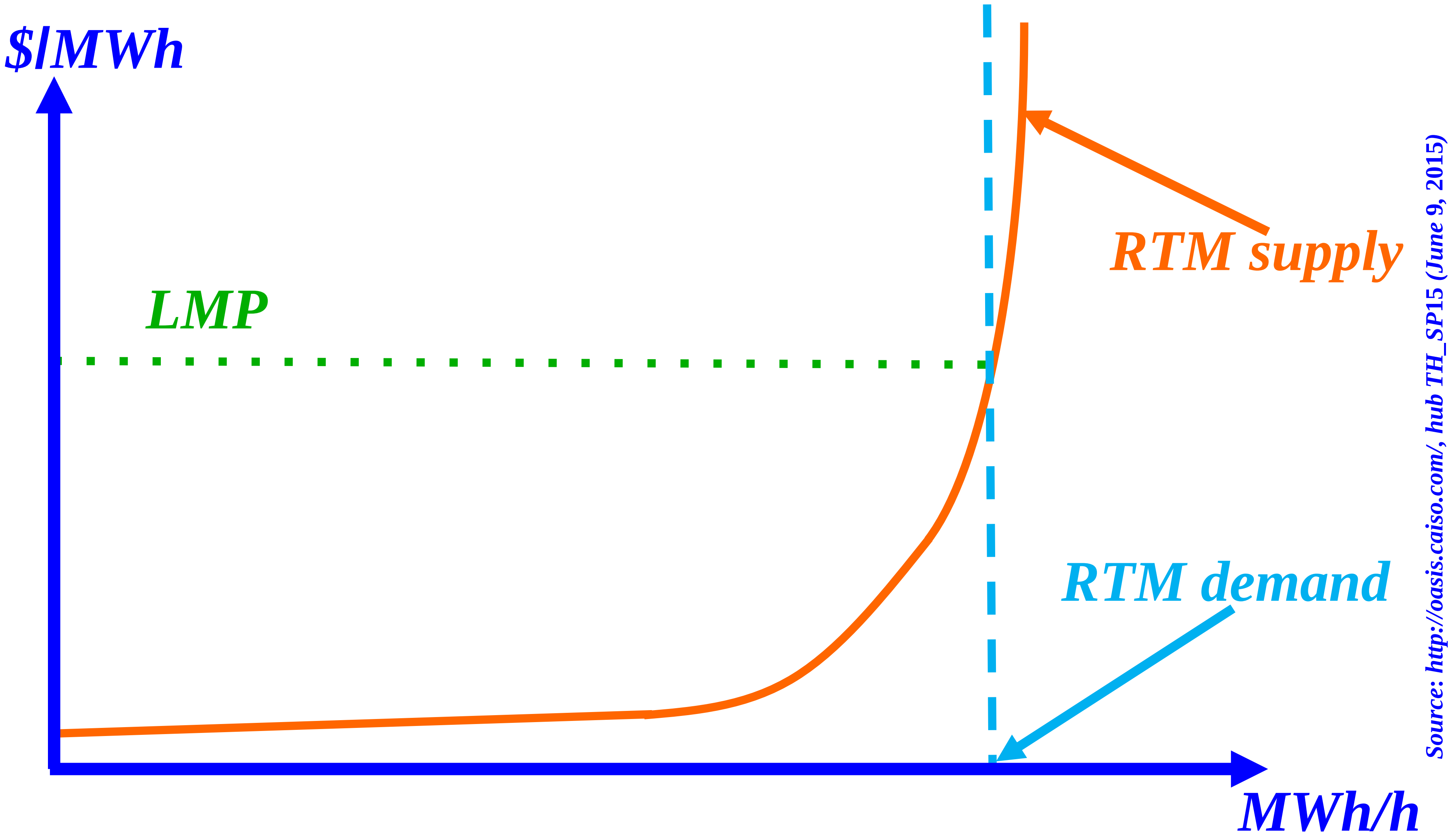
CYCLING UNITS WITH *ESRs*



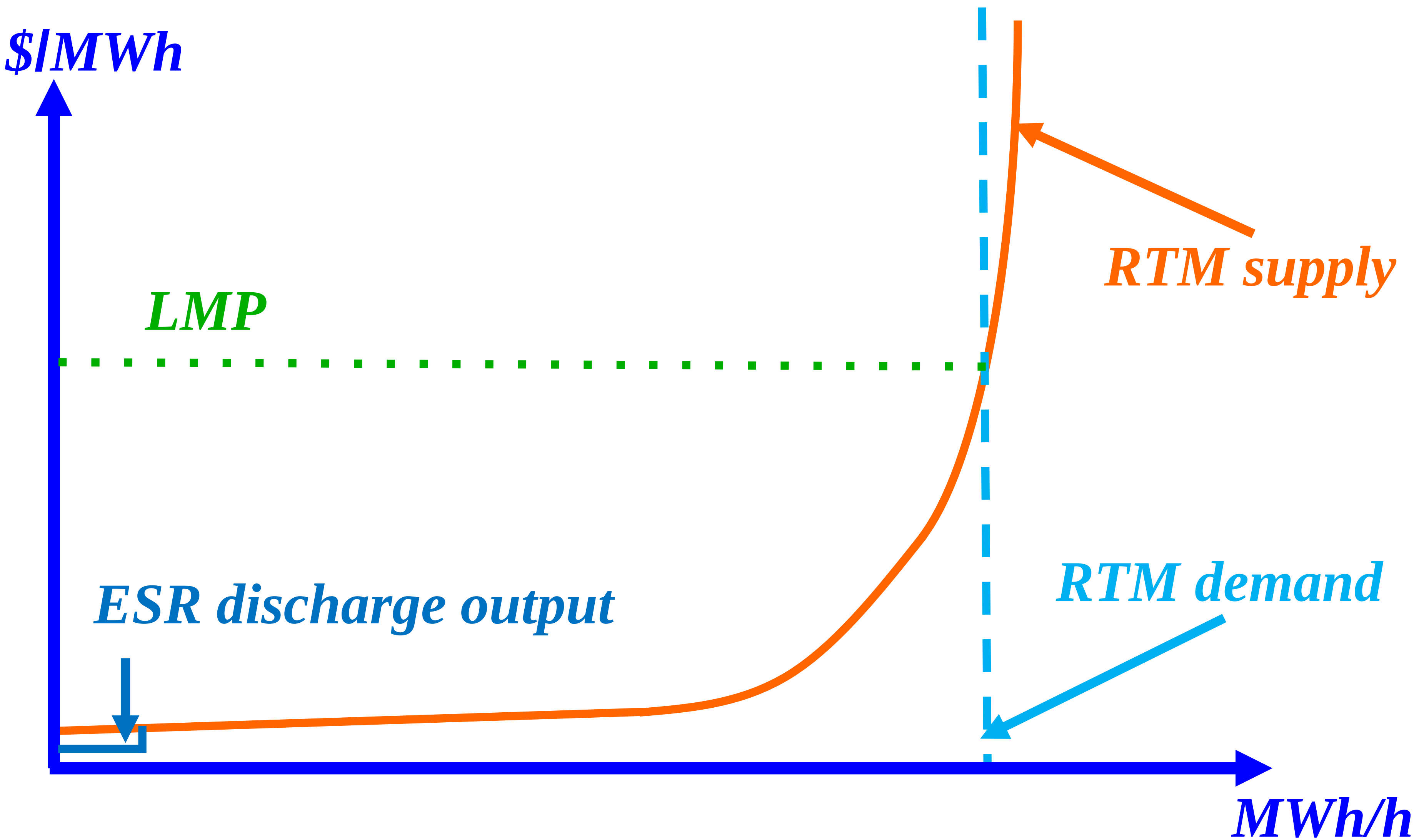
ESR DEPLOYMENT IN *RTMs*



LMP IN A SYSTEM WITHOUT STORAGE

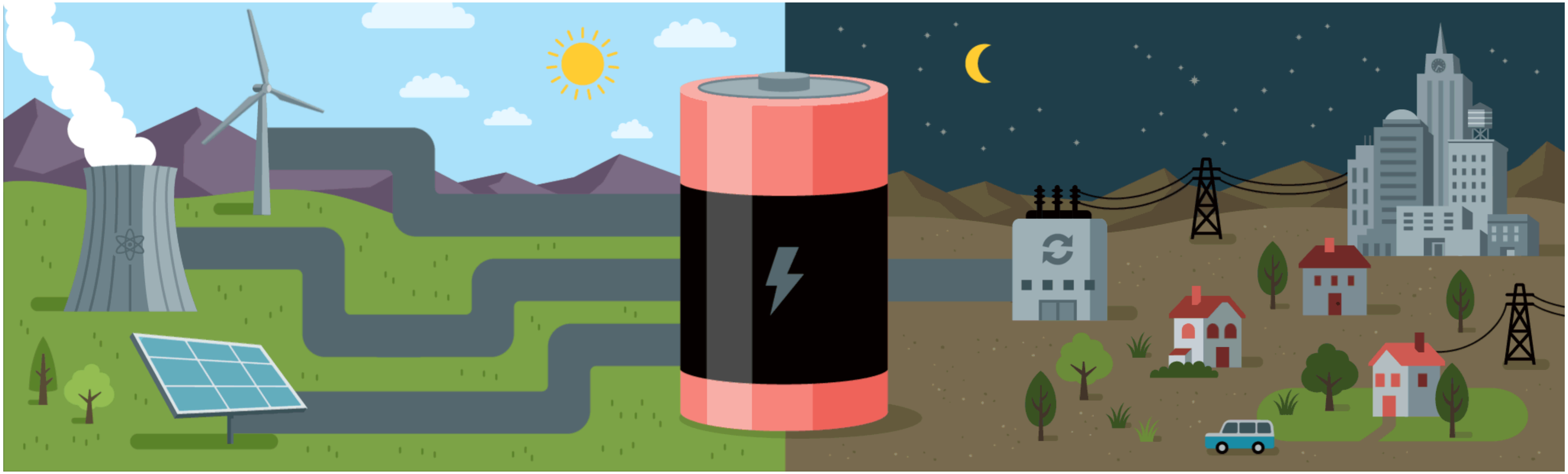


ESR DEPLOYMENT IMPACT ON *LMP*



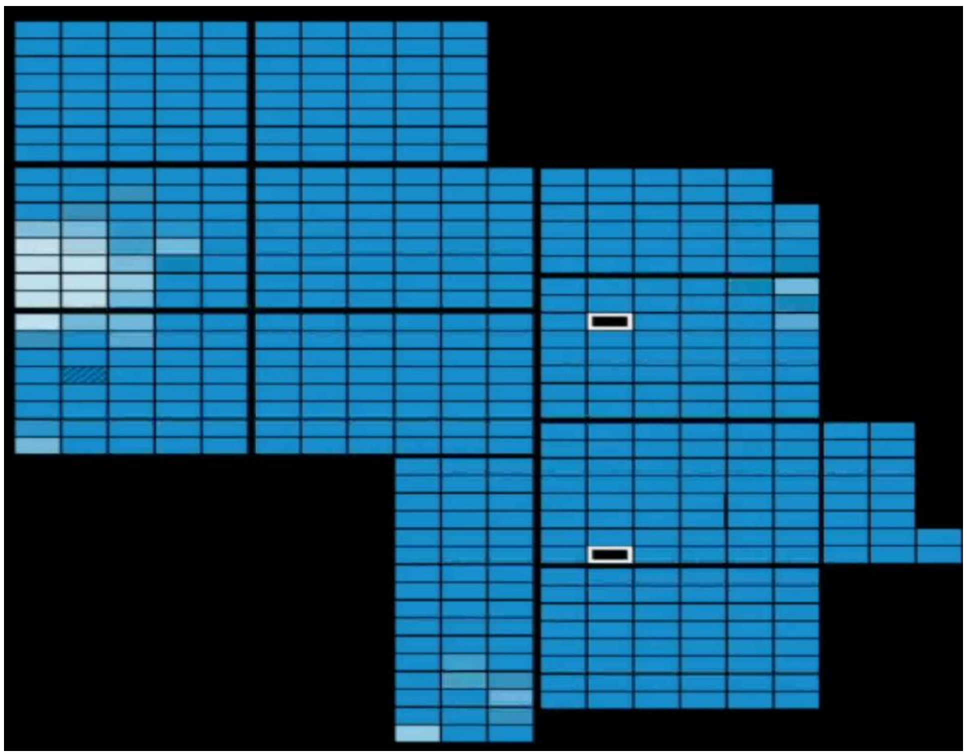
Source: http://oasis.caiso.com/, hub TH_SP15 (June 9, 2015)

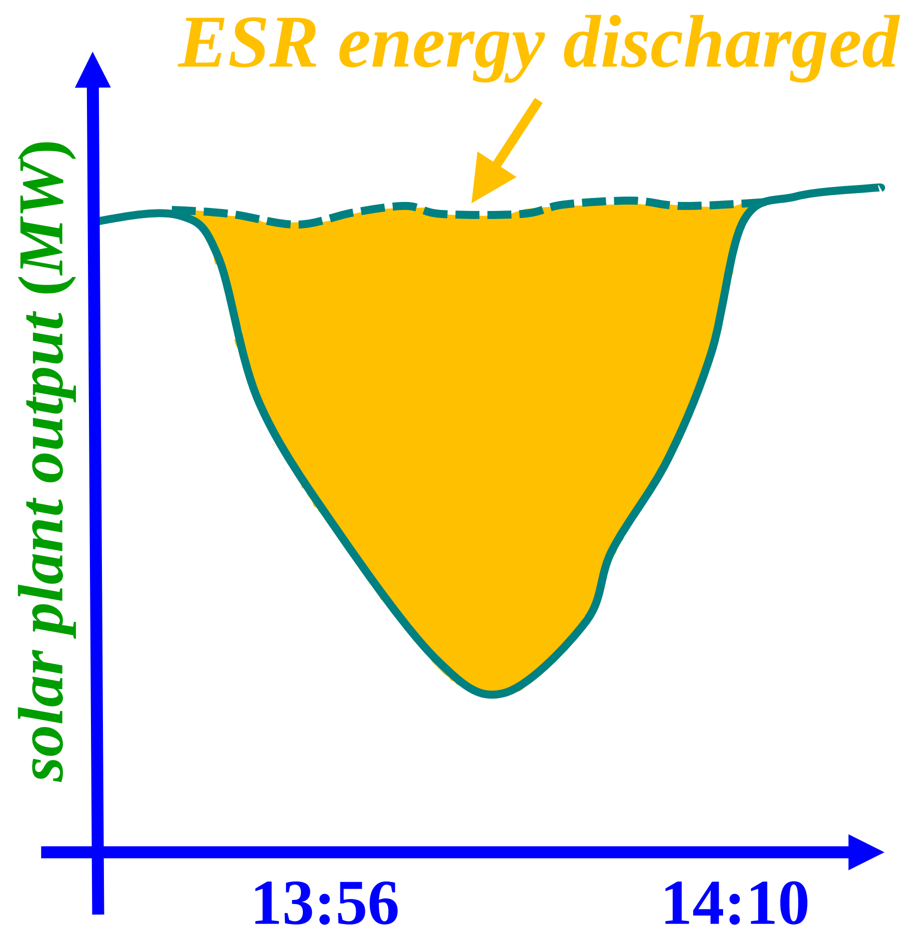
BATTERY STORAGE AND *RER* SYMBIOSIS



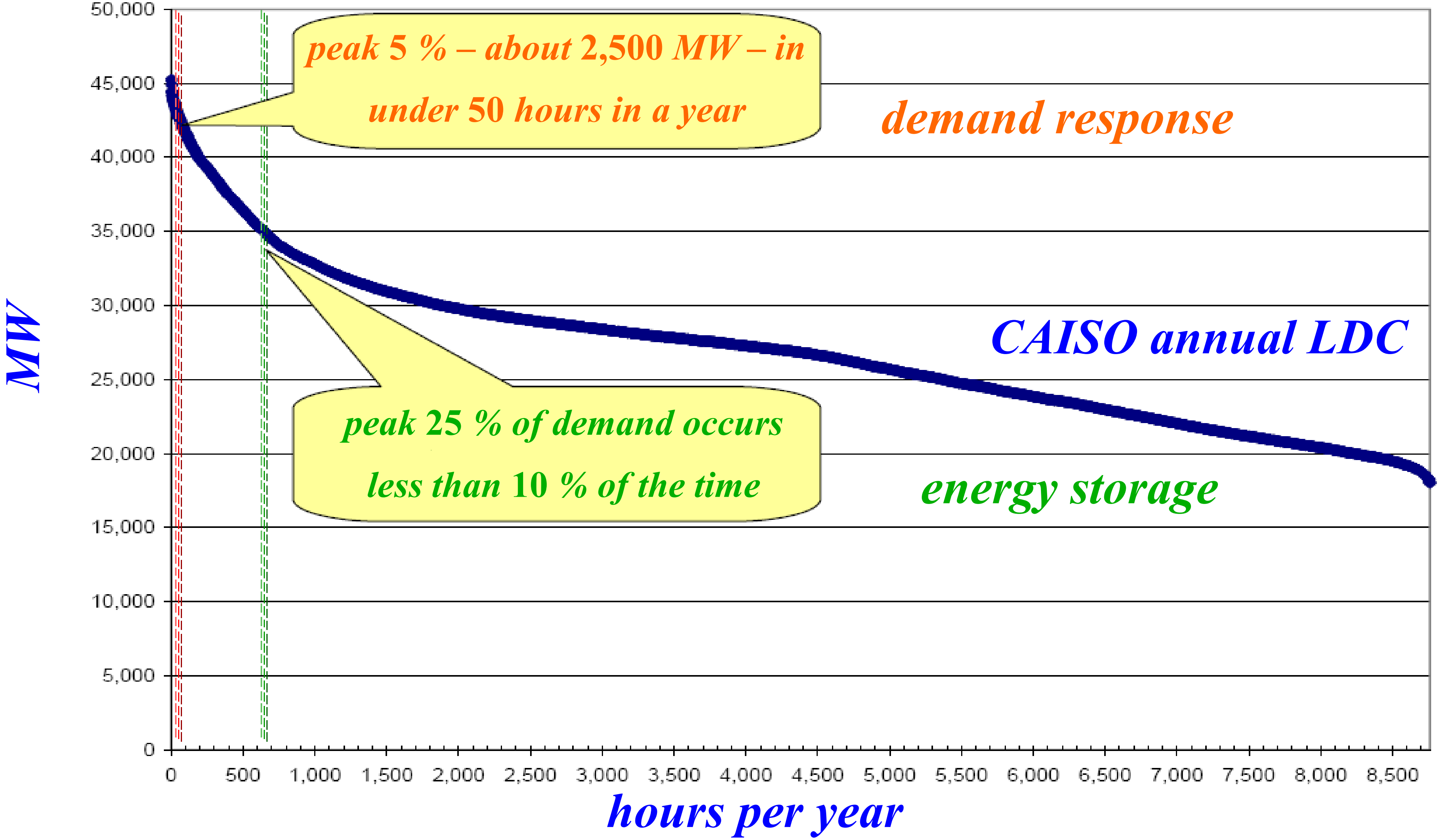
***Source*: *The New York Times* https://static01.nyt.com/images/2017/03/21/business/batteries-cover/batteries-cover-superJumbo.gif**

INTEGRATION OF STORAGE WITH SOLAR RESOURCES



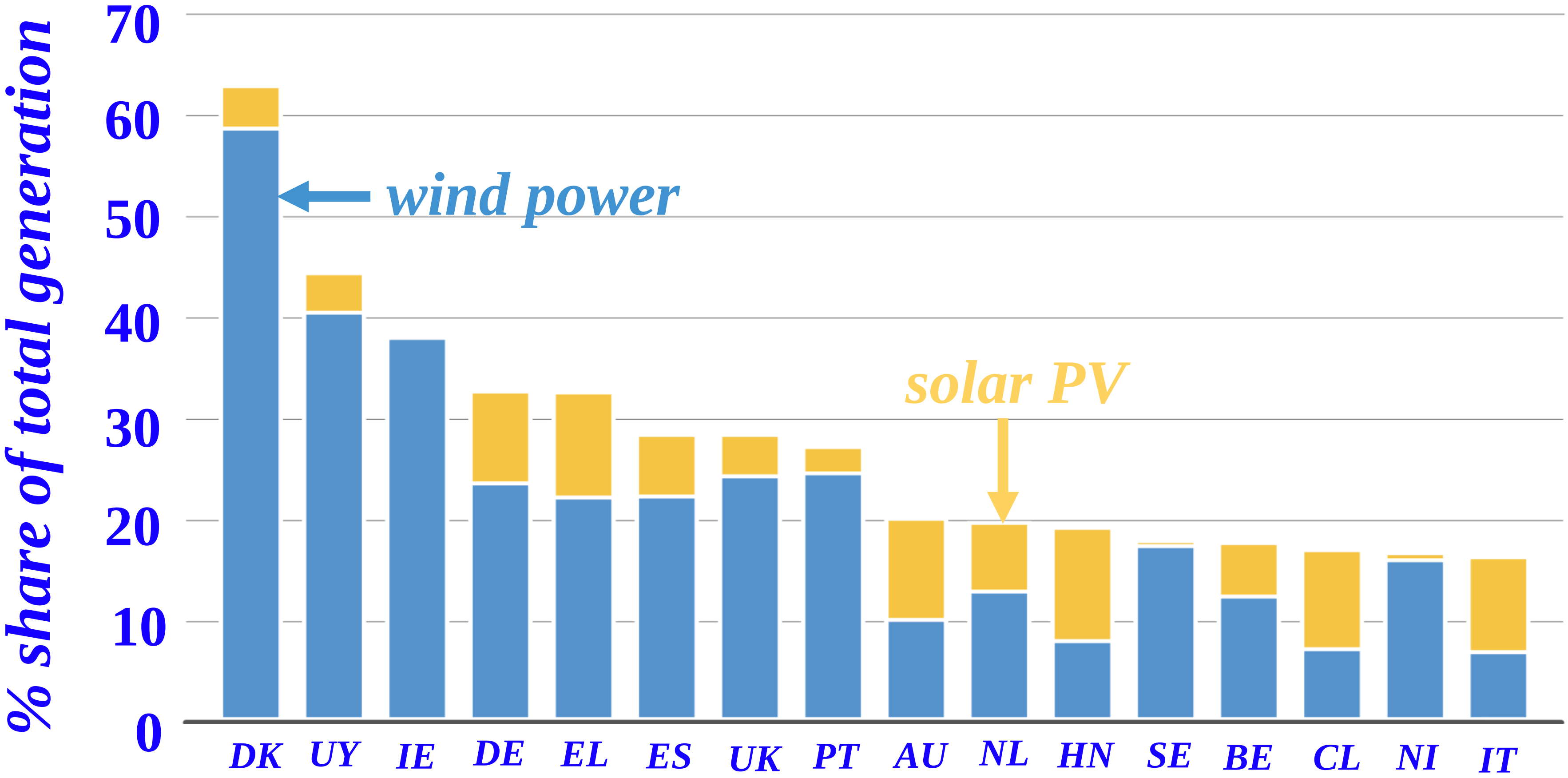


CAISO DRR AND *ESR* DEPLOYMENT



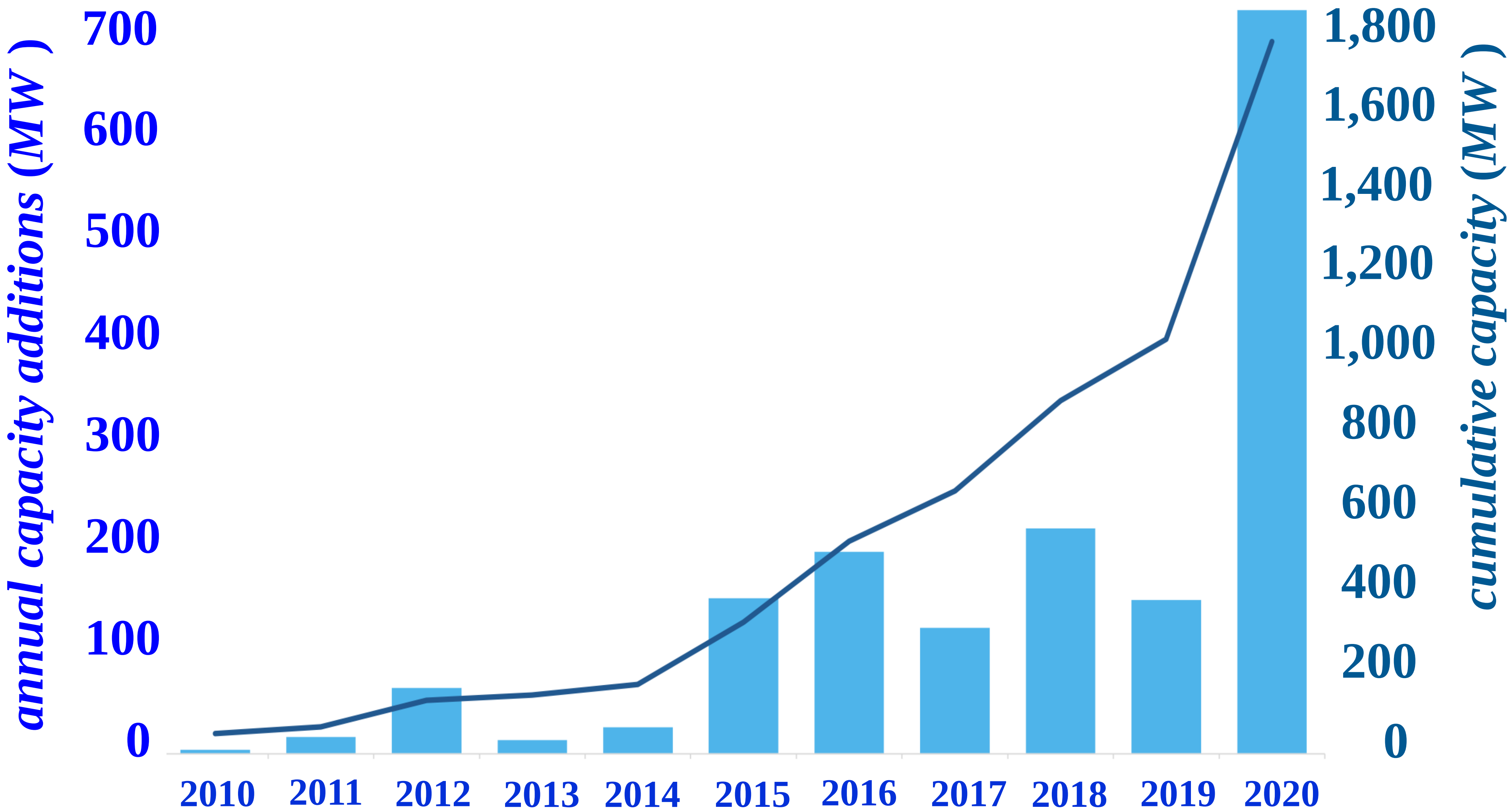
LEADING NATIONS' RENEWABLE ENERGY GENERATION IN 2020

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



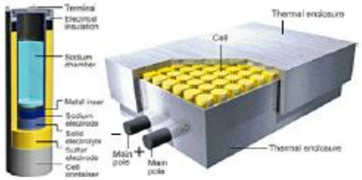
ANNUAL AND CUMULATIVE *US* ENERGY STORAGE CAPACITY

Source: ACP Market Report Fourth Quarter 2020, available at https://cleanpower.org/wp-content/uploads/2021/02/ACP_MarketReport_4Q2020.pdf

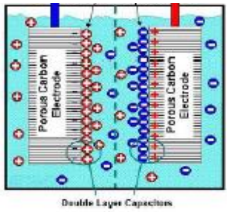


ENERGY STORAGE TECHNOLOGIES

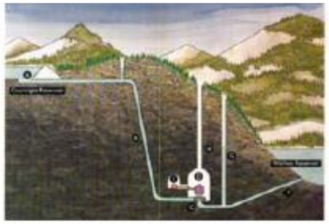
NaS battery



EC capacitor

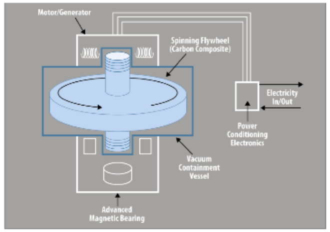


pumped storage

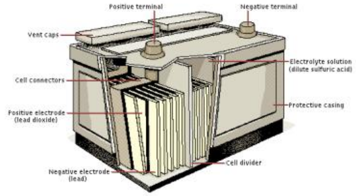


flow battery

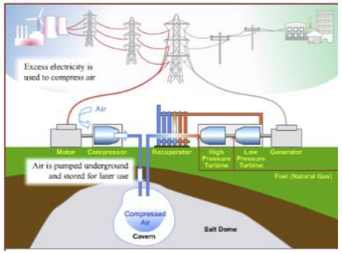
flywheel



lead–acid battery



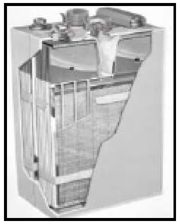
CAES



advanced lead acid battery

Li–ion battery

Ni–Cd battery



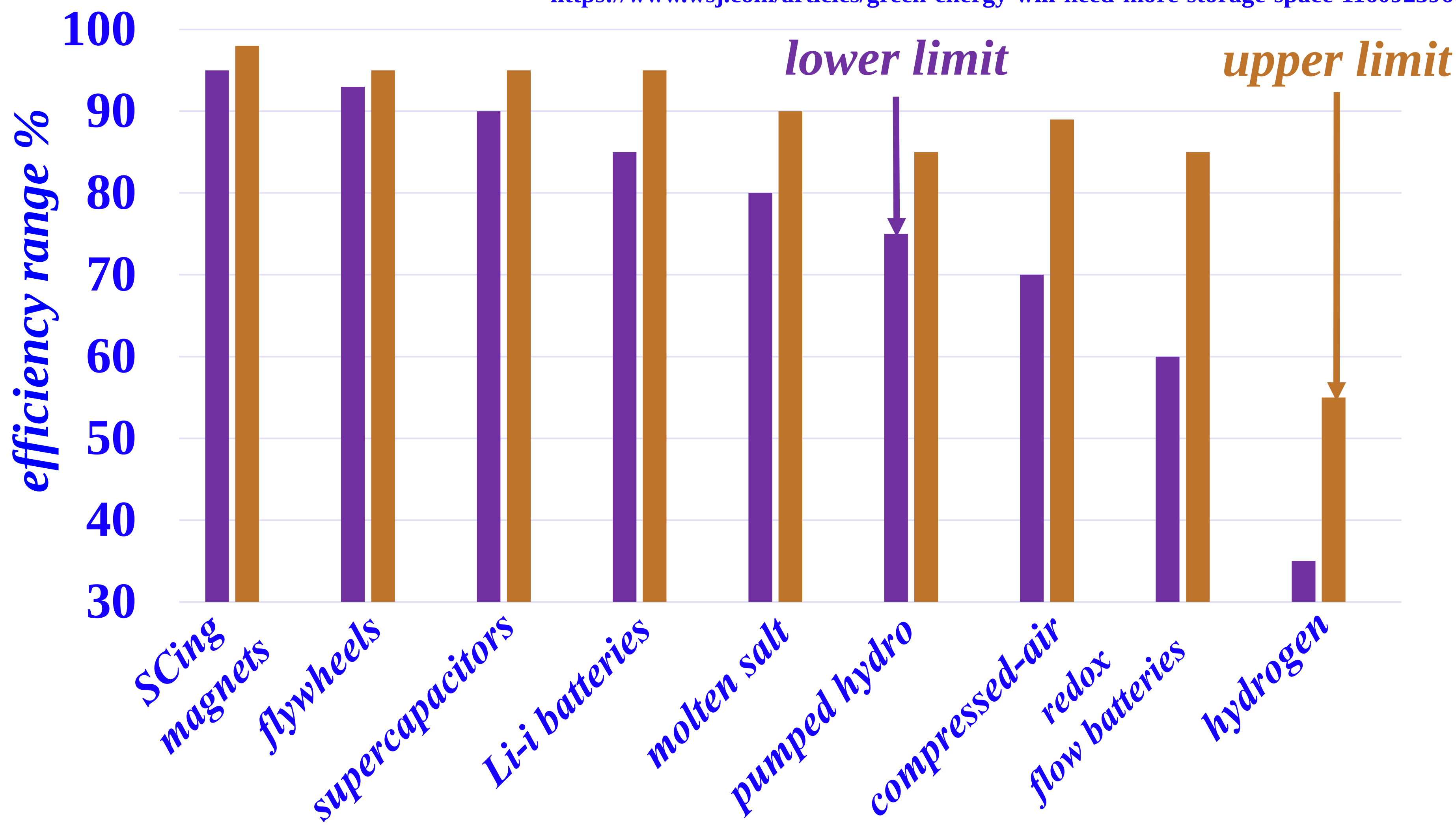
SMES

← *increasing capability*

increasing capacity →

EFFICIENCY RANGES OF *ESR* TECHNOLOGIES

Source: *The Wall Street Journal, available on-line at*
https://www.wsj.com/articles/green-energy-will-need-more-storage-space-11609239601



ESR INTERACTIONS WITH THE GRID

application	*ESR owner interest*	*grid impacts*
substation transformer overload avoidance	*economic overload condition mitigation*	*reliability improvement*
variable energy generation curtailment avoidance/reduction	*more effective renewable energy resource harnessing*	*increase of fraction of green energy and pollution reduction*
energy shift from low–load to high–load periods	*collection of arbitrage benefits*	*low–load condition mitigation and cost reduction*
replacement of reserves requirements from the units in a generation plant	*relaxation of reserve requirements limits on the plant units*	*reliability improvement*

CHALLENGES THAT STORAGE CAN EFFECTIVELY ADDRESS

variable energy resource integration challenge	*the way storage addresses the challenge*
the pressing needs for adequate ramping capability in controllable resources	*fast ms–order ESR response times can meet the steep raise/lower ramping requirements*
variability, intermittency and uncertainty associated with renewable resource outputs	*ESRs are instrumental in smoothing renewable outputs and in higher renewable energy harnessing*
increased need for frequency regulation resources for flexibility in grid operations	*ESRs provide regulation with 2 – 3 times faster response times than gas turbines*

STORAGE TO THE RESCUE

today's electricity grid with limited storage capacity/capability	future electricity grid with measurably increased storage capacity/capability
any increment in peak demand requires use of polluting and inefficient power plants	*additional peak demand is met by ESRs that shift the times of energy consumption*
reserves requirements are met by expensive and polluting fossil–fired generators	*reserves provided by ESRs reduce dependence on the contributions to reserves by conventional units*
renewable generation has to be "spilled" whenever the supply exceeds the demand or under congestion situations	*clean, renewable energy is stored in ESRs during low–demand periods, leading to reduced dependence on conventional units*

KEY BENEFITS OF GRID – INTEGRATED *ESR*s

- Deployment of *ESR*s:
  - raises system reliability
  - improves operational economics
  - provides operators with the badly needed additional flexibility to optimize grid operations and manage grid congestion
  - raises renewable output utilization

KEY BENEFITS OF GRID – INTEGRATED *ESR*s

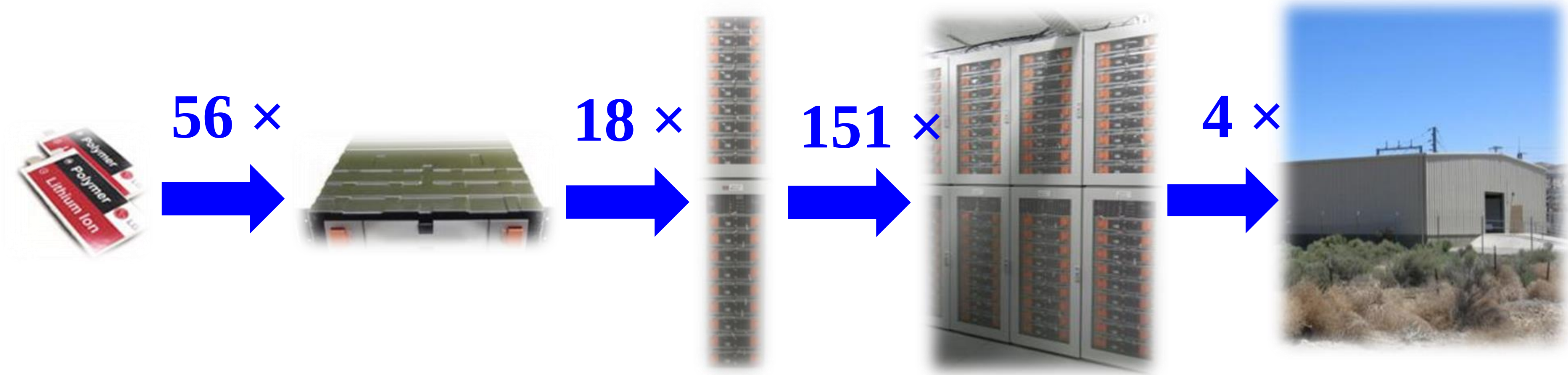
- **Deployment of *ESR*s can reduce *GHG* emissions because *ESR*s:**
  - **facilitate renewable resource integration**
  - **reduce the system reserves requirements on the conventional fossil–fired resources**
  - **displace the generation of inefficient and dirty units used to meet peak loads**

BATTERY ENERGY STORAGE SYSTEMS (*BESS*s)

- **Many practitioners consider the installation of *BESS*s to most effectively address the challenges to integrate deepening penetrations of renewable resources – a game changer for *RER* integration**
- ***BESS*s are highly efficient and can discharge their stored energy at high ramp rates**
- **The development of *new, large–scale, highly–efficient* batteries, appropriate for utility–scale storage, is becoming a huge business rather rapidly**

FROM 60 *Wh* BATTERY CELLS TO A LARGE–SCALE 32 *MWh ESR* (*BESS*)

Source: M. Irwin, "SCE Energy Storage Activities," Proc. IEEE PES General Meeting, Denver, July 26-30, 2015



cell (60 *Wh*) | module (3.2 *kWh*) | rack (58 *kWh*) | section (8.7 *MWh*) | system (32 *MWh*)

NOTREES PROJECT – *GOLDSMITH, TX* (36 *MW* / 23.8 *MWh*)

Source*: *http://www.energystorageexchange.org/projects

The *advanced lead–acid battery* system project was developed to reduce the output variability of the 153 *MW* wind power plant

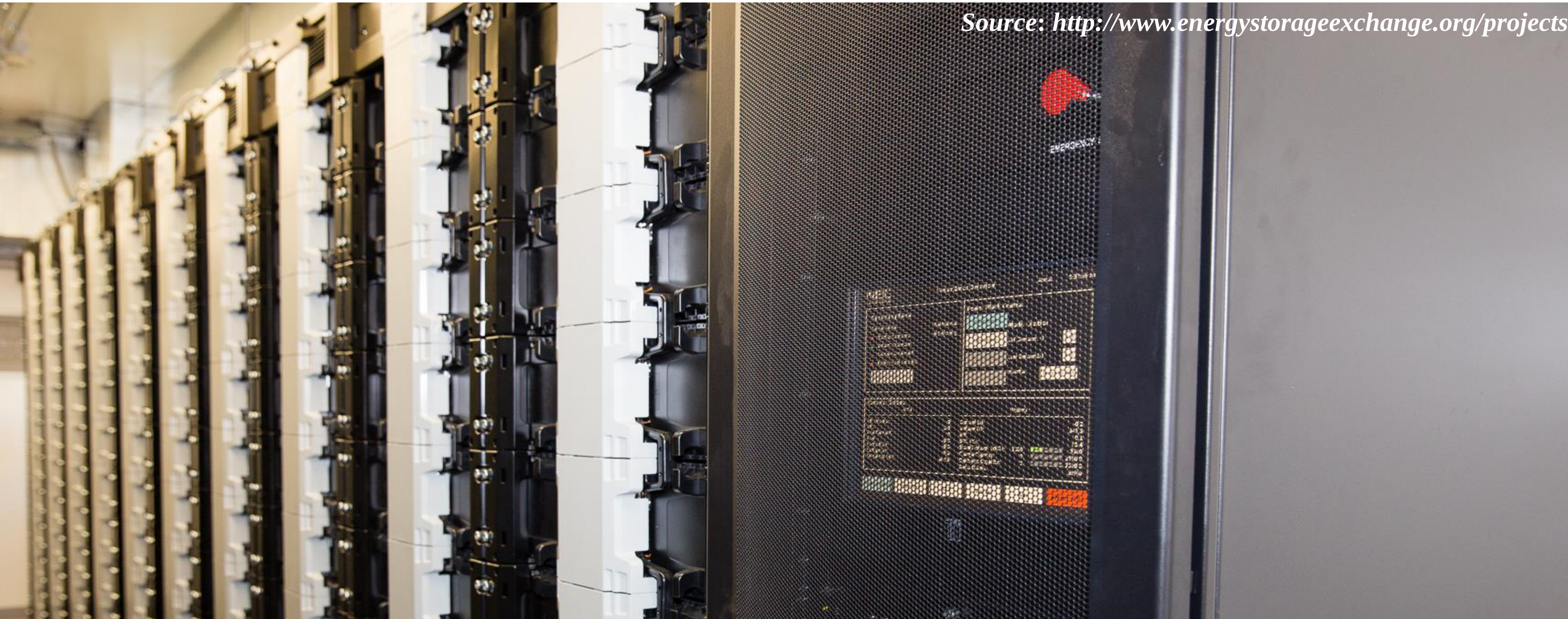
AES LAUREL MOUNTAIN – ELKINS, VA (32 *MW* / 8 *MWh*)

Source: http://www.energystorageexchange.org/projects

The *Li–ion* batteries are installed in a 98–*MW* wind farm to provide operating reserves and frequency regulation in the *PJM* system

SCE PILOT PROJECT – *ORANGE, CA* (2.4 *MW* / 3.9 *MWh*)

Source: http://www.energystorageexchange.org/projects



The set of *Li–ion* batteries relieves transformer overloads and defers distribution network upgrades to ensure summer–time demand peak loads are met

BUZEN SUBSTATION – *BUZEN, FUKUOKA* PREFECTURE (50 *MW* / 300 *MWh*)

Source: http://www.energystorageexchange.org/projects

The world's largest *BESS* in terms of energy storage capability; serves to provide demand – supply balance

SOUTH AUSTRALIA: *TESLA* BATTERY

***Source*: https://www.theguardian.com/australia-news/2017/dec/01/south-australia-turns-on-teslas-100mw-battery-history-in-the-making#img-1**

SOUTH AUSTRALIA'S *TESLA* BATTERY

- **Tesla's battery is connected to the Hornsdale wind farm, which is owned by the French company Neoen and has 99 turbines with a generation capacity of 315 *MW***
- **Elon Musk promised that Tesla would have the battery in place within 100 days and it did**

SOUTH AUSTRALIA'S *TESLA* BATTERY

- The battery was linked to the grid 63 days after the contract was awarded, in a deal between *Tesla*, *Neoen*, the French renewable energy company, and the *South Australian* government
- The estimated cost of the battery system was *US $* 38 *million* (*Australian $* 50 *million*)

SOUTH AUSTRALIA'S *TESLA* BATTERY

- ***South Australian*** **taxpayers will subsidize the battery's operation with up to** ***A $*** **50** ***million*** **over the next 10 years**
- **In return, the** ***South Australian*** **Government has the right to use the battery to prevent load–shedding blackouts and is able to use the battery to provide ancillary services to the grid – critically important to maintain grid integrity – and to lower the prices of such services**

SOUTH AUSTRALIA'S *TESLA* BATTERY EXPANSION

- **In March 23, 2020, *Neoen* increased the installed capacity of the *Hornsdale Power Reserve BESS* by 150 *MW***
- **On September 2, 2020, the *BESS* storage capability was expanded to 185 *MWh***
- **The expansion was completed by *Aurecon* and funded by the *Clean Energy Finance Corporation*, a "green bank" owned by the *Australian* government**

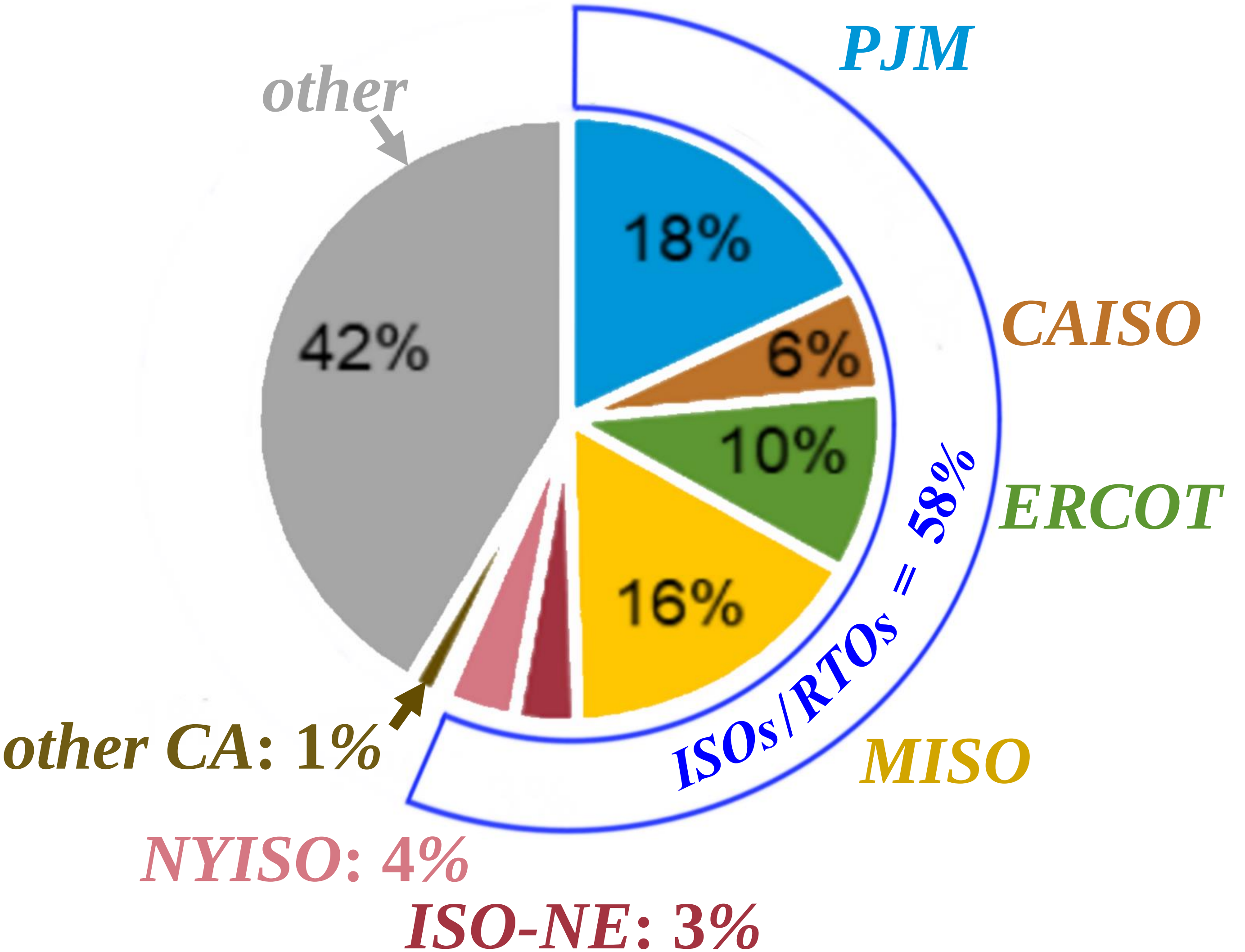
NEW PUSH IN *ESR* DEPLOYMENT

- **Advancements in storage technology, cost reduc–tions and regulatory initiatives have invigorated the interest in large–scale, grid–connected *ESR*s**
- **The deeper renewable resource penetrations lead to the wider deployment of storage – as both a *distributed* and a *grid* resource**
- **Given the strong push to retire fossil-fired supply resources on an accelerated basis, the electricity sector is implementing broader *ESR* deployment**

TOTAL *US* GRID INSTALLED SUPPLY RESOURCE CAPACITY BY REGION

Source: EIA, Battery Storage in the United States: An Update on Market Trends, Aug 2021; p. 6; available at https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage_2021.pdf

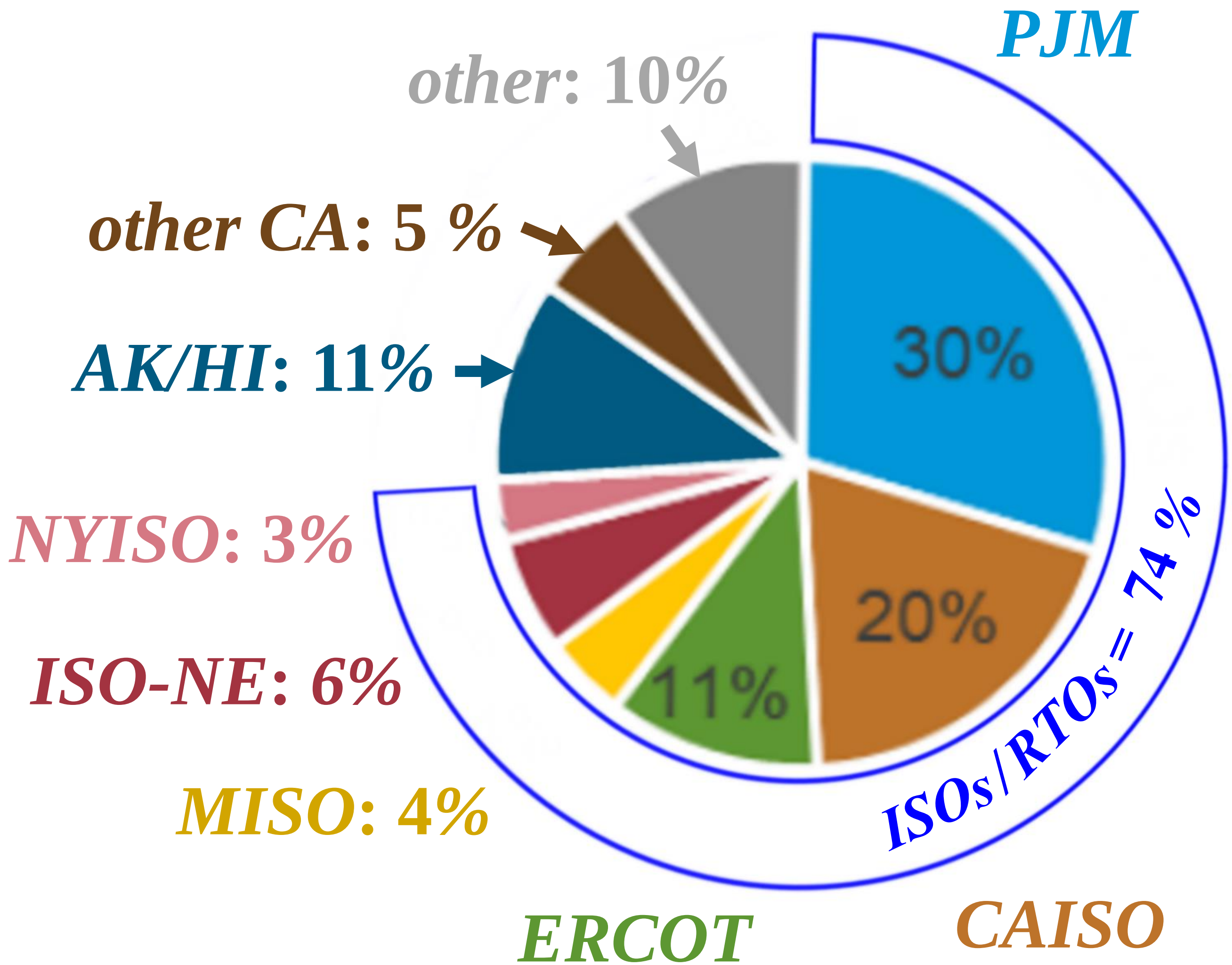
total US grid installed capacity = 1,205 GW



TOTAL *US* LARGE – SCALE *BESS CAPACITY* BY REGION

Source: EIA, Battery Storage in the United States: An Update on Market Trends, Aug 2021; p. 6; available at https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage_2021.pdf

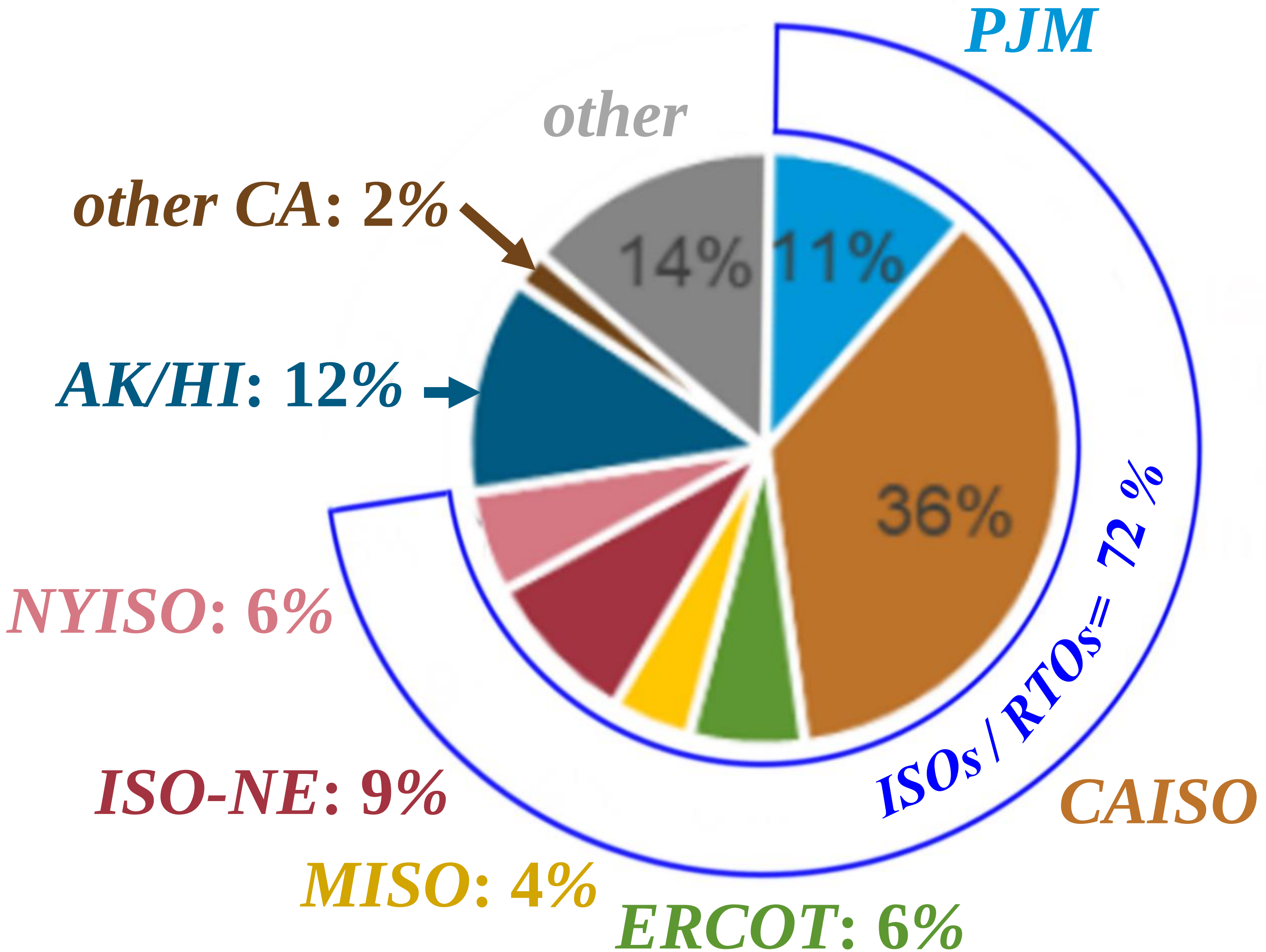
US large-scale BESS capacity = 1,022 MW



TOTAL *US* LARGE – SCALE *BESS CAPABILITY* BY REGION

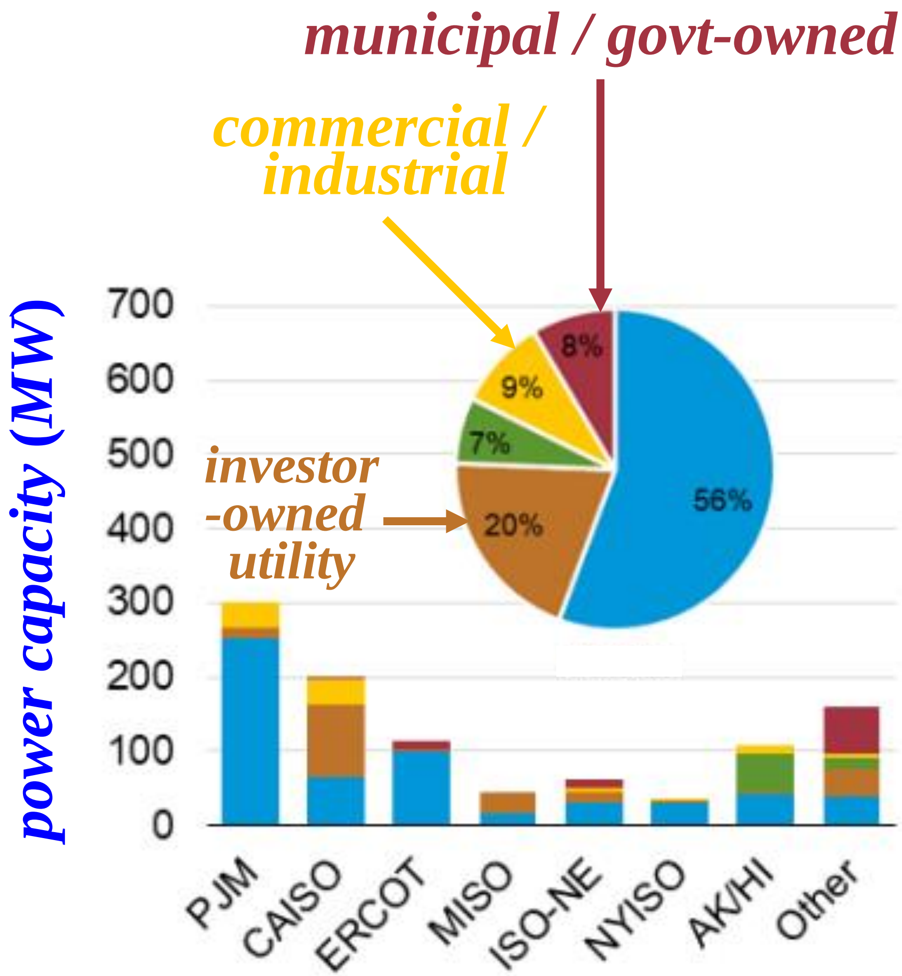
Source: EIA, Battery Storage in the United States: An Update on Market Trends, Aug 2021; p. 6; available at https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage_2021.pdf

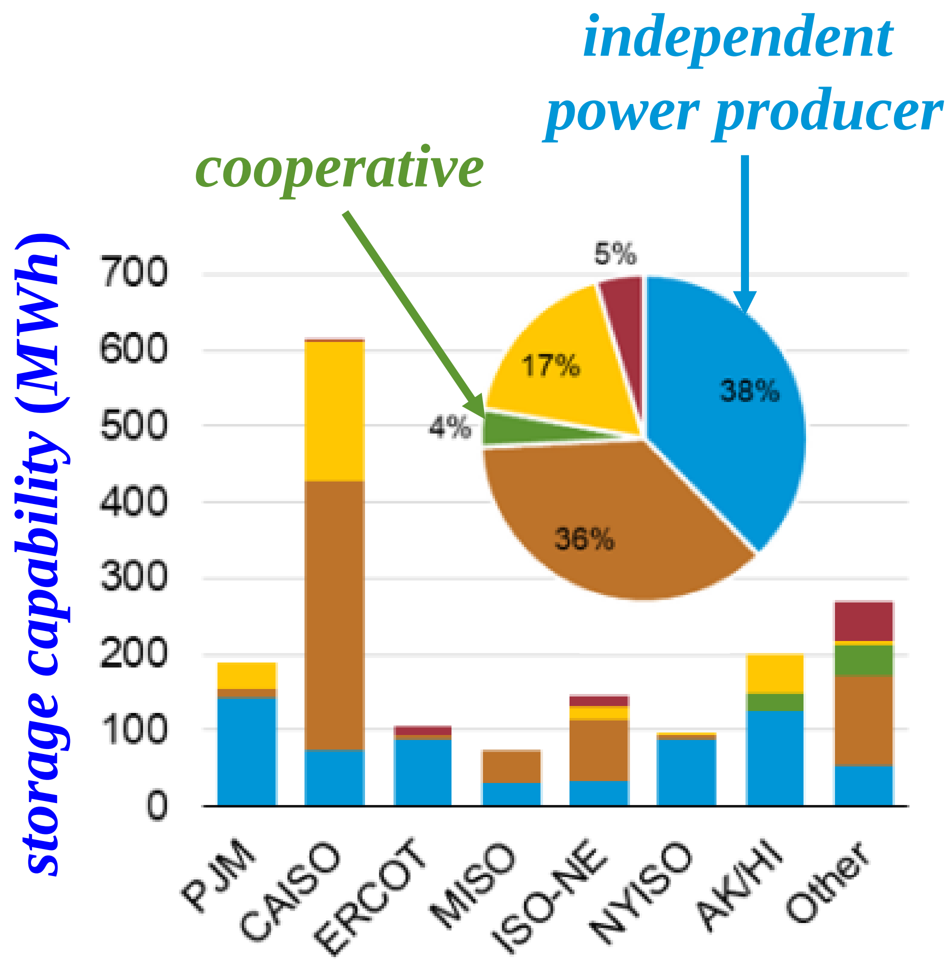
total BESS storage capability = 1,688 MWh



BESS CAPACITY / STORAGE CAPABILITY BY REGION AND OWNERSHIP: 2019

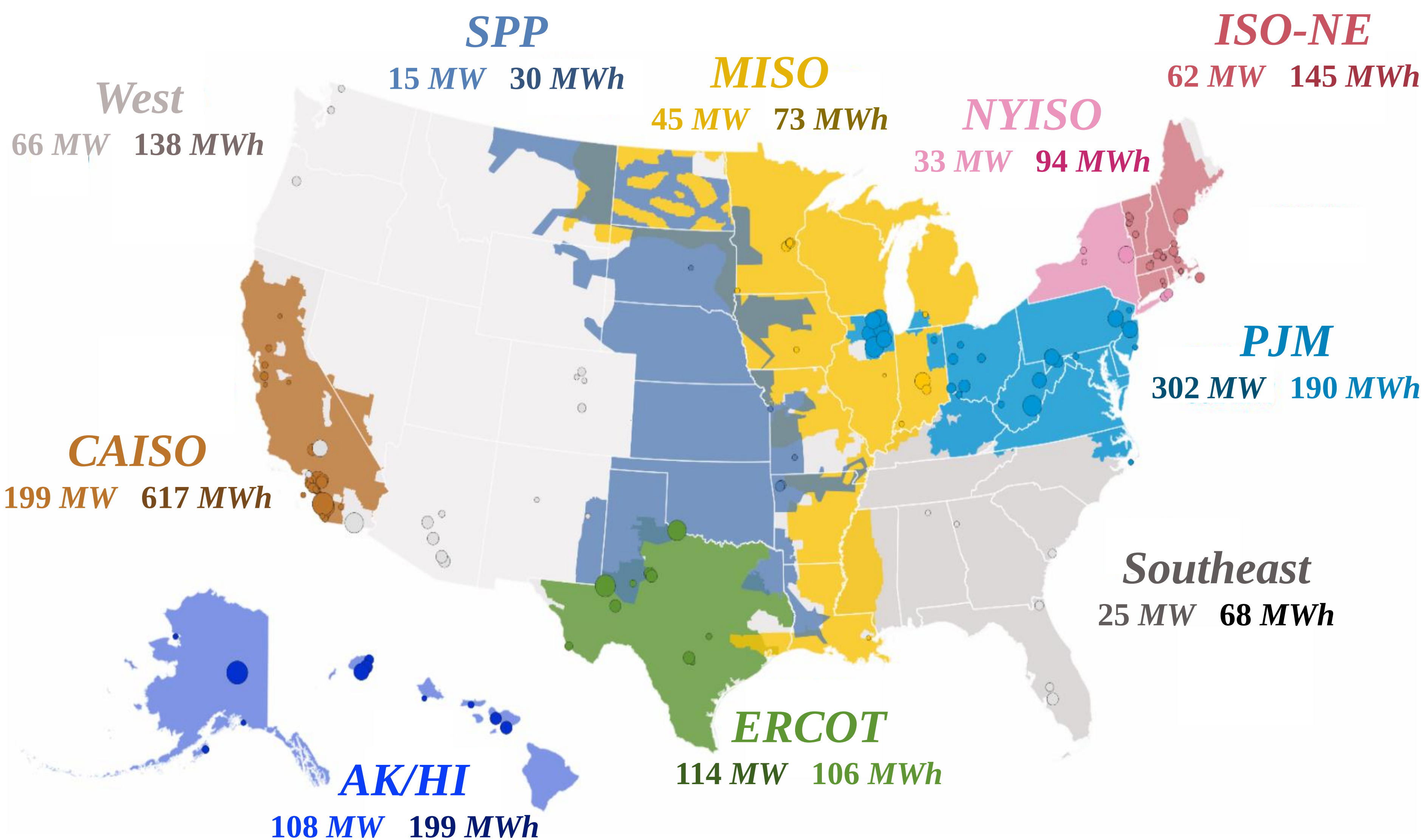
Source: EIA, Battery Storage in the United States: An Update on Market Trends, Aug 2021; p. 10





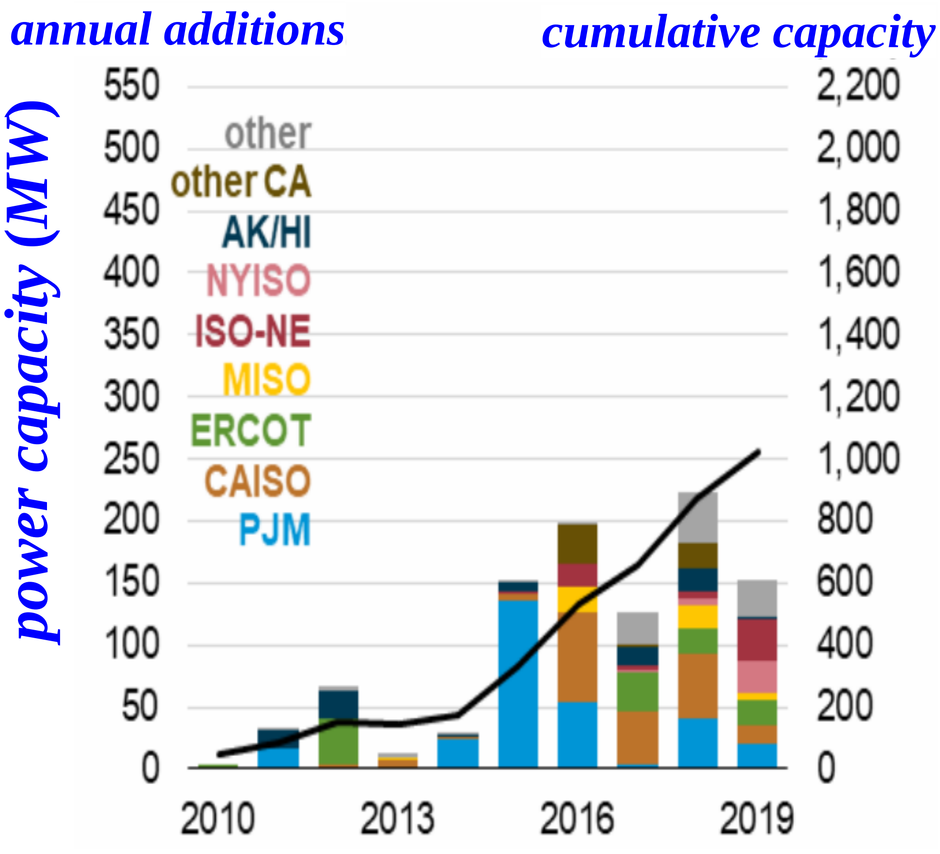
BESS CAPACITY / STORAGE CAPABILITY BY REGION: 2019

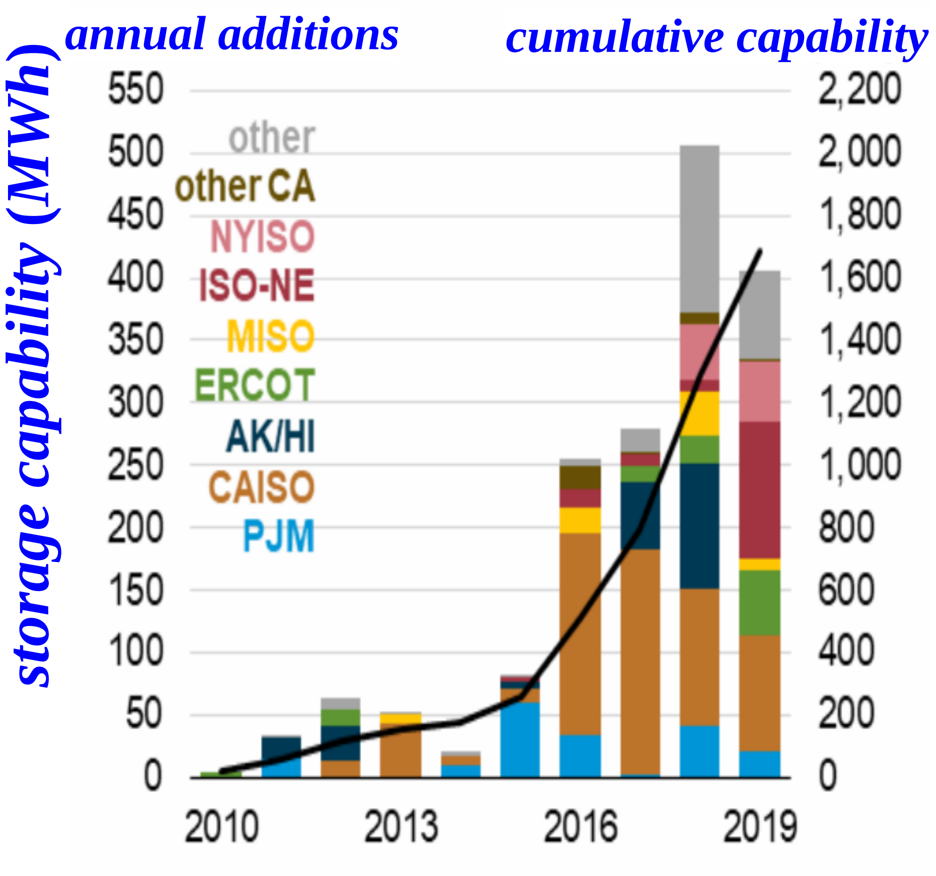
Source: EIA, Battery Storage in the United States: An Update on Market Trends, Aug 2021; p. 7



LARGE – SCALE *BESS CAPACITY / STORAGE CAPABILITY* BY REGION: 2010 – 2019

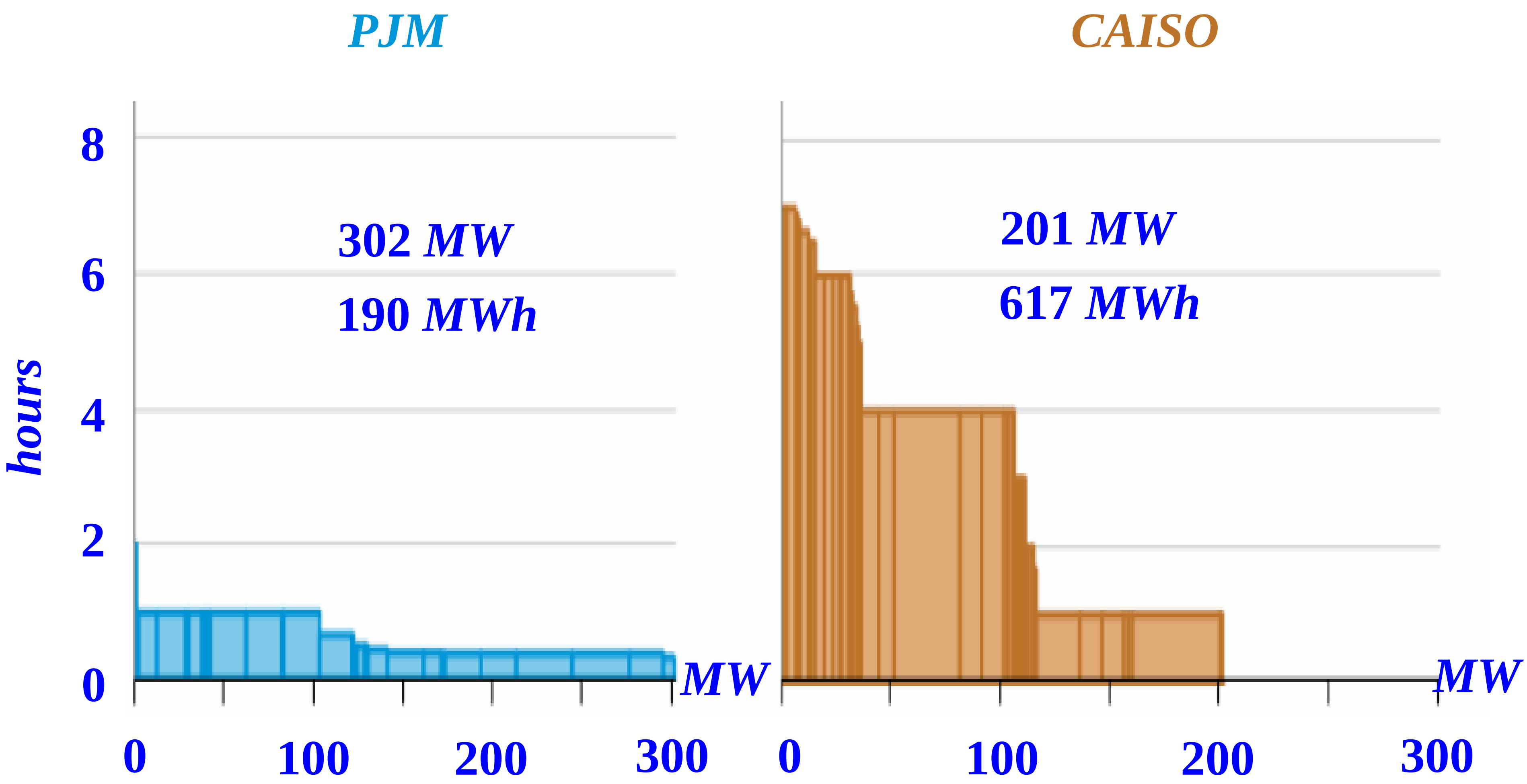
Source: EIA, Battery Storage in the United States: An Update on Market Trends, Aug 2021; p. 8





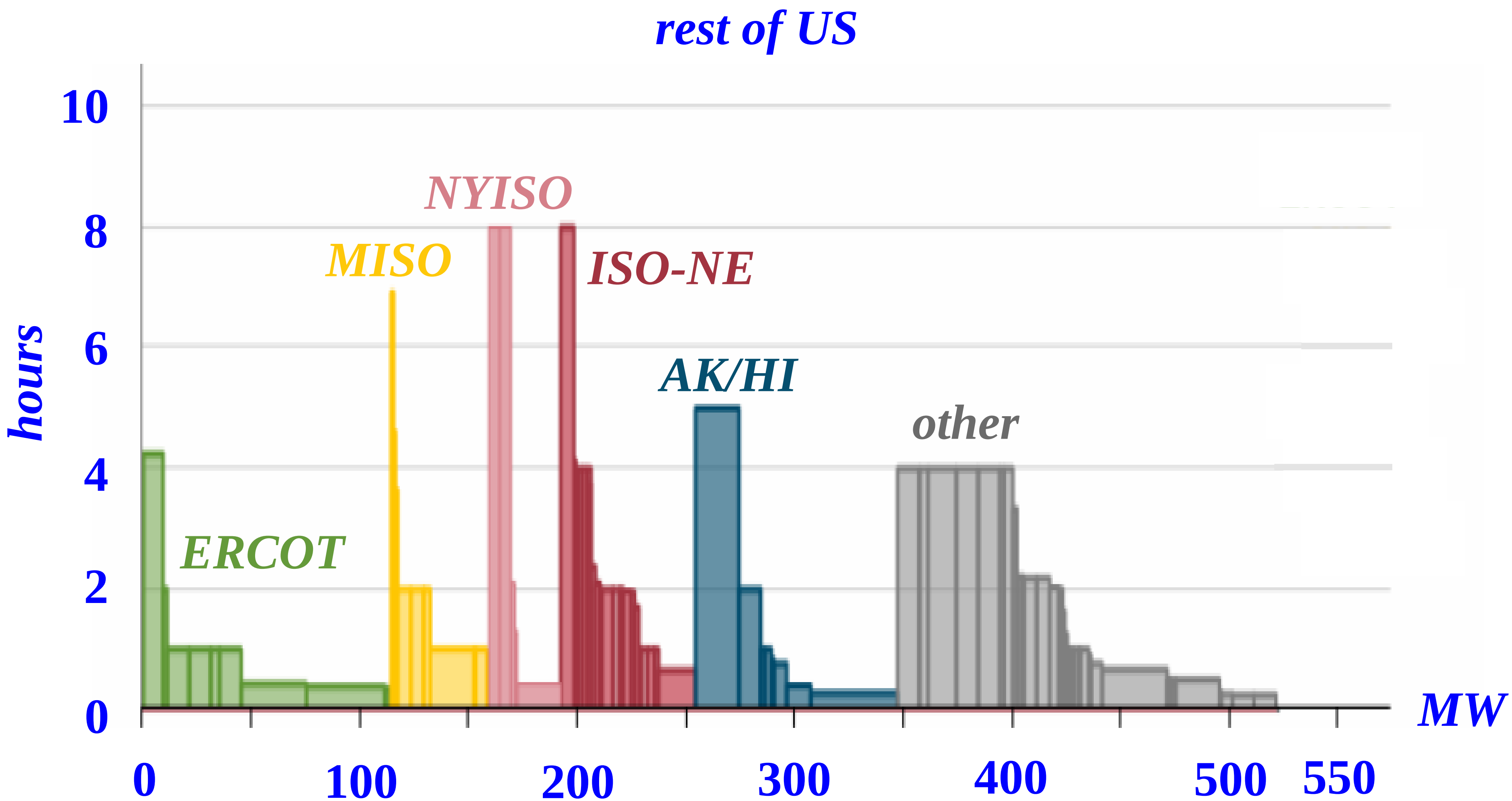
PJM & CAISO BESS CAPACITY / STORAGE CAPABILITY: 2019

Source: EIA, Battery Storage in the United States: An Update on Market Trends, Aug 2021; p. 9



REST OF *US BESS CAPACITY / STORAGE CAPABILITY*: 2019

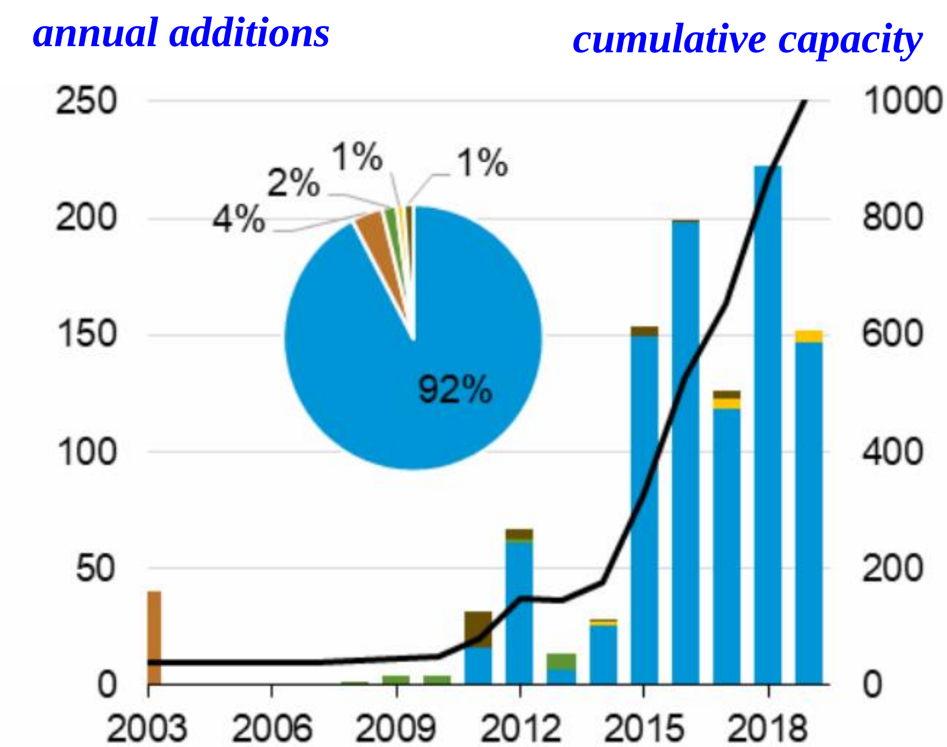
Source: EIA, Battery Storage in the United States: An Update on Market Trends, Aug 2021; p. 9



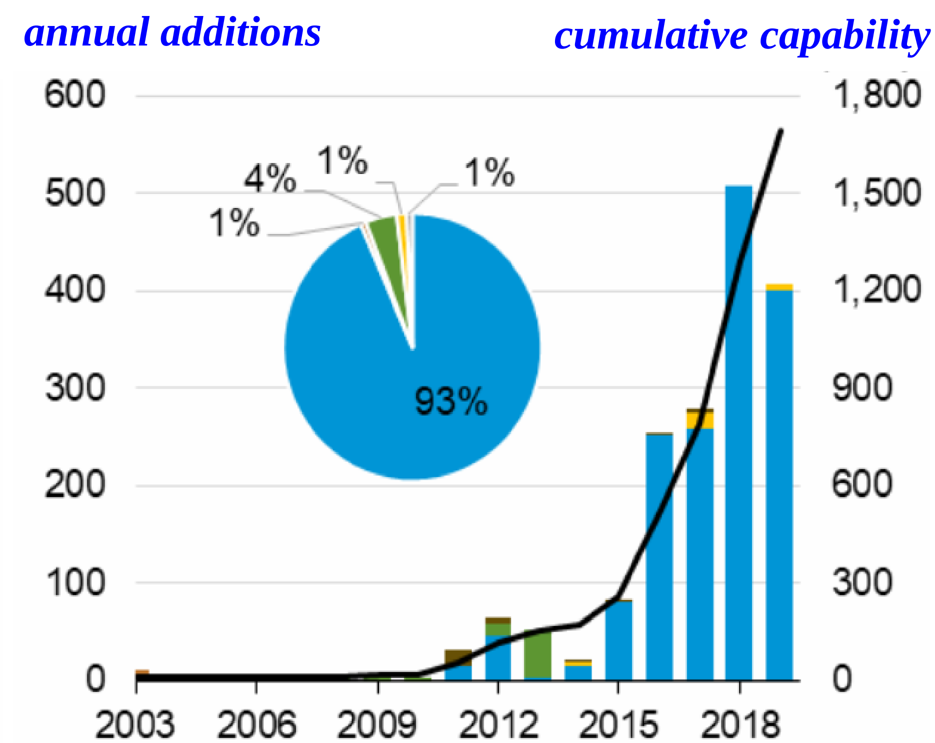
US BESS CAPACITY / STORAGE CAPABILITY ADDITIONS BY CHEMISTRY: 2003 – 2019

Source: EIA, Battery Storage in the United States: An Update on Market Trends, Aug 2021; p. 11

power capacity (MW)



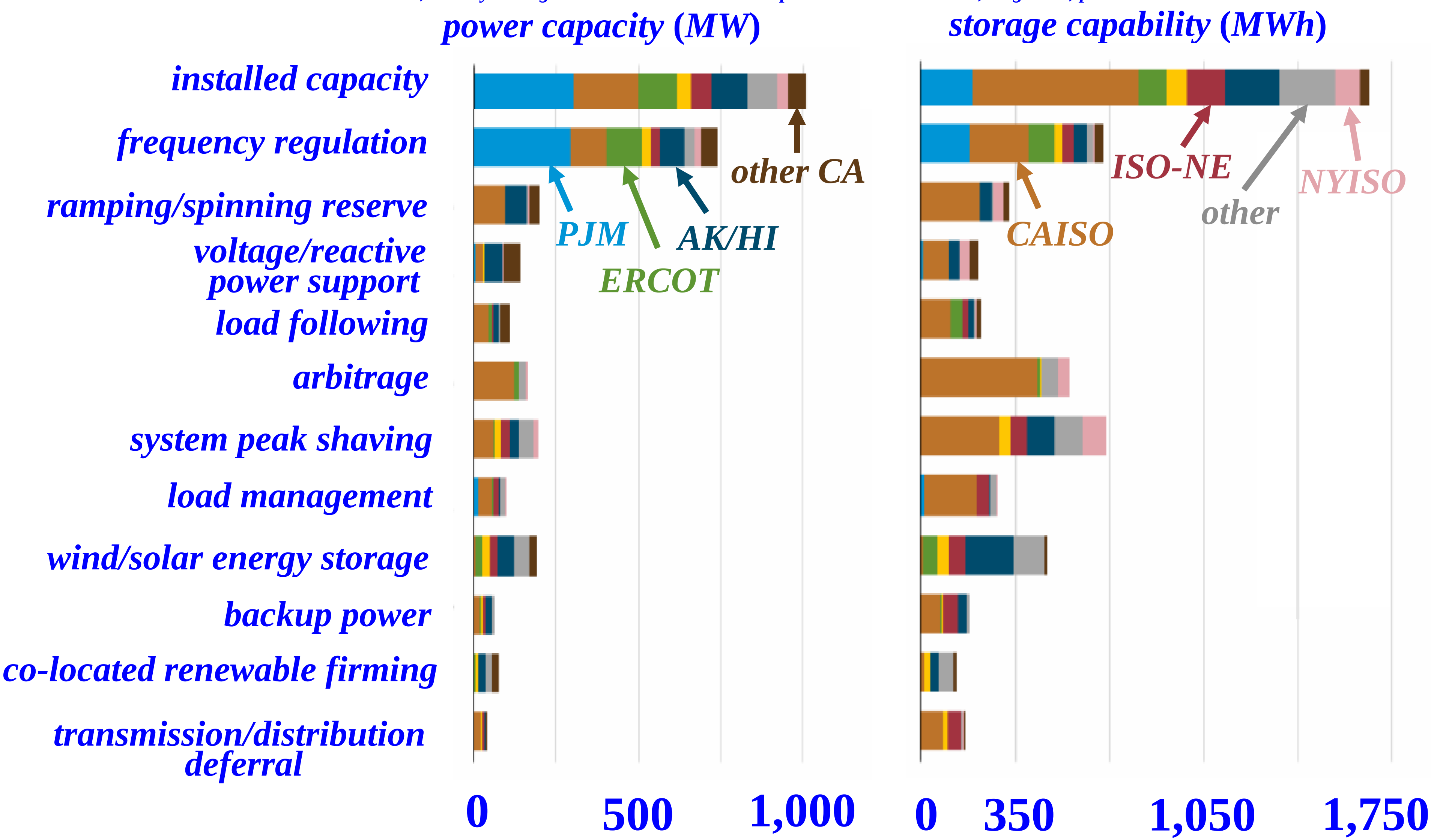
storage capability (MWh)



Li-ion *Ni-based* *Na-based* *flow* *other*

US BESS REGIONAL DEPLOYMENT BY CAPACITY / STORAGE CAPABILITY: 2019

Source: EIA, Battery Storage in the United States: An Update on Market Trends, Aug 2021; p. 14



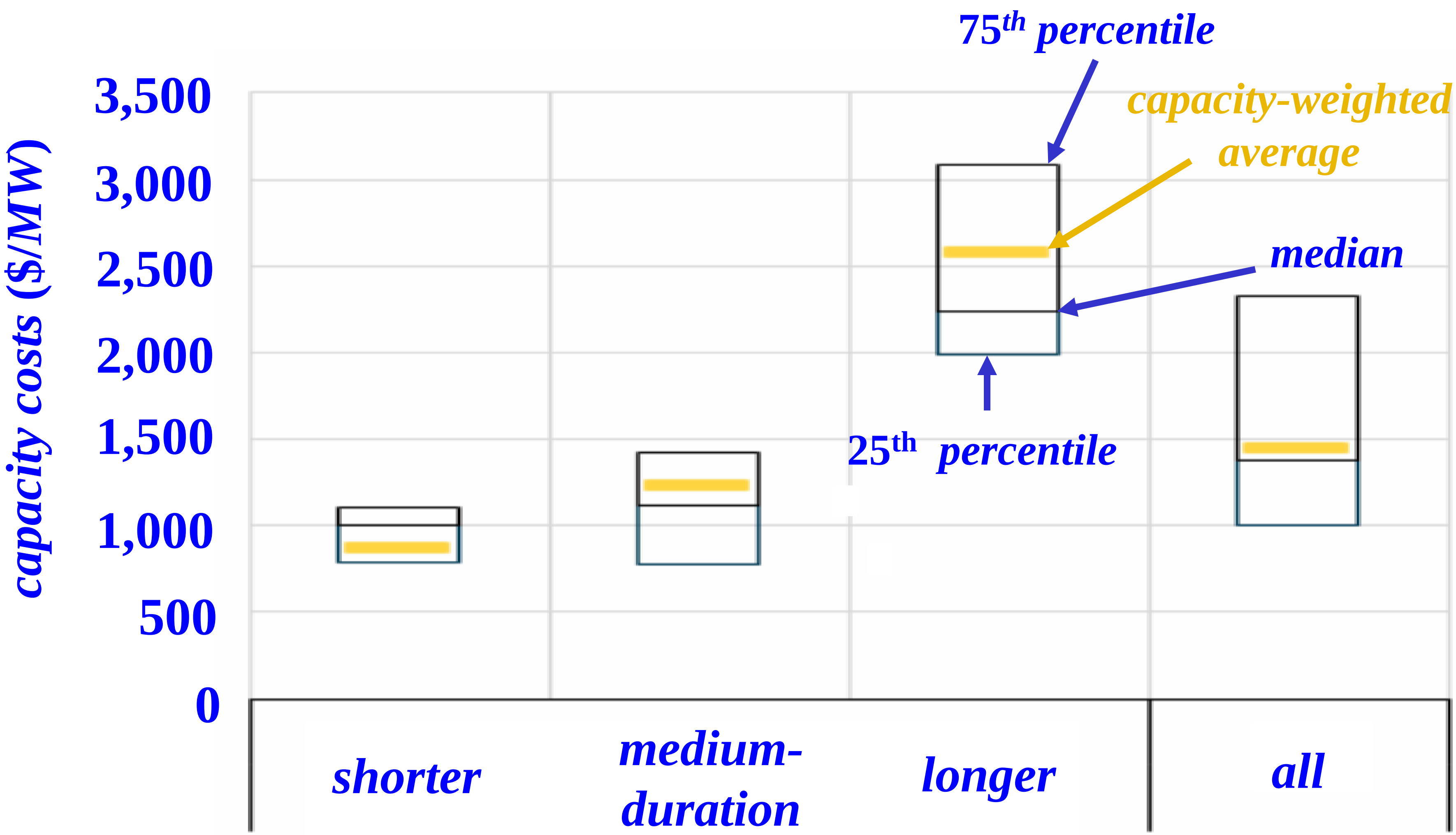
TYPICAL CAPITAL COSTS FOR *BESS* BY STORAGE DURATION: 2013 – 2019

Source: EIA, Battery Storage in the United States: An Update on Market Trends, Aug 2021; p. 16

sample characteristics	*duration in h*		
	short < 0.5	*medium* 0.5 – 2	*longer* > 2
number of BESS with reported costs	24	52	45
average nameplate power capacity (MW)	12.4	6.4	4.7
average nameplate storage capability (MWh)	4.7	6.6	21.2
average nameplate duration (h)	0.4	1.2	4.6
capacity-weighted $ per unit capacity ($/kW)	872	1,224	2,575
capacity-weighted $ per unit capability ($/kWh)	2,329	1,178	575

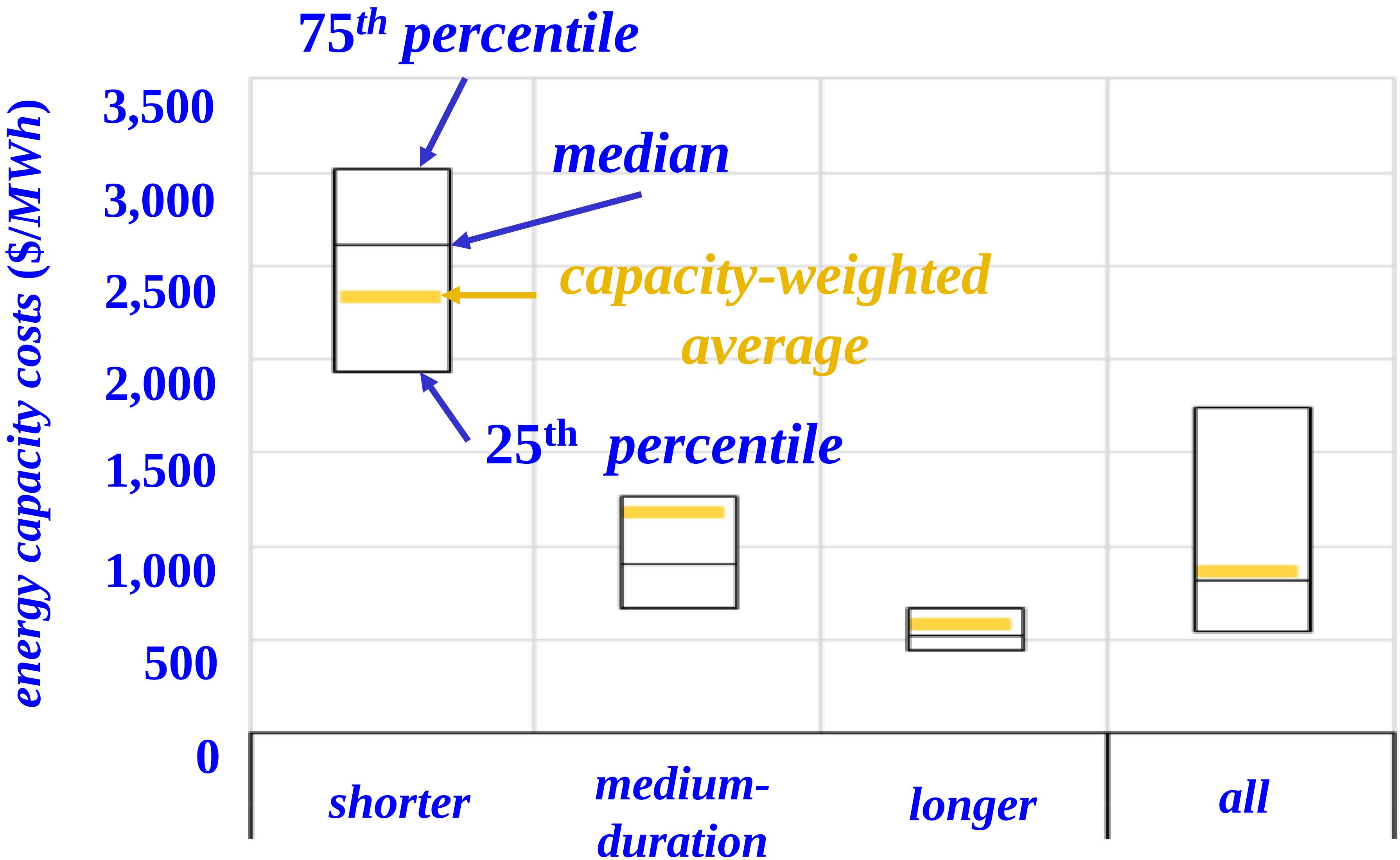
BESS CAPACITY INSTALLATION COSTS BY DURATION: 2013 – 2019

Source: EIA, Battery Storage in the United States: An Update on Market Trends, Aug 2021; p. 17



BESS STORAGE CAPABILITY COSTS BY DURATION FOR PROJECTS: 2013 – 2019

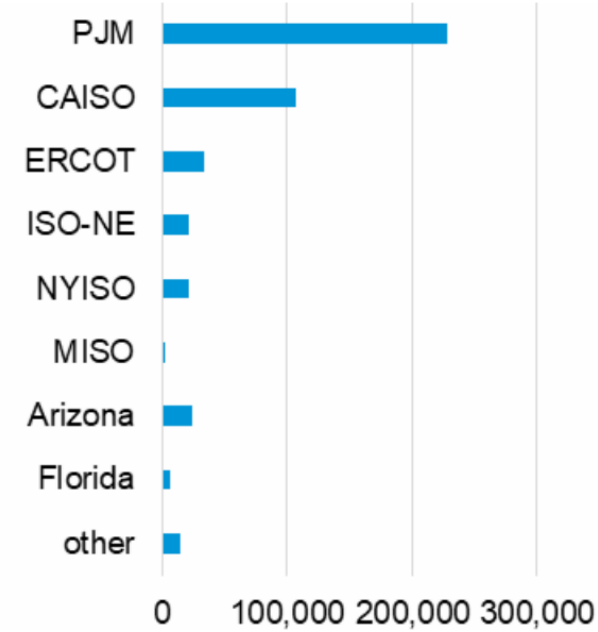
Source: EIA, Battery Storage in the United States: An Update on Market Trends, Aug 2021; p. 17



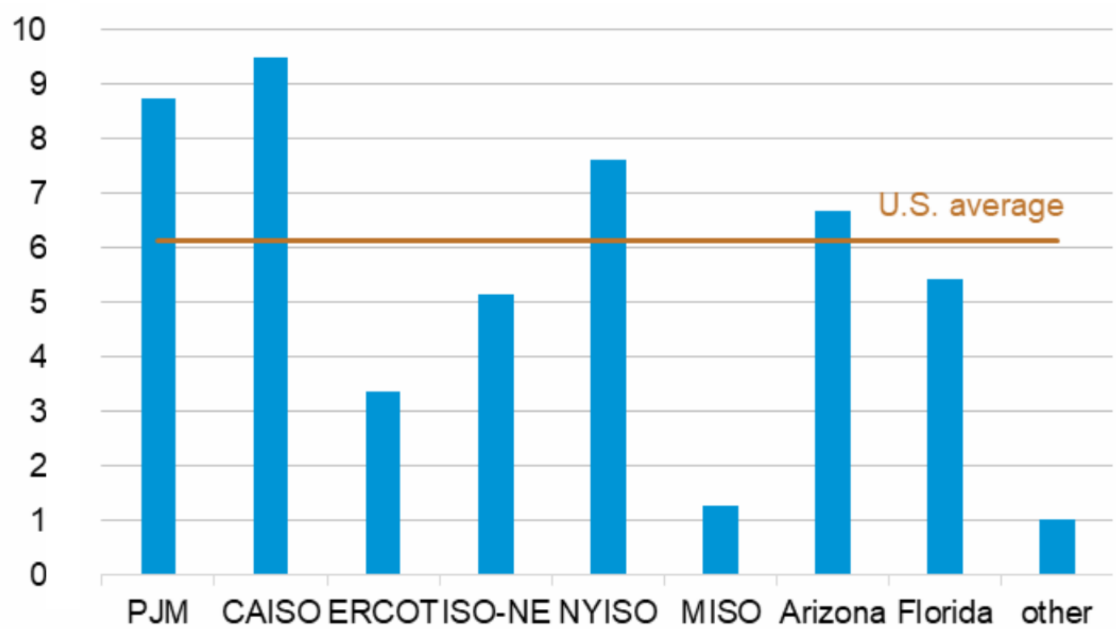
BESS GENERATION AND USAGE FACTOR BY REGION: 2019

Source: EIA, Battery Storage in the United States: An Update on Market Trends, Aug 2021; p. 20

gross generation (MWh)

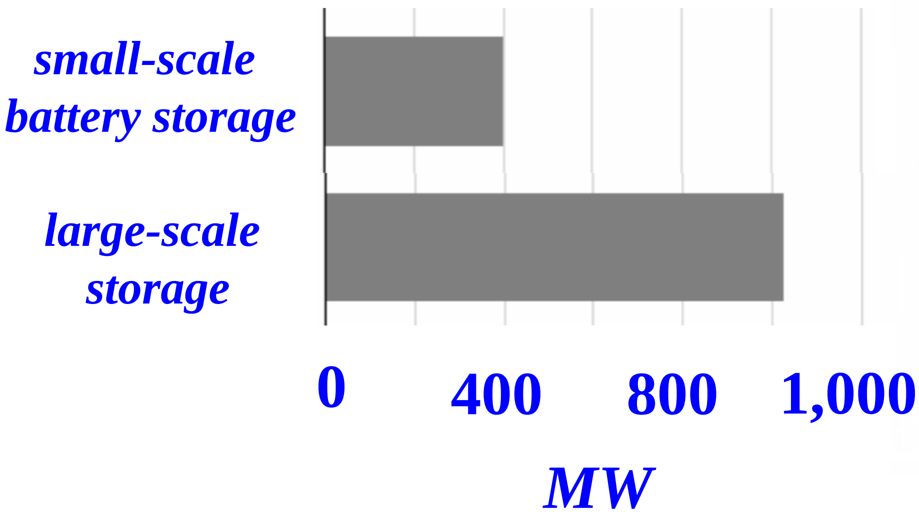


usage factor %

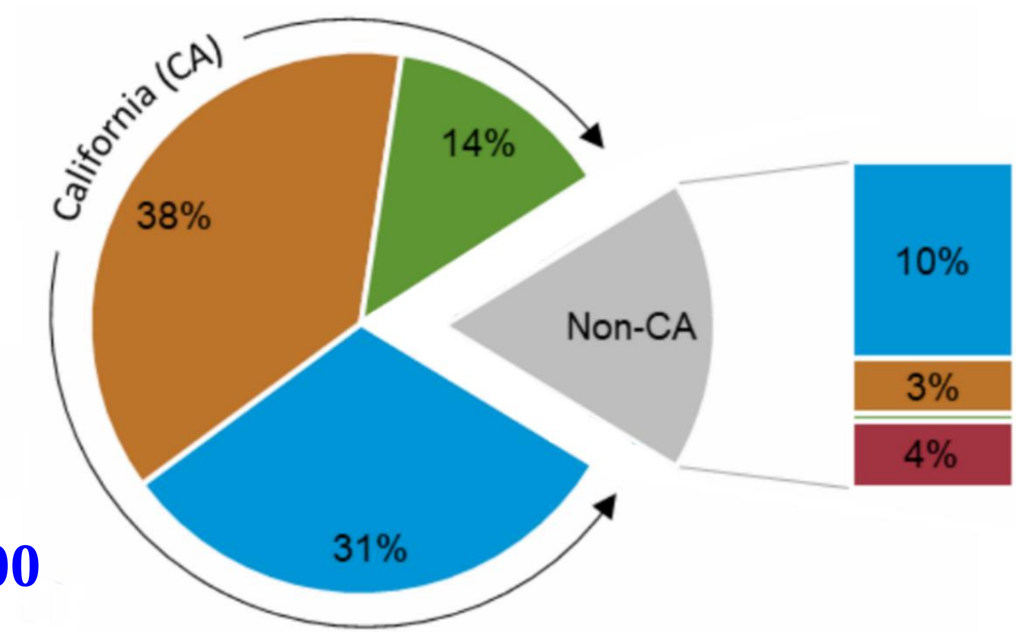


CALIFORNIA STORAGE STATUS: 2019

Source: EIA, Battery Storage in the United States: An Update on Market Trends, Aug 2021; p. 22



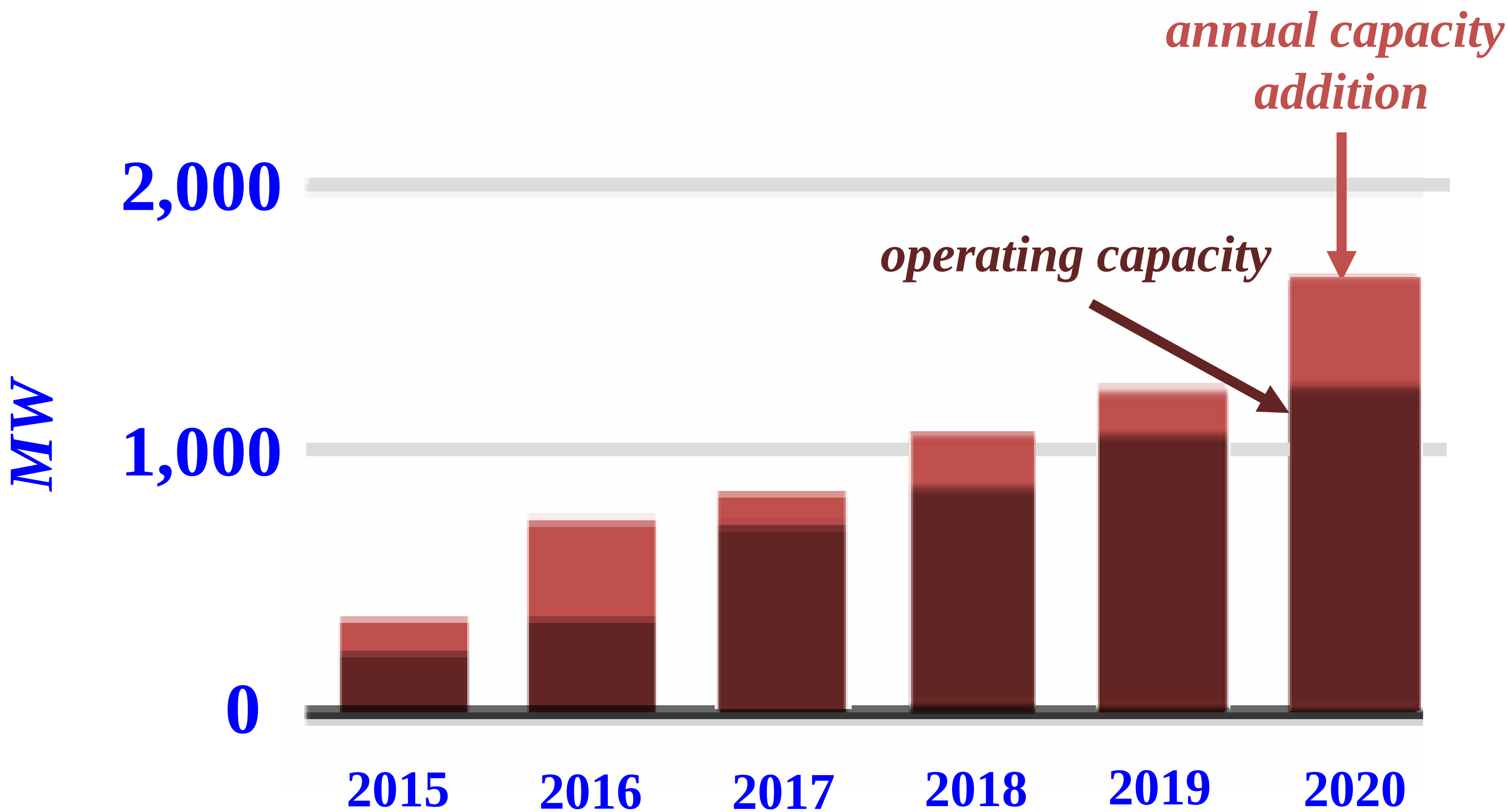
share of small-scale battery storage capacity



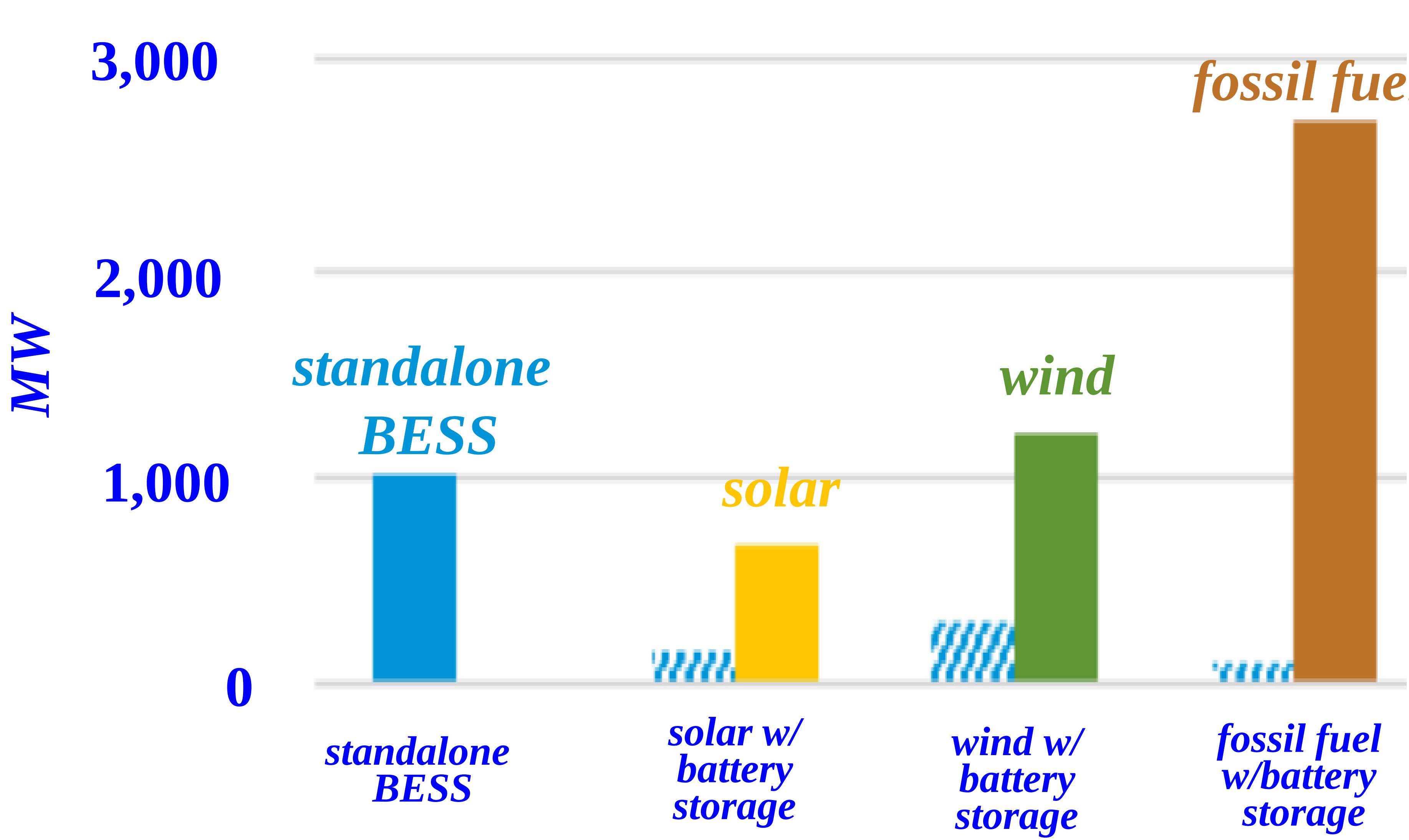
residential *commercial* *industrial* *grid-connected*

ANNUAL AND COMPREHENSIVE *BESS* CAPACITY: 2015 – 2020

Source: EIA, Battery Storage in the United States: An Update on Market Trends, Aug 2021; p. 28



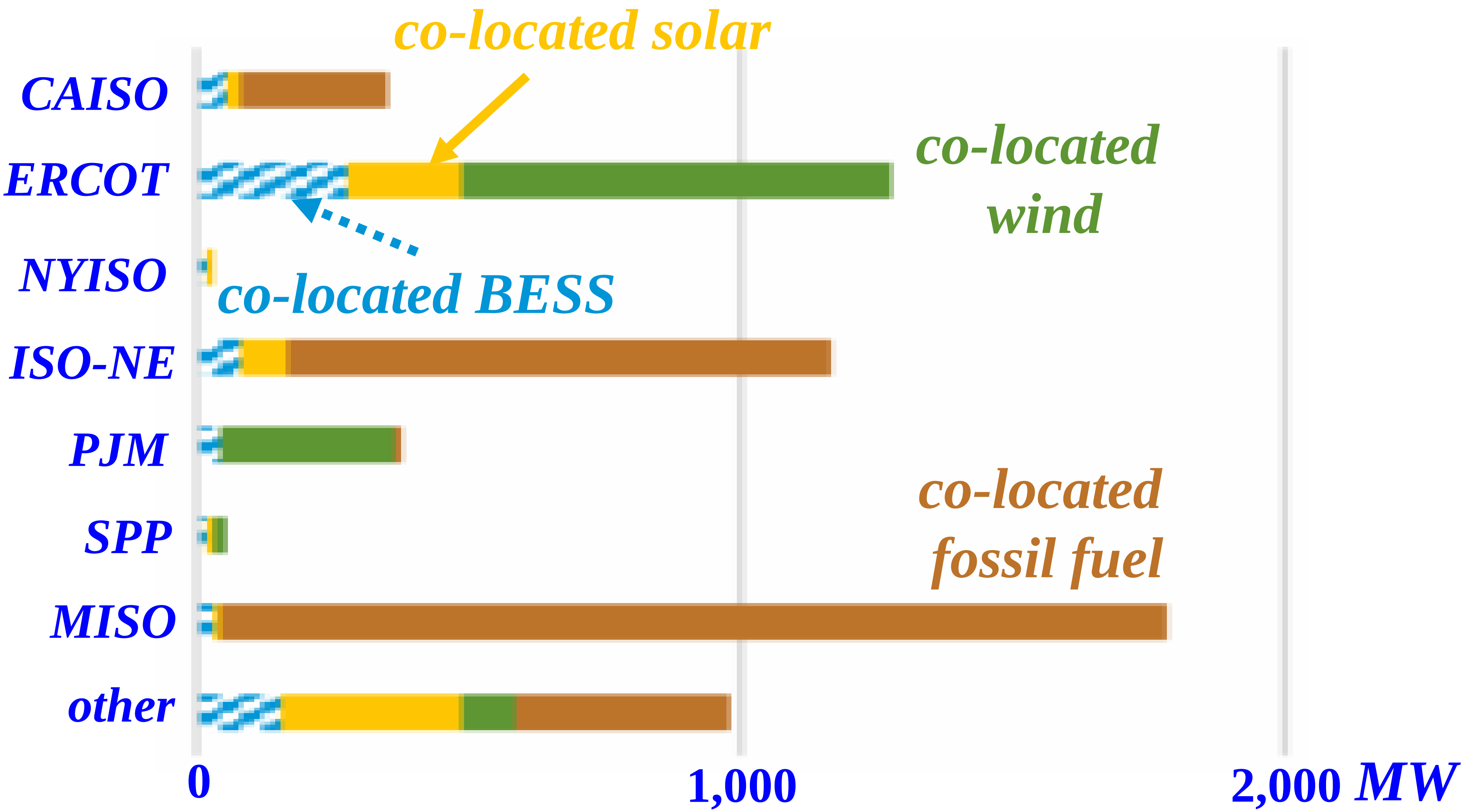
BESS & CO–LOCATED BESS CAPACITY ADDED BY REGION: 2003 - 2020



Source: EIA, Battery Storage in the United States: An Update on Market Trends, Aug 2021; p. 30

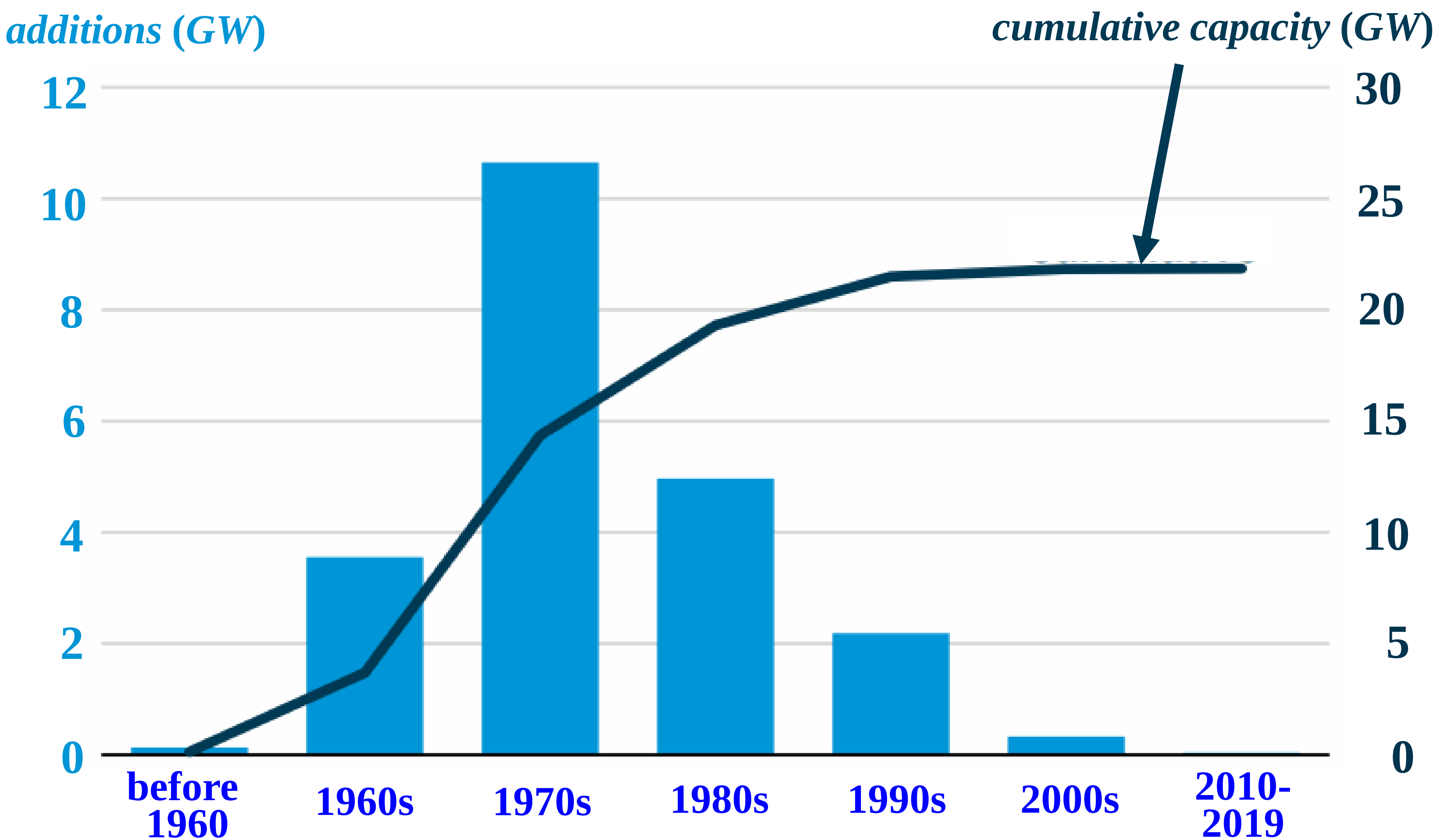
LARGE–SCALE *CO–LOCATED BESS* BY REGION: 2020

Source: EIA, Battery Storage in the United States: An Update on Market Trends, Aug 2021; p. 29, p. 31



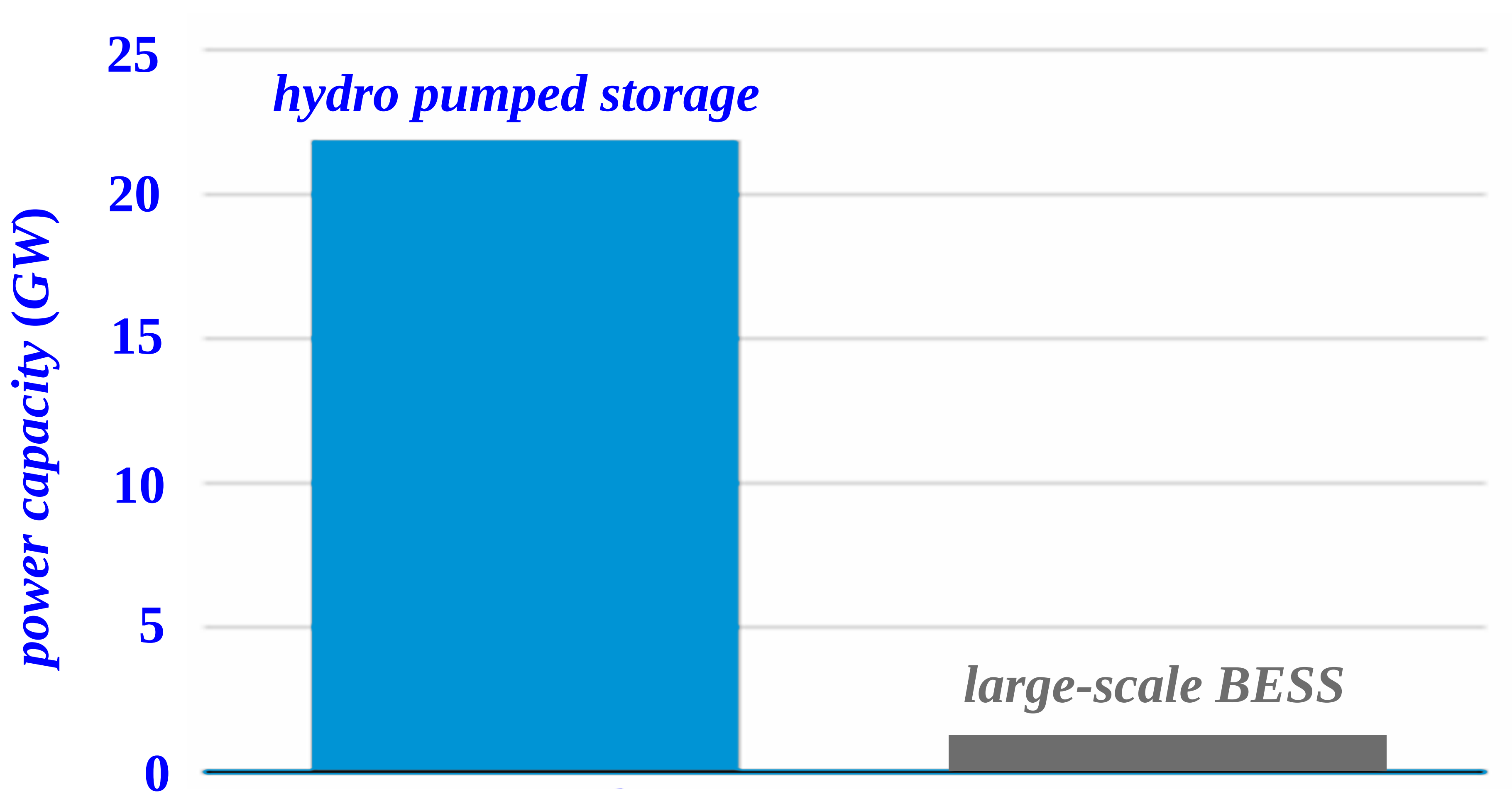
HYDRO PUMPED STORAGE ADDITIONS AND CUMULATIVE CAPACITY: 1960 – 2019

Source: EIA, Battery Storage in the United States: An Update on Market Trends, Aug 2021; p. 35

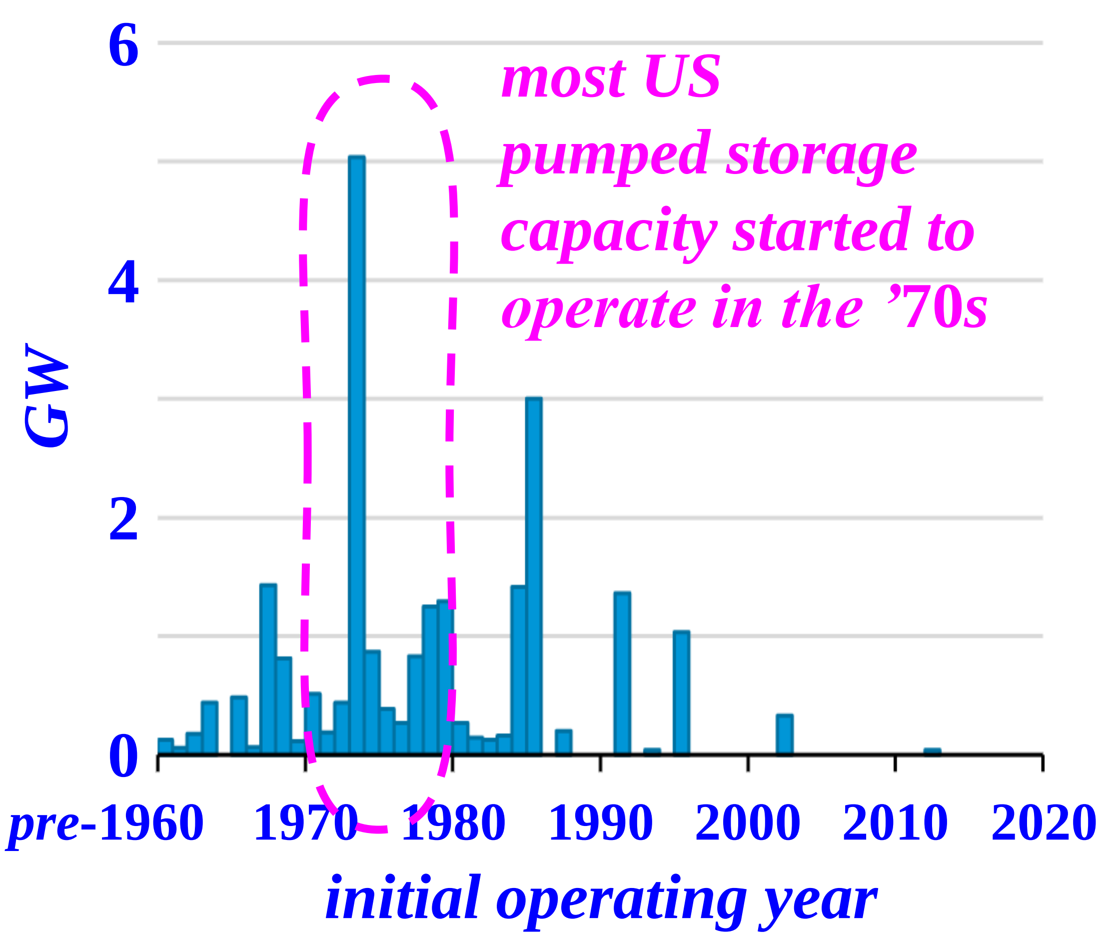


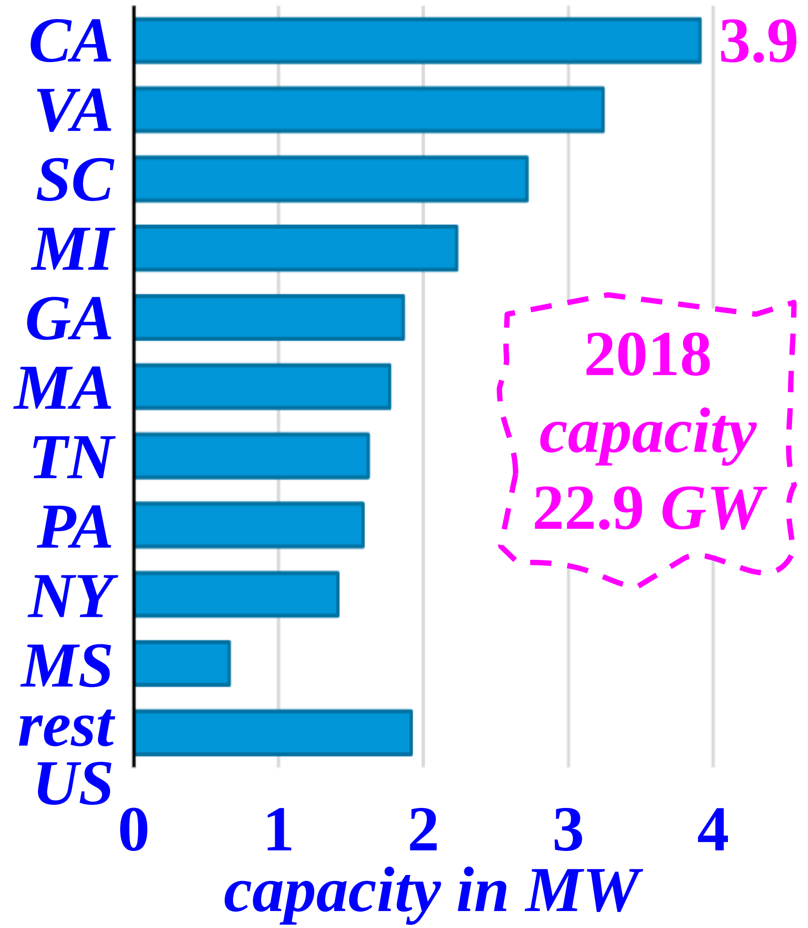
INSTALLED HYDRO PUMPED STORAGE AND *BESS* CAPACITY 2019

Source: EIA, Battery Storage in the United States: An Update on Market Trends, Aug 2021; p. 29, p. 35



US OPERATIONAL PUMPED STORAGE CAPACITY





Source: *EIA October 31, 2019; available at https://www.eia.gov/todayinenergy/detail.php?id=41833*

BARRIERS TO LARGE–SCALE STORAGE DEPLOYMENT

- **The pace of energy storage deployment has been very slow in the past, mainly due to the extremely high costs of storage**
- **The reductions in storage costs over the past decade have remained inadequate to stimulate the large–scale deployment of *ESR*s**
- **The high costs of storage present a *chicken and egg* problem: costs remain high due to low demand and the high costs impede any growth in demand**

CALIFORNIA

163,696 square miles; 3rd largest *US* state by area; 4 % of the size of Europe

38 million people

electricity consumption is about 8 % of *US* total

Source: http://www.usamaps2015.xyz/california-map/

CALIFORNIA PUSH FOR STORAGE DEPLOYMENT

- The *CA* government has recognized the significant role of storage in the grid and the need for a bold move on storage to *drastically reduce the price* of storage through a sharp increase in demand

- The *CPUC* mandate to deploy 1,325 *MW* of cost–effective energy storage by 2020 in California constitutes a *big push* for the global storage sector

CALIFORNIA PUSH FOR STORAGE DEPLOYMENT

- The *CPUC* energy storage requirements arise from the 2010 *Assembly Bill* 2514 (*AB* 2514)
- *AB* 2514 requires the *CPUC* to "open a proceeding to determine appropriate targets, if any, for each load–serving entity to procure viable and cost–effective energy storage systems and, by October 1, 2013, to adopt an energy storage system pro–curement target, if determined to be appropriate, to be achieved by each load–serving entity by December 31, 2015, and a second target to be achieved by December 31, 2020"

GUIDING PRINCIPLES

"1. The optimization of the grid, including peak reduction, contribution to reliability needs, or deferment of transmission and distribution upgrade investments;

2. The integration of renewable energy; and

3. The reduction of greenhouse gas emissions to 80 percent below 1990 levels by 2050, per California's goals"

THE *CPUC* STORAGE REQUIREMENTS

- In Decision 13-10-040, *CPUC* has mandated a target by 2020 of 1,325 *MW* of energy storage to be installed by the three major jurisdictional investor owned utilities (*IOU*s) by 2024
- The *CPUC Decision* provided the framework with whose specifications the procurement and deployment of storage projects must comply

THE *CPUC* STORAGE PROCUREMENT FRAMEWORK SPECIFICATIONS

- Storage capacity targets for each of the 3 major *California IOU*s
- Procurement schedule for the authorized storage projects
- Storage capacity targets for each of the specified grid interconnection point given below:
  - transmission
  - distribution
  - customer side of the meter

THE *CPUC* STORAGE PROCUREMENT FRAMEWORK SPECIFICATIONS

- **Allowed deviations to meet the *CPUC* targets by:**
  - **shifting targets among grid interconnection points**
  - **ownership of storage resources by *IOU*s, customers and third parties**
  - **deferral of *IOU* targets in the *CPUC*–specified schedule**

CPUC DECISION RAMIFICATIONS

- **The *CPUC Decision* is a harbinger of regulatory initiatives in the large–scale grid–connected storage domain that signals the realization by the government of the significant role storage plays to further the smart grid implementation**
- **The *CPUC pumped–hydro–capacity constraint* became a key driver to spur *BESS* advances and reduce the drought–ridden *CA* reliance on hydro**

OPPORTUNITIES FOR LARGE–SCALE *ESR*s

- **The *CPUC Decision* has paved the way for new opportunities in the storage sector**
- **The need for storage to meet the *CPUC* mandate created a strong push in the storage market and considerably weakened the reluctance to invest in the storage sector**
- **A key example is the new *TESLA Gigafactory*, the large–scale *NV* plant in to manufacture storage batteries for commercial and residential uses**

CONCLUDING REMARKS

- In the development of sustainable paths to meet future energy needs, renewable resources must play a key role and storage is, by far, the most promising option to enable such paths
- The *CA* mandate provided the *appropriate stimulus to jump start grid–connected storage* deployment and to further reduce storage prices
- There remain daunting challenges at many levels – from science to engineering to policy – to effectively implement *ESR* deployment in the grid

CONCLUDING REMARKS

- We need to **systematically address** the major challenges in storage technology improvement, modeling and tool development, regulatory, environmental and policy formulation arenas – to name just a few – in order to realize the goal of large–scale deployment of storage in future grids