LARGE – SCALE ELECTRIC ENERGY STORAGE INTEGRATION IN GRIDS WITH INTEGRATED RENEWABLE ENERGY RESOURCES

presentation by

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for the *PSERC Webinar*

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OUTLINE OF THE PRESENTATION

- The critical importance of energy storage
- Overview of *ESR* technologies
- *ESR* roles and applications to power systems
- The current status of storage
- The California push for storage deployment
- The opportunities and the challenges ahead

*ESR*s IN THE NEWS

Some energy storage already cost competitive, new valuation study shows

Utility Dive (November 24, 2015)

The Energy Storage Market Is About To Boom

Forbes (September 9, 2015)

Batteries start to compete for power grid

Financial Times (November 17, 2015)

Storage in 2016: Utility-scale, long-duration markets take the lead

Behind-the-meter storage grew by a factor of 16 this year, but bigger batteries will be the focus come 2016

Utility Dive (December 22, 2015)

Energy storage could save UK electricity system £2.4bn by 2030

Business Green (March 2, 2016)

Energy Storage Industry Gaining Momentum

New York Times (October 25, 2015)

Batteries and Renewable Energy Set to Grow Together

New York Times (April 20, 2015)

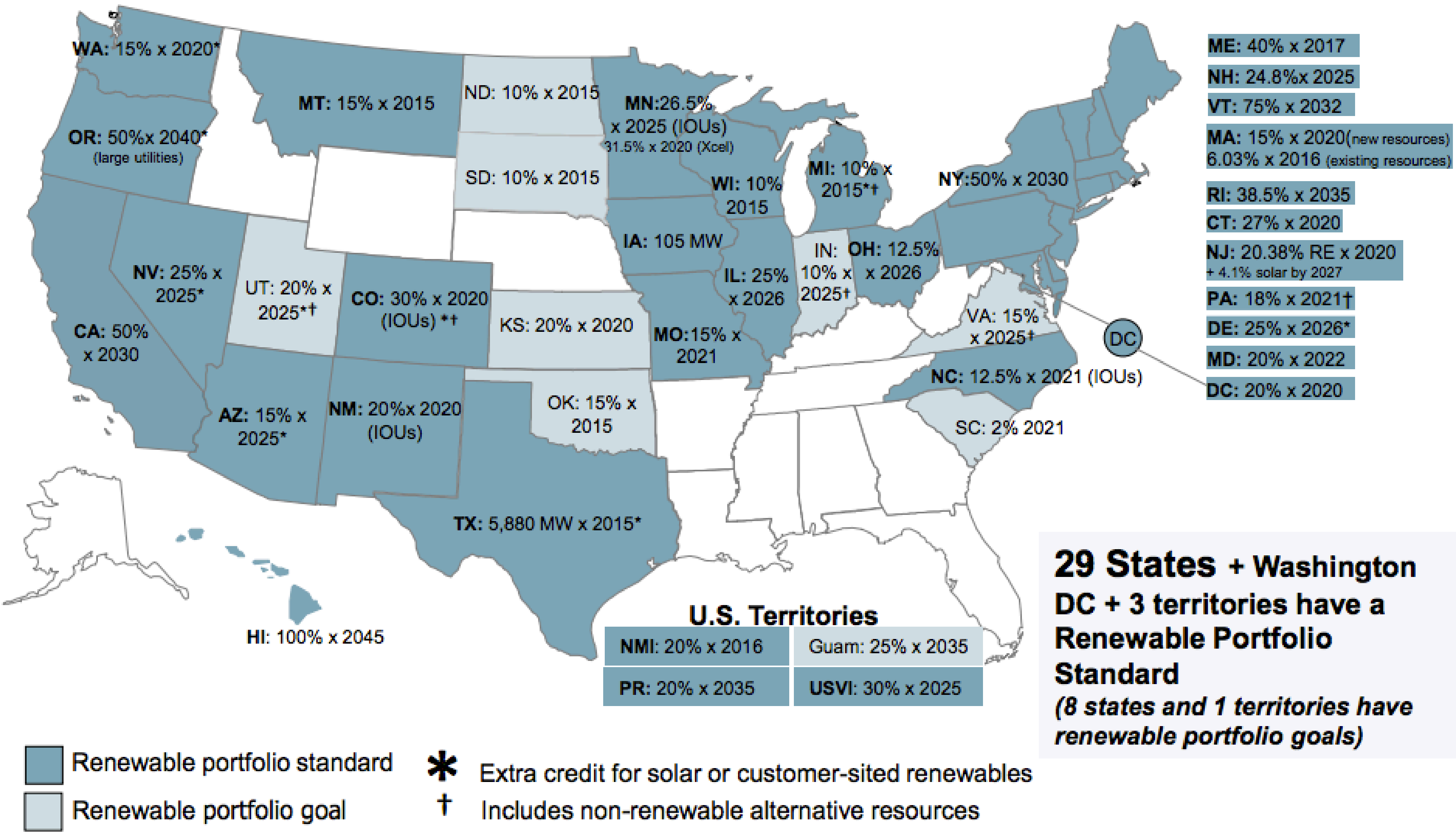
THE *DIRE NEED* FOR STORAGE

- 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* for every time scale
- Storage provides added flexibility to maintain demand–supply balance *around the clock*

CHANGING REALITY IN POWER SYSTEMS

- Mitigation of *climate change impacts* and *sustainability* are key drivers of the growing deployment of renewable resources to reduce CO_2 emissions
- In various jurisdictions, legislative/regulatory initiatives stipulate specific targets with the dates by which they must be met to result in a cleaner environment

RENEWABLE PORTFOLIO STANDARDS (RPS)

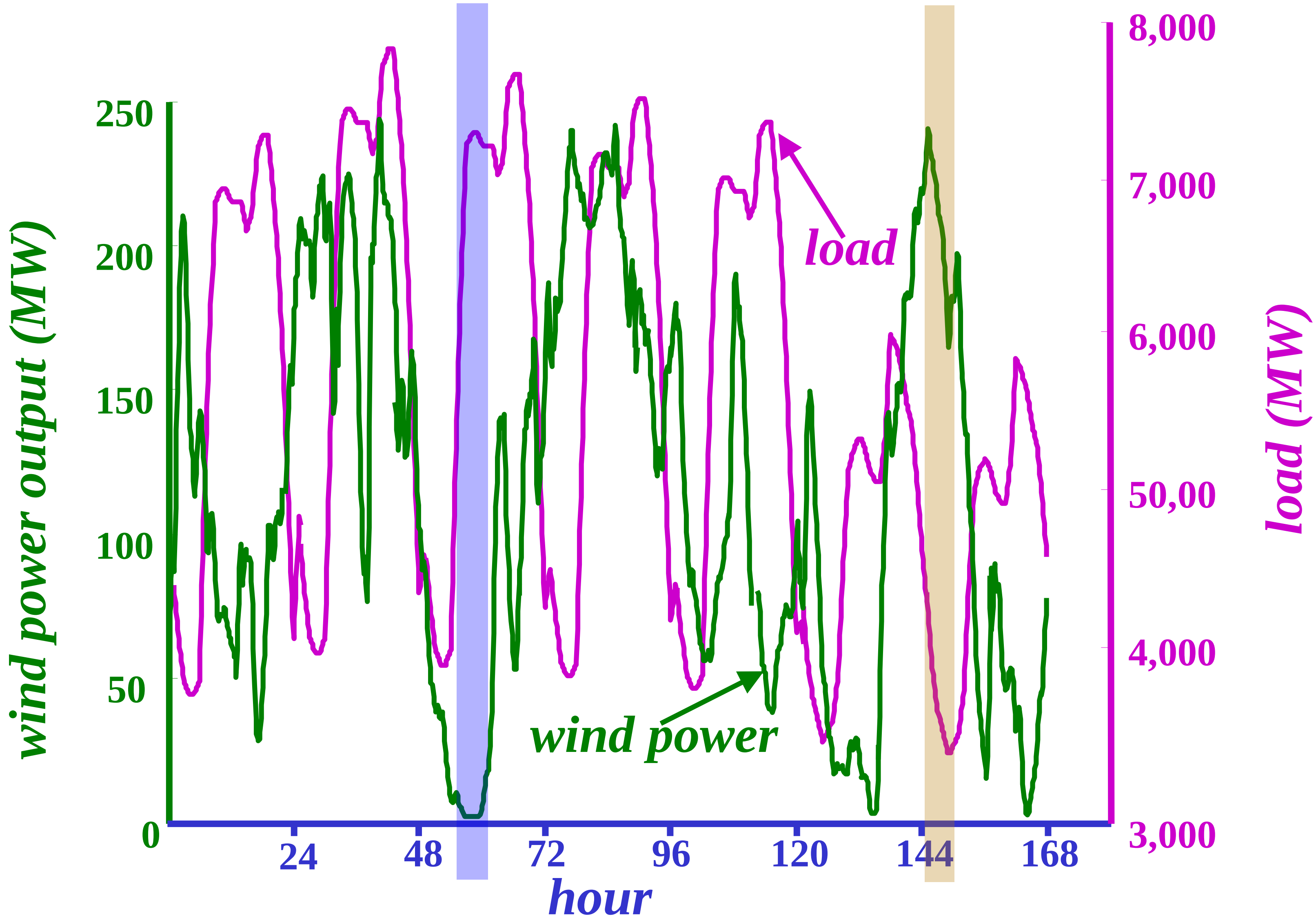


29 States + Washington DC + 3 territories have a Renewable Portfolio Standard

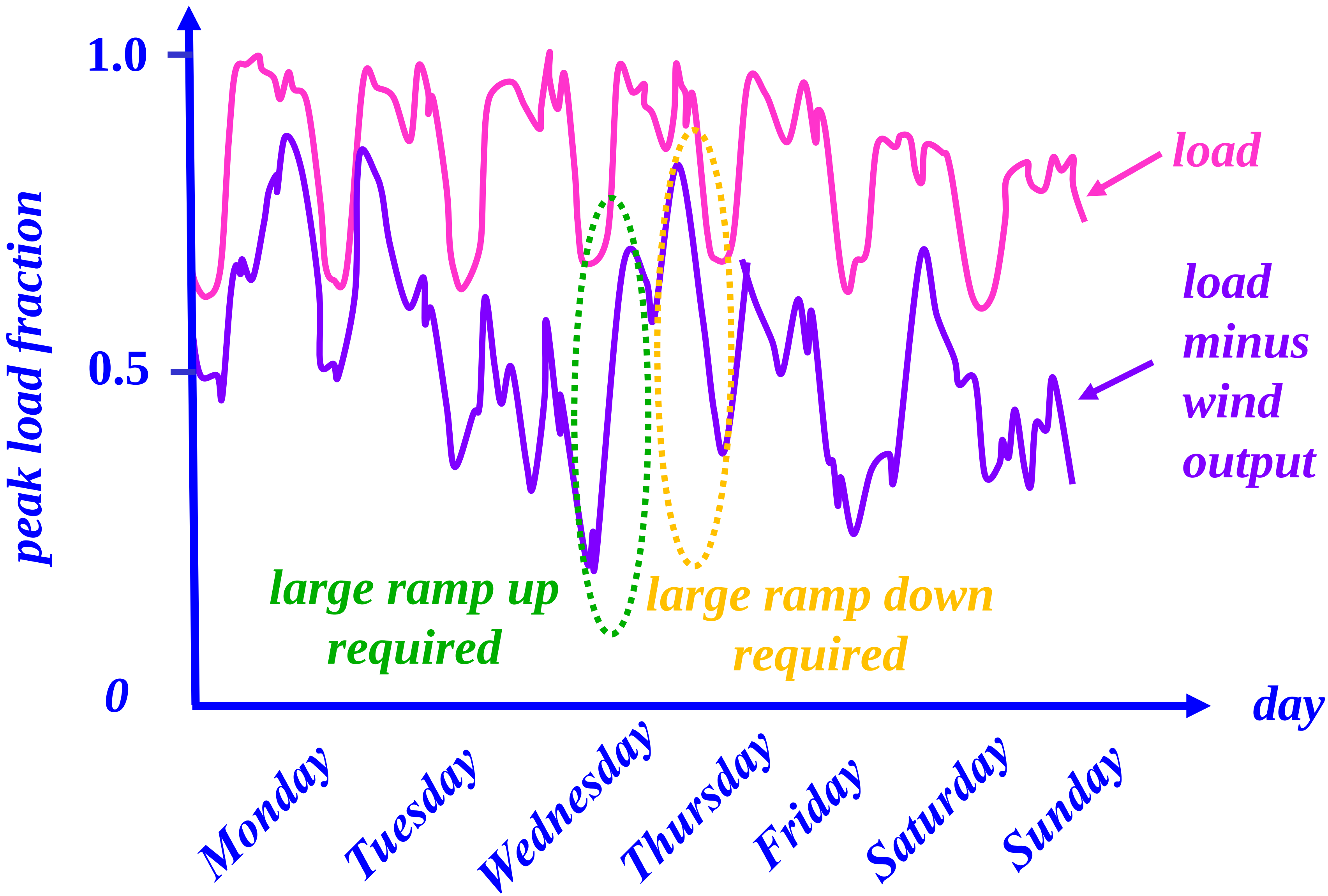
(8 states and 1 territories have renewable portfolio goals)

Source: http://www.dsireusa.org/resources/detailed-summary-maps/; February 2017

MISALIGNMENT OF WIND POWER OUTPUT AND LOAD

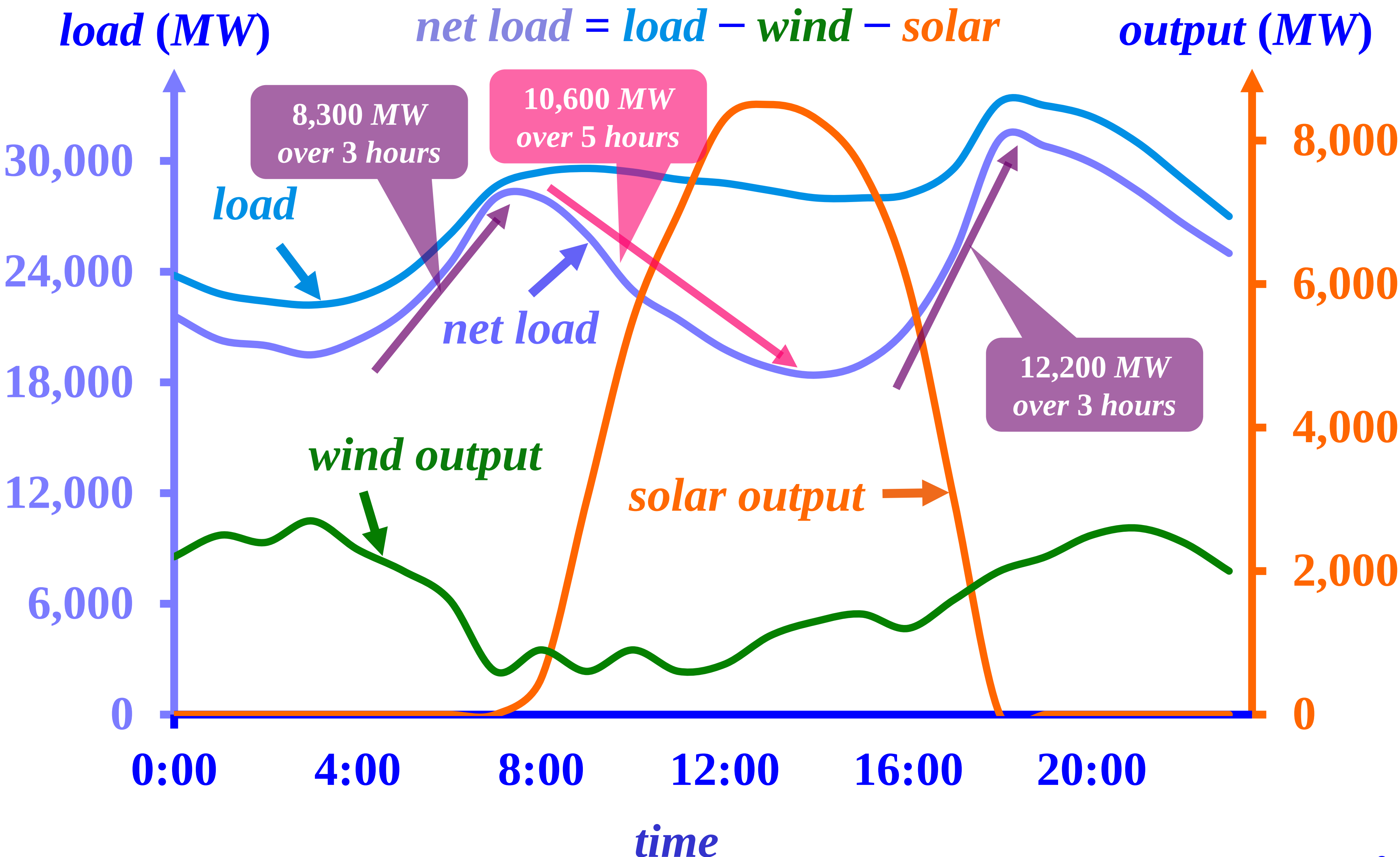


NEED FOR LARGER AND FASTER RAMPING RESERVES

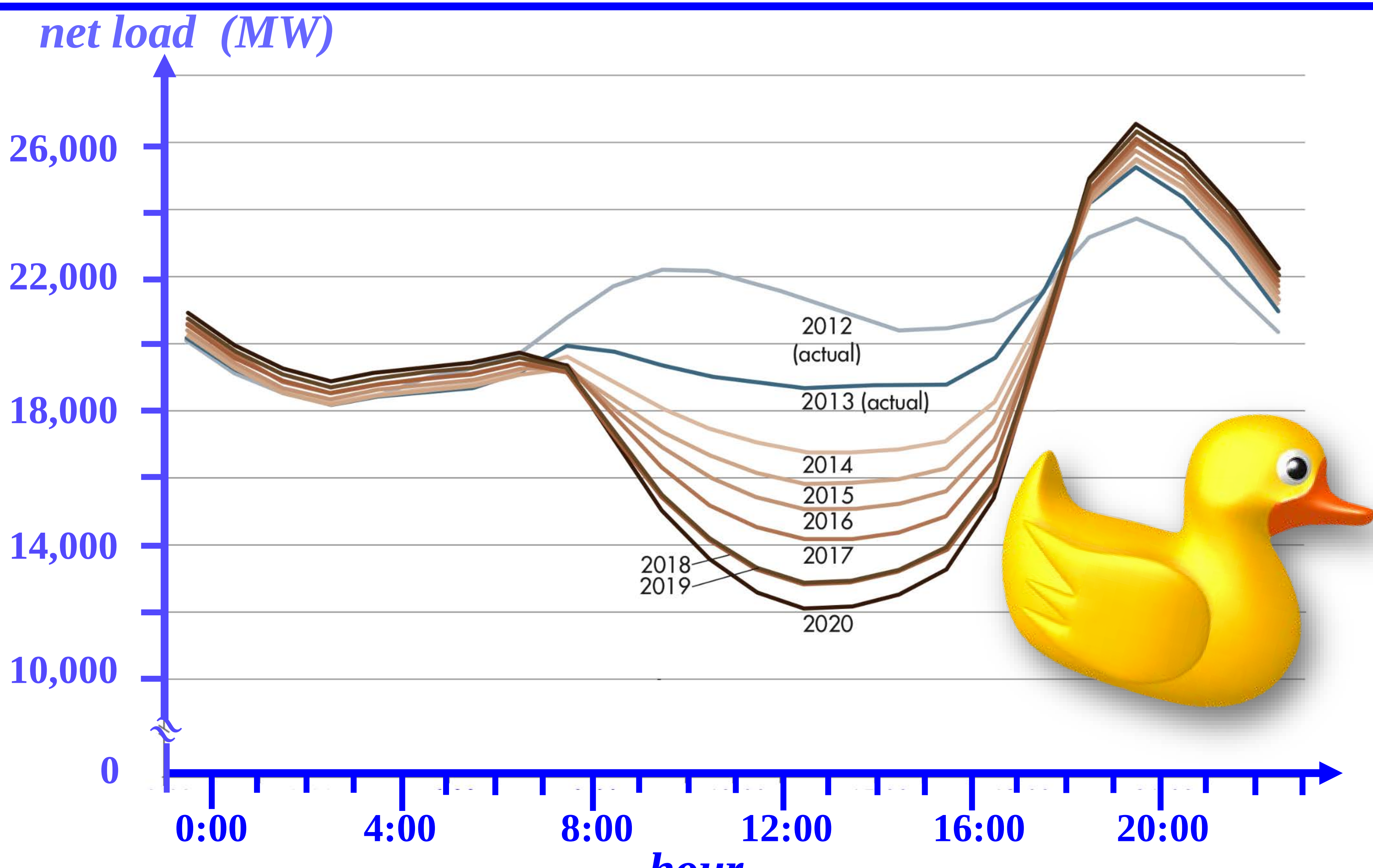


Adapted from: M. Lange & U. Focken, "Physical Approach to Short-Term Wind Power Prediction", Springer, 2006

INCREASED FLEXIBILITY NEEDS

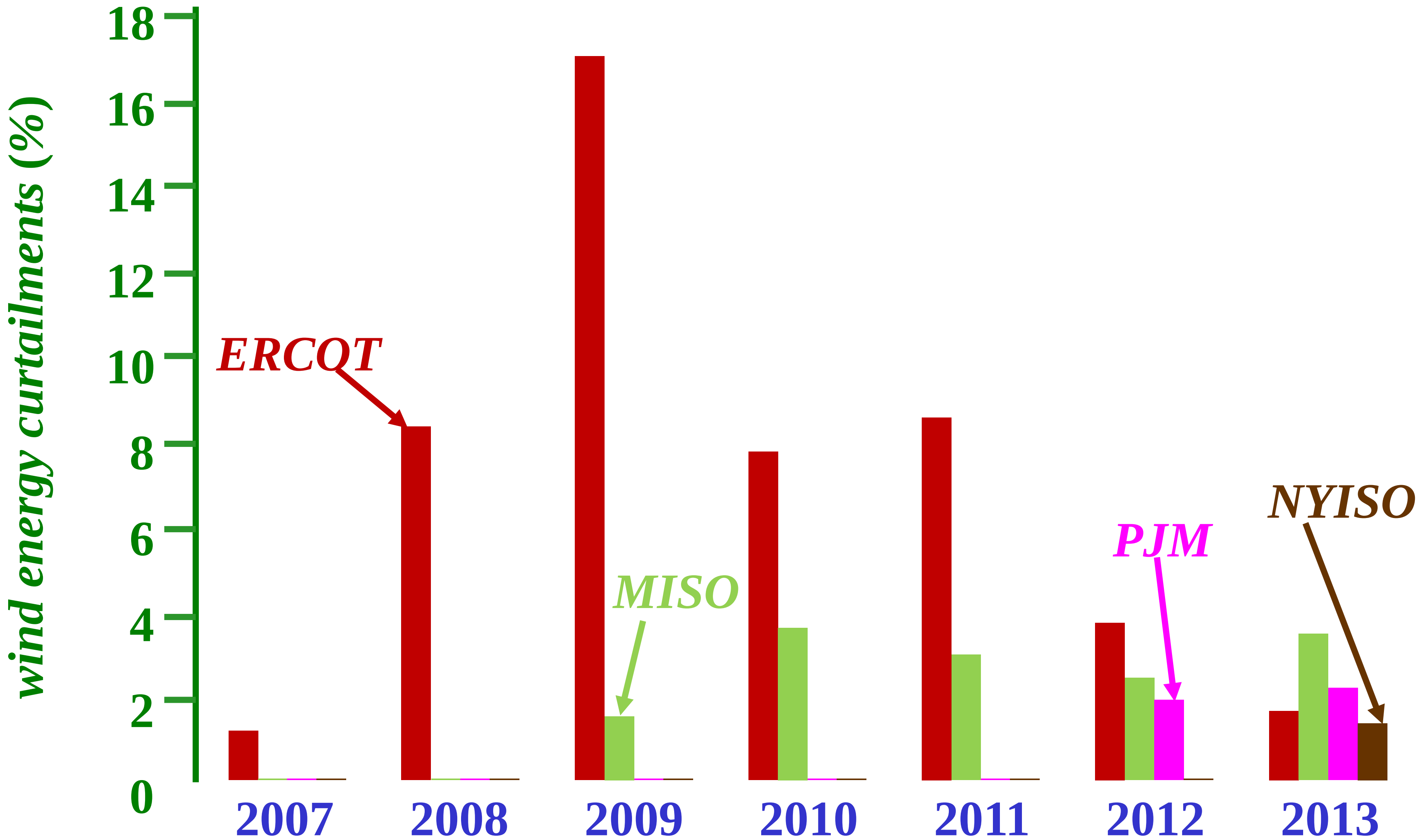


CAISO DAILY NET LOAD CURVE UNDER DEEPENING PENETRATION

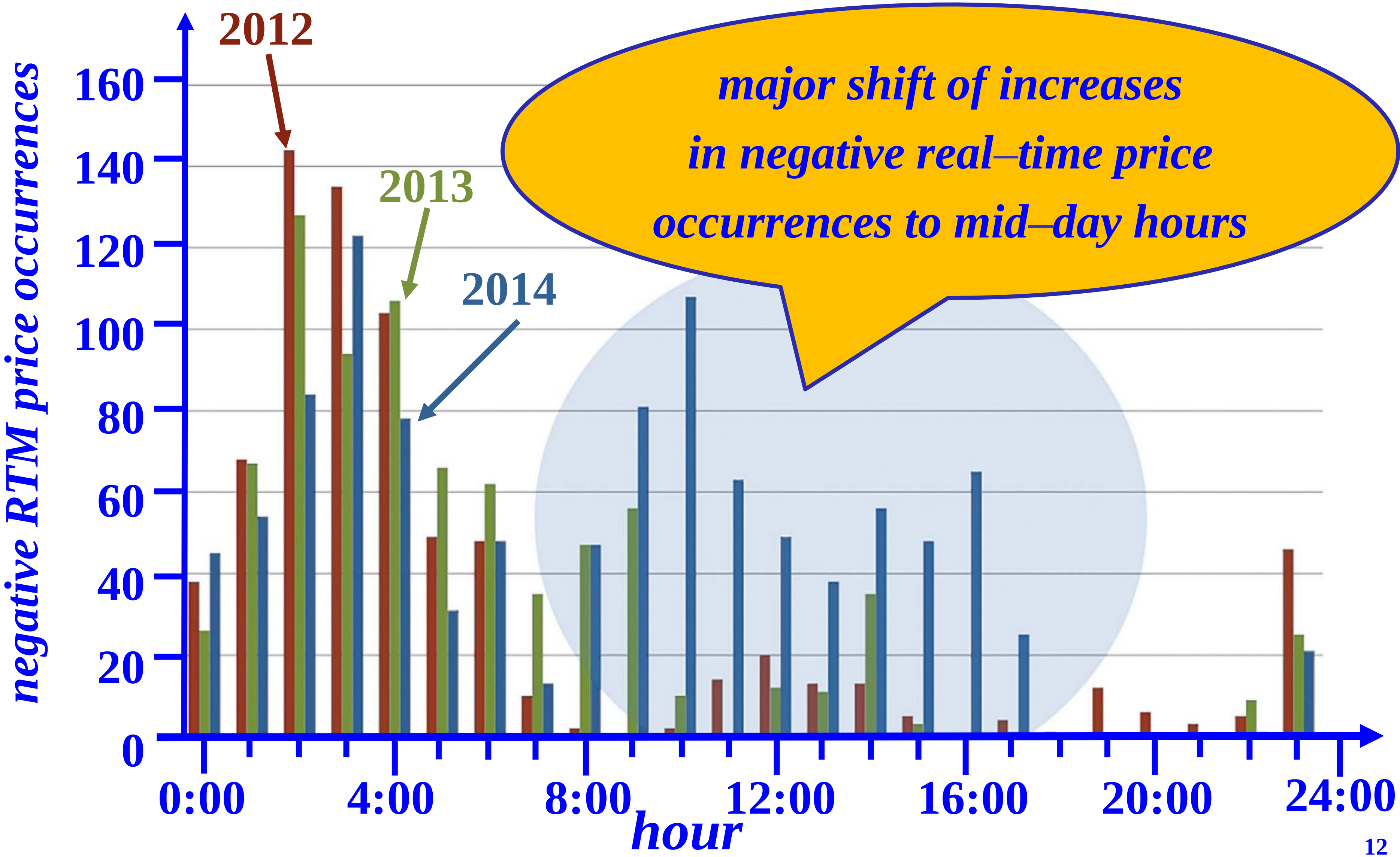


Source: CAISO

CURTAILMENT PERCENTAGES OF WIND GENERATION : 2007 – 2013

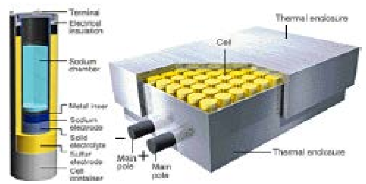


CAISO NEGATIVE *RTM* PRICES

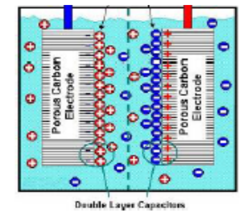


ENERGY STORAGE TECHNOLOGIES

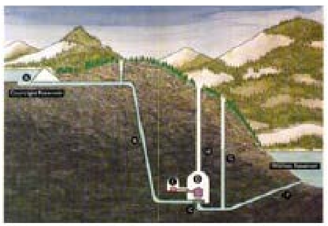
NaS battery



EC capacitor

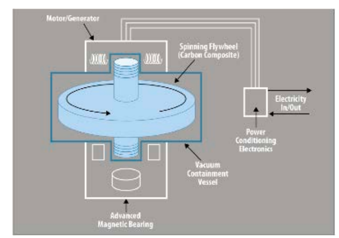


pumped storage

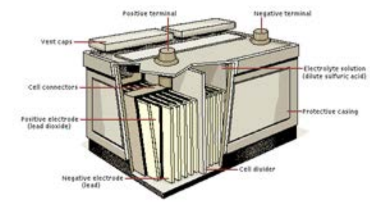


flow battery

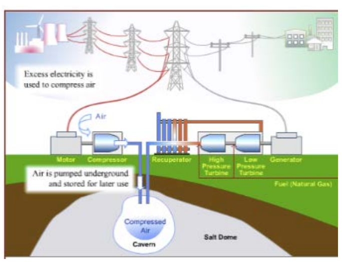
flywheel



lead–acid battery



CAES



advanced lead acid battery

Li–ion battery

Ni–Cd battery

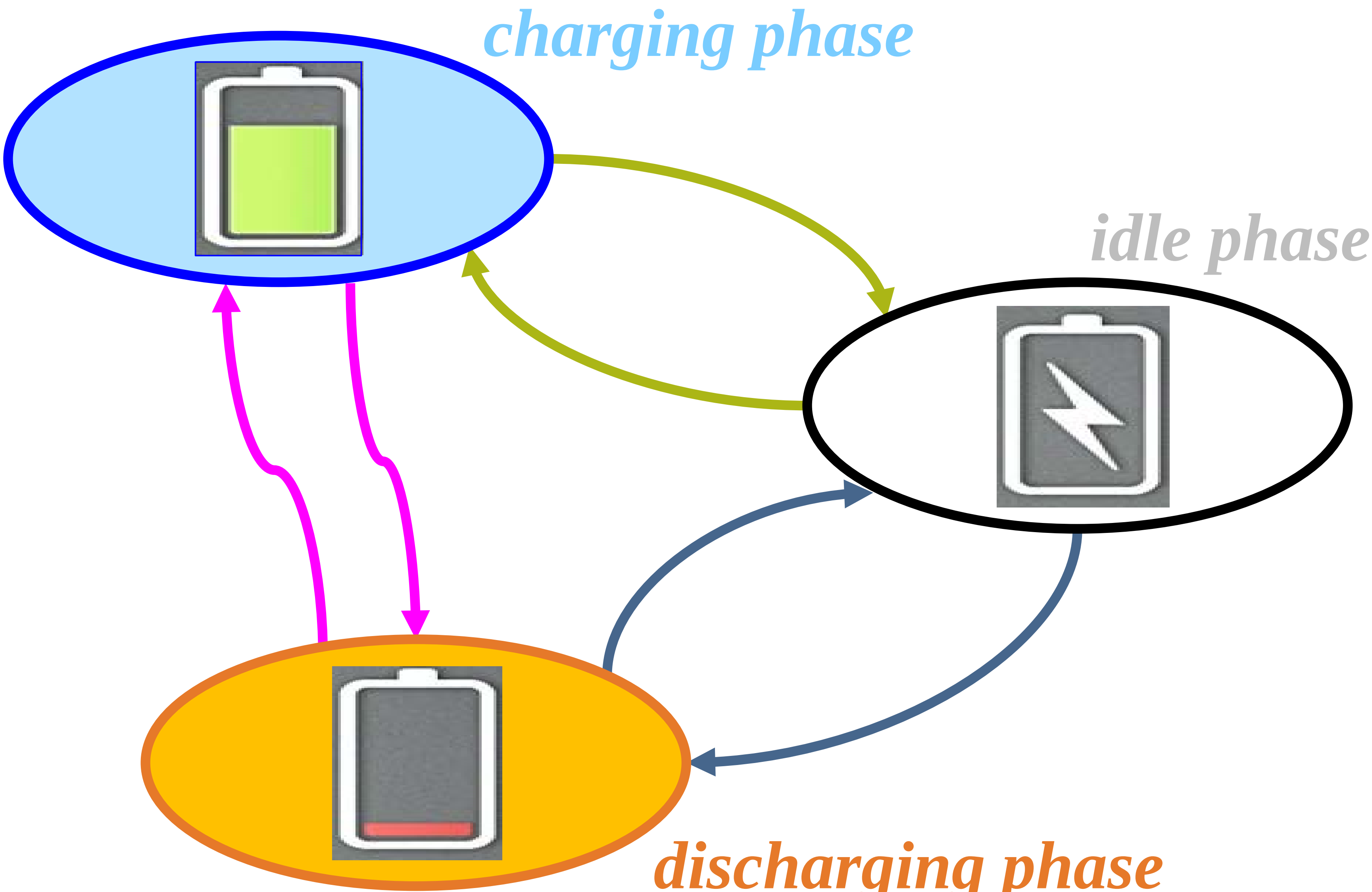
SMES

increasing capability

increasing capacity

13

THE STORAGE RESOURCE PHASES



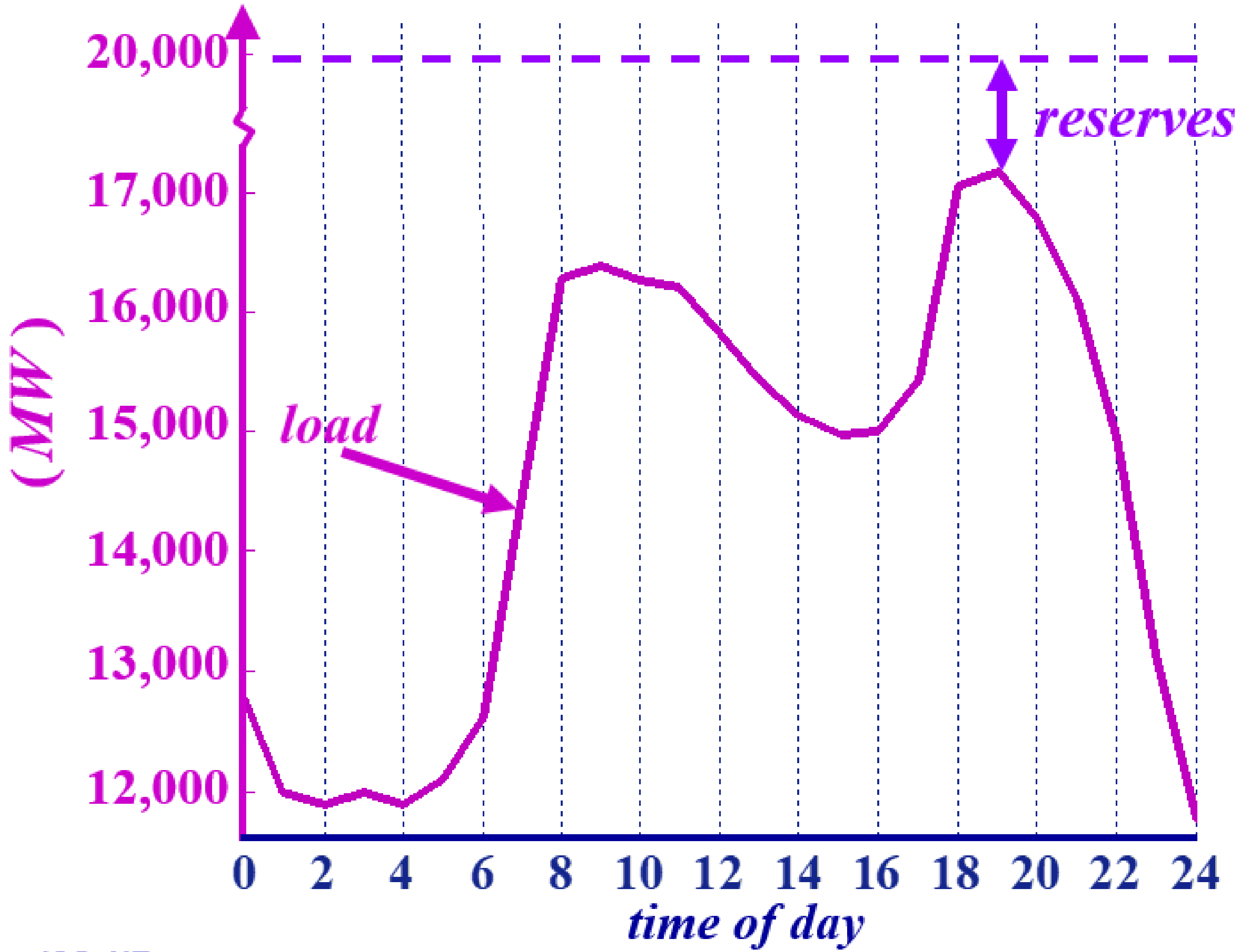
PRINCIPAL ROLES *ESR*s CAN PLAY

- **Storage enables deferral of investments in:**
  - **new generation resources**
  - **new transmission lines**
  - **distribution circuit upgrades**
- **Storage is key to the development of microgrids in both grid–connected and autonomous situations**

MORE ROLES *ESR*s CAN PLAY

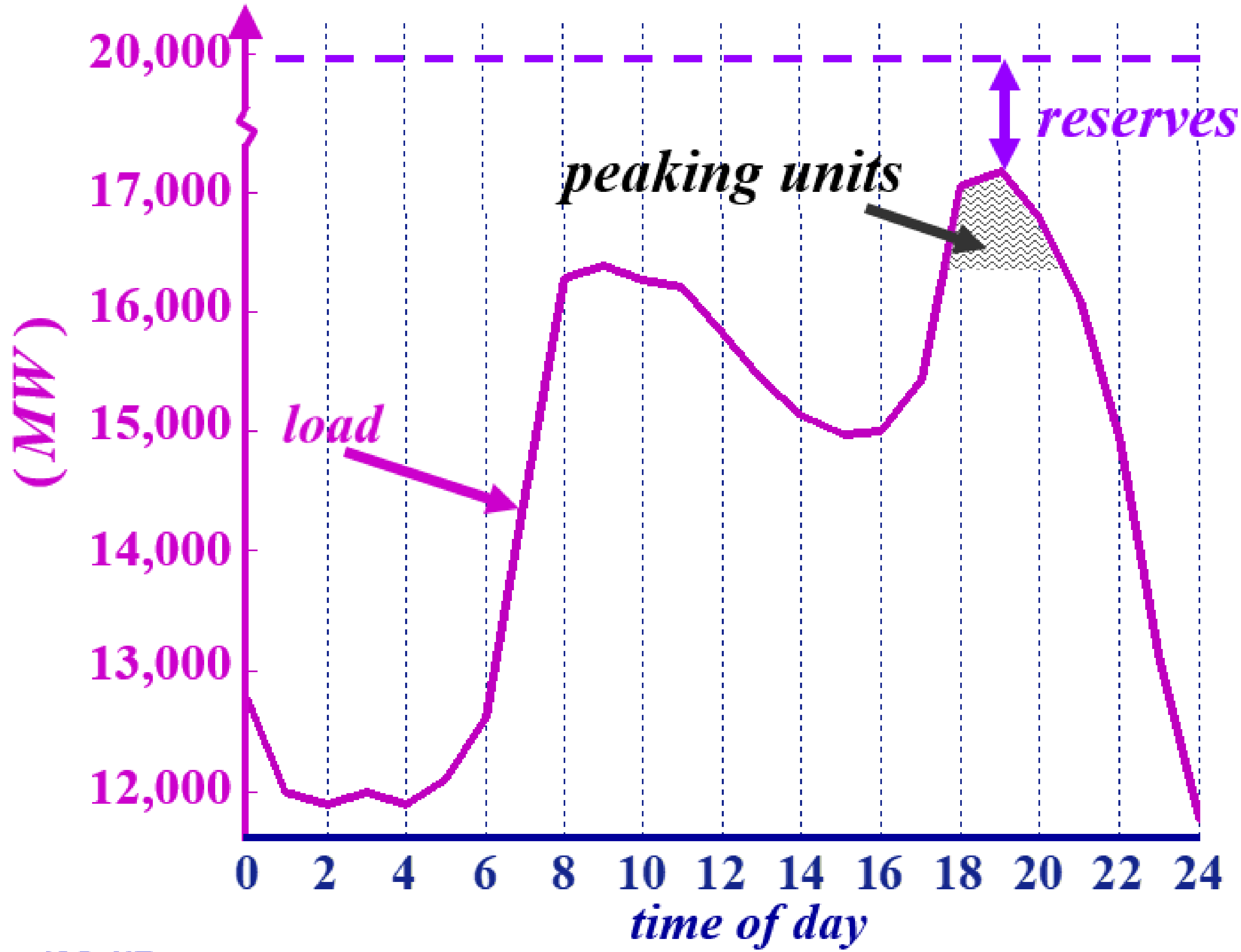
- In short–term operations, storage provides:
  - flexibility in time of energy consumption: demand shift; peak–load shaving
  - ability to delay the start up of cycling units
  - levelization of substation load
  - reserves and frequency regulation services
  - demand response action
  - capability to provide voltage support
- Storage can, also, provide *virtual inertia service* to replace part of the missing inertia in grids with integrated renewable resources

CYCLING UNITS WITHOUT *ESRs*



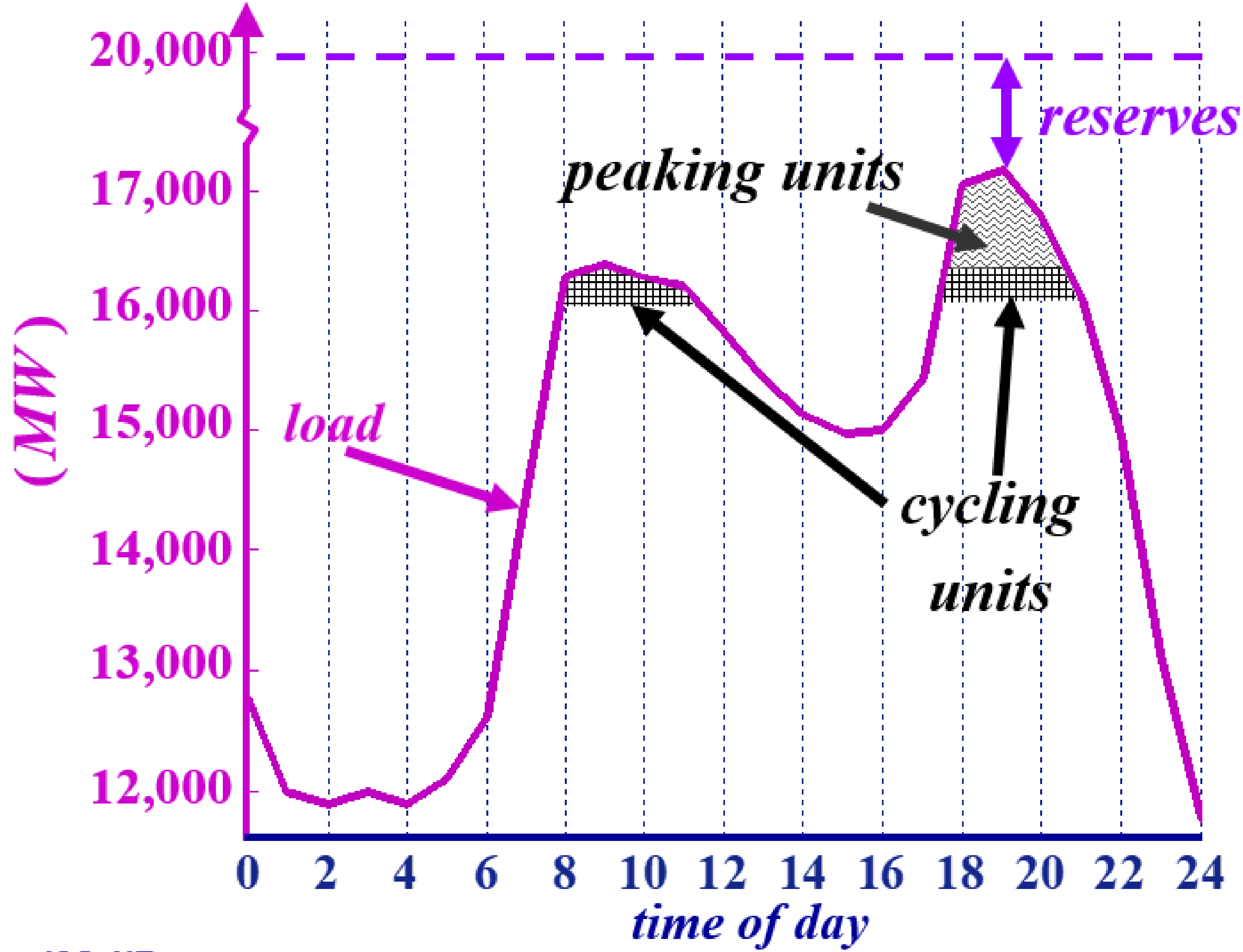
Source: ISO–NE

CYCLING UNITS WITHOUT *ESRs*



Source: ISO–NE

CYCLING UNITS WITHOUT *ESR*s



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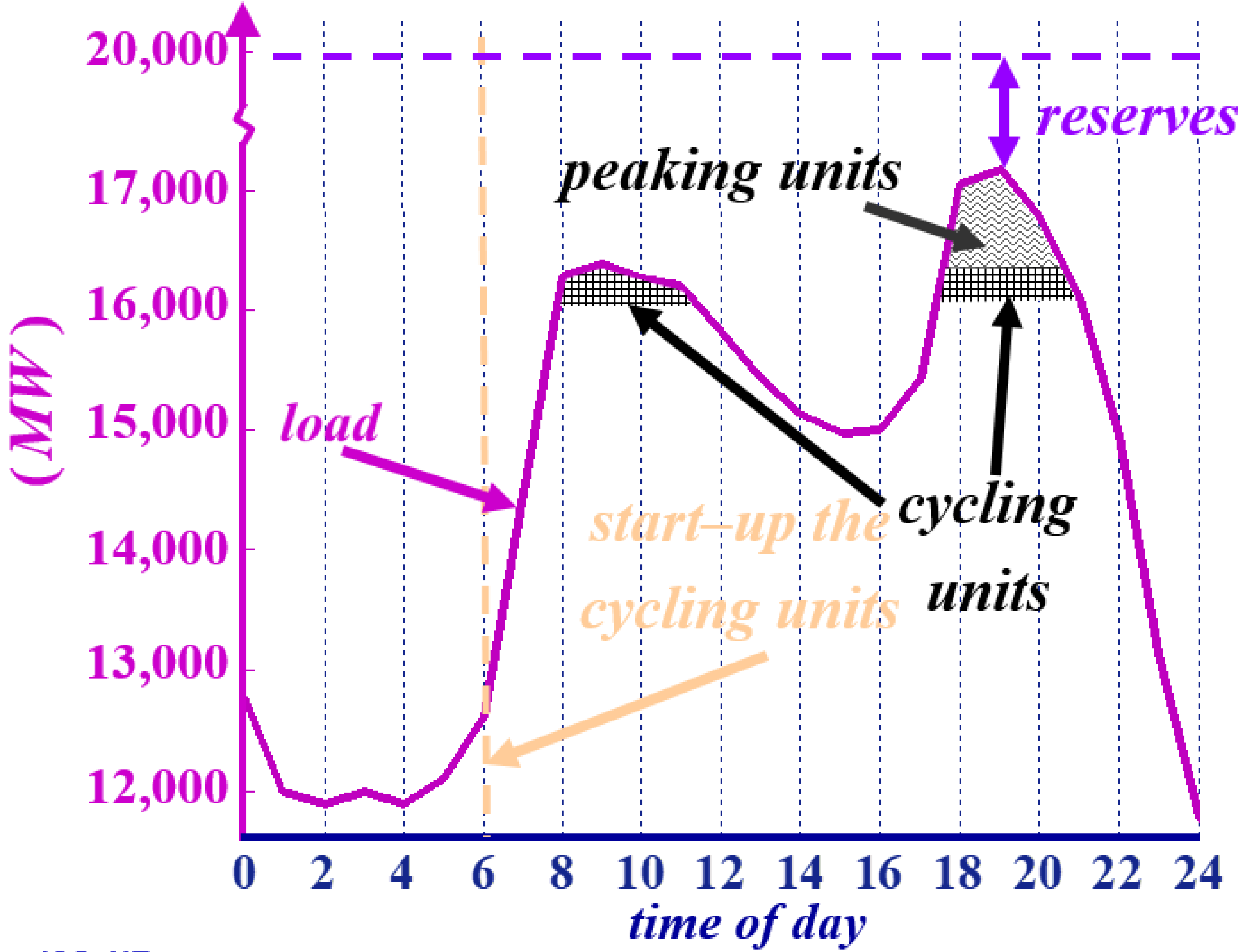
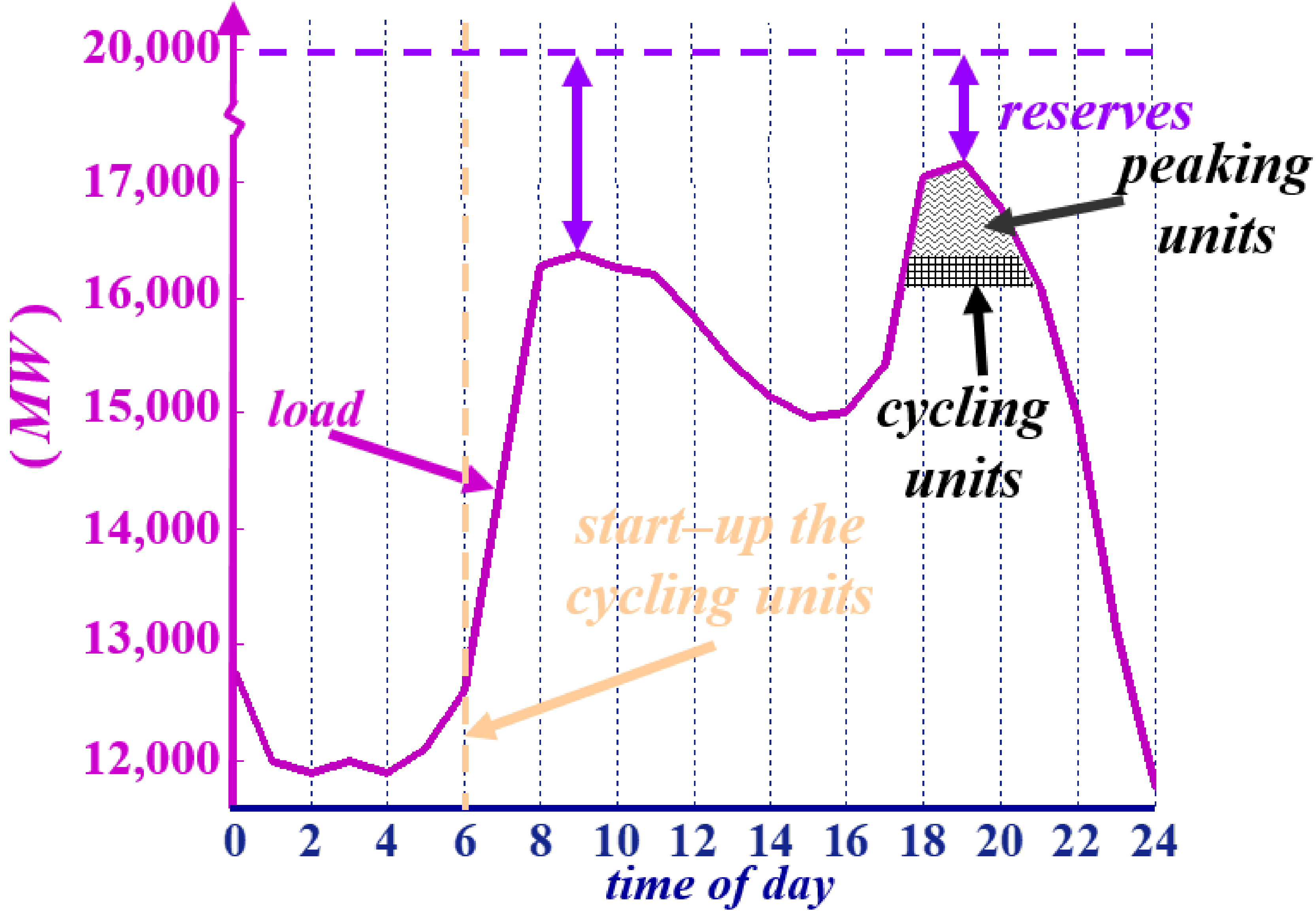
CYCLING UNITS WITHOUT *ESR*s



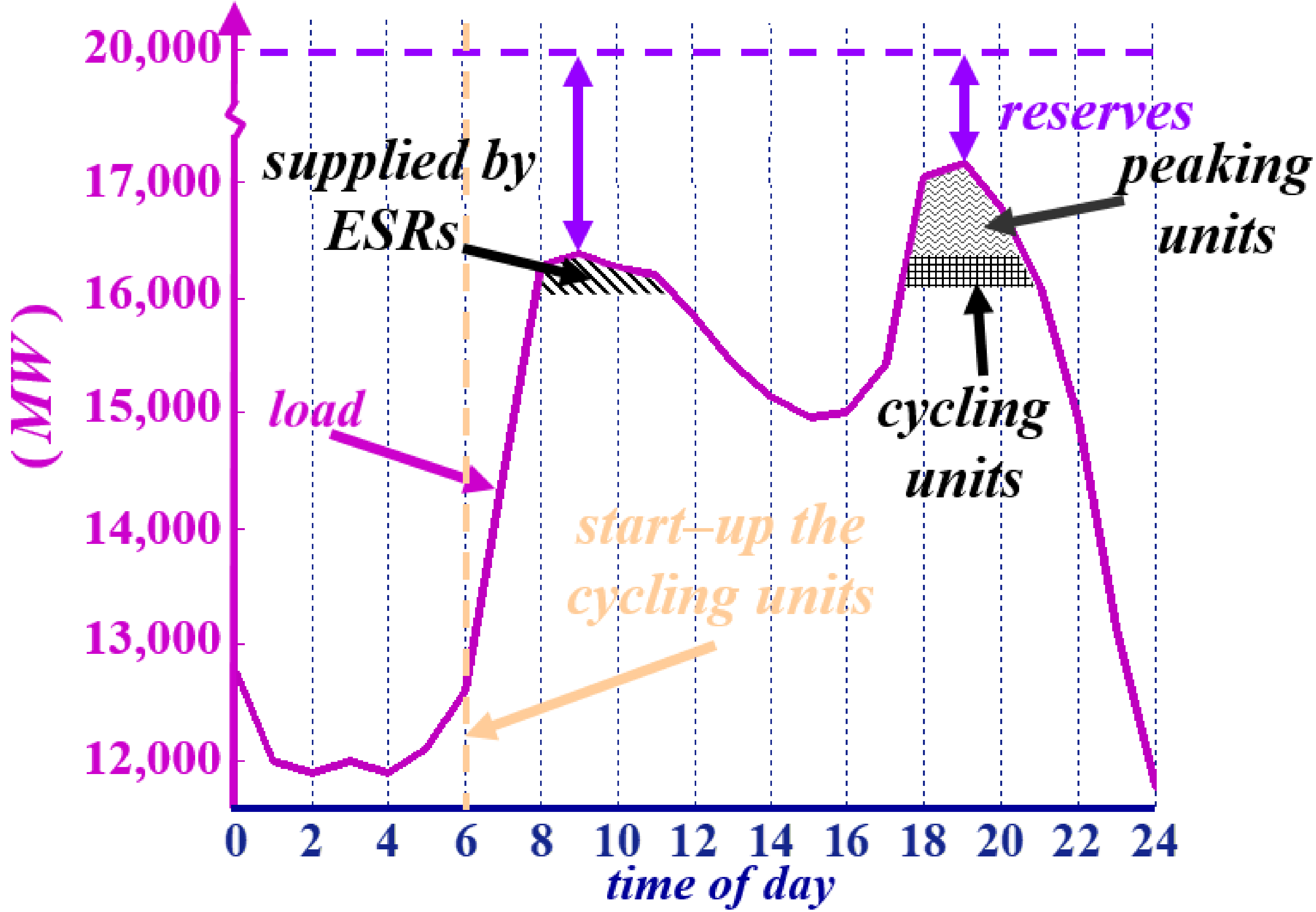
Source: ISO–NE

CYCLING UNITS WITH *ESRs*



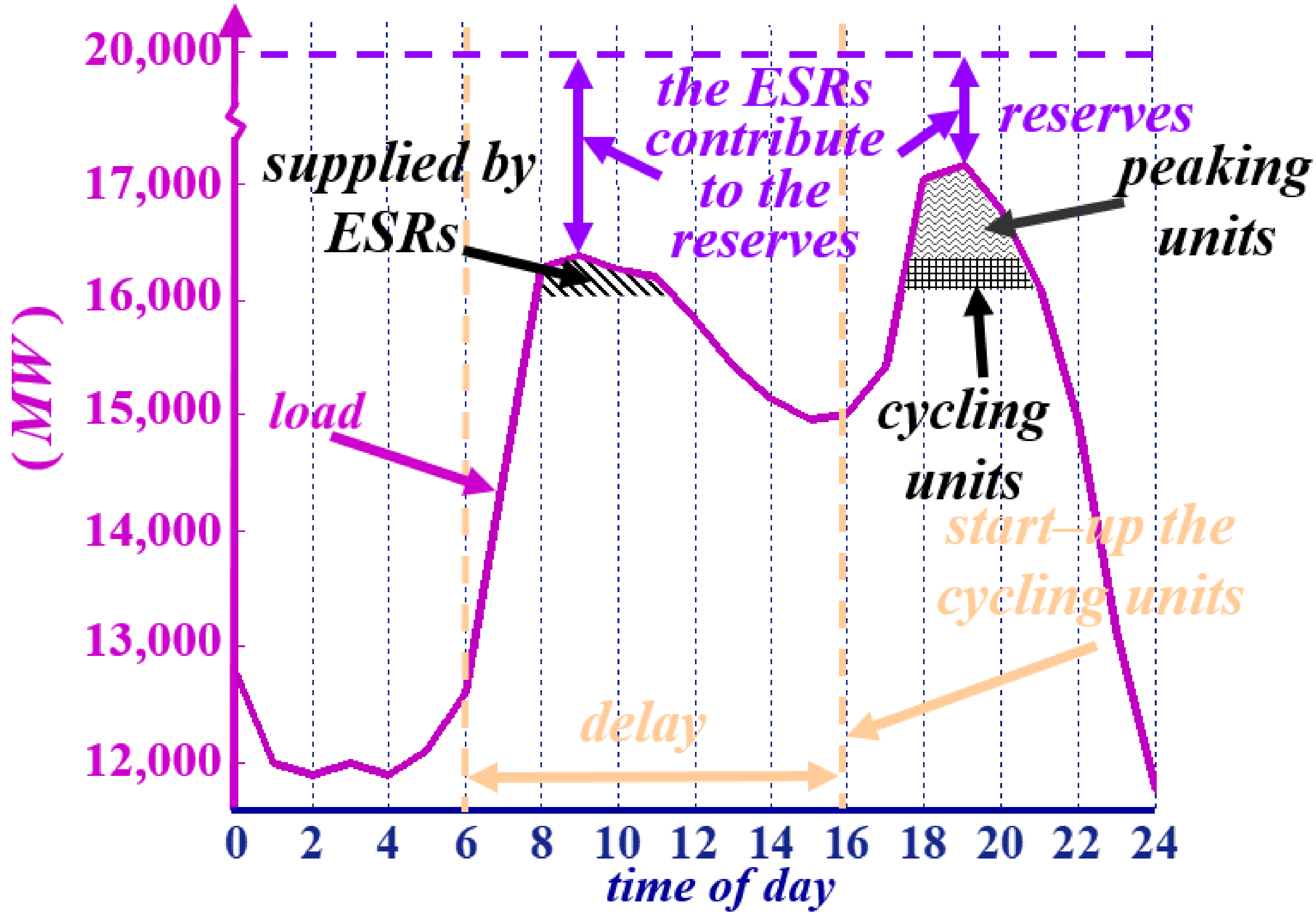
Source: ISO–NE

CYCLING UNITS WITH *ESRs*



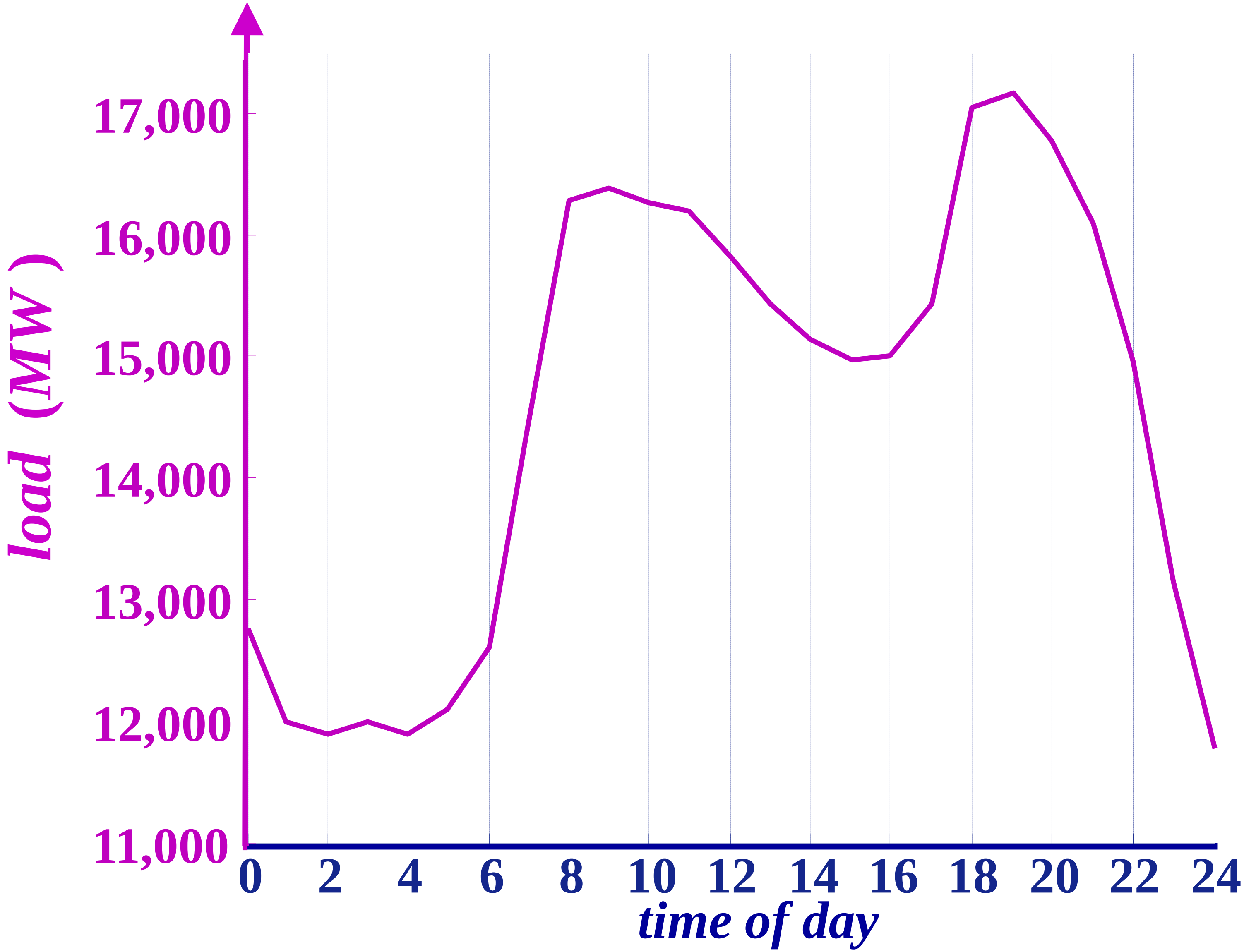
Source: ISO–NE

CYCLING UNITS WITH *ESRs*



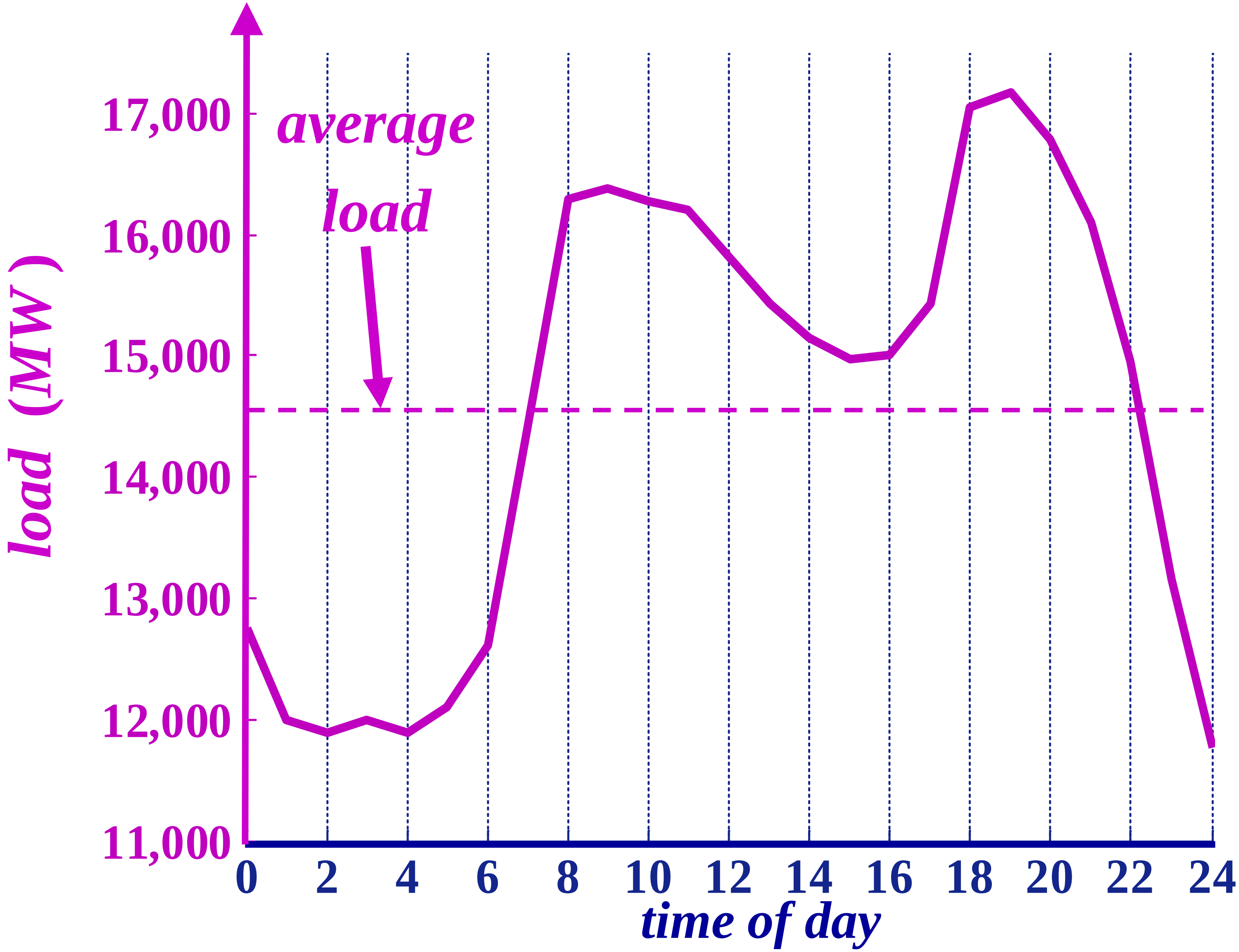
Source: ISO–NE

LOAD AND *LMP*



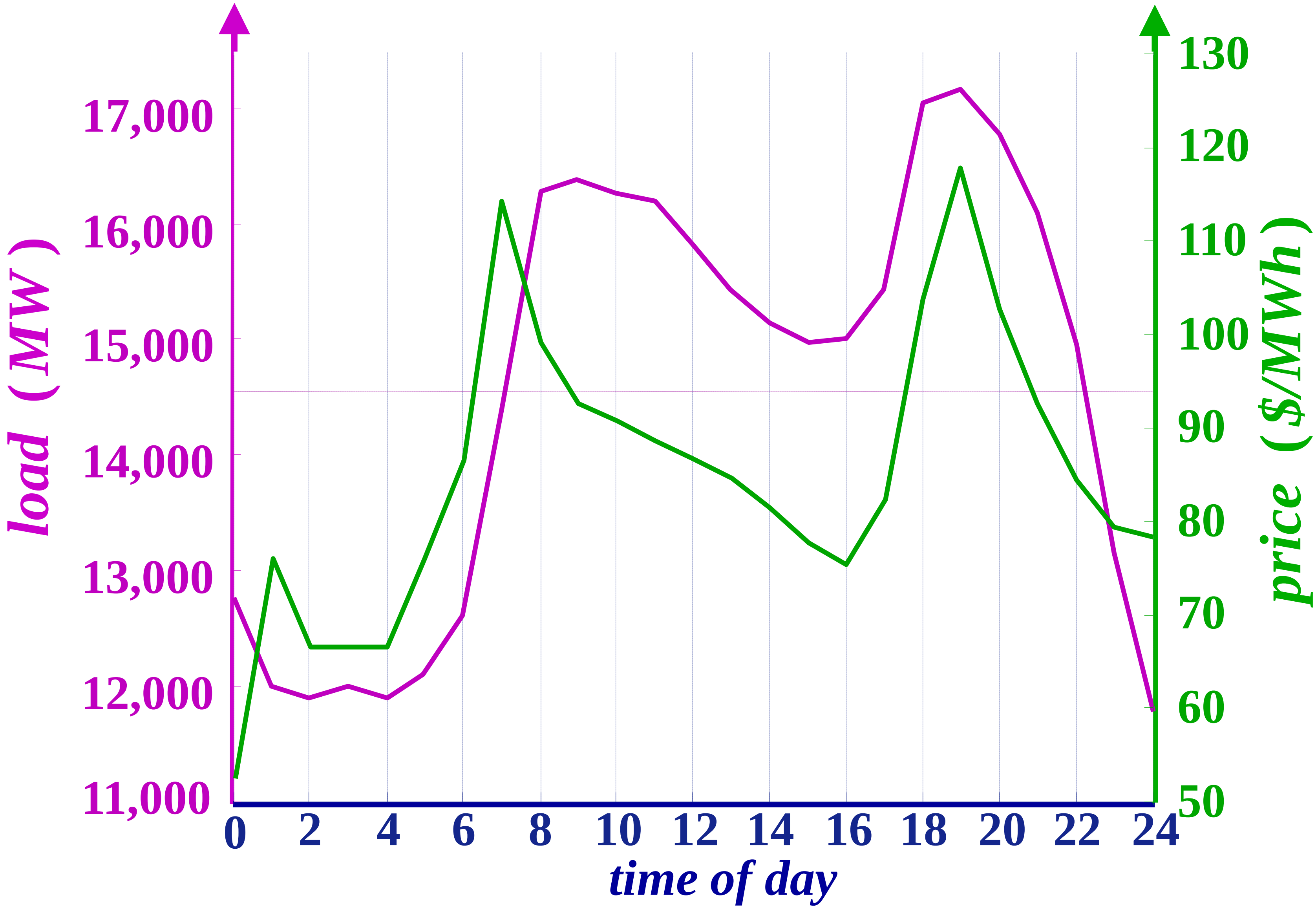
Source: NE ISO

LOAD AND *LMP*



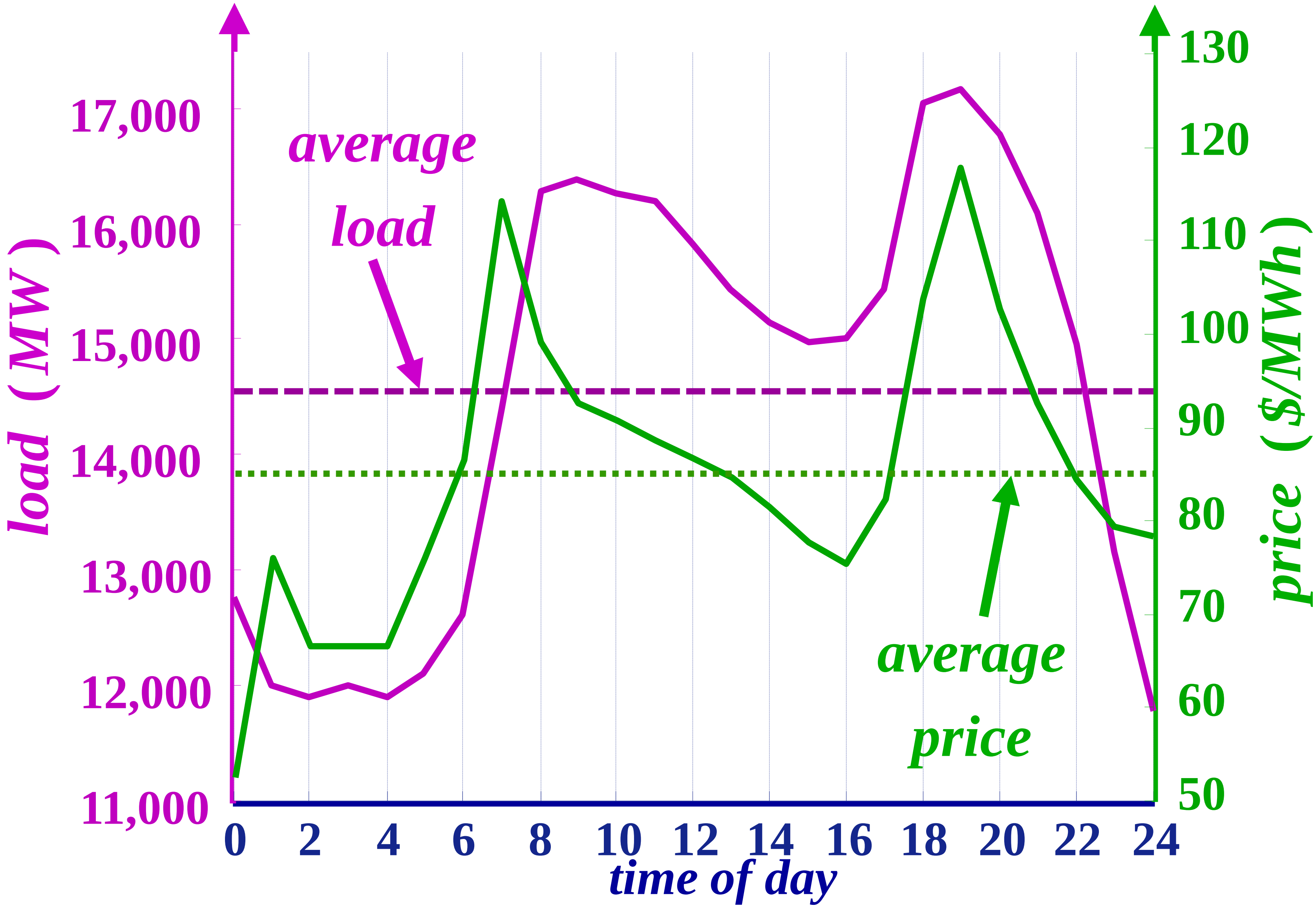
Source: NE ISO

LOAD AND *LMP*



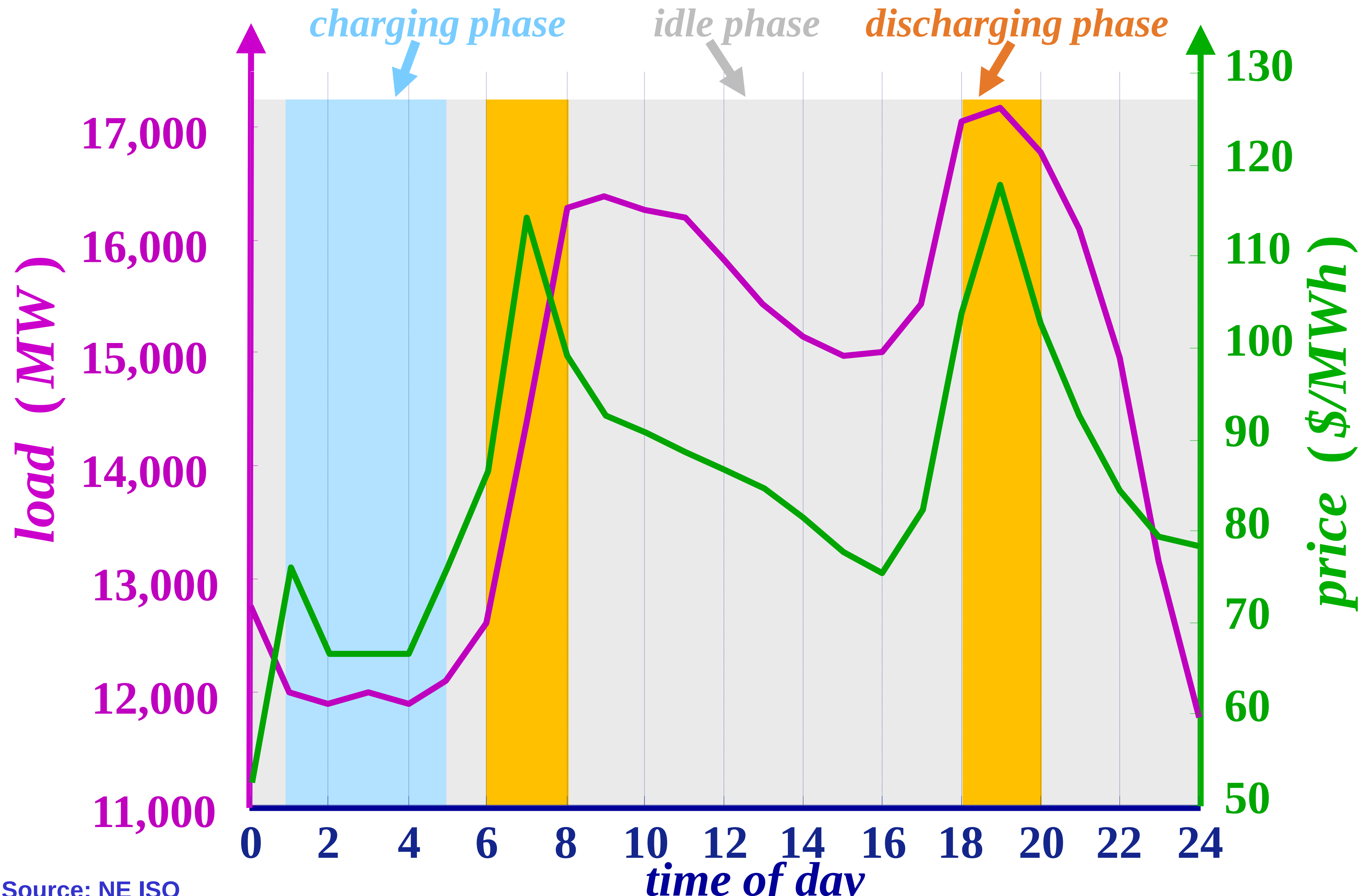
Source: NE ISO

LOAD AND *LMP*



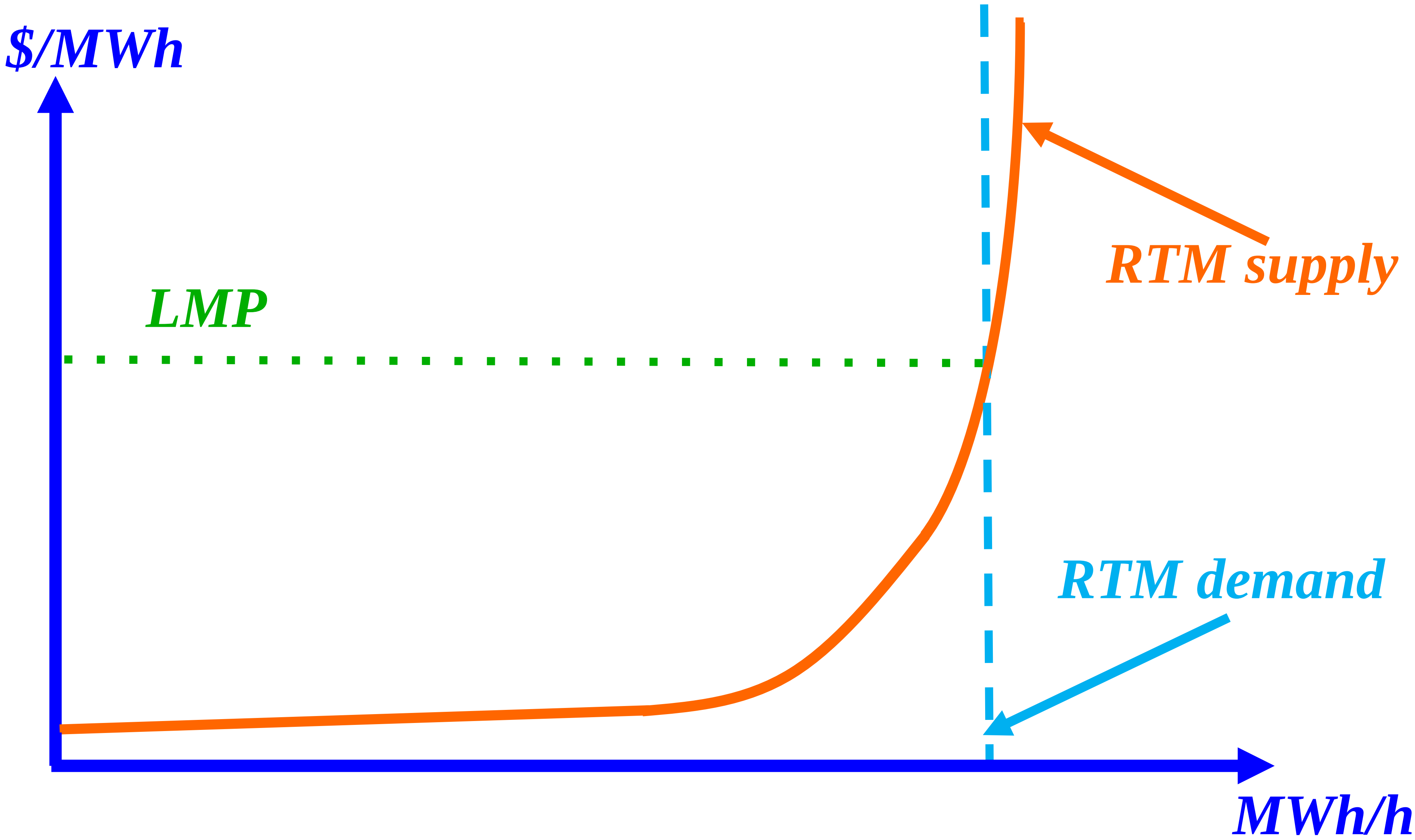
Source: NE ISO

STORAGE UTILIZATION



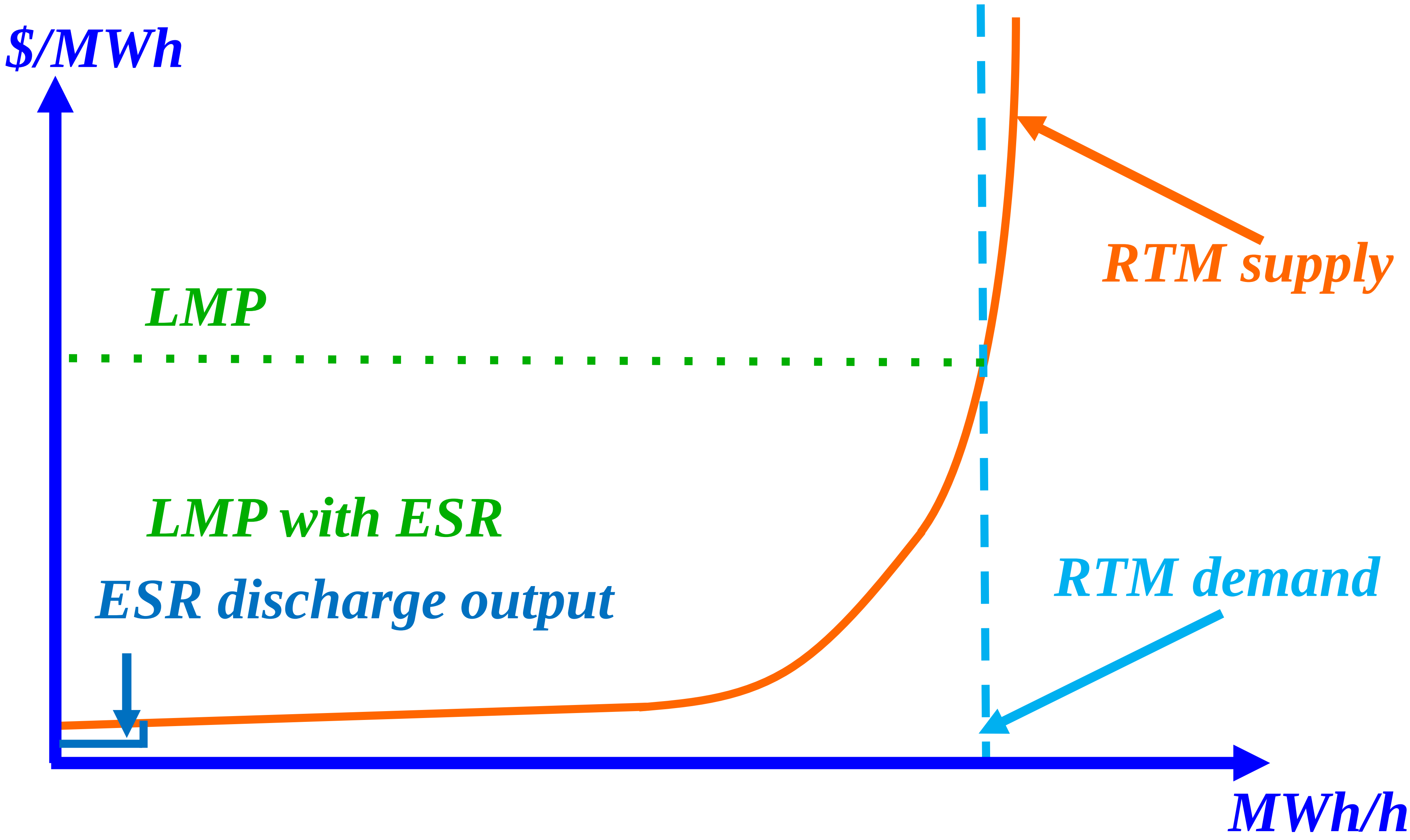
Source: NE ISO

LMP IN A SYSTEM WITHOUT STORAGE



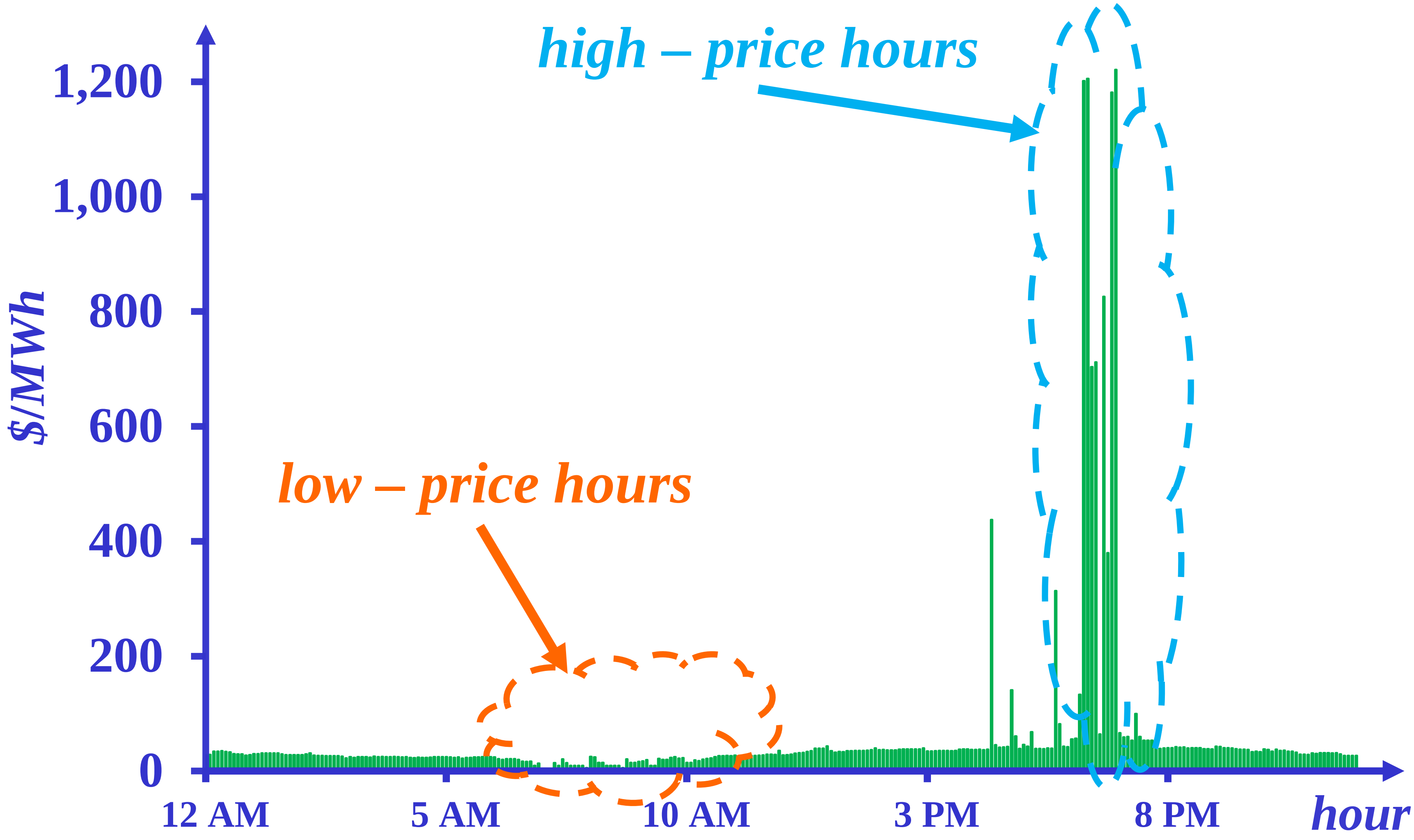
Source: http://oasis.caiso.com/, hub TH_SP15 (June 9, 2015)

ESR DEPLOYMENT IMPACT ON *LMP*



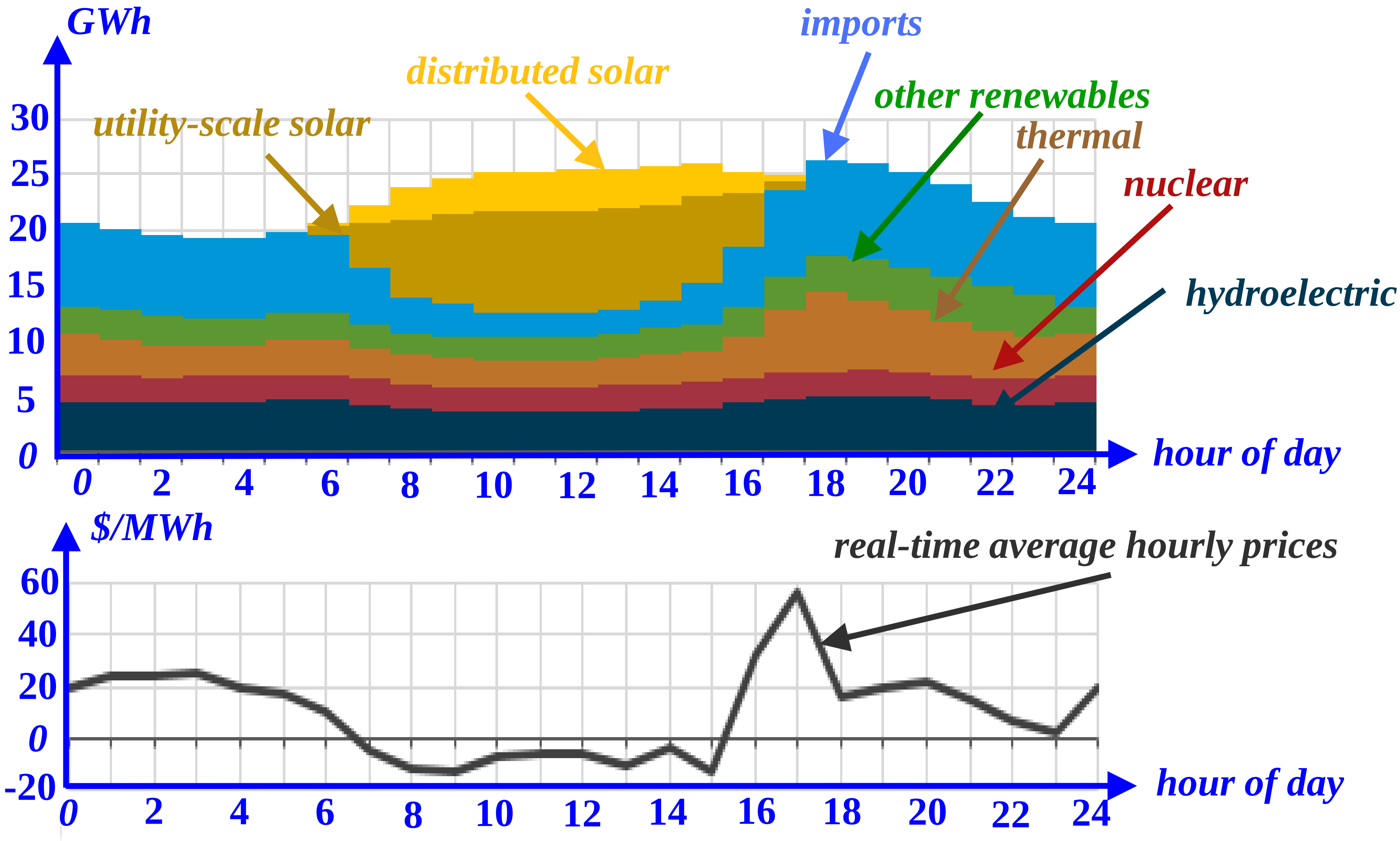
Source: http://oasis.caiso.com/, hub TH_SP15 (June 9, 2015)

ESR DEPLOYMENT IN *RTM*s



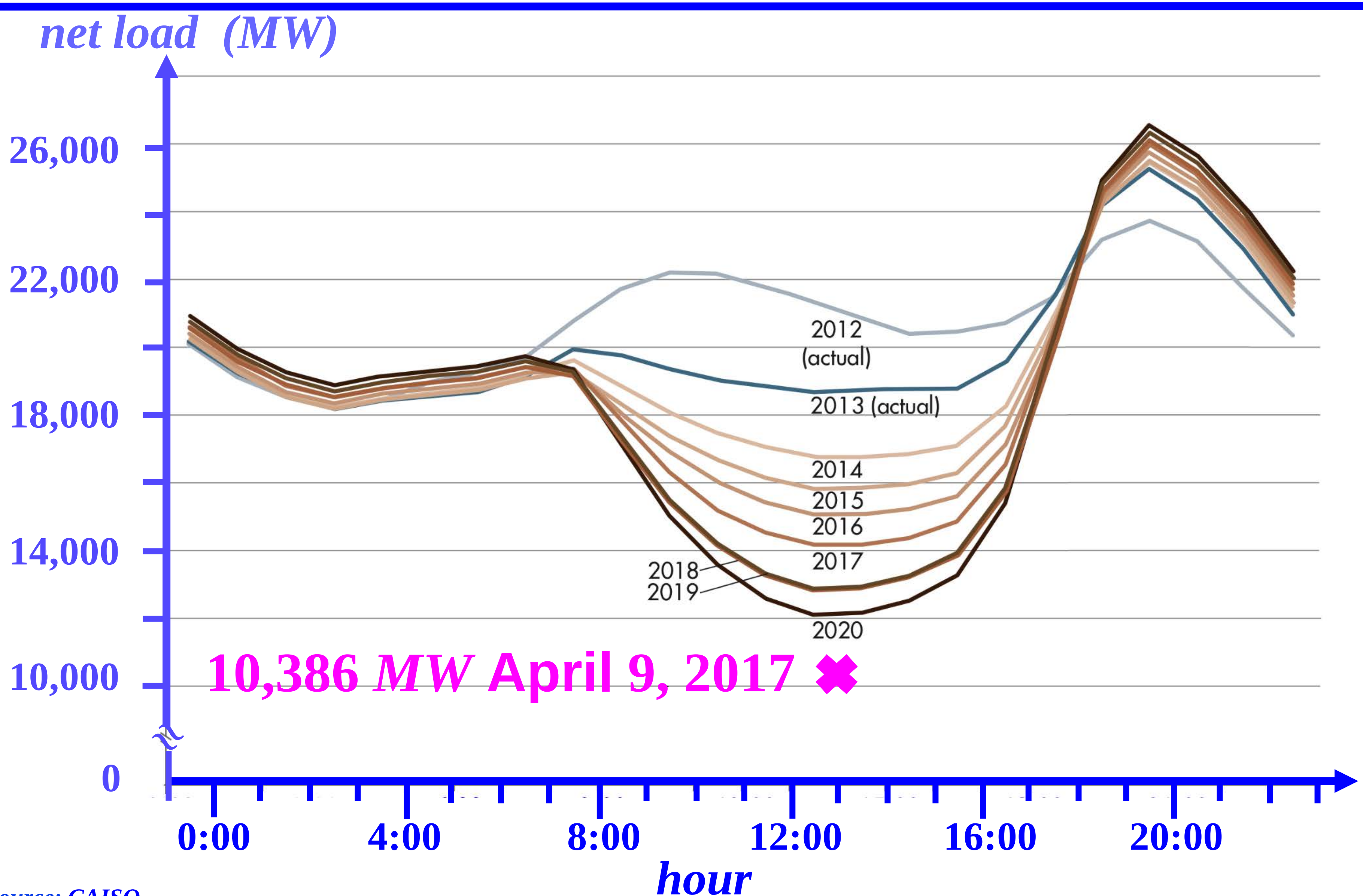
Source: http://oasis.caiso.com/, hub TH_SP15 (*June* 9, 2015)

CALIFORNIA ROOFTOP SOLAR IMPACTS: MARCH 11, 2017



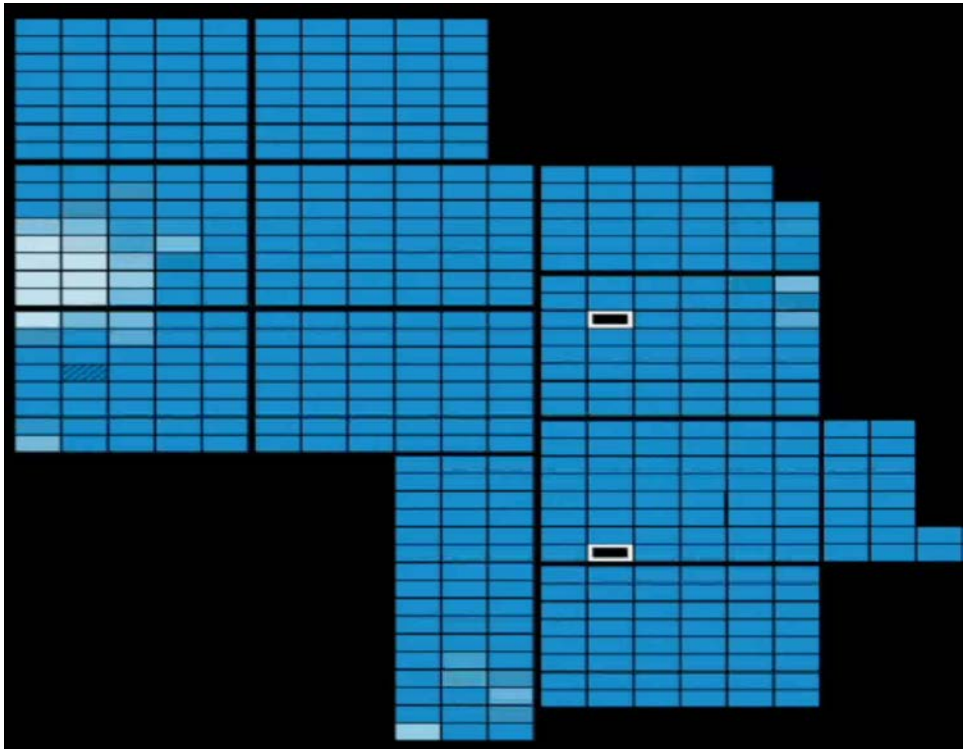
Source: US EIA based on https://www.eia.gov/electricity/data/eia861m/index.html and http://www.caiso.co

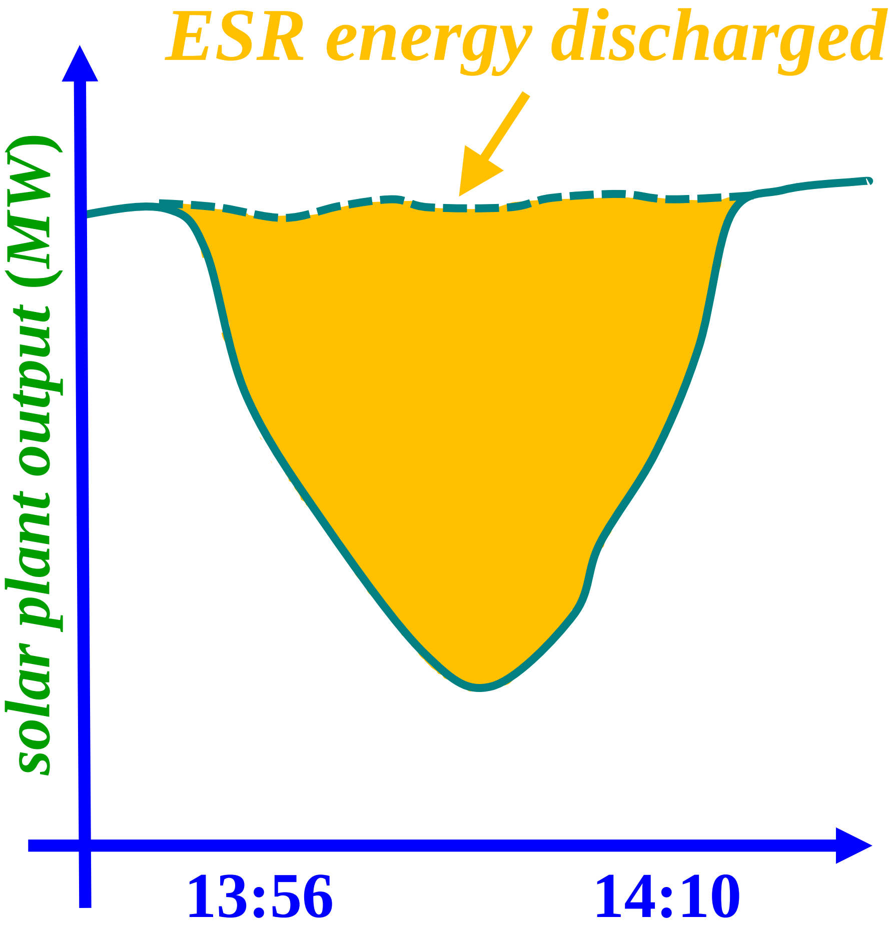
CAISO DAILY NET LOAD CURVE UNDER DEEPENING PENETRATION



Source: CAISO

INTEGRATION OF STORAGE WITH SOLAR RESOURCES





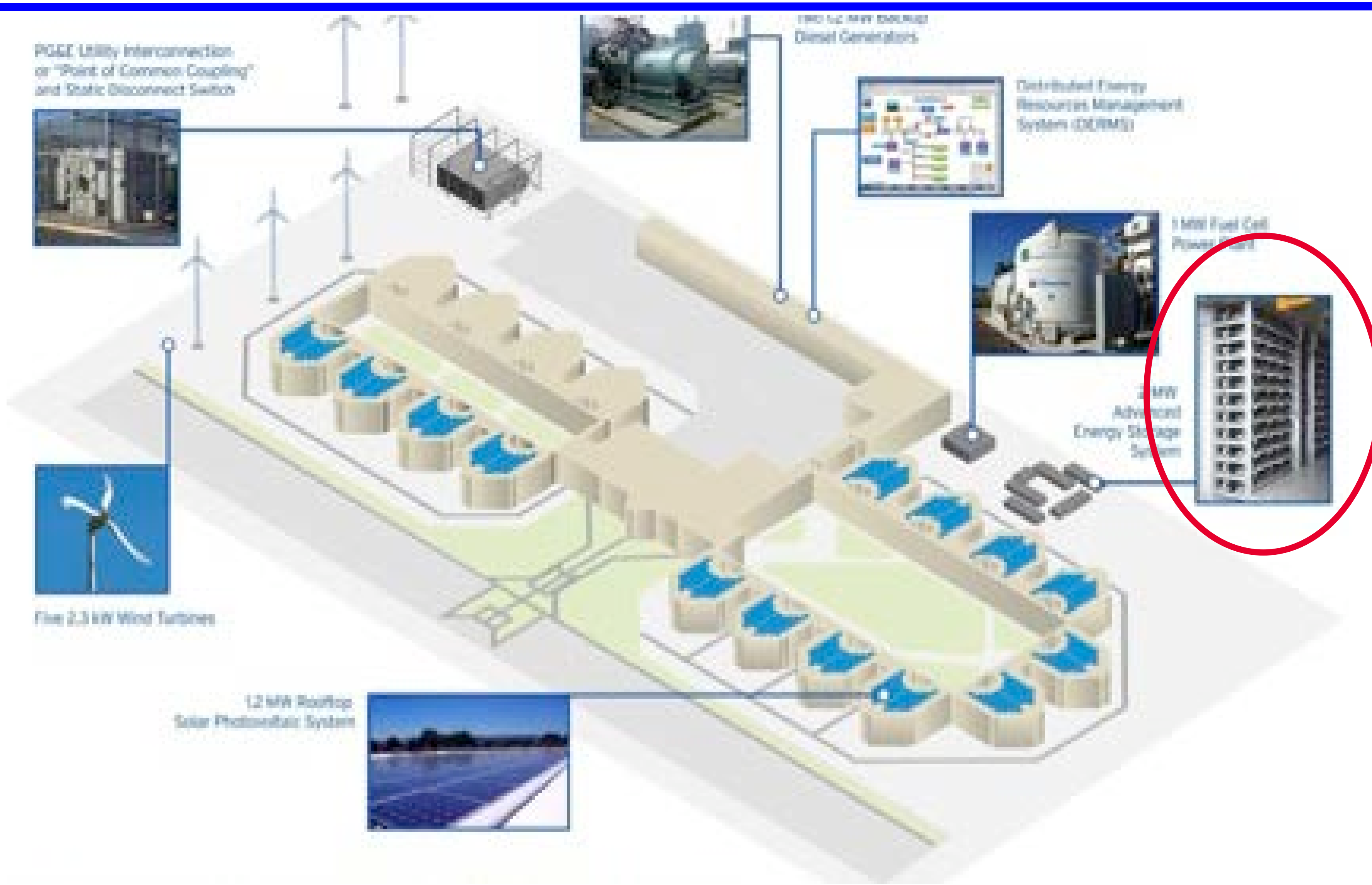
STORAGE APPLICATION IN MICROGRIDS (μgs)

- **A μg is a *time–varying network* in the distribution grid with control of its resources to *either* consume *or* generate electricity or act as an idle entity with *zero* injection/withdrawal in the *isolated mode***
- **Storage plays an integral role in the management of generation and load resources in a μg and thus is a critical component in the development of grid–connected, autonomous and community μgs**

MICROGRID: DEFINITION

A microgrid (μg) is a network of interconnected loads and distributed energy resources, within clearly defined geographic boundaries, with the properties that it is a single controllable entity, from the grid perspective, and that it operates either connected to or disconnected from the grid, *i.e.*, either in the *parallel* or in the *islanded* mode.

APPLICATION IN MICROGRIDS



Santa Rita Jail Microgrid

ESR GRID APPLICATIONS

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 used and reduce pollution*
energy shift from low – to high – demand periods	*collect 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* DEPLOYMENT

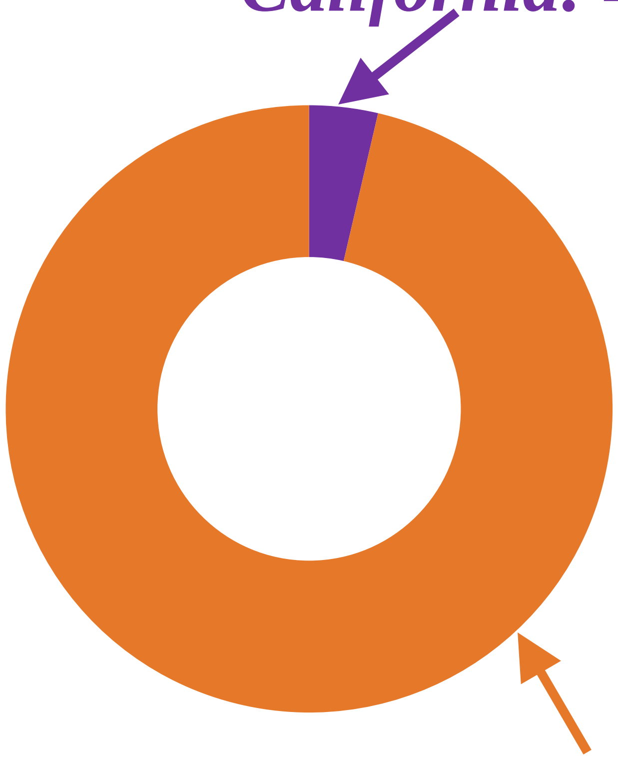
- **Deployment of *ESR*s**
  - **raises system reliability**
  - **improves operational economics**
  - **provides operators with additional flexibility to optimize grid operations and manage grid congestion**
  - **increases renewable output utilization**

KEY BENEFITS OF GRID – INTEGRATED *ESR*s

- *ESR* deployment reduces *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

CURRENT WORLD STORAGE STATUS

- There are currently 1,619 *ESR* projects implemented throughout the world with a total capacity of 193,127 *MW*
- 288 out of these projects are in California with a capacity of 7,512 *MW*



Source: *DOE* Global Energy Storage Database, *http://www.energystorageexchange.org/projects*

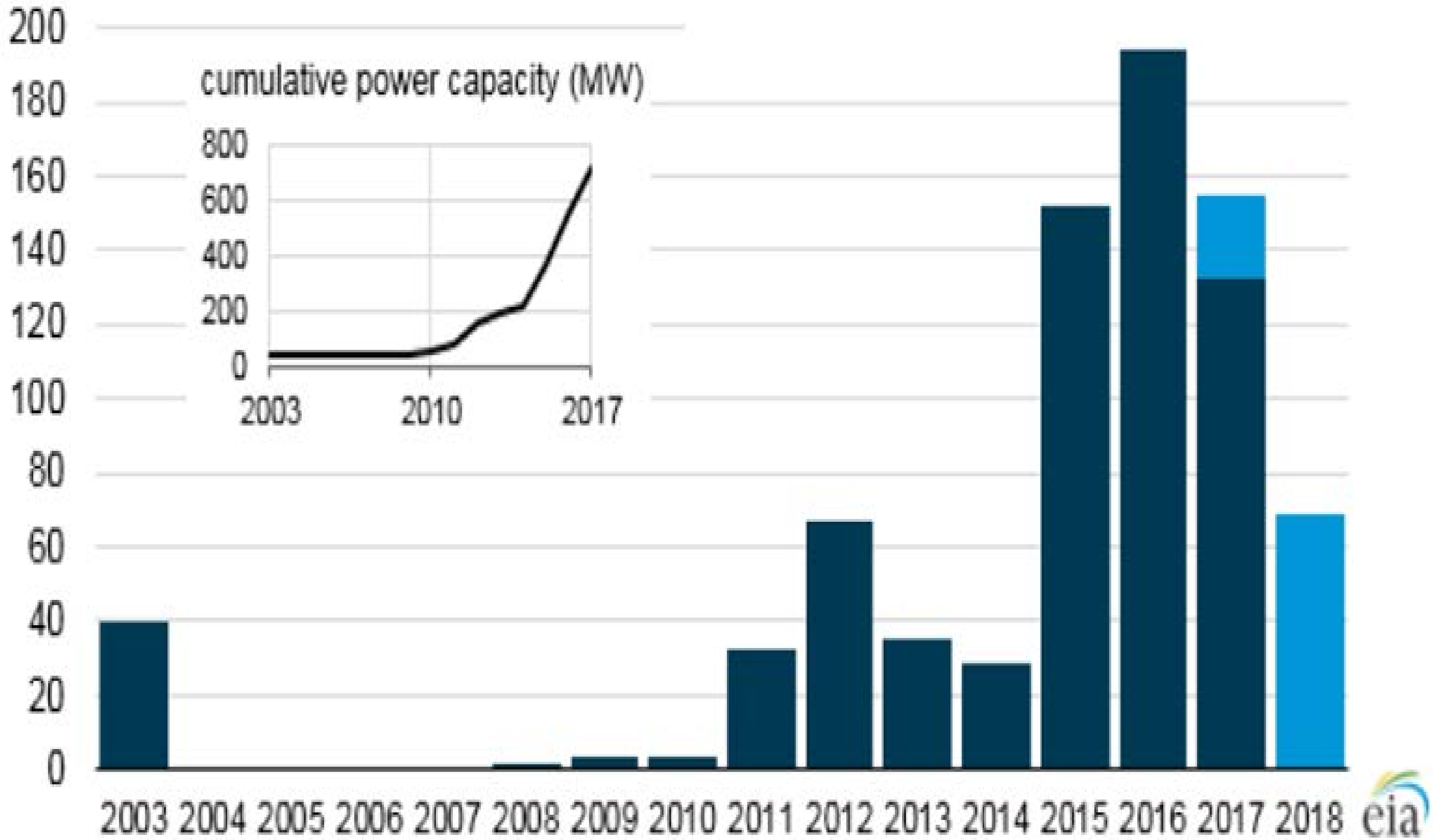
BATTERY ENERGY STORAGE SYSTEMS (*BESS*s)

- Many practitioners consider the installation of *BESS*s to most effectively address the challenges to integrate deepening penetrations of renewable resources – the *holy grail* of energy storage
- A *BESS* may be highly efficient and can discharge the stored energy with high ramp rates
- The development of new, very large, highly effi–cient batteries, appropriate for utility–scale storage, is predicted to grow into a huge business

BESS

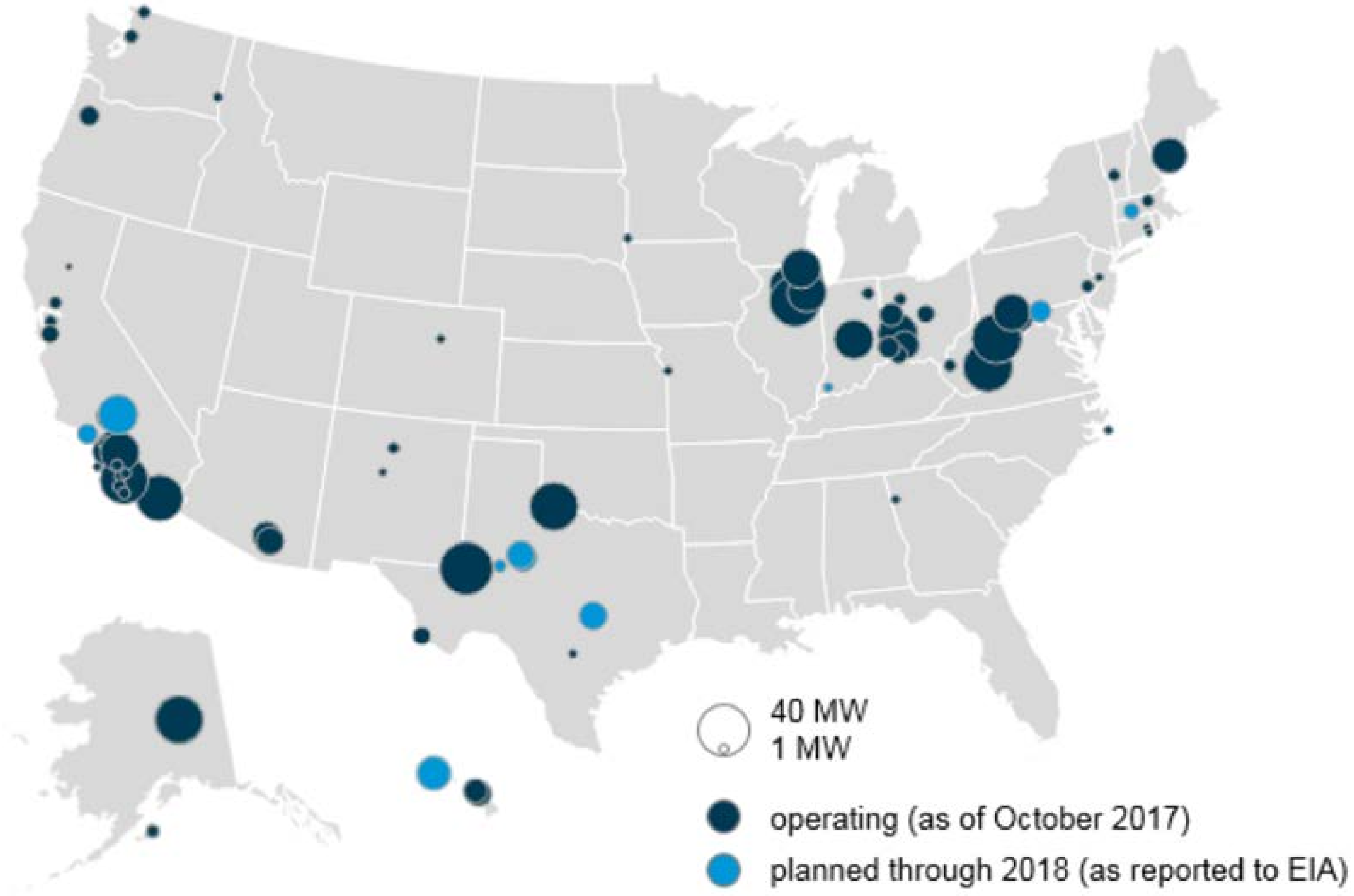
Source: *http://www.bbc.com/news/business-42090991*

US UTILITY – SCALE ANNUAL BATTERY INSTALLATIONS



Source: *EIA https://www.eia.gov/todayinenergy/detail.php?id=34432*

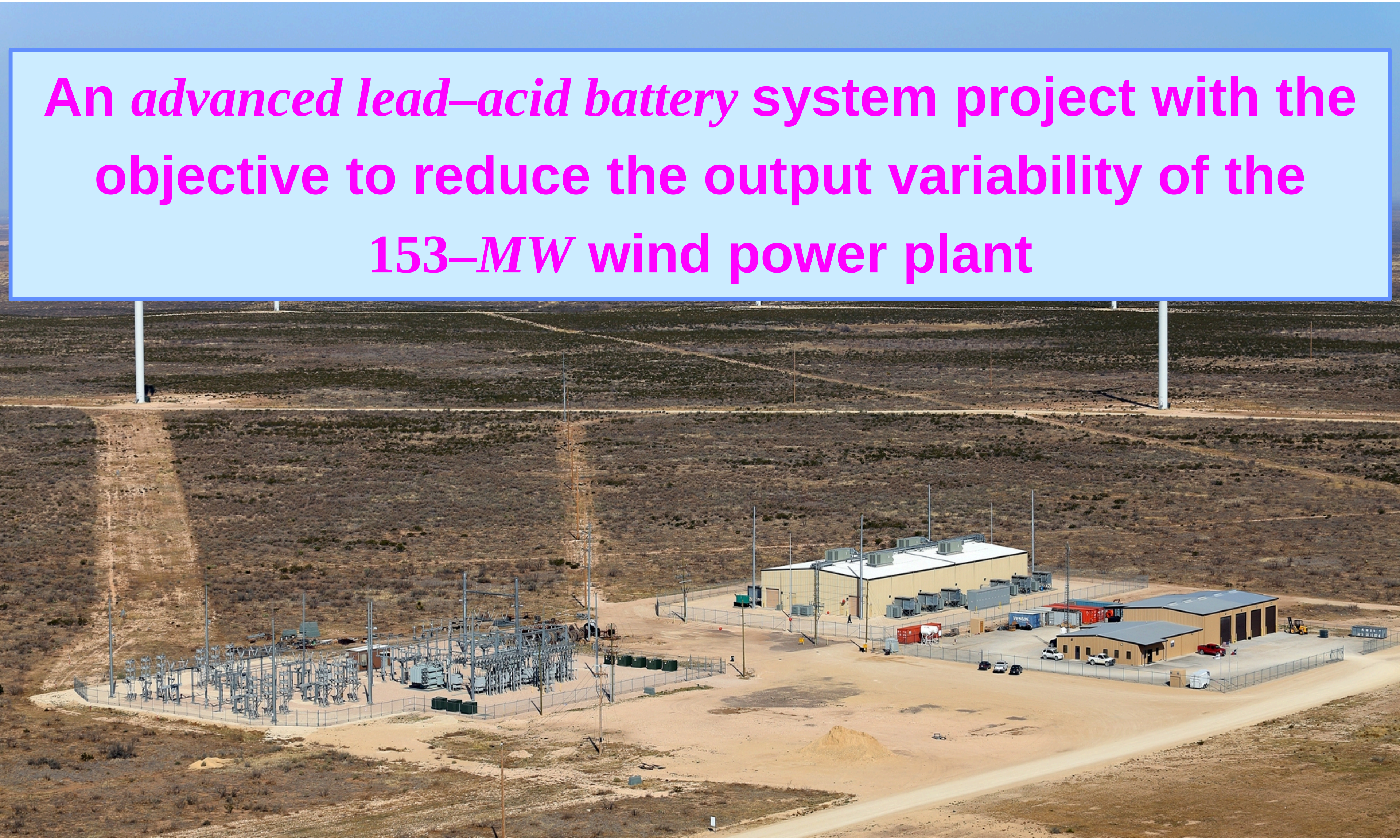
US UTILITY – SCALE BATTERY INSTALLATIONS



Source: *EIA https://www.eia.gov/todayinenergy/detail.php?id=34432*

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

An *advanced lead–acid battery* system project with the objective to reduce the output variability of the 153–*MW* wind power plant



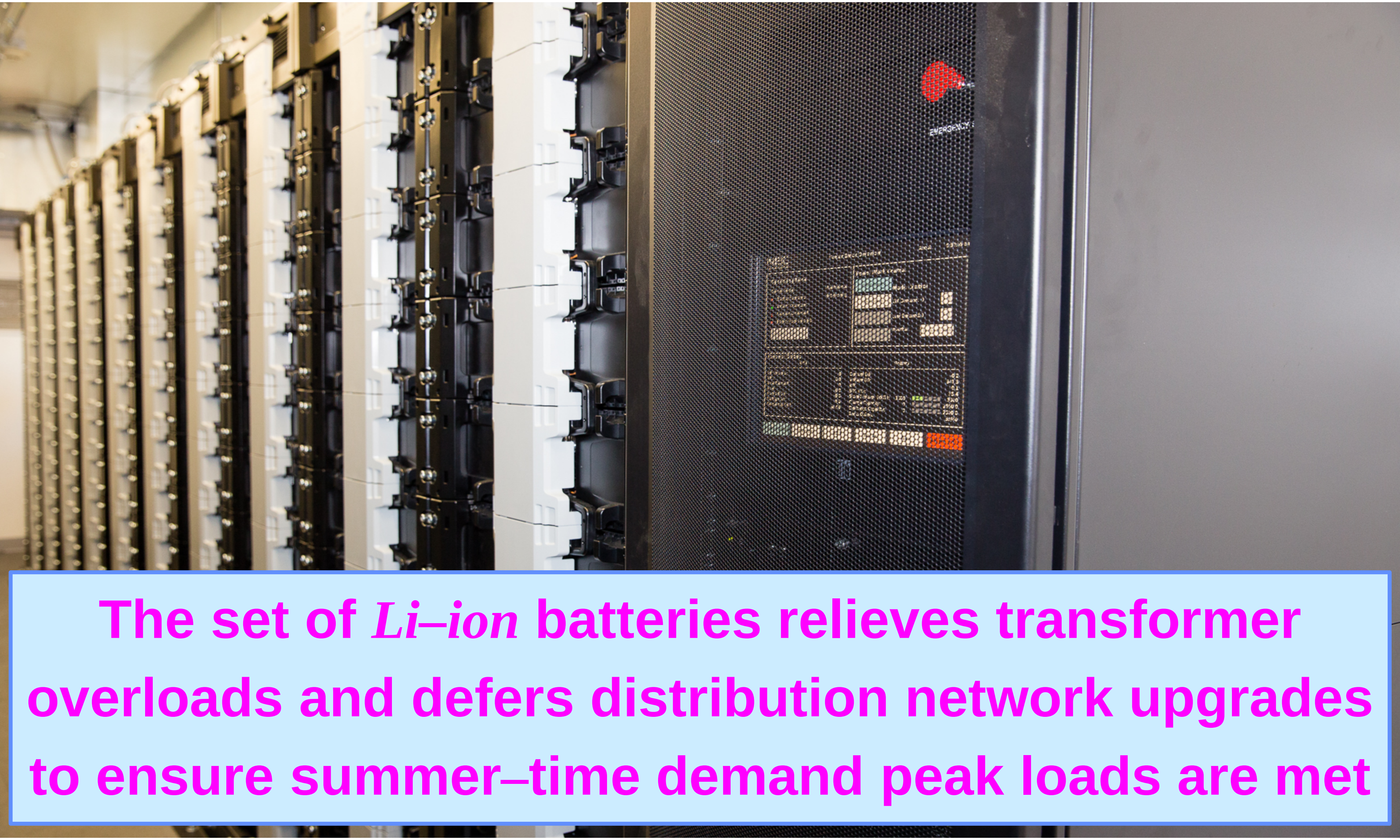
Source: http://www.energystorageexchange.org/projects

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

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

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

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



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

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

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

The world's largest *BESS* serves to provide demand – supply balance

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

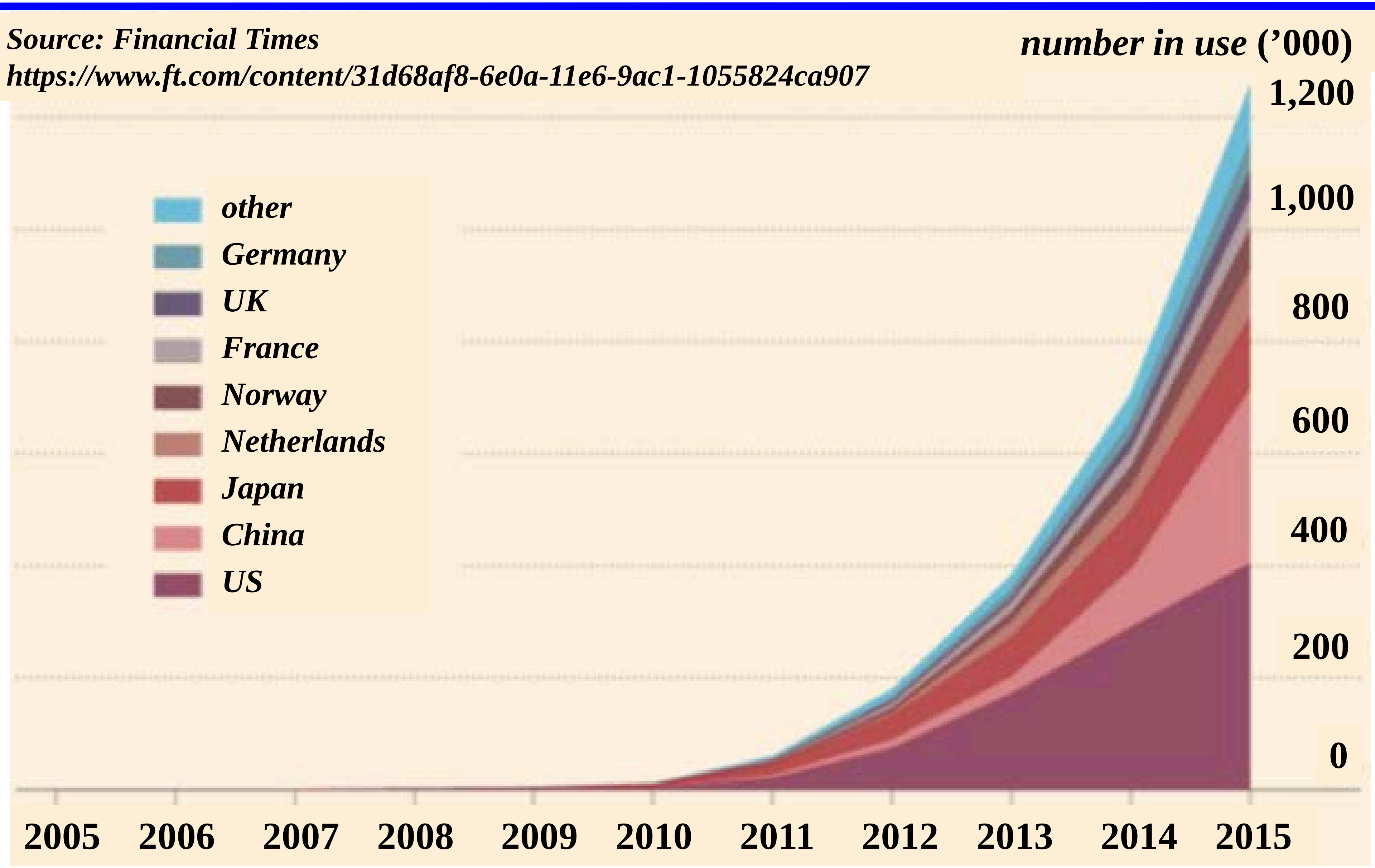
NEW PUSH IN *ESR* DEPLOYMENT

- **Advancements in storage technology, cost reduc–tions and regulatory initiatives have invigorated the interest in large–scale grid–connected *ESR*s**
- **The push to deeper renewable resource penetra–tions leads to the wider deployment of storage – as both a *distributed* and a *grid* resource**
- **Major deployments include utility–scale batteries, flywheels and battery vehicle (*BV*) aggregations**

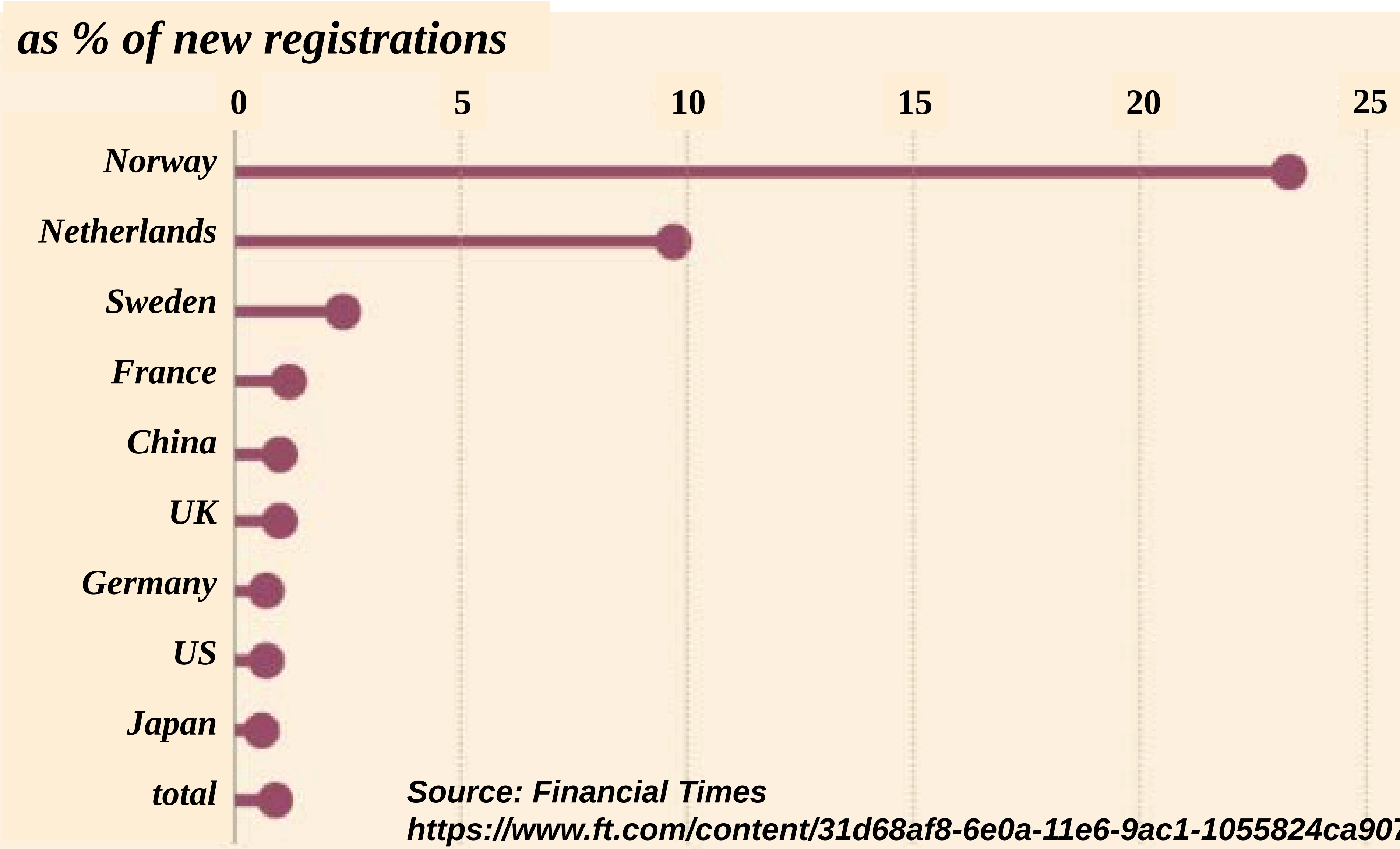
THE VEHICLE–TO–GRID (*V2G*) FRAMEWORK AS A PRACTICAL *ESR*

The use of bidirectional power flow interconnec–tions of the *BV*s under the *V2G* framework allows aggregations of *BV*s to constitute a storage project whose total capacity and capability can provide a valuable resource to the grid

EVs ON THE ROAD

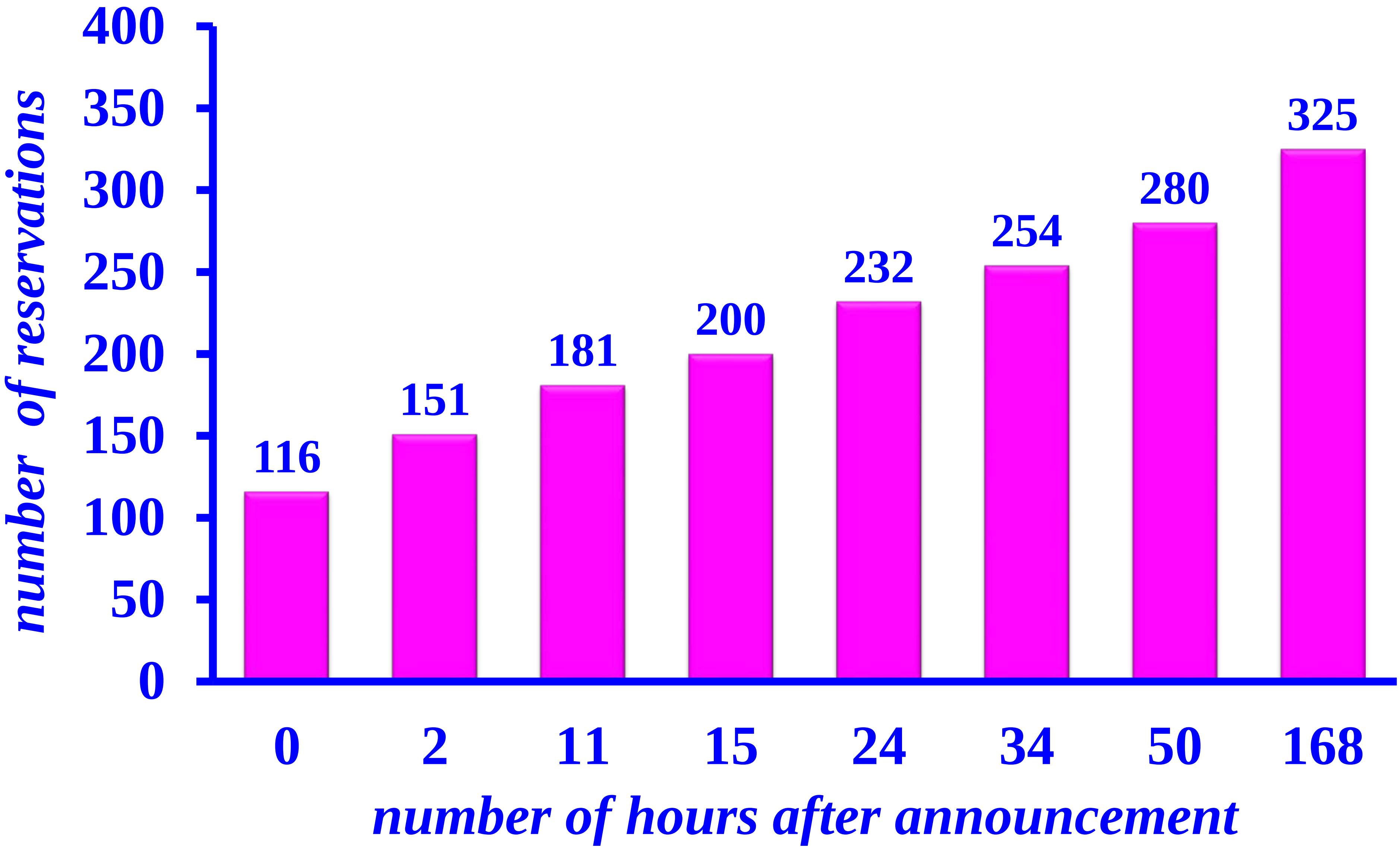


SALES OF NEW *EVs*



Source: Financial Times
https://www.ft.com/content/31d68af8-6e0a-11e6-9ac1-1055824ca907

TESLA MODEL 3 RESERVATIONS



Source: http://electrek.co/2016/04/03/tesla-model-3-reservations-timeline/, issued April 2015

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

OREGON
IDAHO
UTAH
CALIFORNIA
NEVADA
ARIZONA
MEXICO
PACIFIC OCEAN
N
0 50 100 Mi
REDWOOD NP
WHISKEYTOWN-SHASTA-TRINITY NRA
LASSEN VOLCANIC NP
YOSEMITE NP
KINGS CANYON NP
SEQUOIA NP
DEATH VALLEY NP
MOJAVE DESERT
MOJAVE NAT'L PRES
JOSHUA TREE NP
ANZA-BORREGO SP
CHANNEL ISLANDS NP
Redding
Reno
SACRAMENTO
Vallejo
Stockton
BERKELEY
SAN FRANCISCO
OAKLAND
SAN JOSÉ
Modesto
Merced
Madera
Fresno
Salinas
Bakersfield
Lancaster
Santa Barbara
Pasadena
San Bernardino
Riverside
LOS ANGELES
Santa Monica
Long Beach
Huntington Beach
Anaheim
Santa Ana
SAN DIEGO
TIJUANA
LAS VEGAS

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

CALIFORNIA

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

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

CALIFORNIA

163,696 ***square miles*; 3rd *largest US state by area*;**

4 % *of the size of Europe*

38 *million people*

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

CALIFORNIA

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

38 million people

electricity consumption is 8 % of US total of 293,269 GWh

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

CALIFORNIA PUSH FOR STORAGE DEPLOYMENT

- The *CA* government has recognized the significant role storage can play in the grid and the need for a bold move on storage to *drastically reduce the storage price* through a sharp increase in demand
- The recent *CPUC* mandate to deploy 1,325 *MW* of cost–effective energy storage by 2020 in California launches a *major 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 required 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 procure–ment 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* provides the framework with whose specifications the procurement and deployment of storage projects must comply

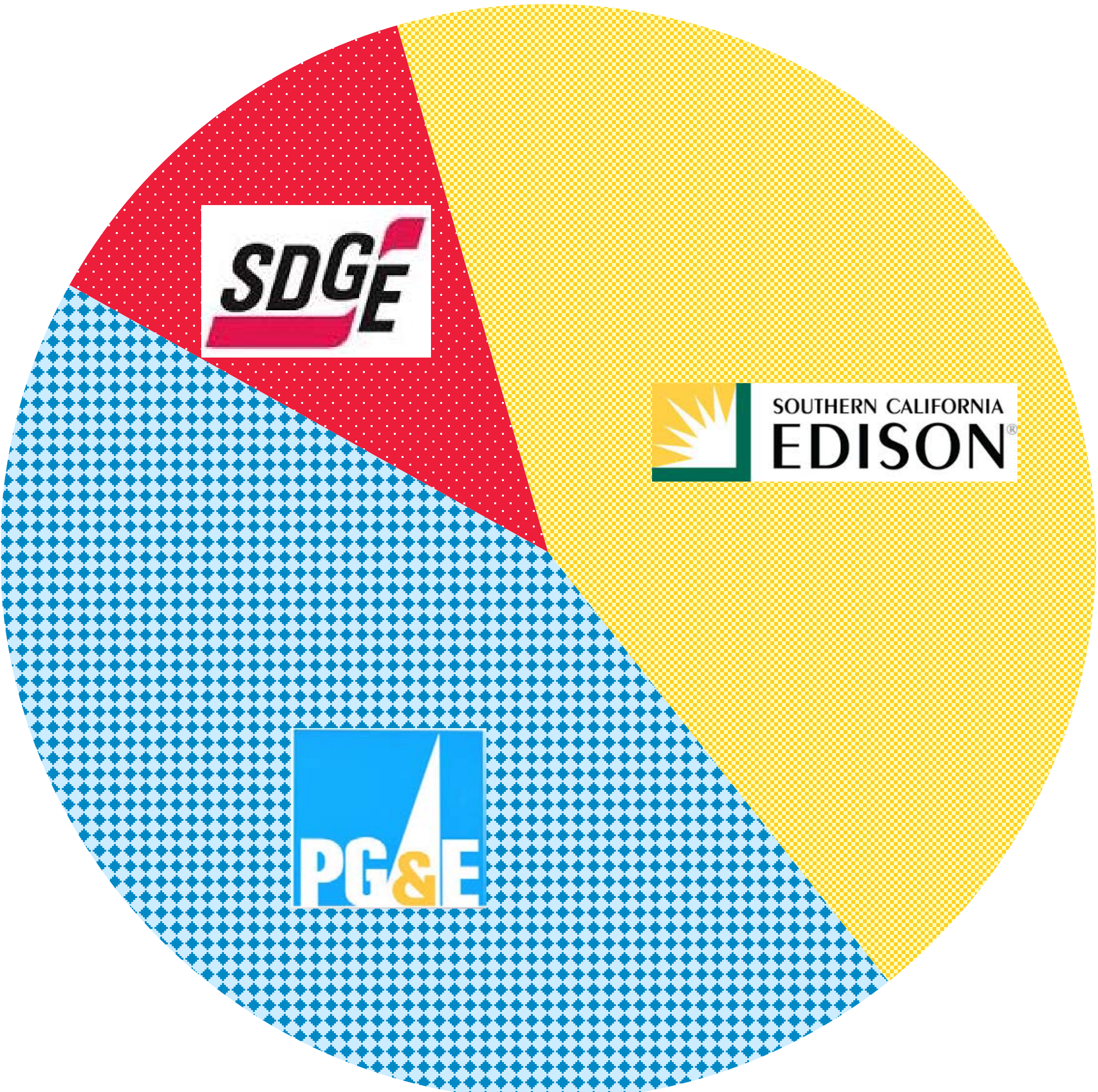
THE *CPUC* STORAGE PROCUREMENT FRAMEWORK SPECIFICATIONS

- Storage capacity targets for each of the 3 major *California IOU*s
- Procurement schedule for the authorized storage projects
- Storage capacity targets at 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:**
  - **shifts of the targets among the grid interconnection points**
  - **ownership of storage resources by *IOU*s, customers and third parties**
  - **deferral of *IOU* targets in the *CPUC*–specified schedule**

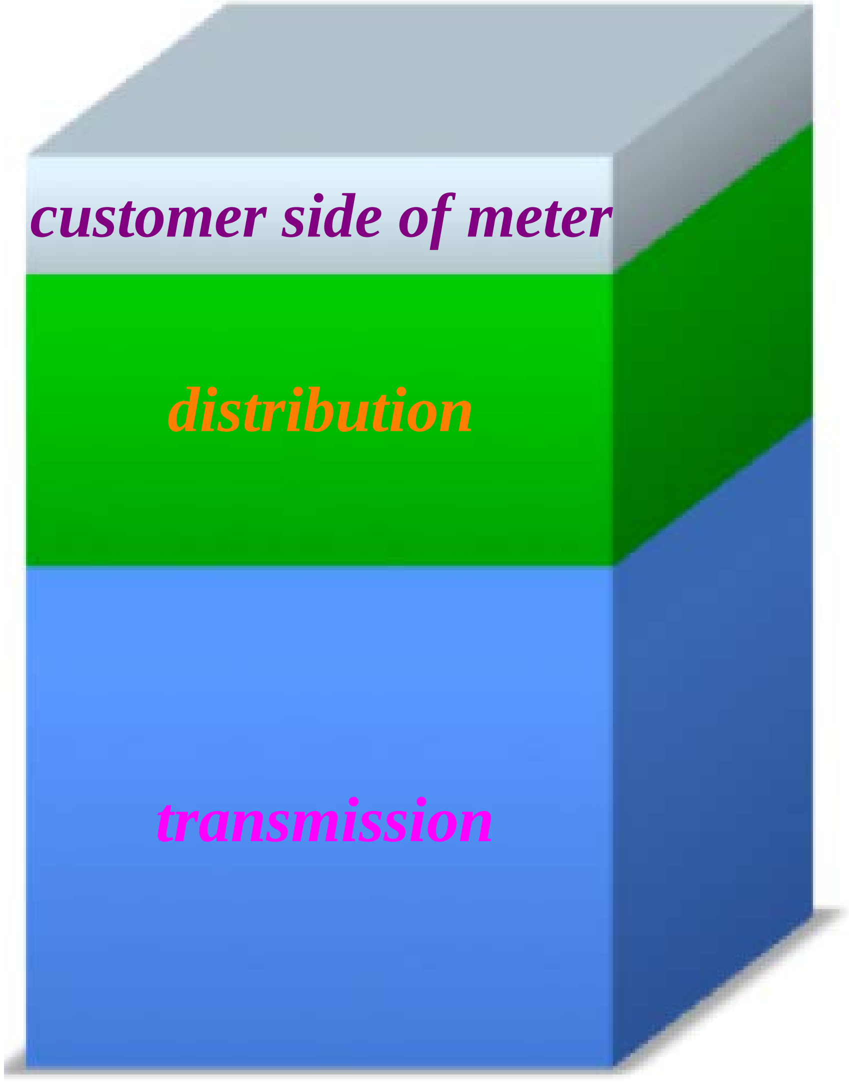
IOU STORAGE CAPACITY TARGETS



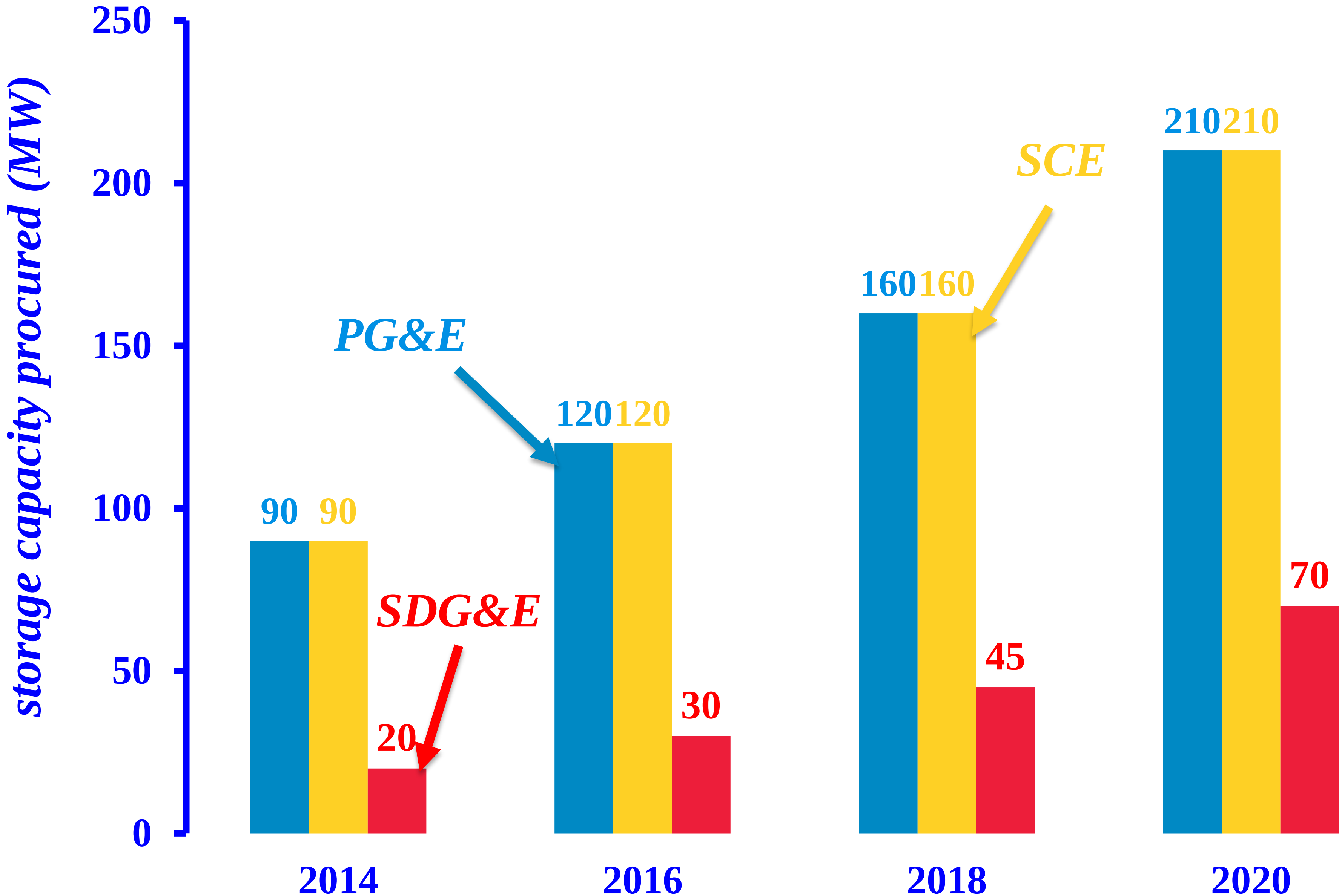
IOU	*target (MW)*	*%*
PG&E	580	43.77
SCE	580	43.77
SDG&E	165	12.26

STORAGE CAPACITY TARGETS AND GRID INTERCONNECTION POINTS

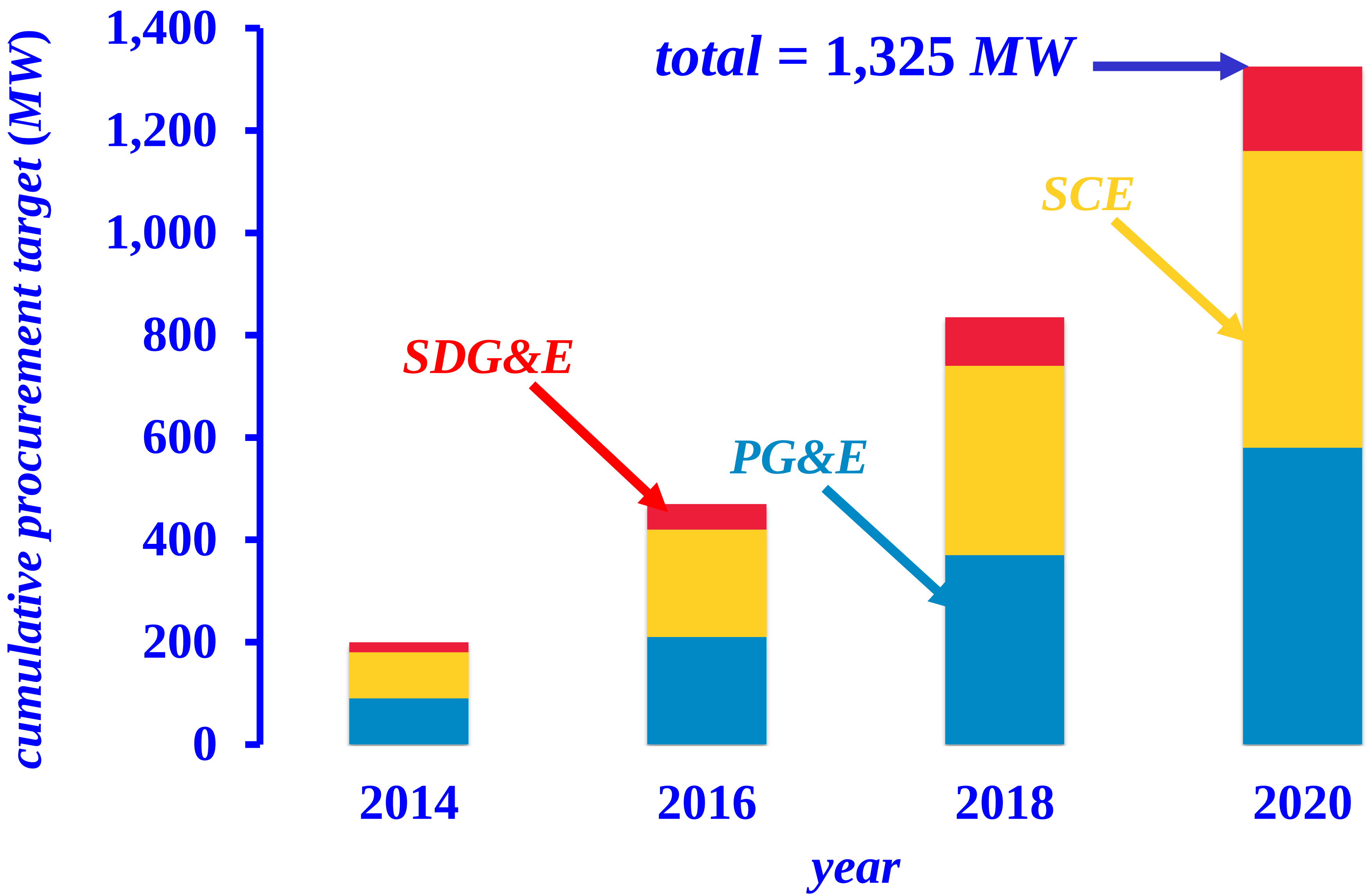
grid intercon–nection point	*target (MW)*	*%*
customer side of meter	200	15.09
distribution	425	32.08
transmission	700	52.83



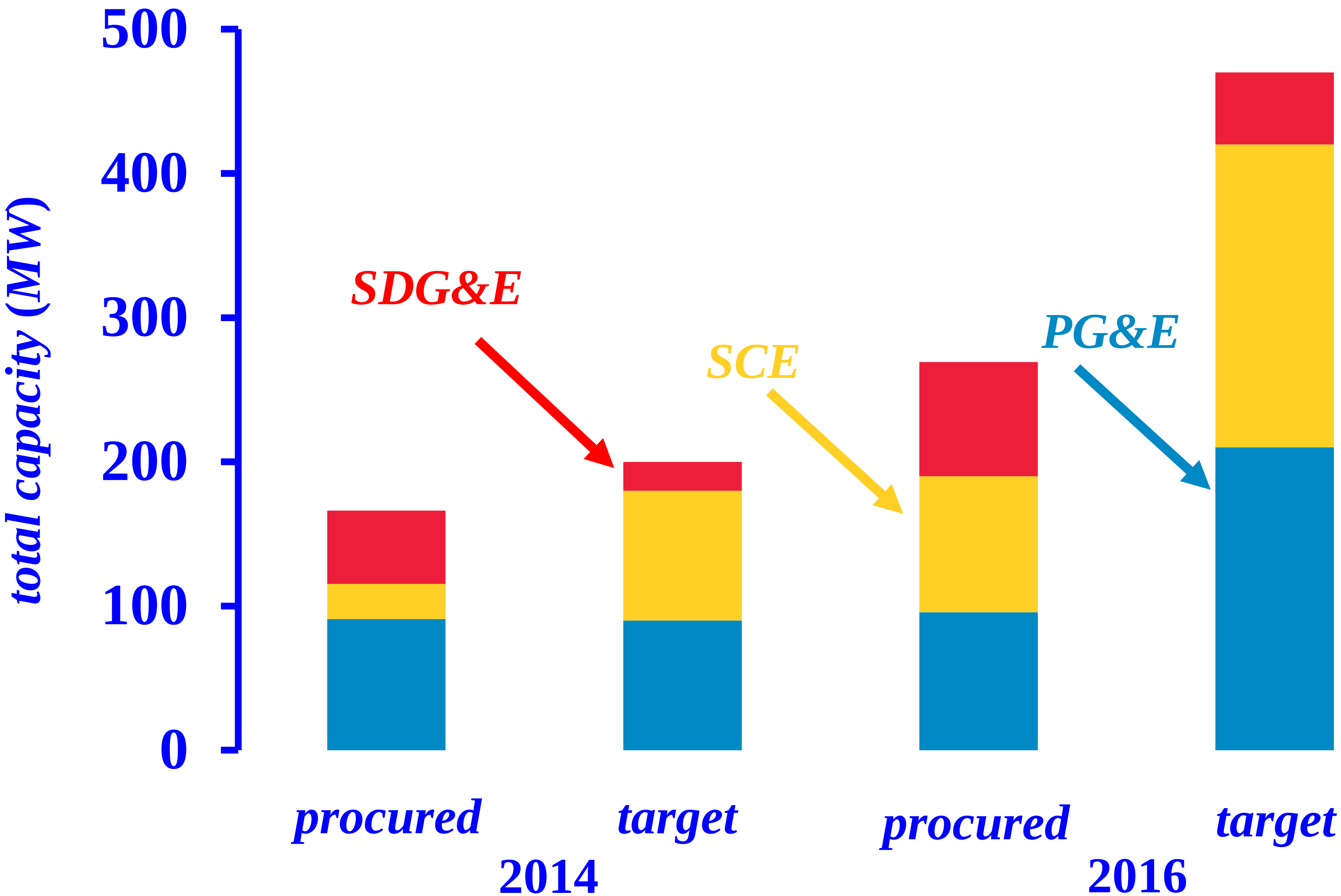
PROCUREMENT SCHEDULE



CUMULATIVE PROCURED CAPACITY



TOTAL PROCURED CAPACITY *VERSUS* TARGET CAPACITY



CPUC STORAGE PROCUREMENT FRAMEWORK FEATURES

- The procurement targets are mandated for each *IOU* and may not be traded among the *IOU*s
- Biannual procurement applications are to be filed by each *IOU* by March of each applicable year
- At least 50 % of each project approved to meet the targets must be owned by third parties, customers or joint third party/customer ownership

CPUC STORAGE PROCUREMENT FRAMEWORK FEATURES

- **The *CPUC* Decision 13-10-040 also sets the energy storage procurement targets for *Community Choice Aggregators* and the *Electric Service Providers* at 1 % of their year 2020 peak loads; projects must be initiated by 2020, with installation to be completed by the end of 2024**

CURRENT STATUS OF ENERGY STORAGE PROCUREMENT IN *CA*

- **There has been an upsurge in behind–the–meter projects that have helped the *IOU*s meet some of their *T&D* storage targets in 2016 and 2017**
- **Each *IOU* has invested also in large battery *ESR* projects, currently under construction; the timely completion of these projects is required to meet the target of each *IOU***

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

56 × →

18 × →

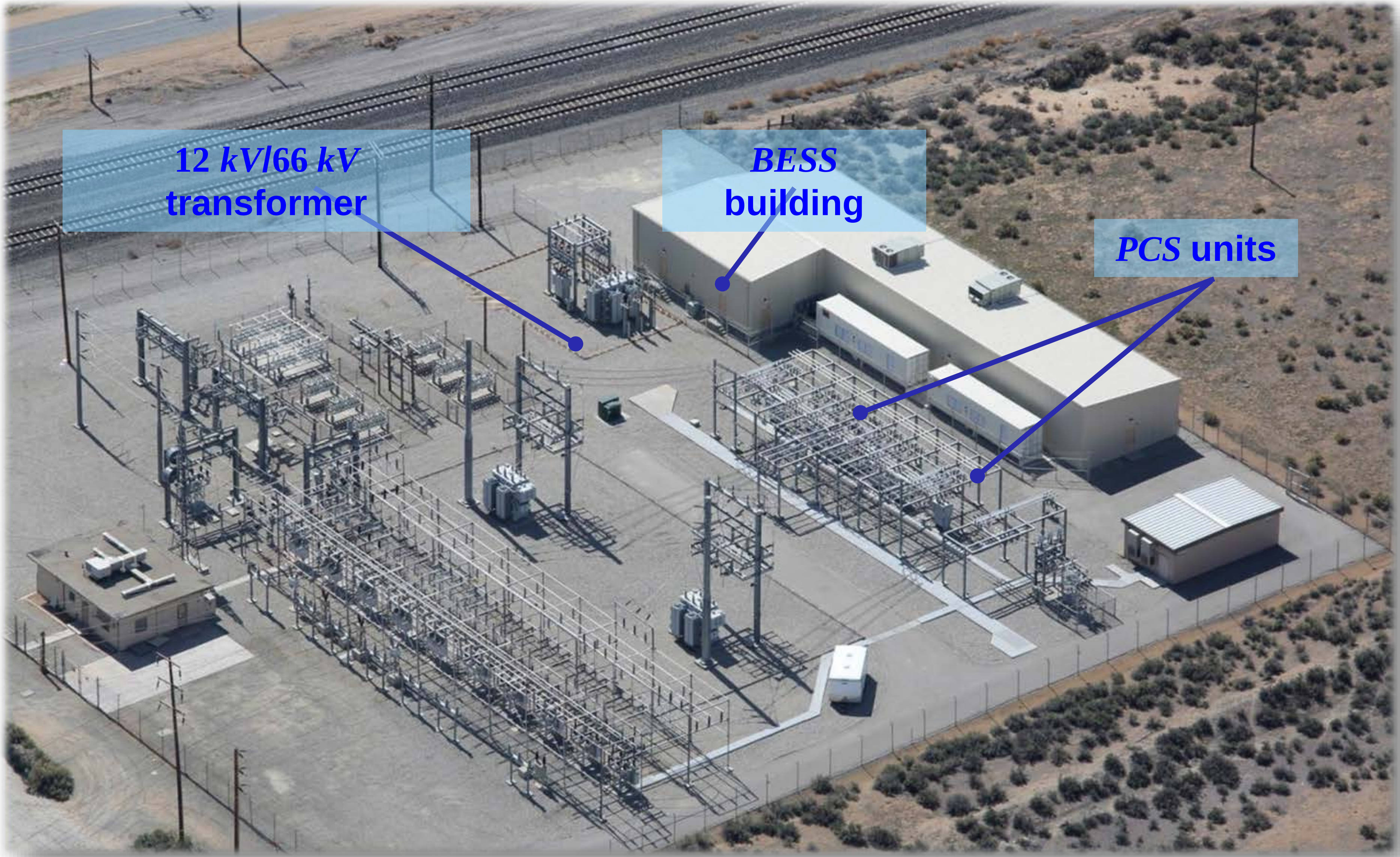
151 × →

4 × →

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

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

LARGE – SCALE *ESR*



Source : SCE

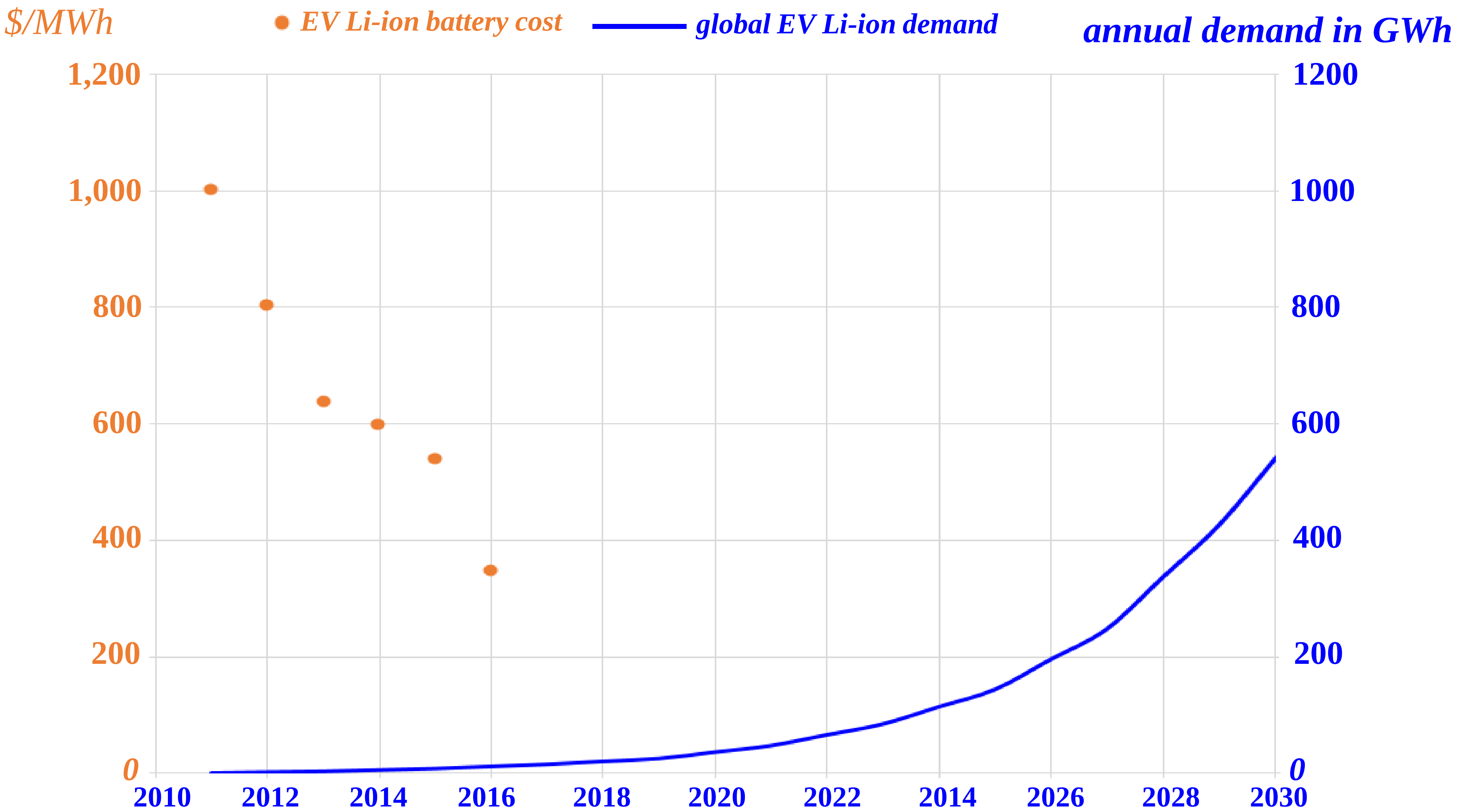
CPUC DECISION RAMIFICATIONS

- **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 Decision* stimulus to reduce *ESR* costs by increased demand is likely to reappear in many other venues to promote wider *ESR***

OPPORTUNITIES FOR LARGE–SCALE *ESR*s

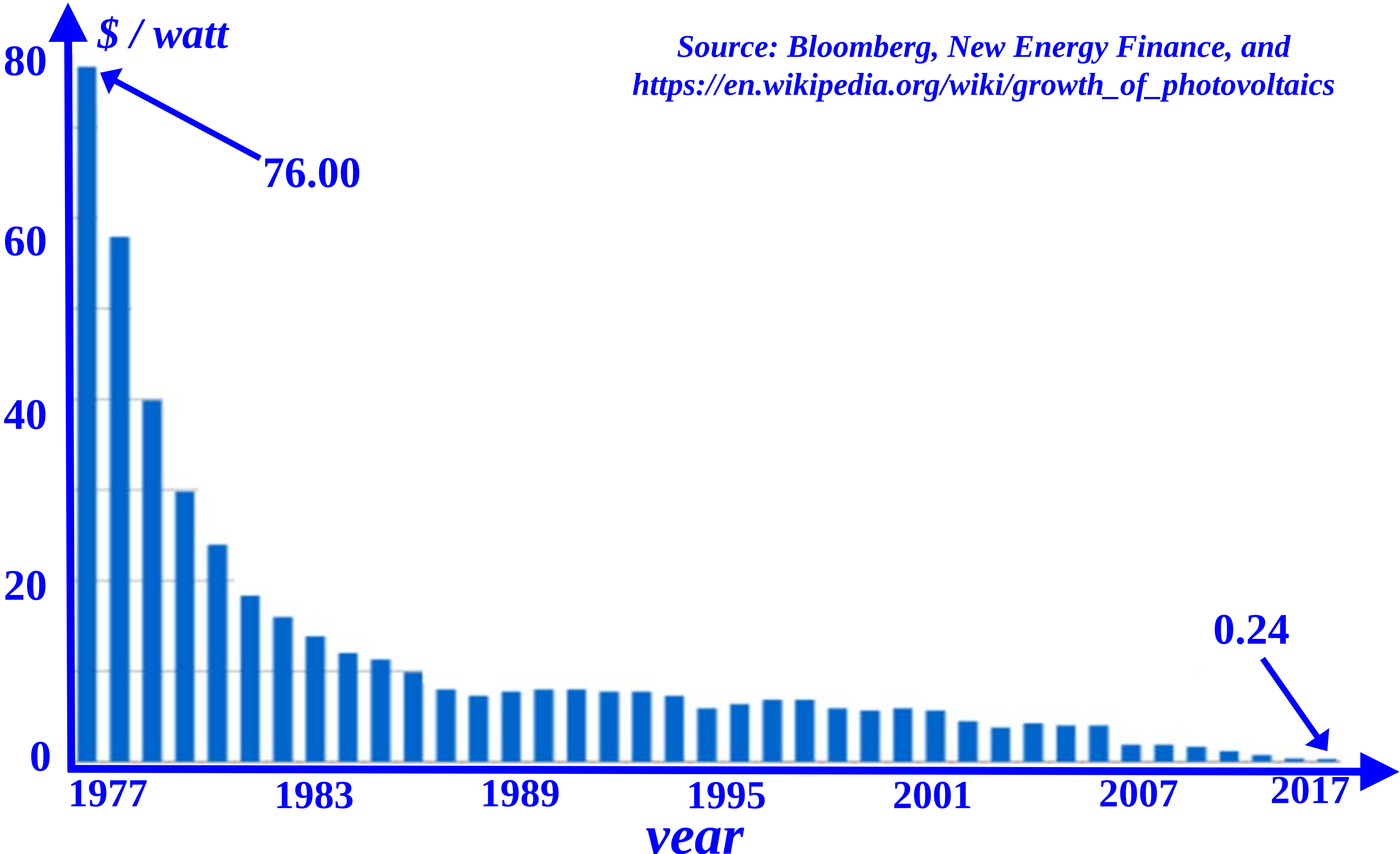
- The *CPUC Decision* is paving the way for new opportunities in the storage sector
- The need for storage to meet the *CPUC* mandate creates a strong push in the storage market and considerably weakens the reluctance to invest in the storage sector
- A key example is the new *TESLA Gigafactory*, the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

Li – ION BATTERY PRICES AND DEMAND



Source: Bloomberg New Energy Finance
https://www.bloomberg.com/news/articles/2016-06-13/batteries-storing-power-seen-as-big-as-rooftop-solar-in-12-years

WILL STORAGE FOLLOW THE PATH OF *PV* SOLAR CAPACITY COSTS ?



CHALLENGES TO LARGE–SCALE STORAGE DEPLOYMENT

- **The deployment of large–scale *ESR*s brings forth many *economic, regulatory and technical challenges* that must be overcome to effectively harness the myriad benefits such resources provide**
- **While the of large–scale *ESR* implementations are certainly beneficial to grid operations, the actual quantification of the various benefits and impacts and their allocation to the *ISO*, the *ESR* owners and the customers is a very difficult problem**

GRAND CHALLENGES

challenge	*operations*	*planning*	*market design*	*policy*
analytic framework	✓	✓	✓	✓
appropriate metrics	✓	✓	✓	
new tools	✓	✓	✓	✓
battery life estimation	✓	✓		

GRAND CHALLENGES

challenge	*operations*	*planning*	*market design*	*policy*
battery data analytics	✓	✓	✓	
limitations to large–scale deployment	✓	✓	✓	✓
symbiosis of ESR and DRR	✓	✓	✓	✓
environmental impacts	✓	✓	✓	✓

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 facilitate such paths
- The *CA* mandate may provide 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**