ECE 333 – GREEN ELECTRIC ENERGY

19. Energy Storage Resources

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OUTLINE

- The critical importance of energy storage
- *ESR* roles and applications to power systems
- The current status of storage
- The California push for storage deployment
- Other state and federal regulatory developments
- The opportunities and the challenges ahead

ESRs 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* at all points in time
- Storage provides considerable, added flexibility to maintain demand–supply balance *around the clock*

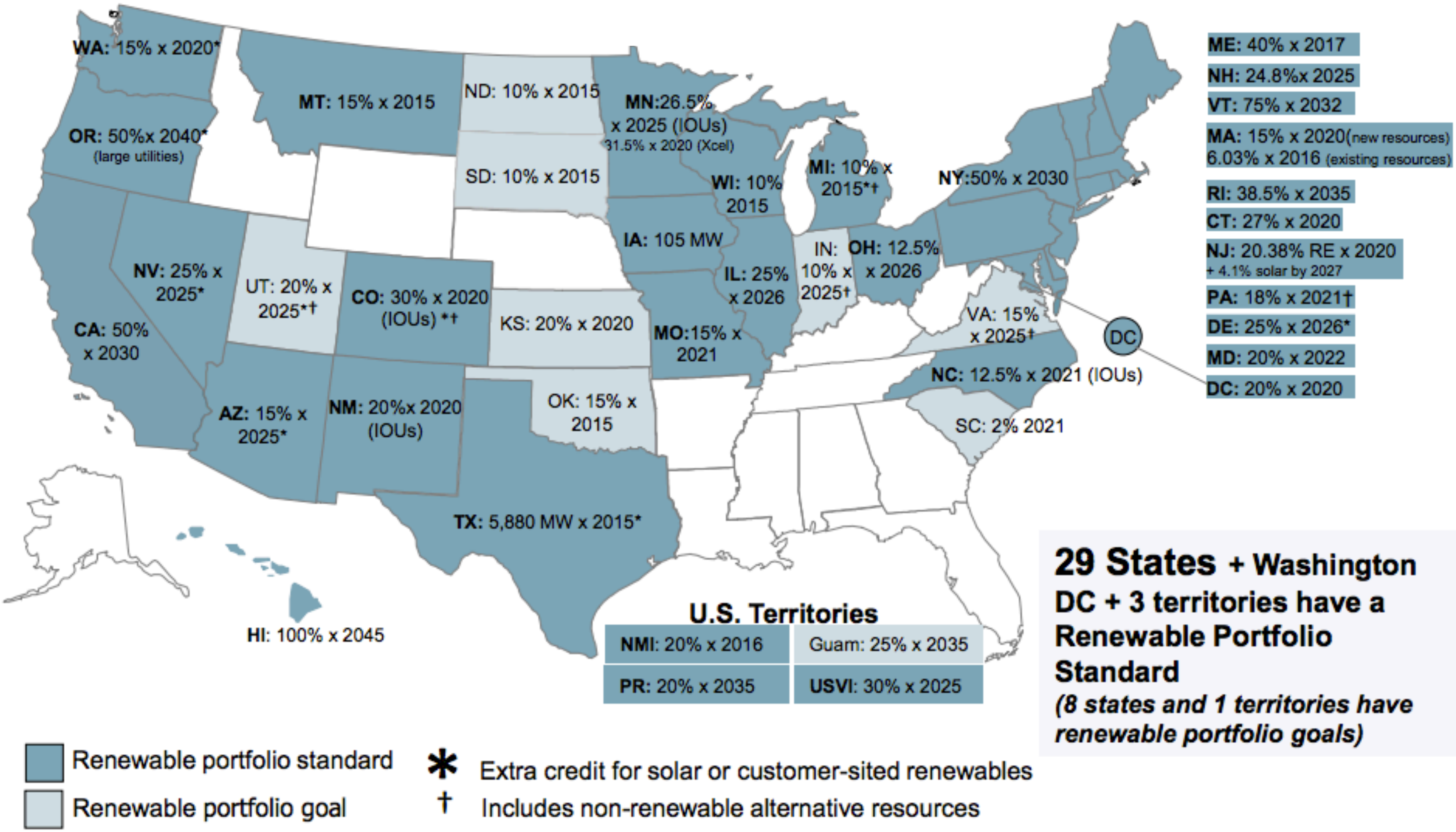
CHANGING REALITY IN POWER SYSTEMS

- **Climate change impacts** 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 bring about a greener environment

RENEWABLE PORTFOLIO STANDARDS

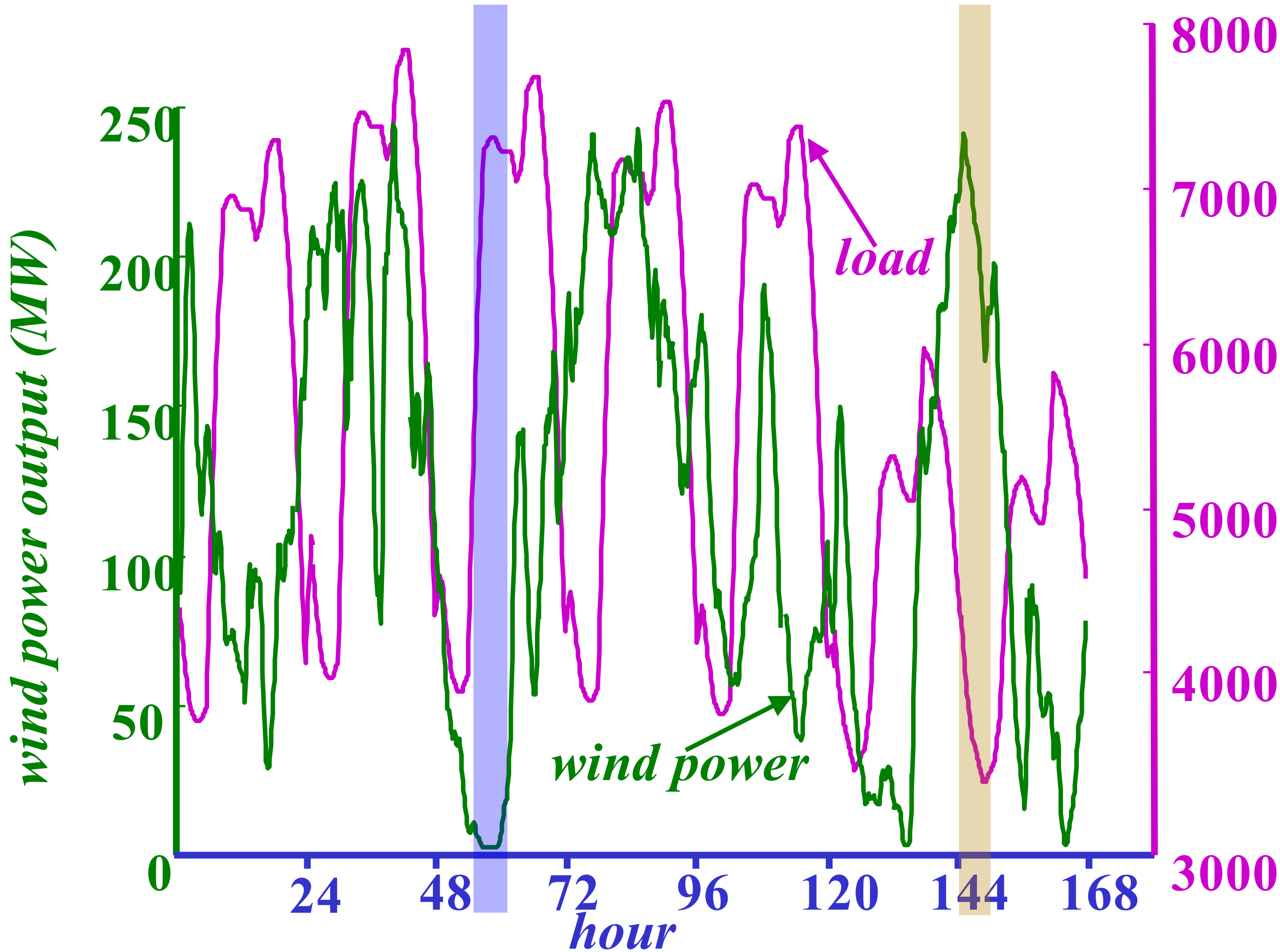
- **States have been active in the adoption of *renewable portfolio standards* (*RPS*) – 29 states, *DC*, and 3 *territories* have adopted such standards**
- ***RPS* require a specified percentage or amount of renewable electricity – typically in terms of *MWh* – by the specified date that must be met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

RENEWABLE PORTFOLIO STANDARDS (RPS)

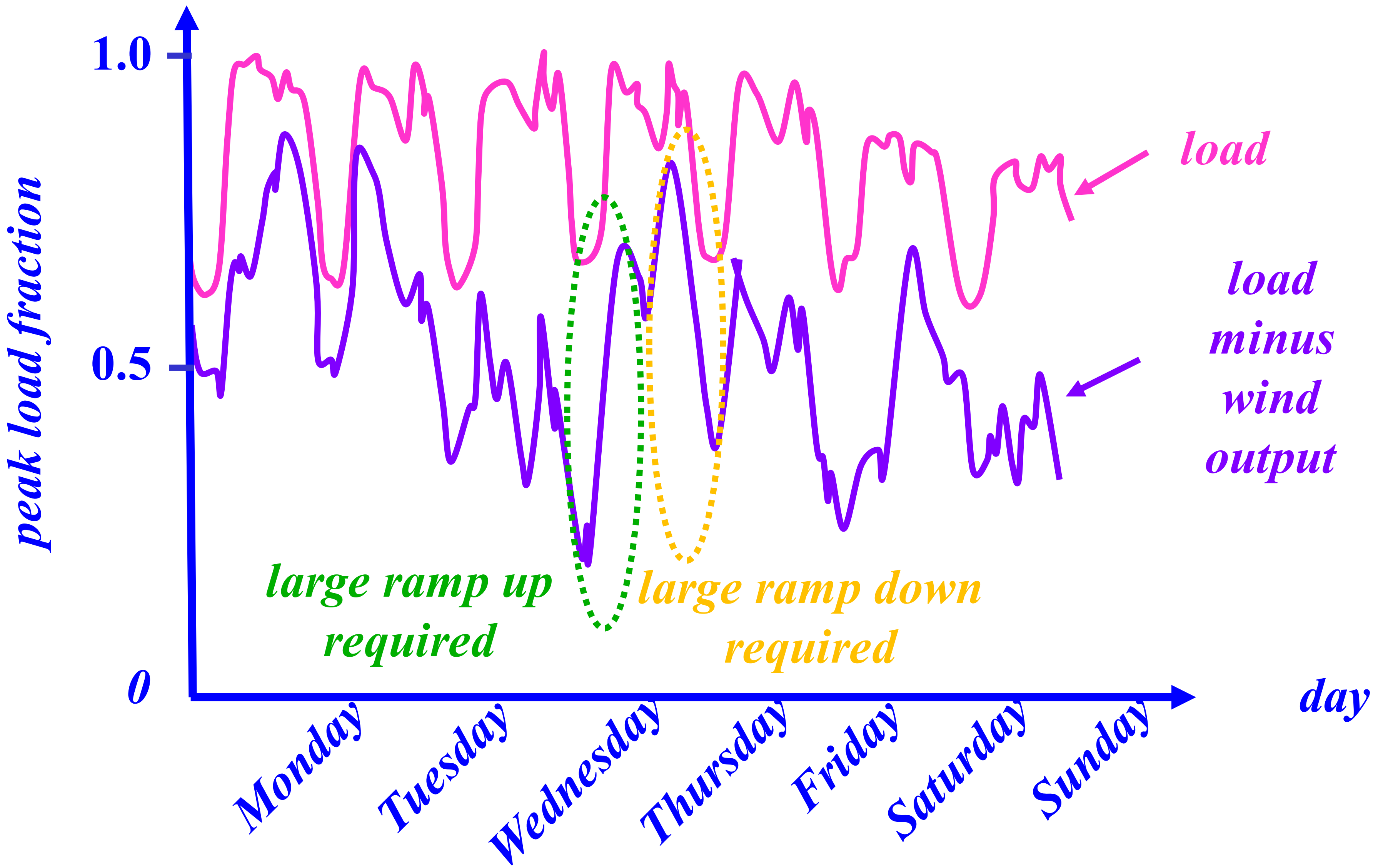


Source: http://www.dsireusa.org/resources/detailed-summary-maps/; February 2017

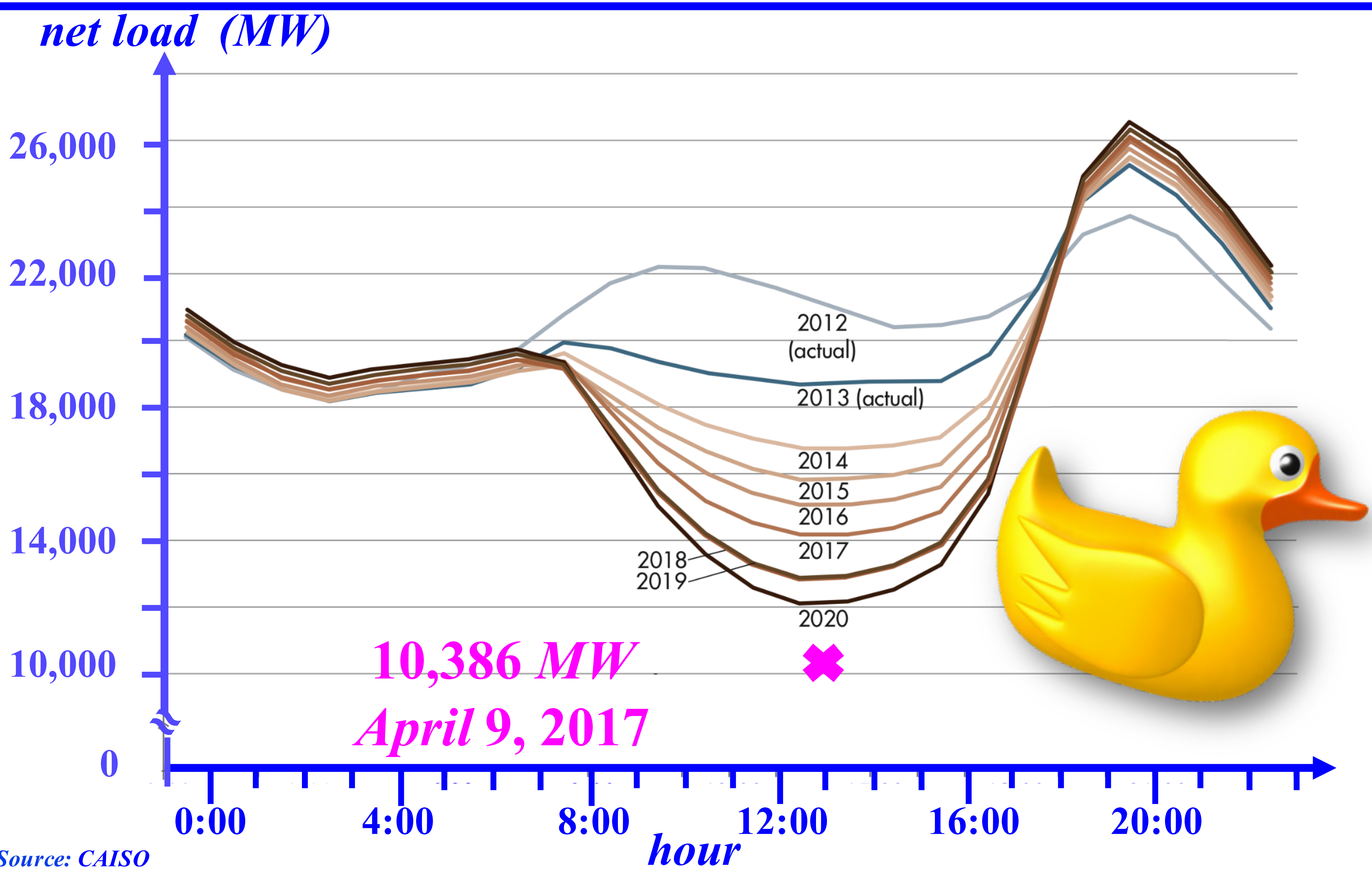
MISALIGNMENT OF WIND POWER OUTPUT AND LOAD



NEED FOR LARGER AND FASTER RAMPING RESERVES

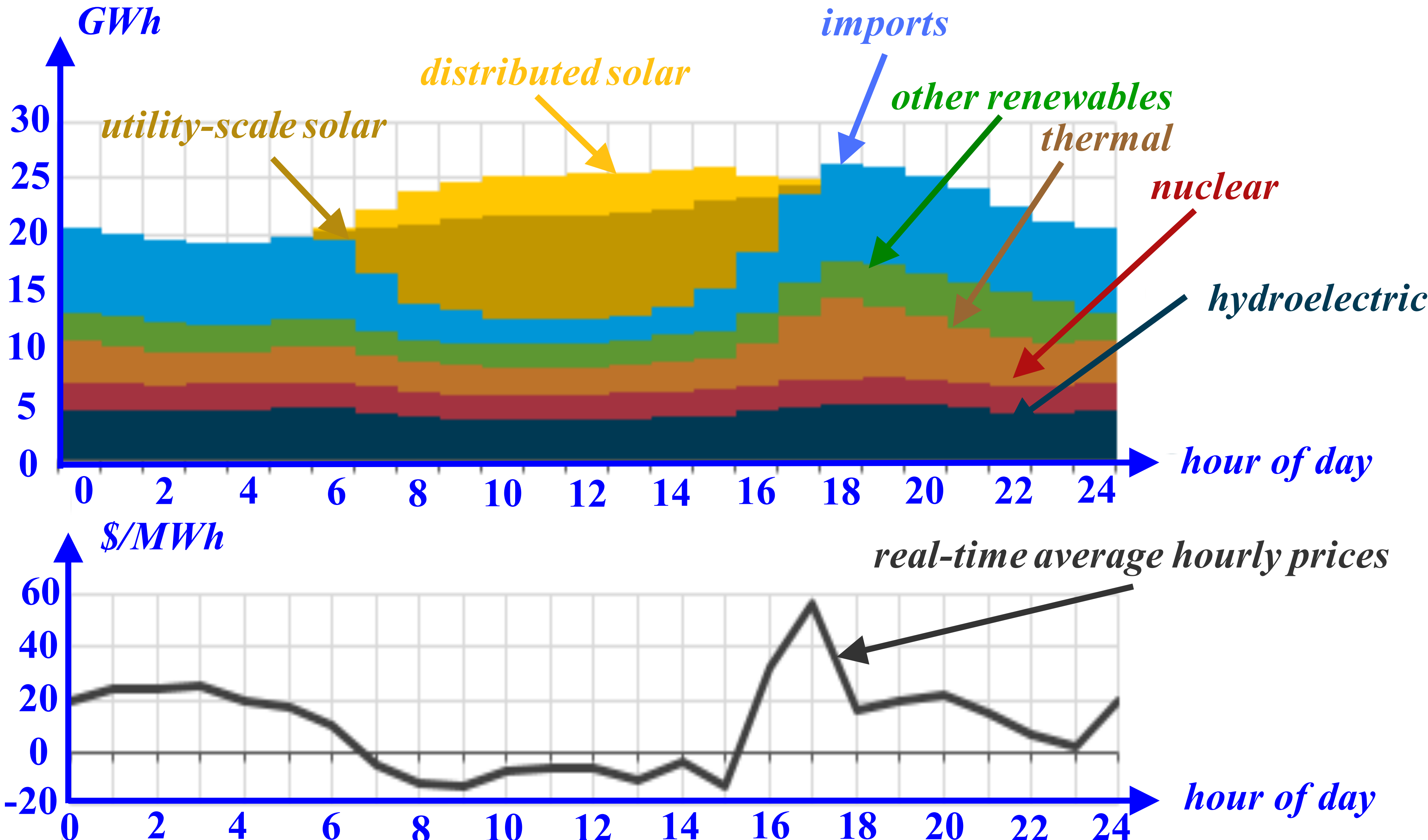


CAISO DAILY NET LOAD CURVE UNDER DEEPENING PENETRATION



Source: CAISO

CALIFORNIA ROOFTOP SOLAR IMPACTS: MARCH 11, 2017

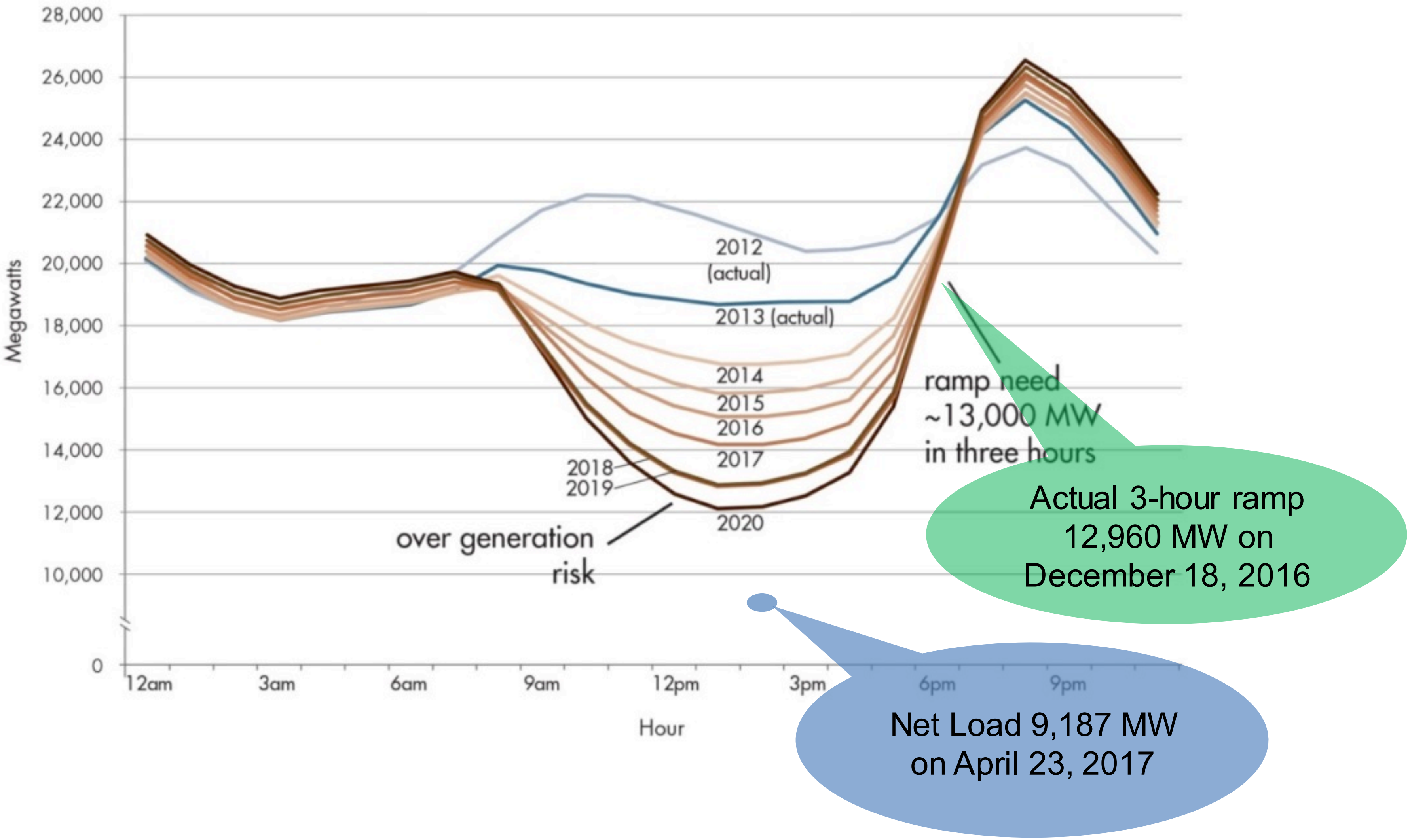


Source: US EIA based on https://www.eia.gov/electricity/data/eia861m/index.html and http://www.caiso.co

NET LOAD IN *CALIFORNIA* IN SPRING 2017

- *CAISO* recorded a 147 % increase in renewable curtailment from the first quarter of 2016 to the first quarter of 2017
- In the first quarter of 2017, about 3 % of the total potential wind and solar generation was curtailed, and about 1 % of the total potential renewable generation was curtailed
- On March 11, 2017, the solar curtailment exceeded 30 % of the solar production for an hour

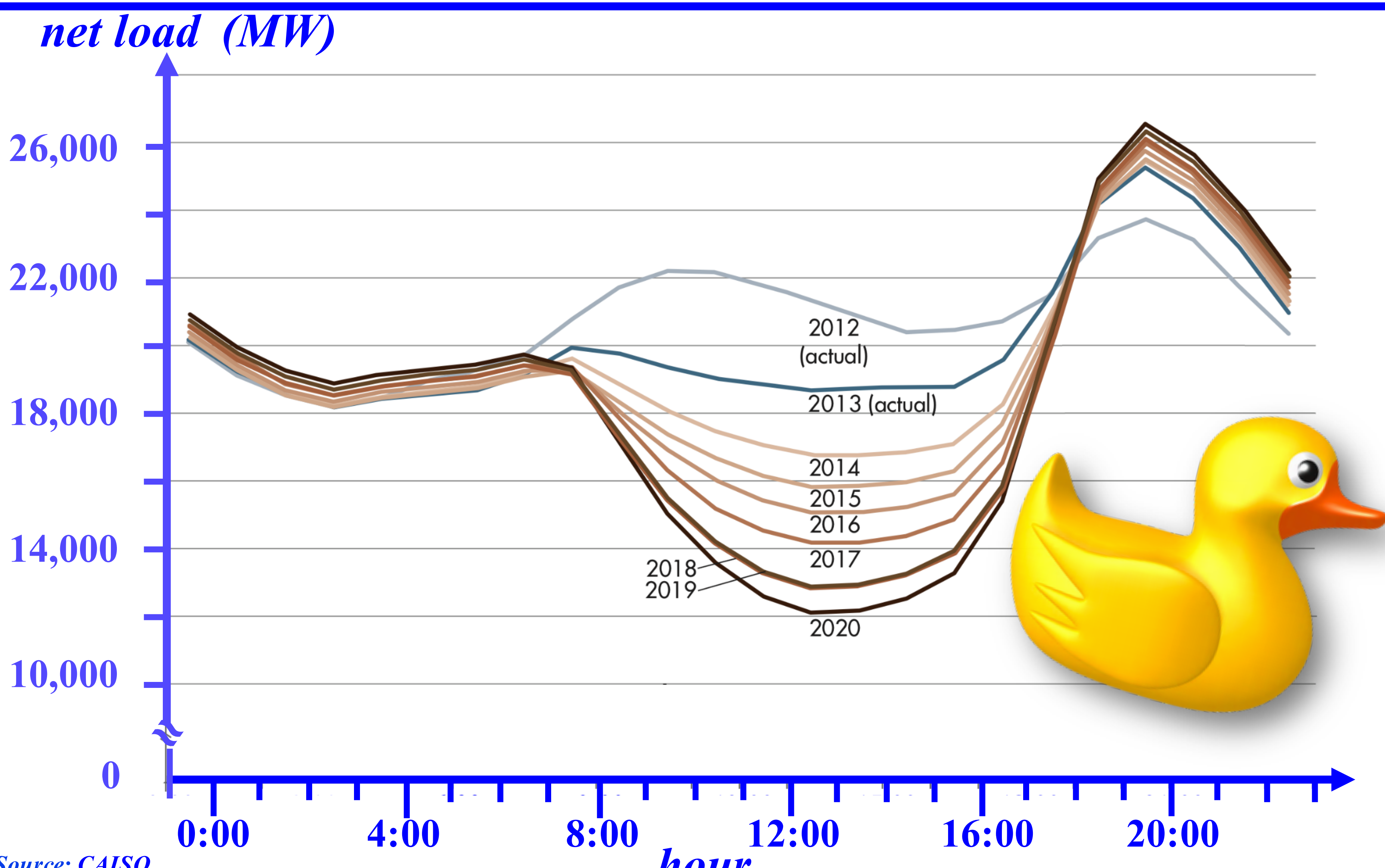
CAISO DAILY *NET LOAD* CURVE UNDER DEEPENING PENETRATION



NET LOAD IN CALIFORNIA IN SPRING 2017

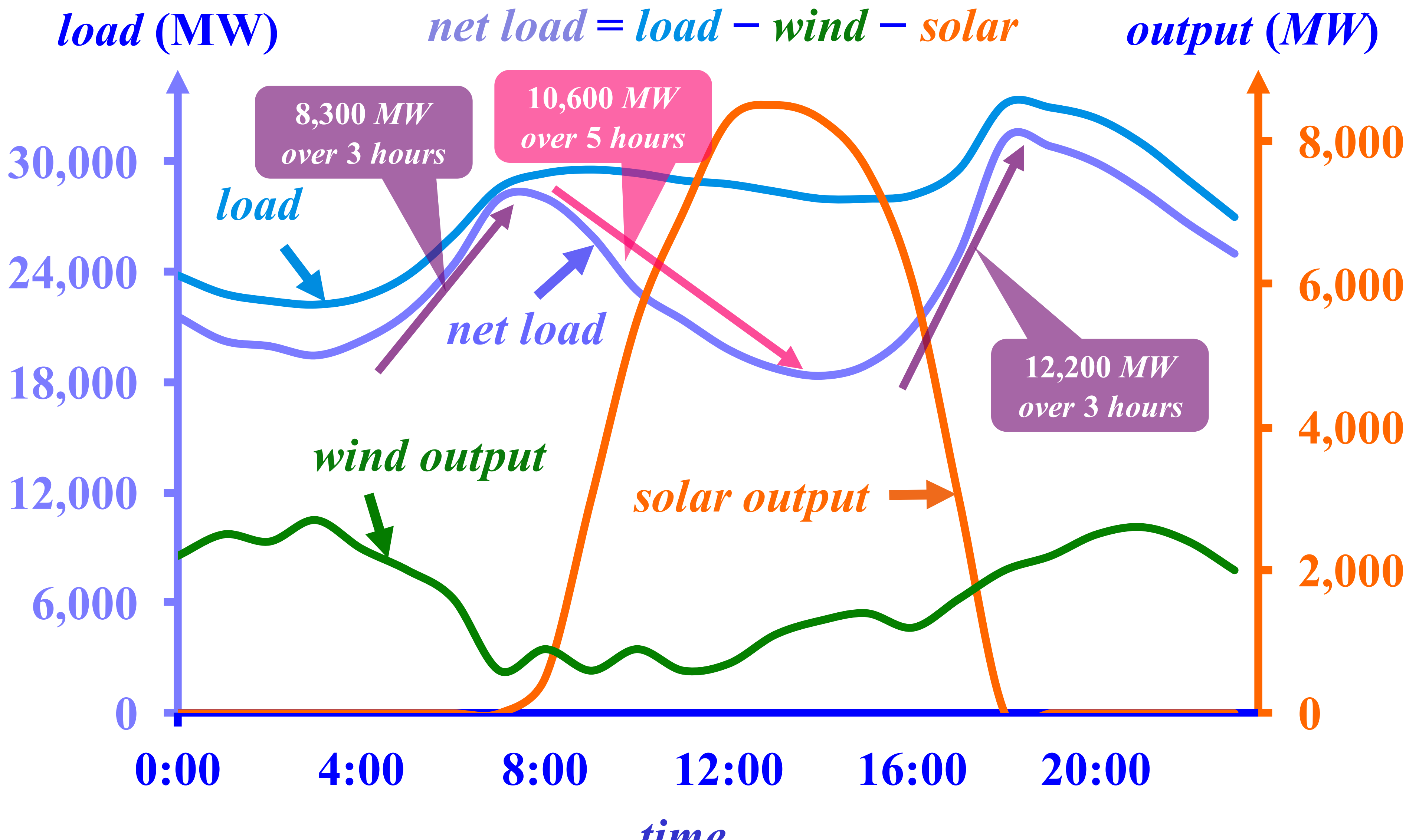
- **On April 23, 2017, the *CAISO net load* of 9,187 *MW* was 2,800 *MW* below the forecasted *net load* for a typical spring day in 2020**
- **Such a low *net load* is, in part, due to the strong hydropower generation in 2017 compared to that in previous years, as *California* has not had such a good hydro situation since 2011 and with markedly high capacity derates – as much as 4,000 *MW* – during the past five years**

CAISO DAILY *NET LOAD* CURVE UNDER DEEPENING PENETRATION

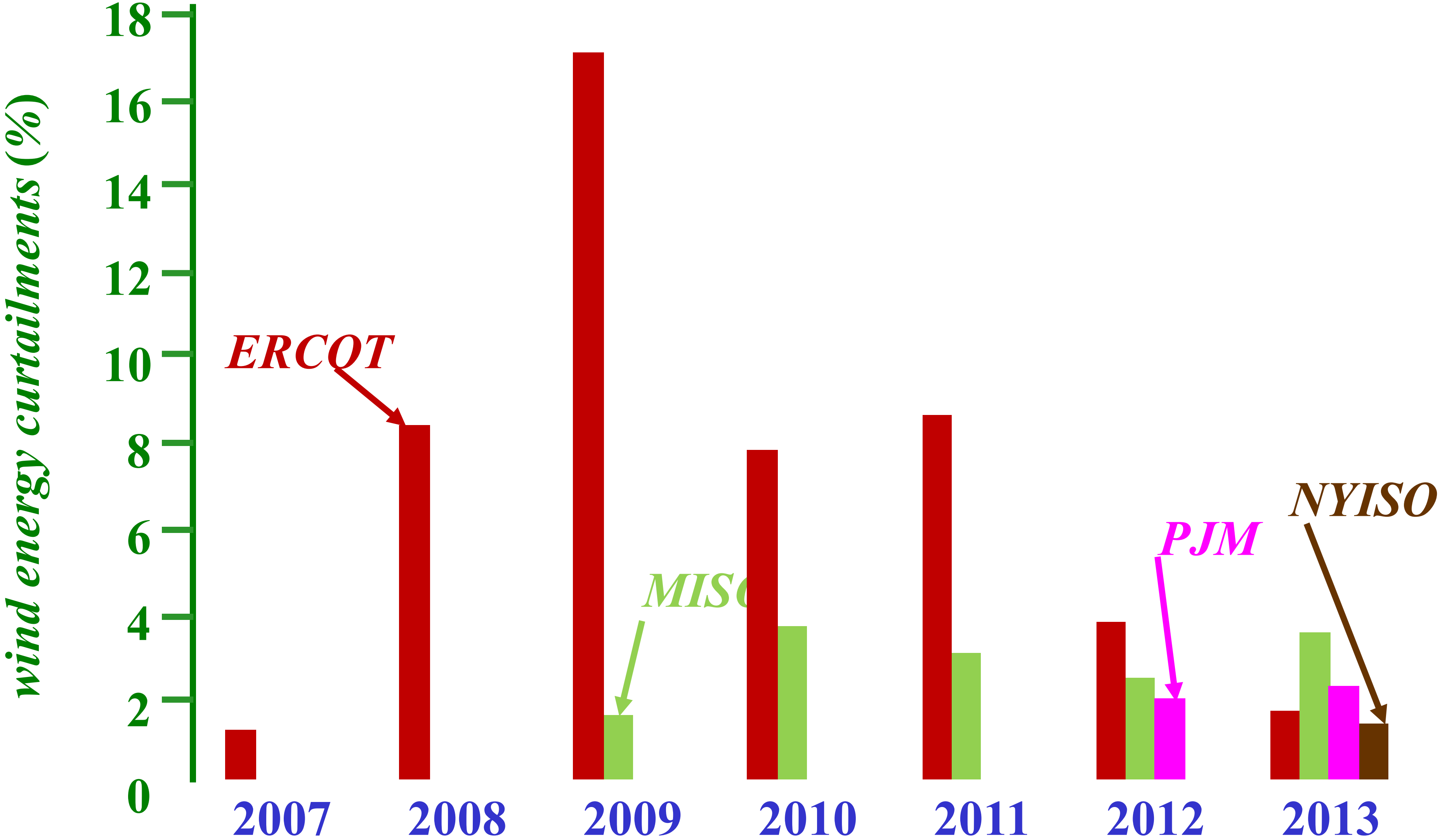


Source: CAISO

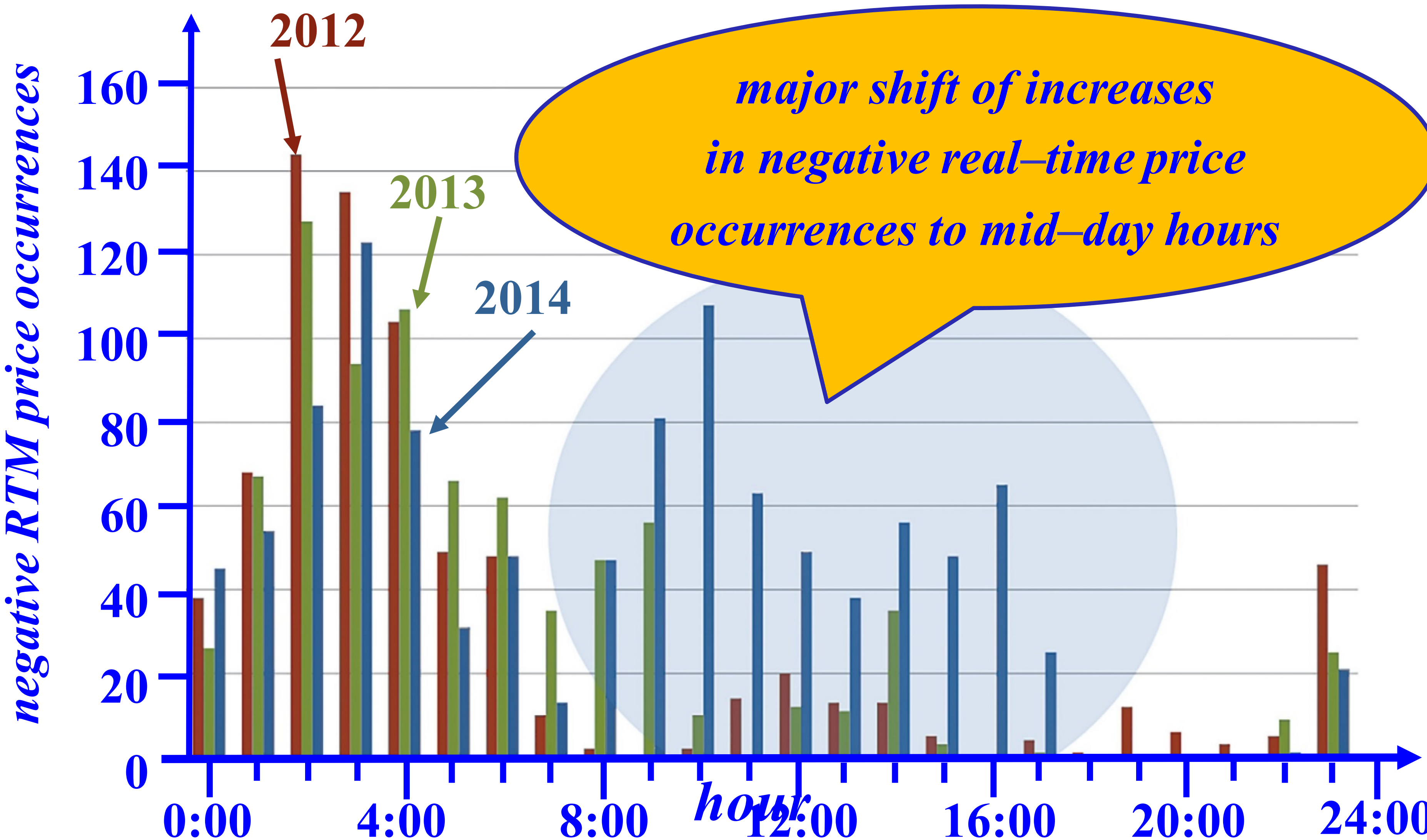
INCREASED FLEXIBILITY NEEDS



CURTAILMENT PERCENTAGES OF WIND GENERATION : 2007 – 2013



CAISO NEGATIVE *RTM* PRICES



PRINCIPAL ROLES *ESRs* 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

- In 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

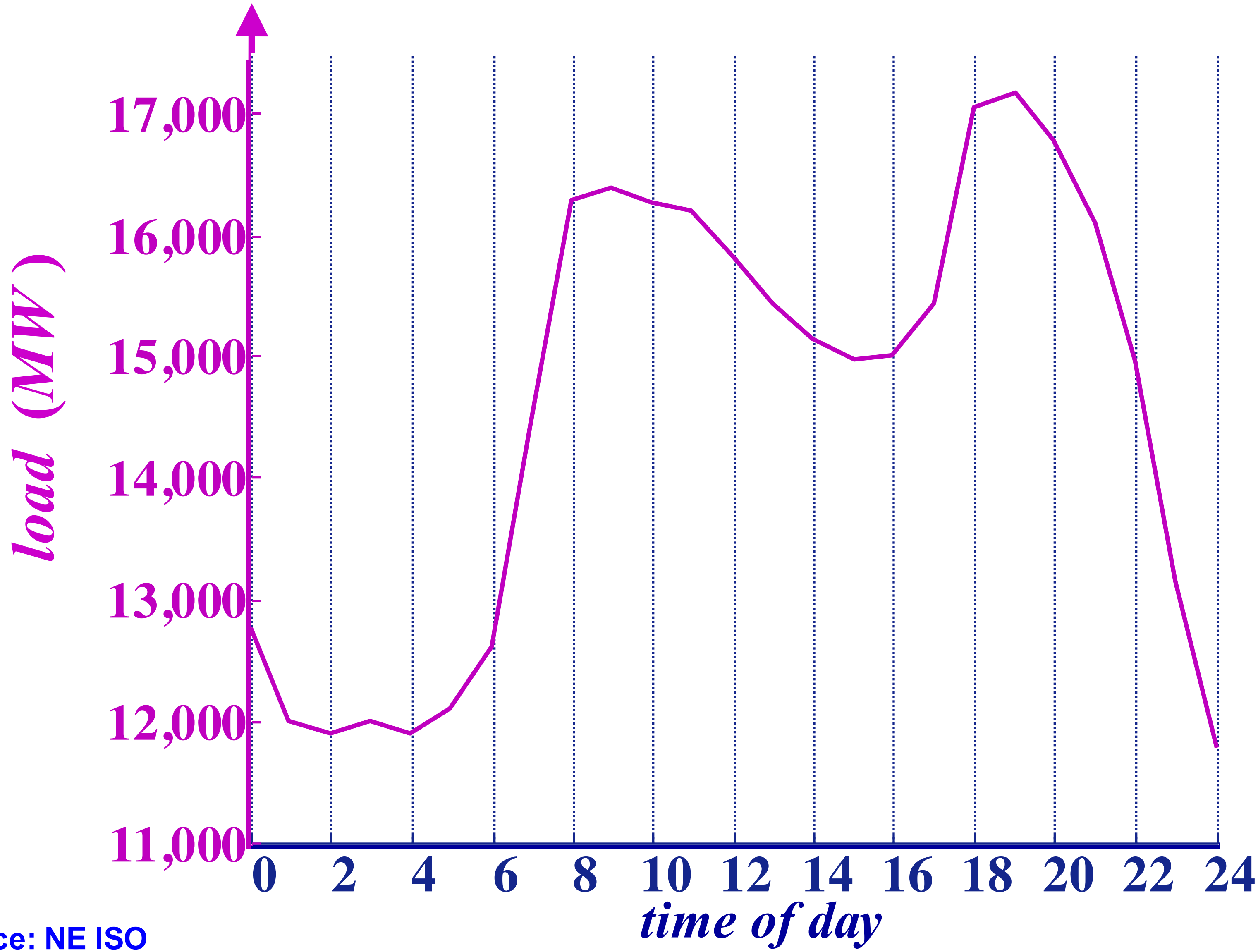
MORE ROLES *ESR*s CAN PLAY

- demand response action

- capability to provide voltage support

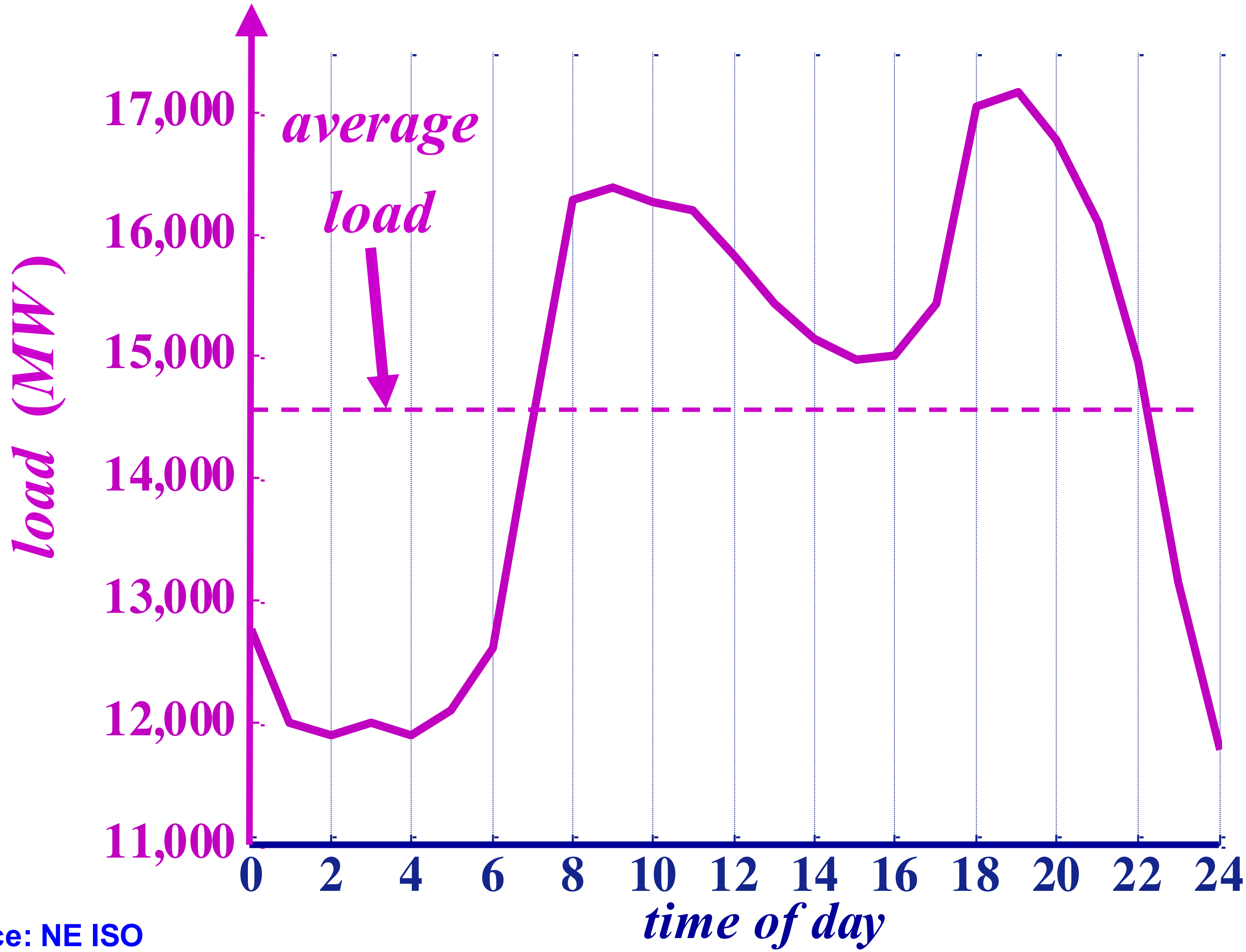
- Storage can also provide *virtual inertia service* to replace part of the missing inertia in grids with integrated renewable resources – a major issue in grids with deep renewable resource integration

LOAD AND *LMP*



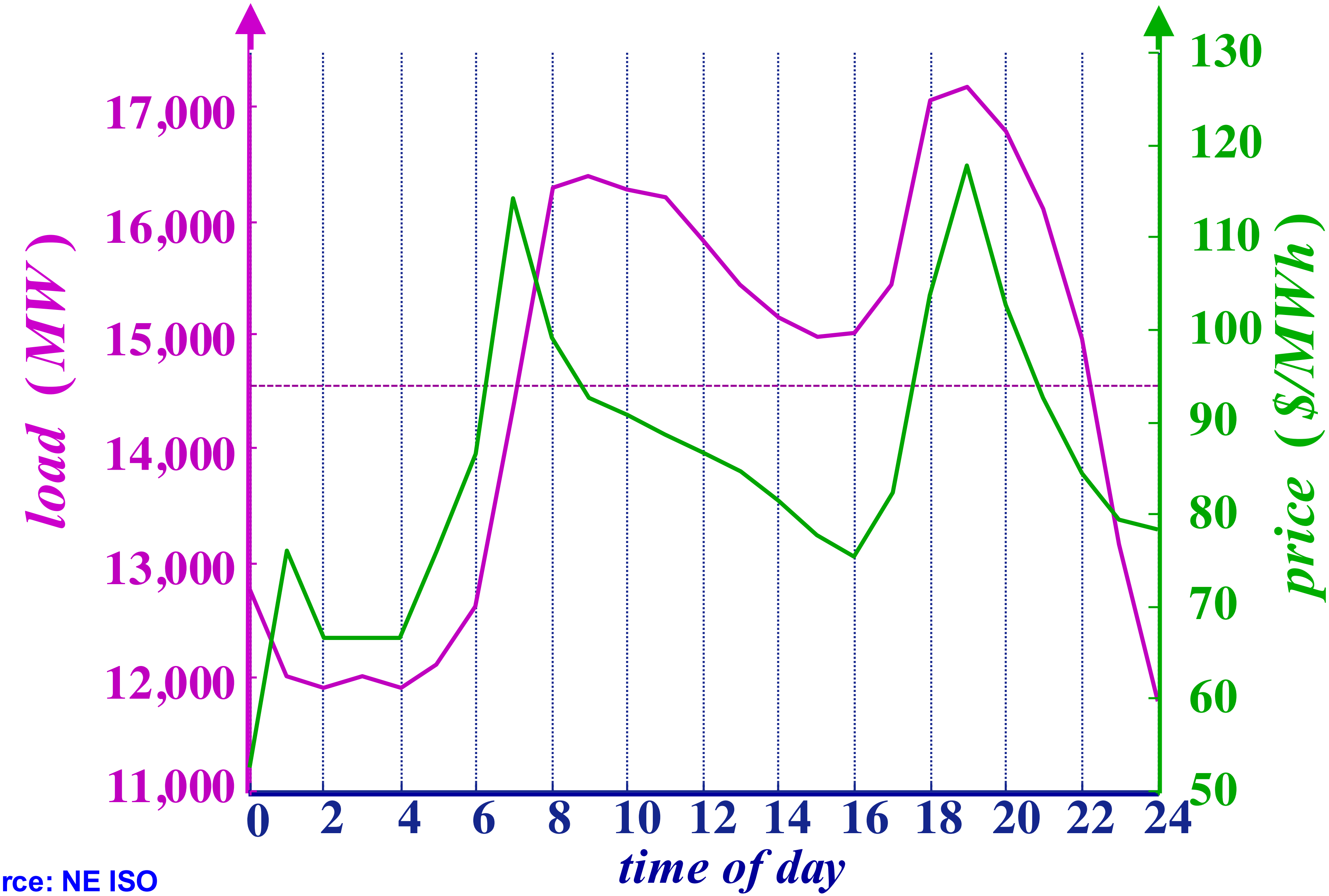
Source: NE ISO

LOAD AND *LMP*



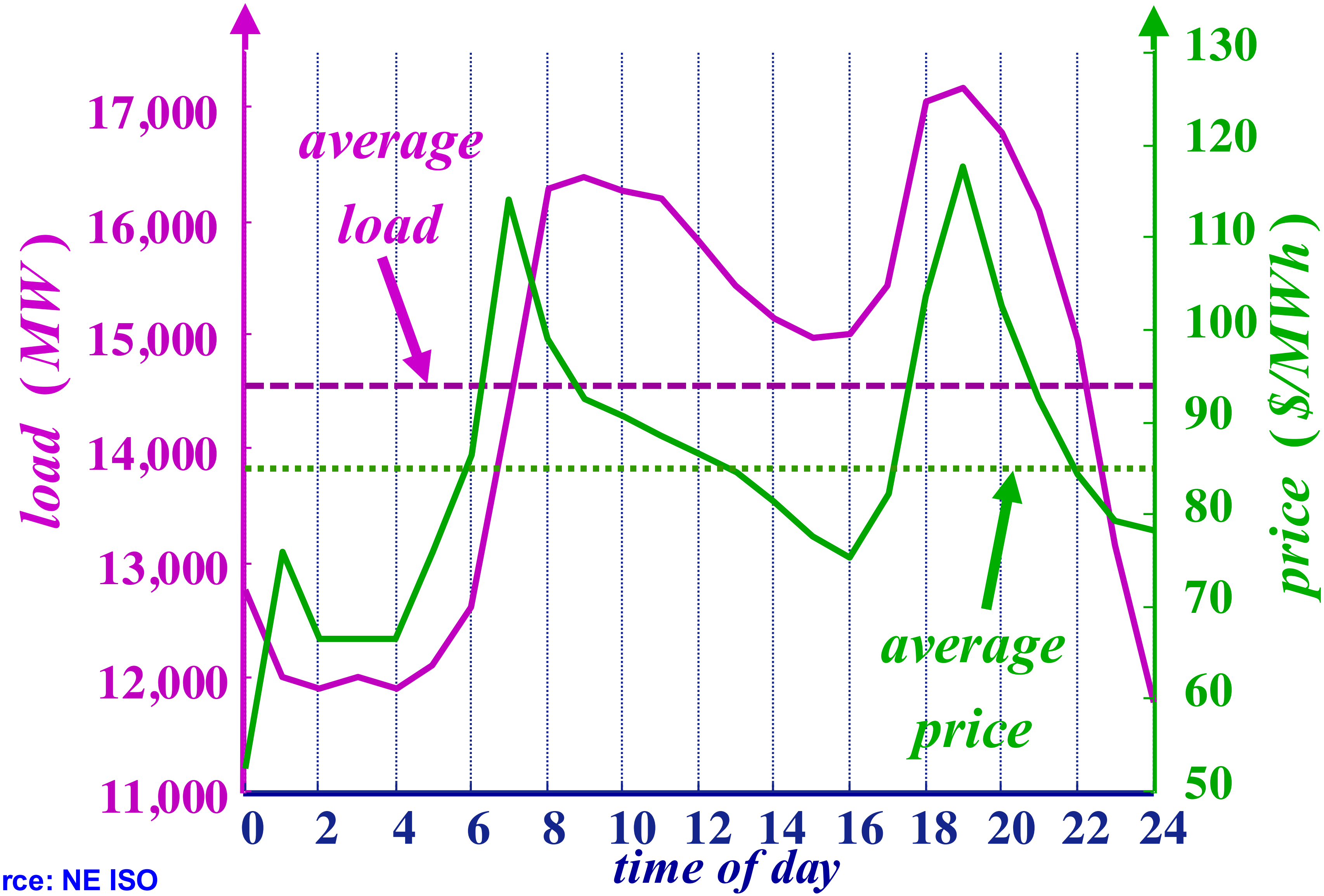
Source: NE ISO

LOAD AND *LMP*



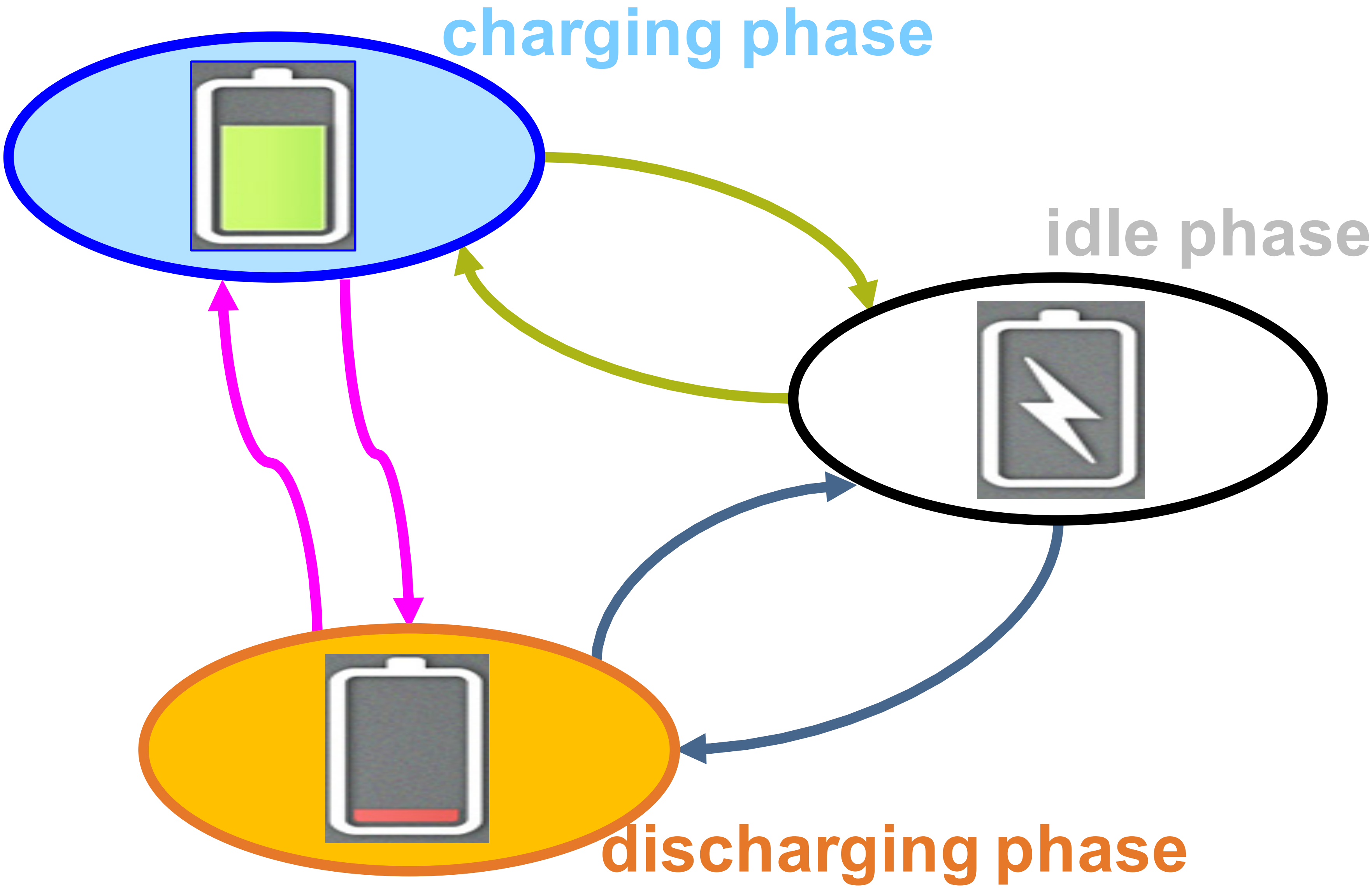
Source: NE ISO

LOAD AND *LMP*

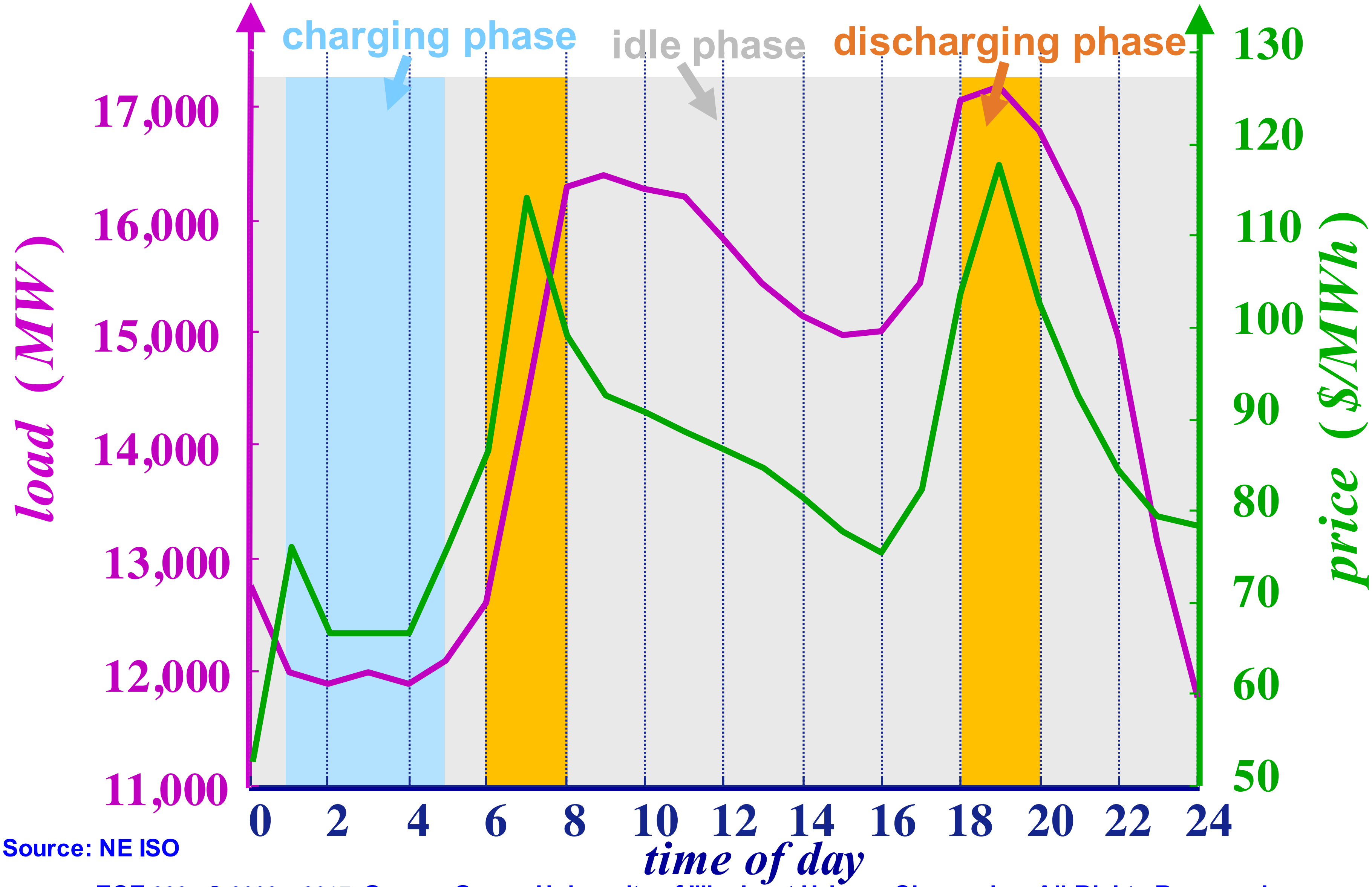


Source: NE ISO

THE STORAGE RESOURCE PHASES

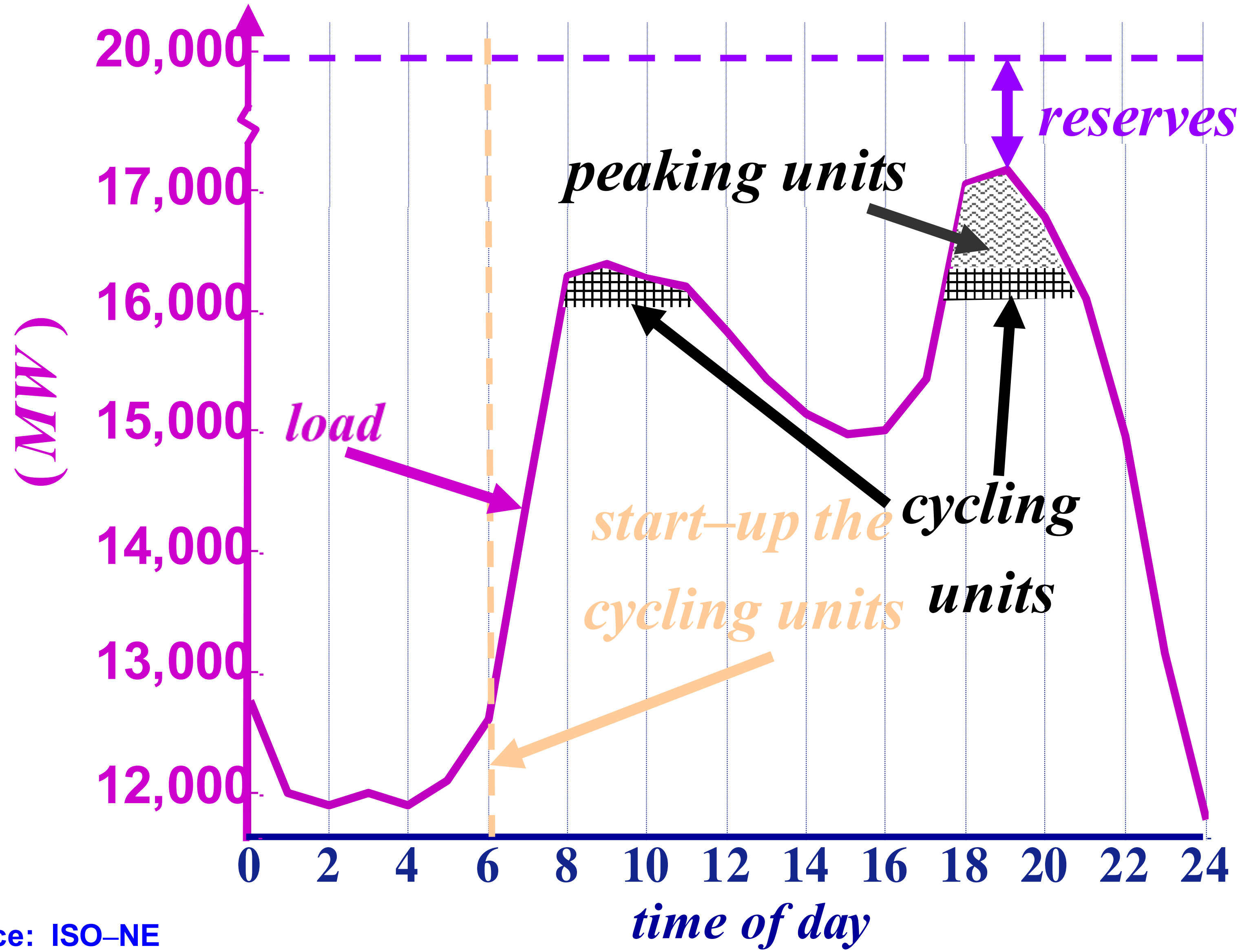


STORAGE UTILIZATION



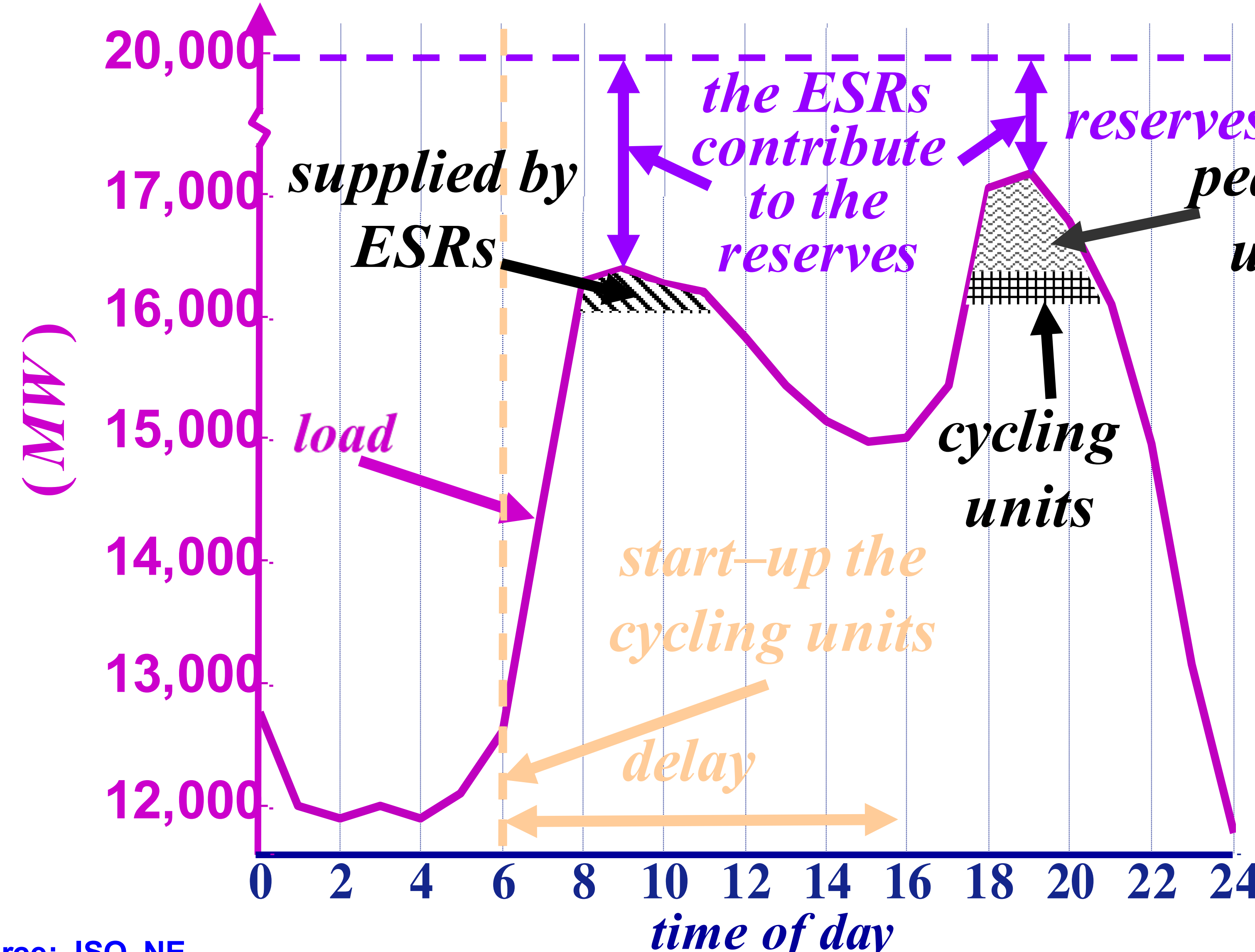
Source: NE ISO

CYCLING UNITS WITHOUT *ESRs*



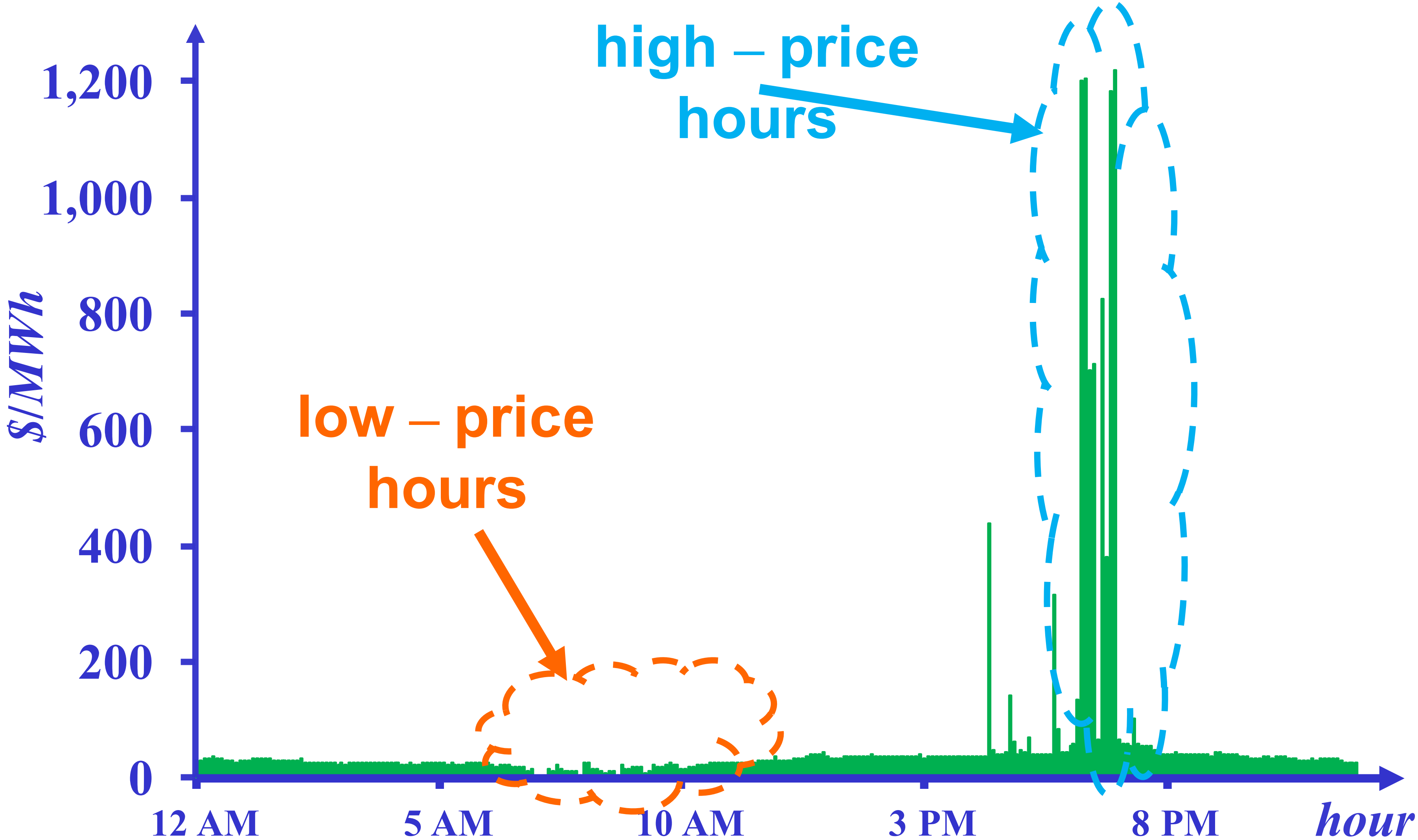
Source: ISO–NE

CYCLING UNITS WITH *ESRs*



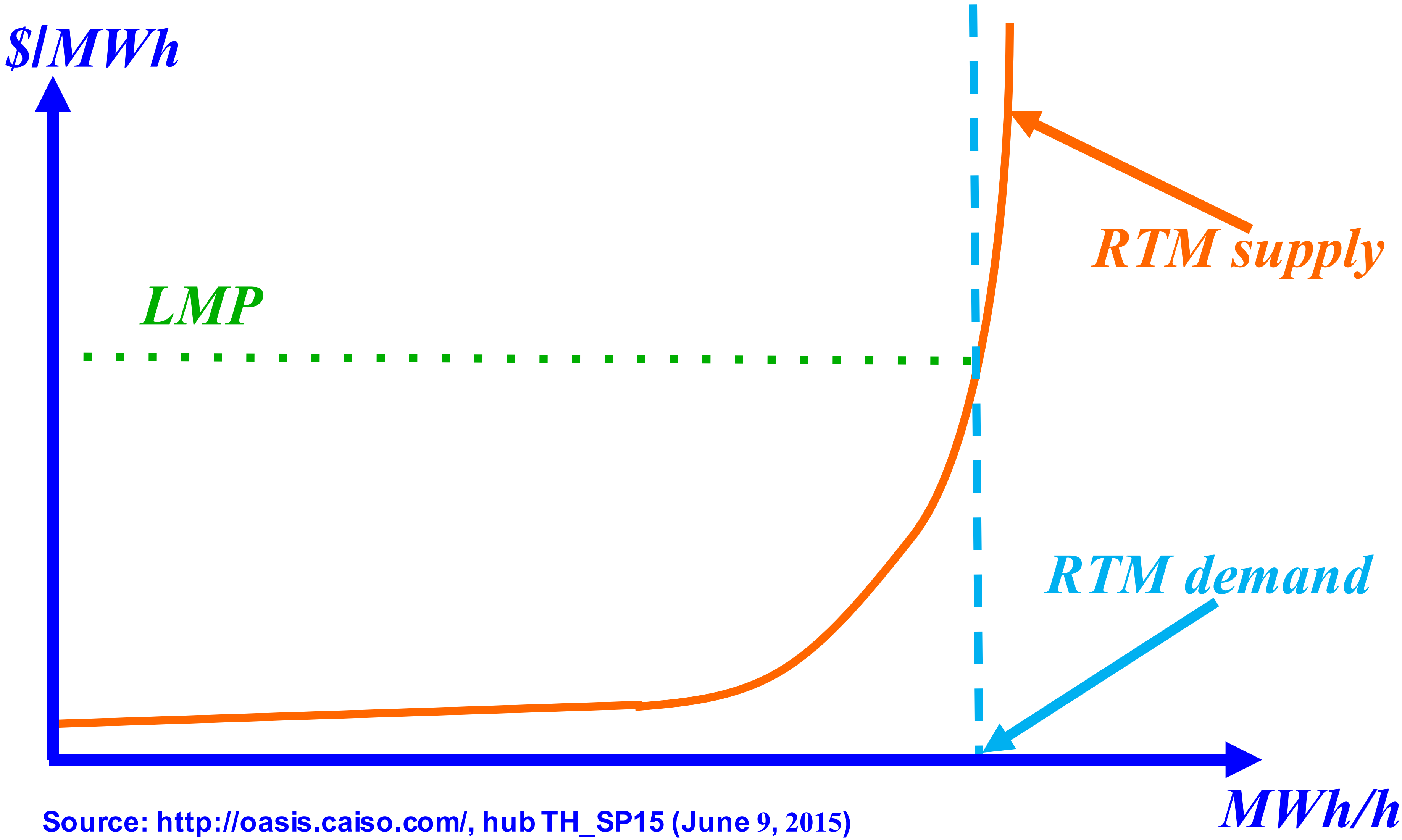
Source: ISO–NE

ESR DEPLOYMENT IN *RTMs*



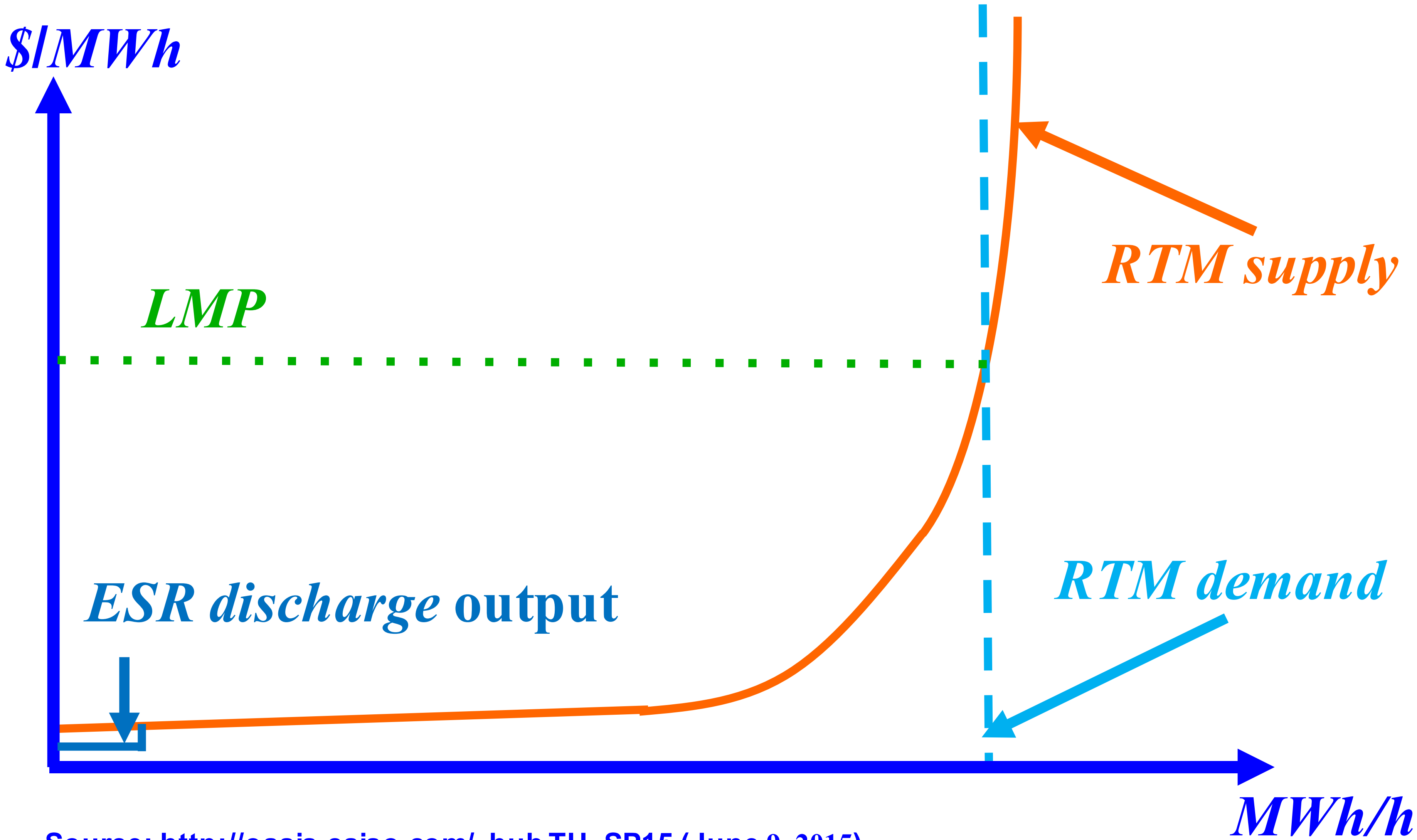
Source: http://oasis.caiso.com/, hub TH_SP15 (June 9, 2015)

LMP IN A SYSTEM WITHOUT STORAGE



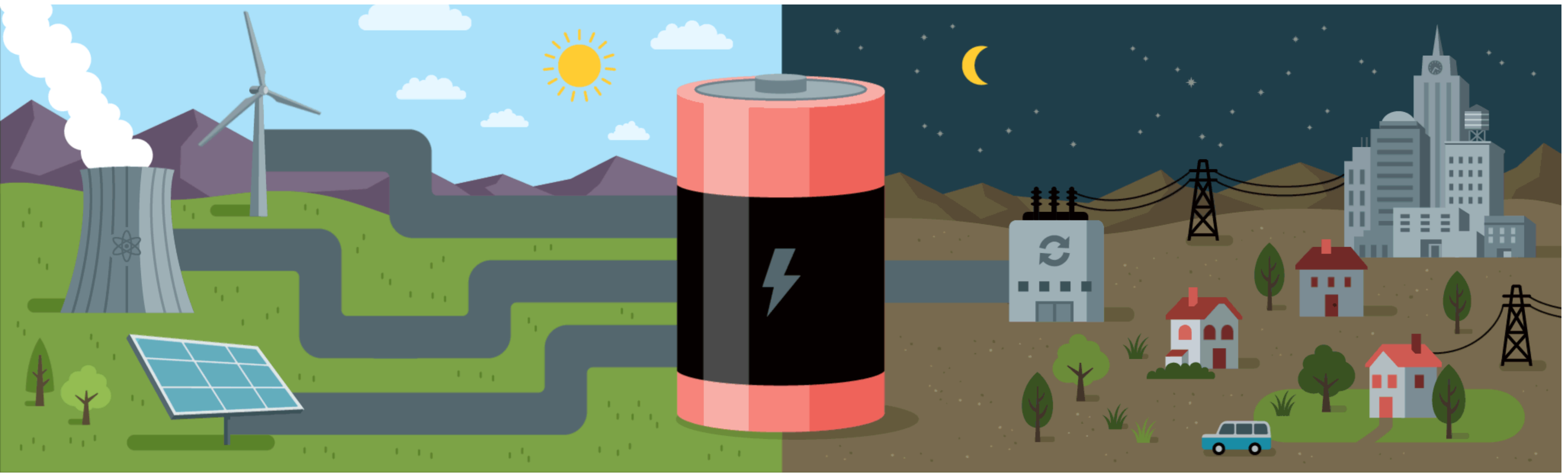
Source: http://oasis.caiso.com/, hub TH_SP15 (June 9, 2015)

ESR DEPLOYMENT IMPACT ON *LMP*



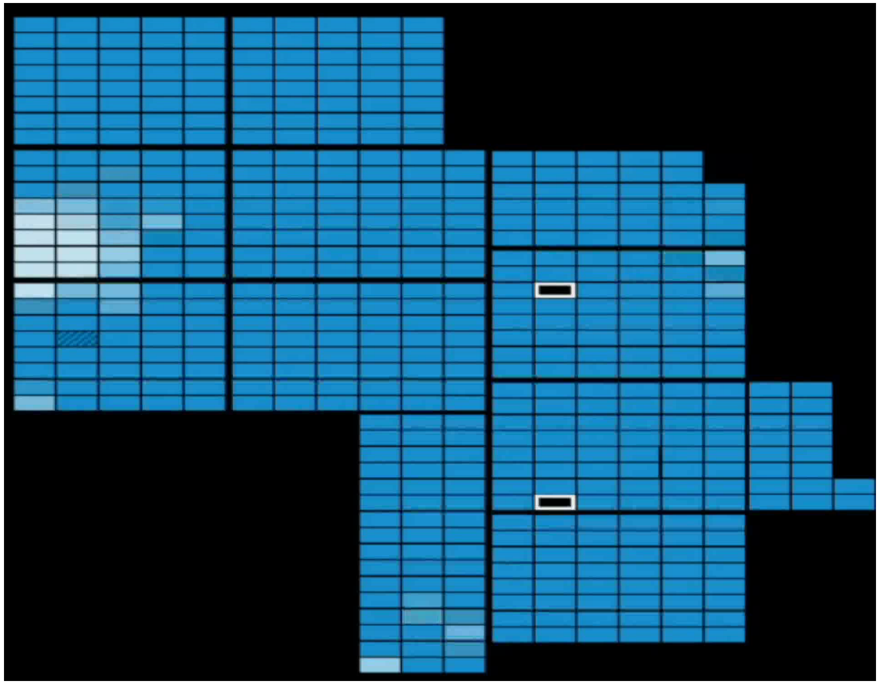
Source: http://oasis.caiso.com/, hub TH_SP15 (June 9, 2015)

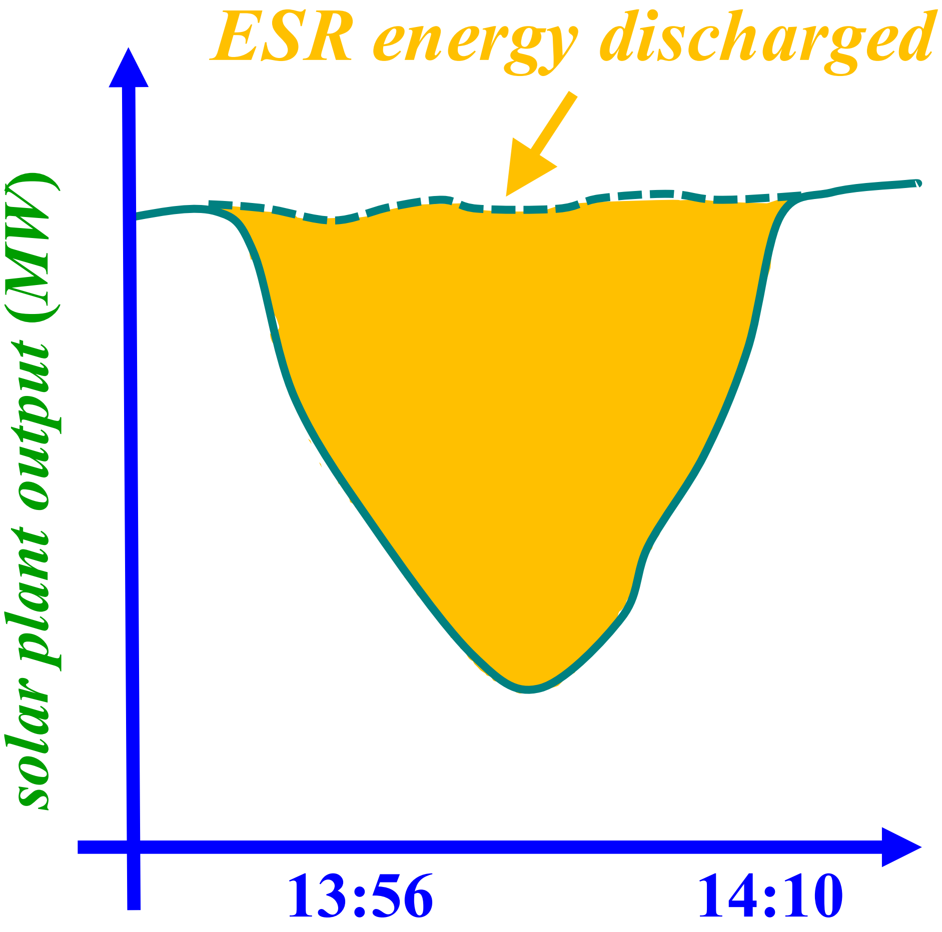
BATTERY STORAGE AND *RER* SYMBIOSIS



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

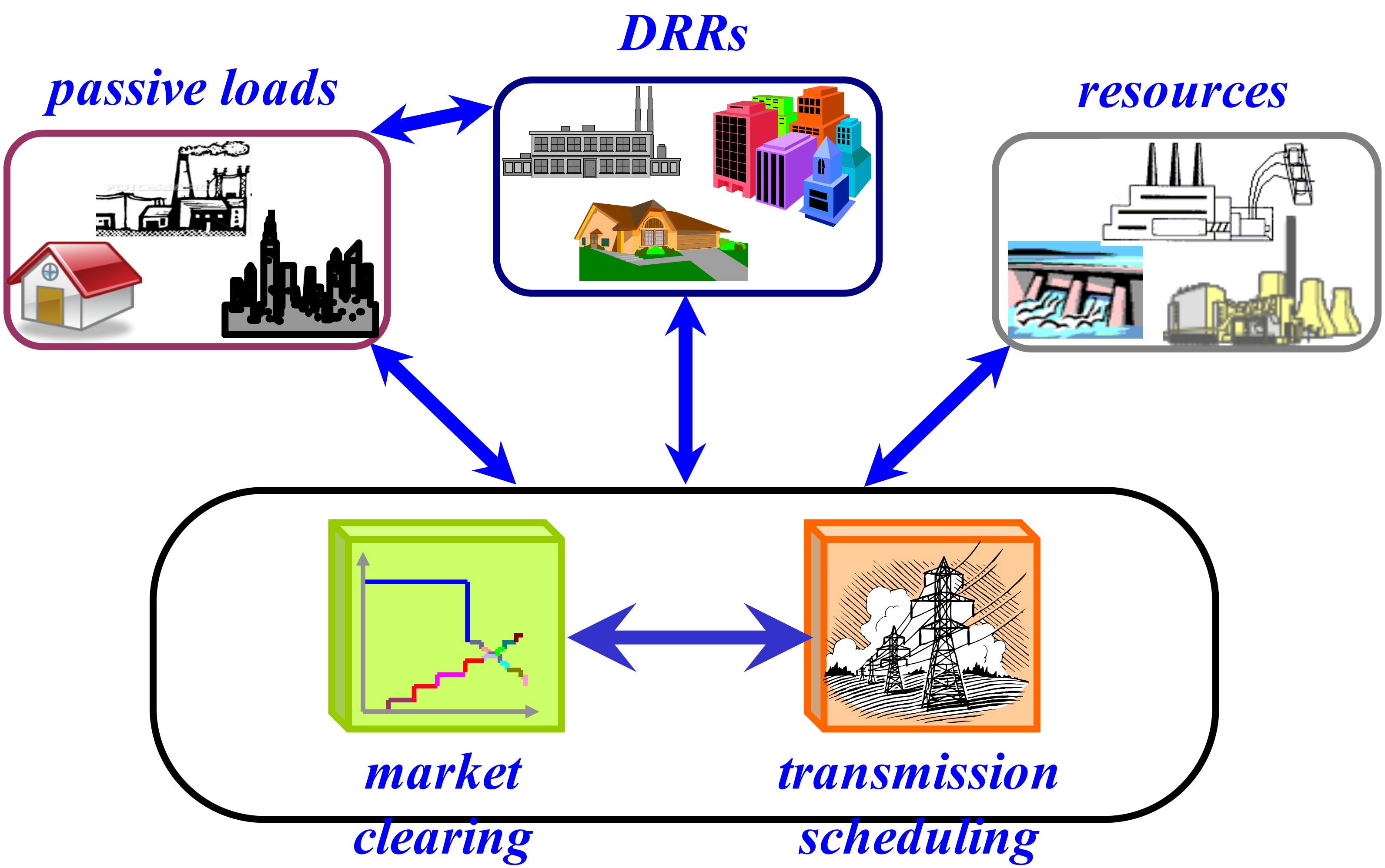




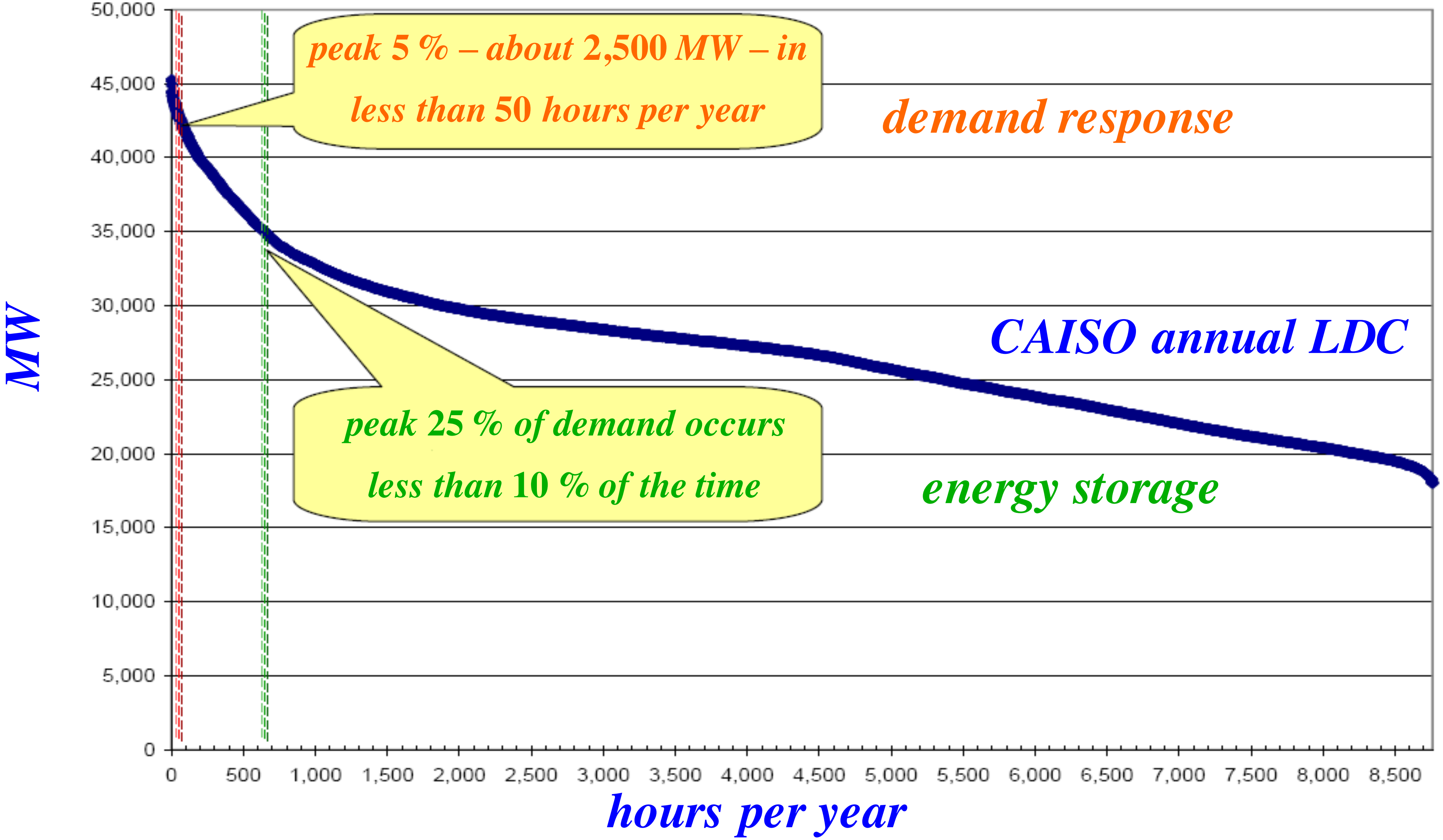
DEMAND RESPONSE RESOURCES (*DRR*s) IN SYMBIOSIS WITH *ESR*s

- ***DRRs*** **are demand–side entities which actively participate in the markets as both buyers of electricity and sellers of load curtailment services**
- ***DRRs*** **reduce the load during peak hours and/or shift the demand, in part or in whole, from peak hours to low–load hours**
- **The coordinated deployment of *ESR*s and *DRR*s can be symbiotic to further reduce the operational costs and emissions via reduced unit cycling and avoided delays in the start–up of cycling units**

DEMAND RESPONSE RESOURCES (*DRR*s)



CAISO DRR AND ESR DEPLOYMENT



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.

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**

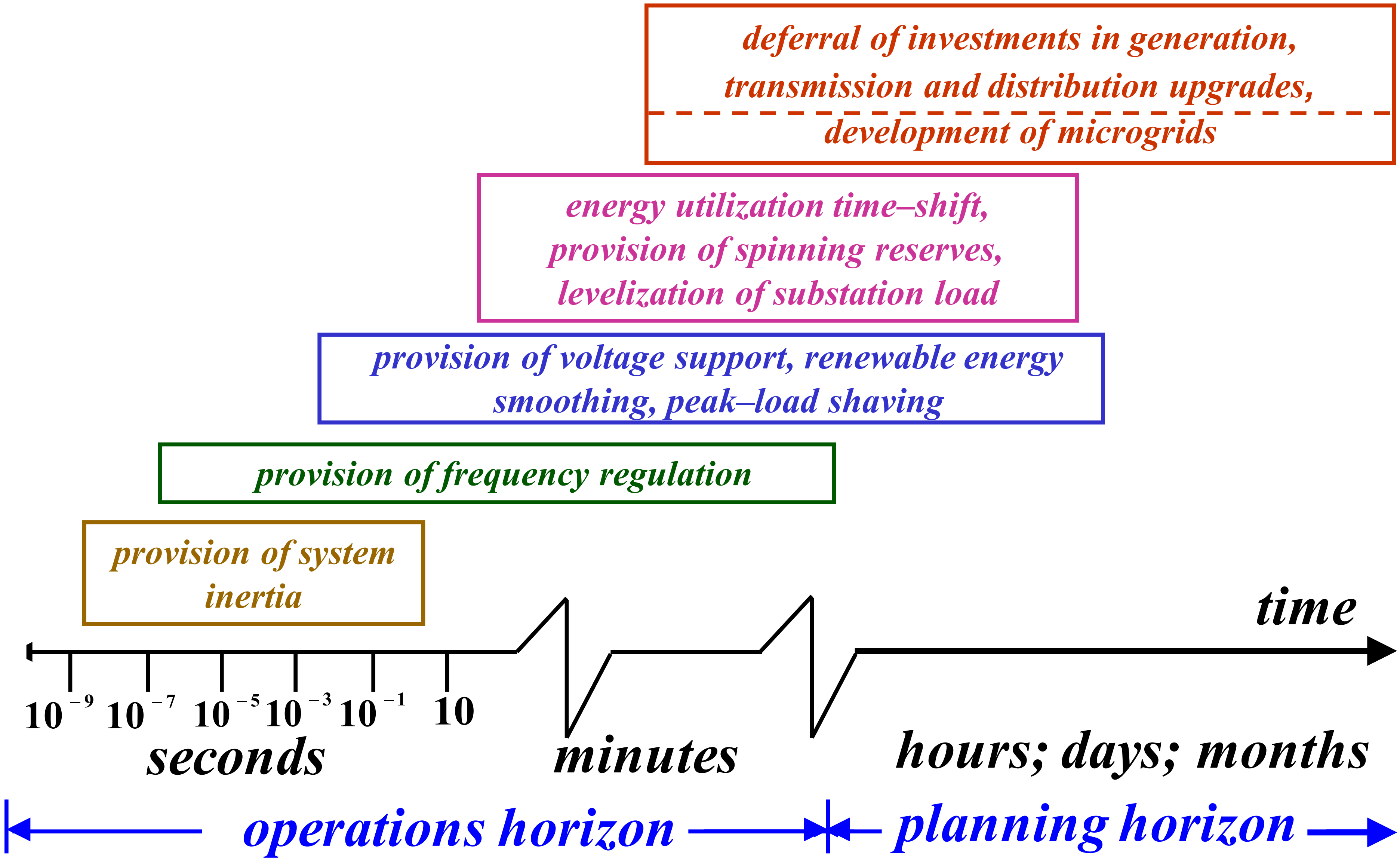
APPLICATION IN MICROGRIDS

Santa Rita Jail Microgrid

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 – to high – demand 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*

ENERGY STORAGE APPLICATIONS



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

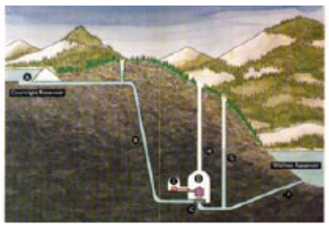
- Deployment of *ESR*s:
  - raises system reliability
  - improves operational economics
  - provides operators with additional flexibility to optimize grid operations and manage grid congestion
  - raises renewable output utilization

KEY BENEFITS OF GRID – INTEGRATED *ESR*s

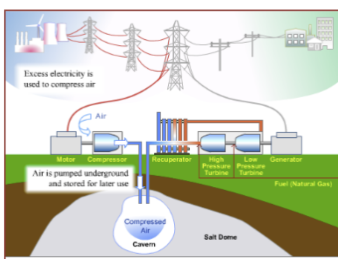
- Deployment of *ESR*s can reduce *GHG* emissions because *ESR*s:
  - facilitate renewable resource integration
  - reduce the system reserves requirements on the conventional fossil–fired resources
  - displace the generation of inefficient and dirty units used to meet peak loads

ENERGY STORAGE TECHNOLOGIES

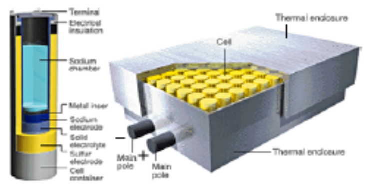
pumped storage



CAES



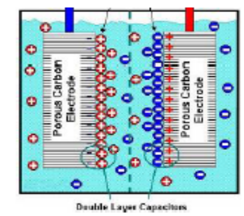
NaS battery



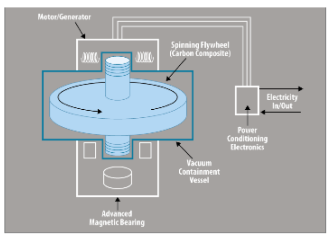
flow battery

advanced lead acid battery

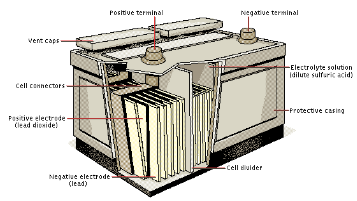
EC capacitor



flywheel



lead–acid battery



Li–ion battery

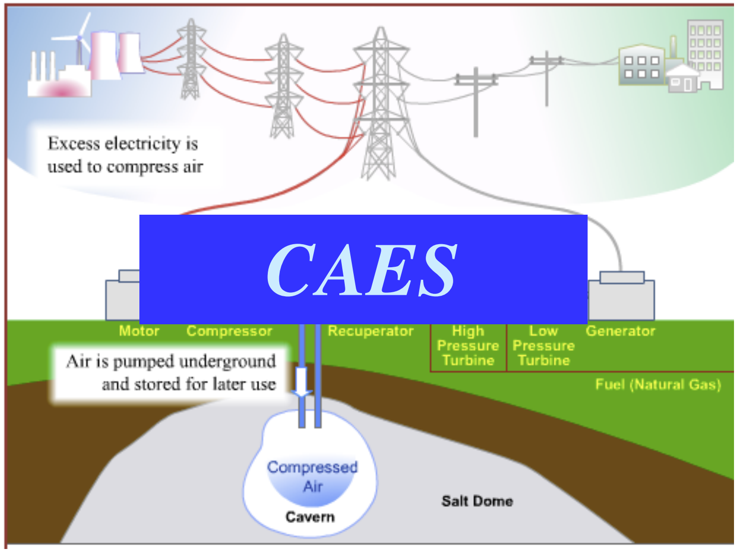
Ni–Cd battery

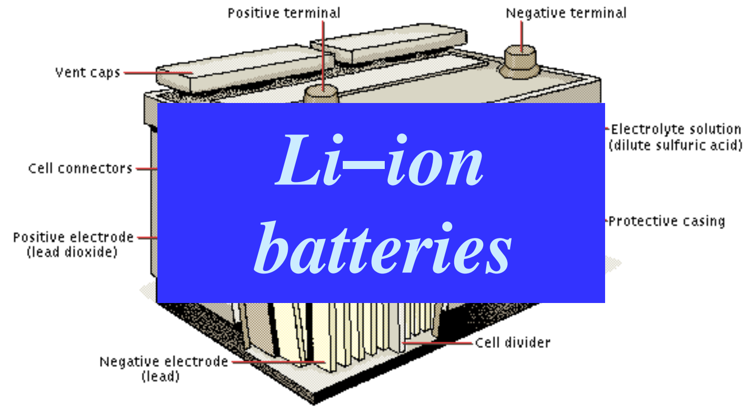
SMES

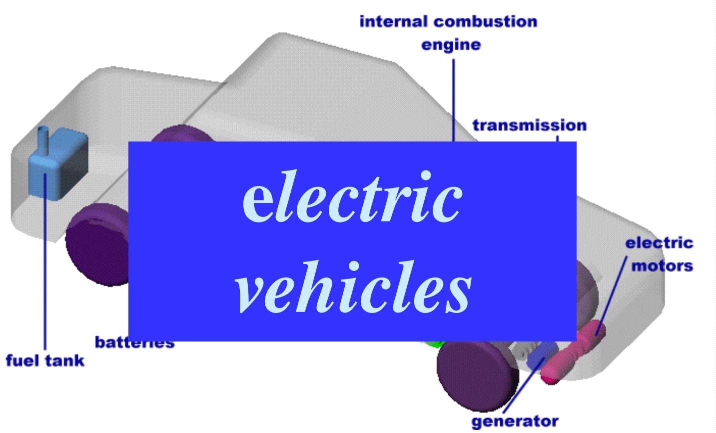
increasing capability ←

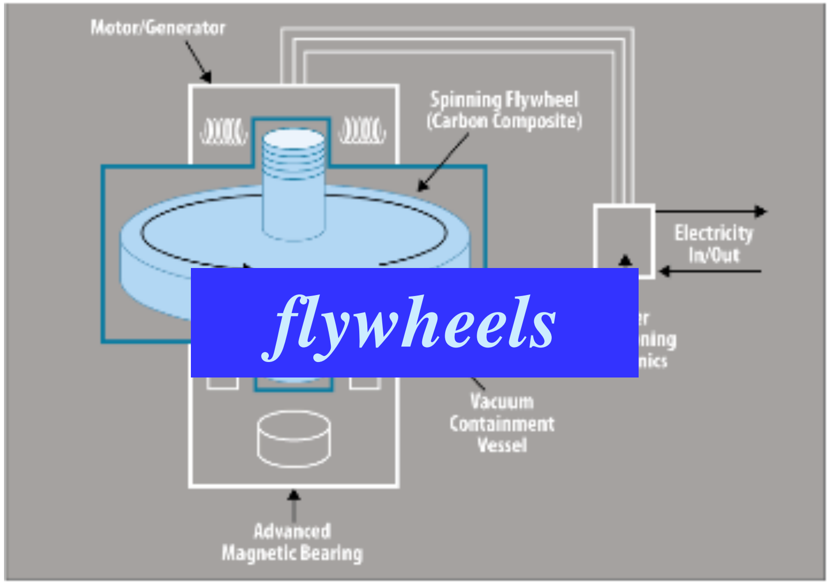
increasing capacity →

STORAGE TECHNOLOGY ADVANCES

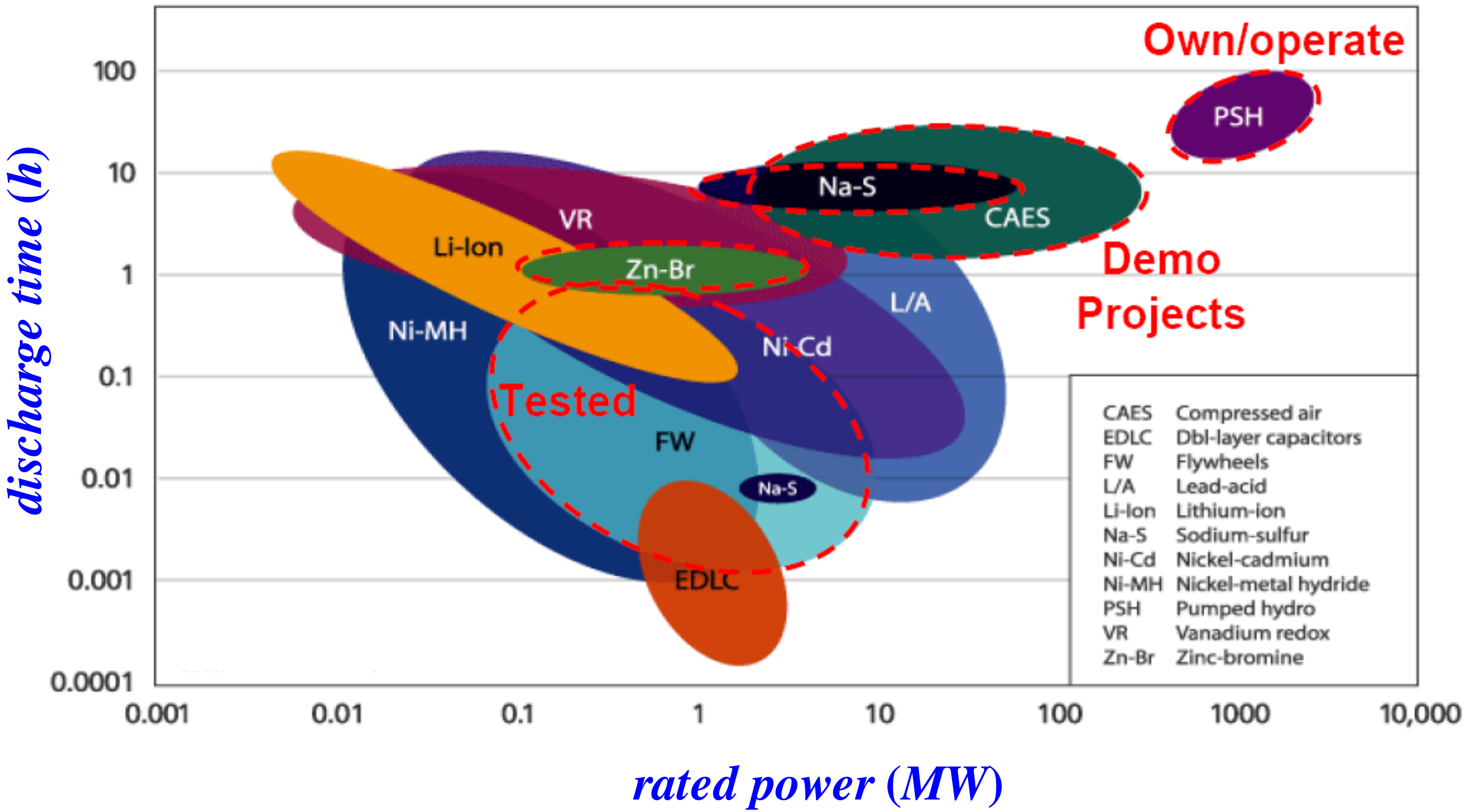








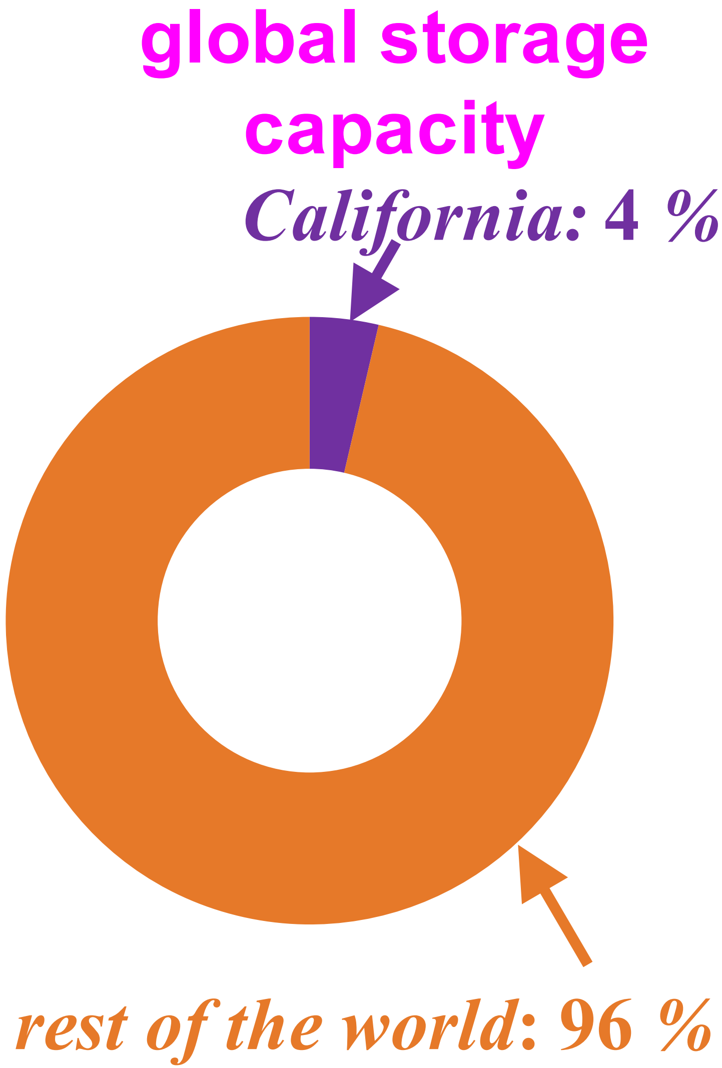
ENERGY STORAGE TECHNOLOGY CHARACTERIZATION



Source: Electricity Storage Association

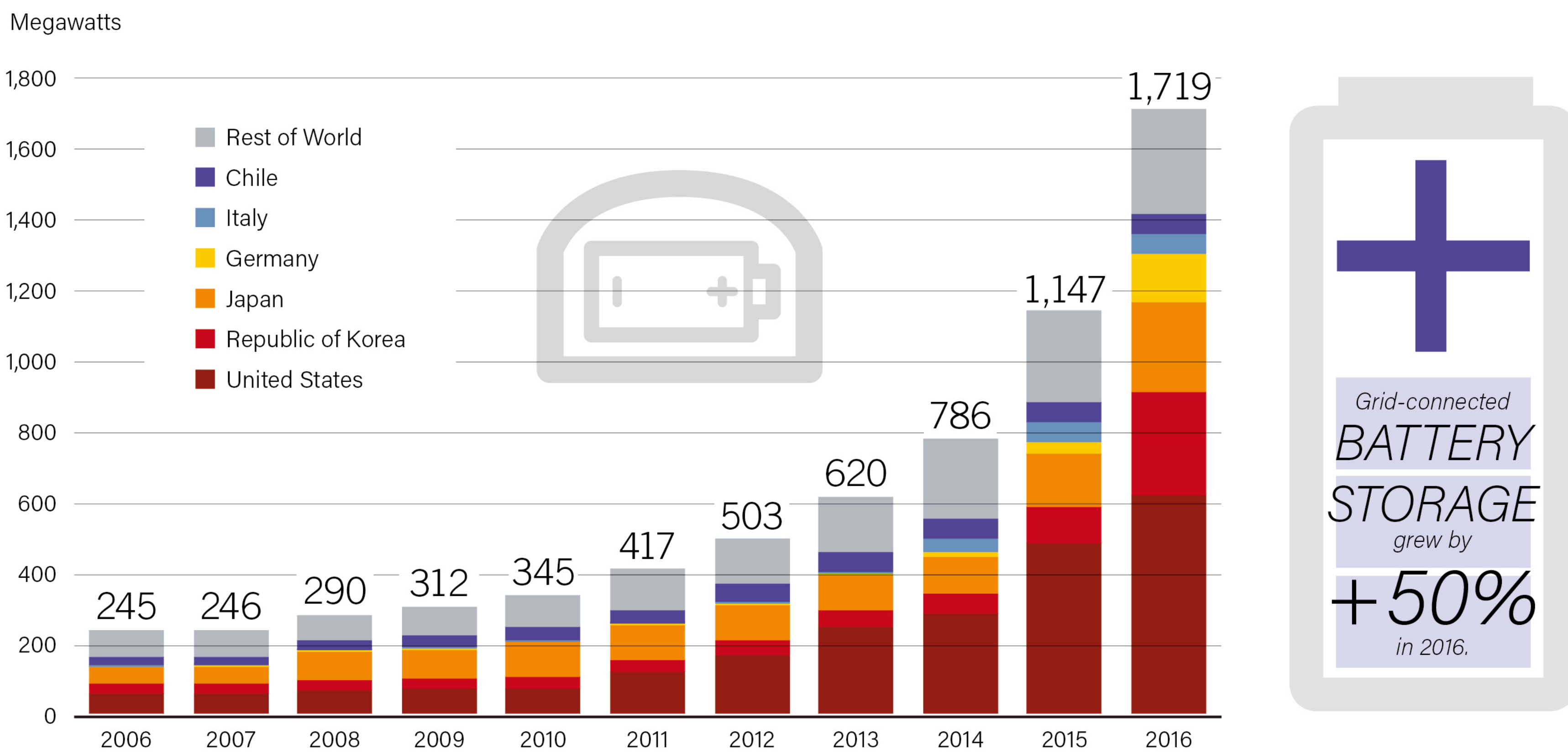
CURRENT WORLD STORAGE STATUS

- 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

2016 TOP NATIONS WITH GRID – CONNECTED BATTERY STORAGE

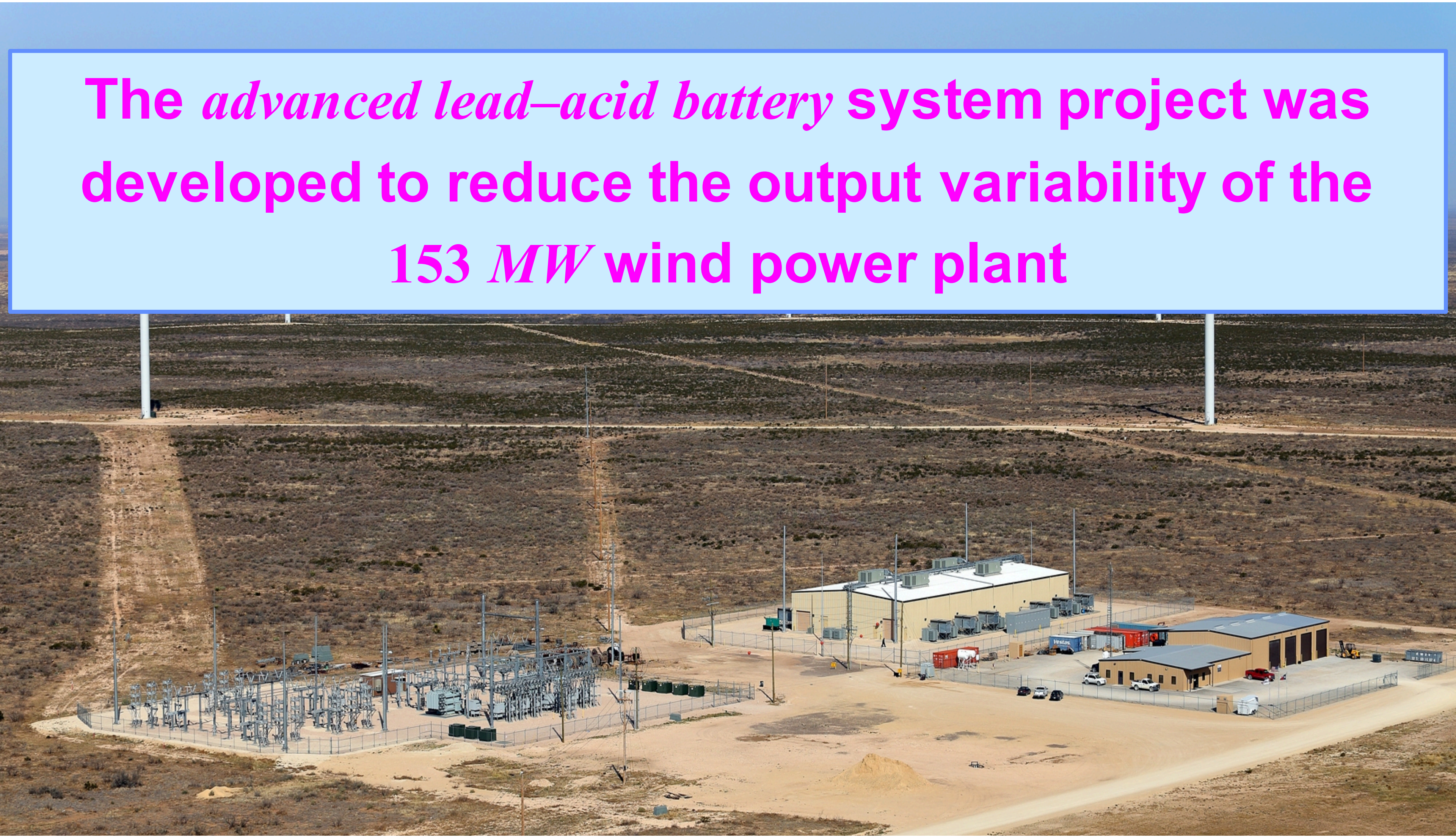


REN21 *Renewables 2017 Global Status Report*

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* may be highly efficient and discharges 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

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



The *advanced lead–acid battery* system project was developed 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

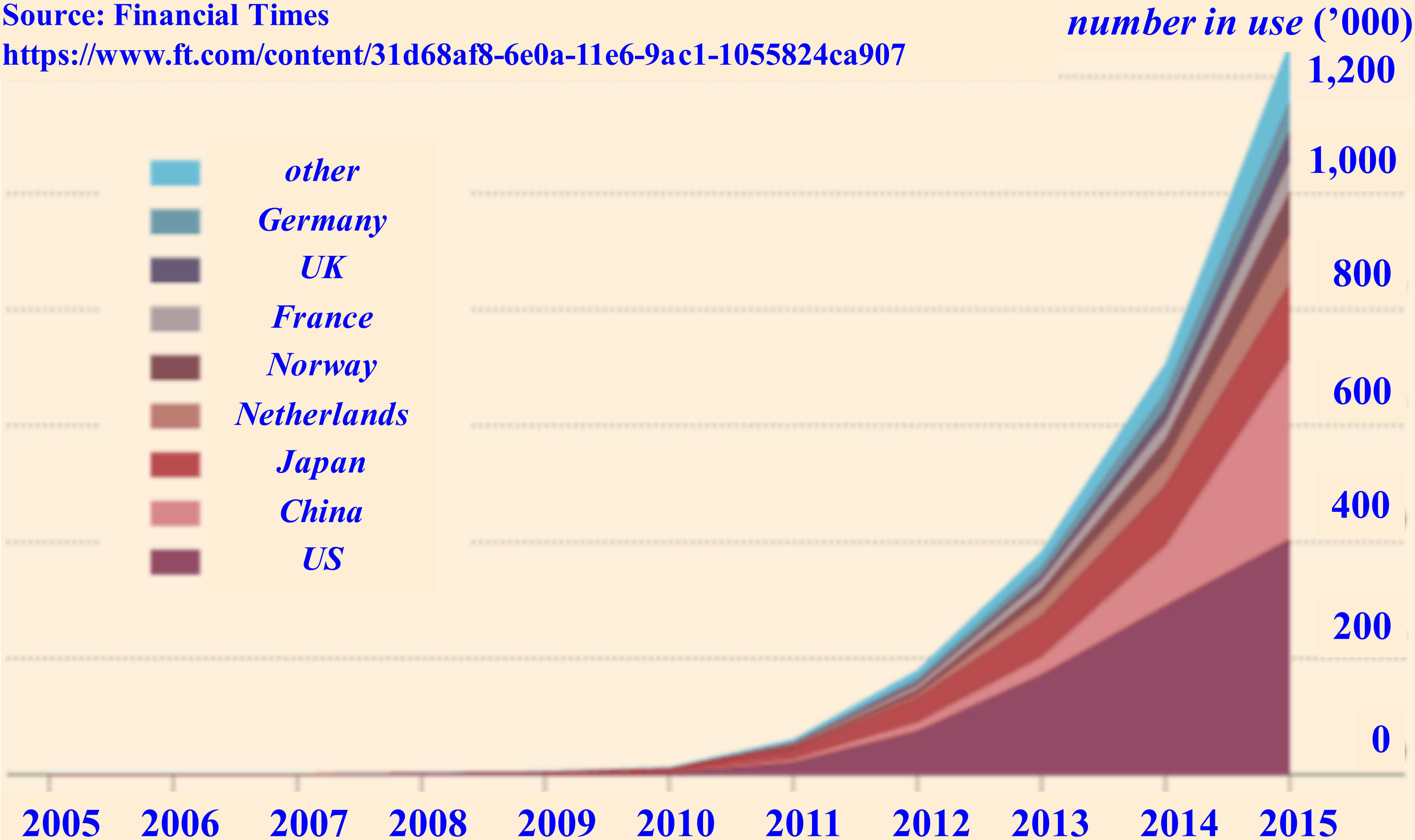
- Advancements in storage technology, cost reduc–tions and regulatory initiatives have invigorated the interest in large–scale grid–connected *ESR*s
- The push to deeper renewable resource penetra–tions leads to the wider deployment of storage – as both a *distributed* and a *grid* resource
- Key technological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

BATTERY VEHICLES (*BV*s)

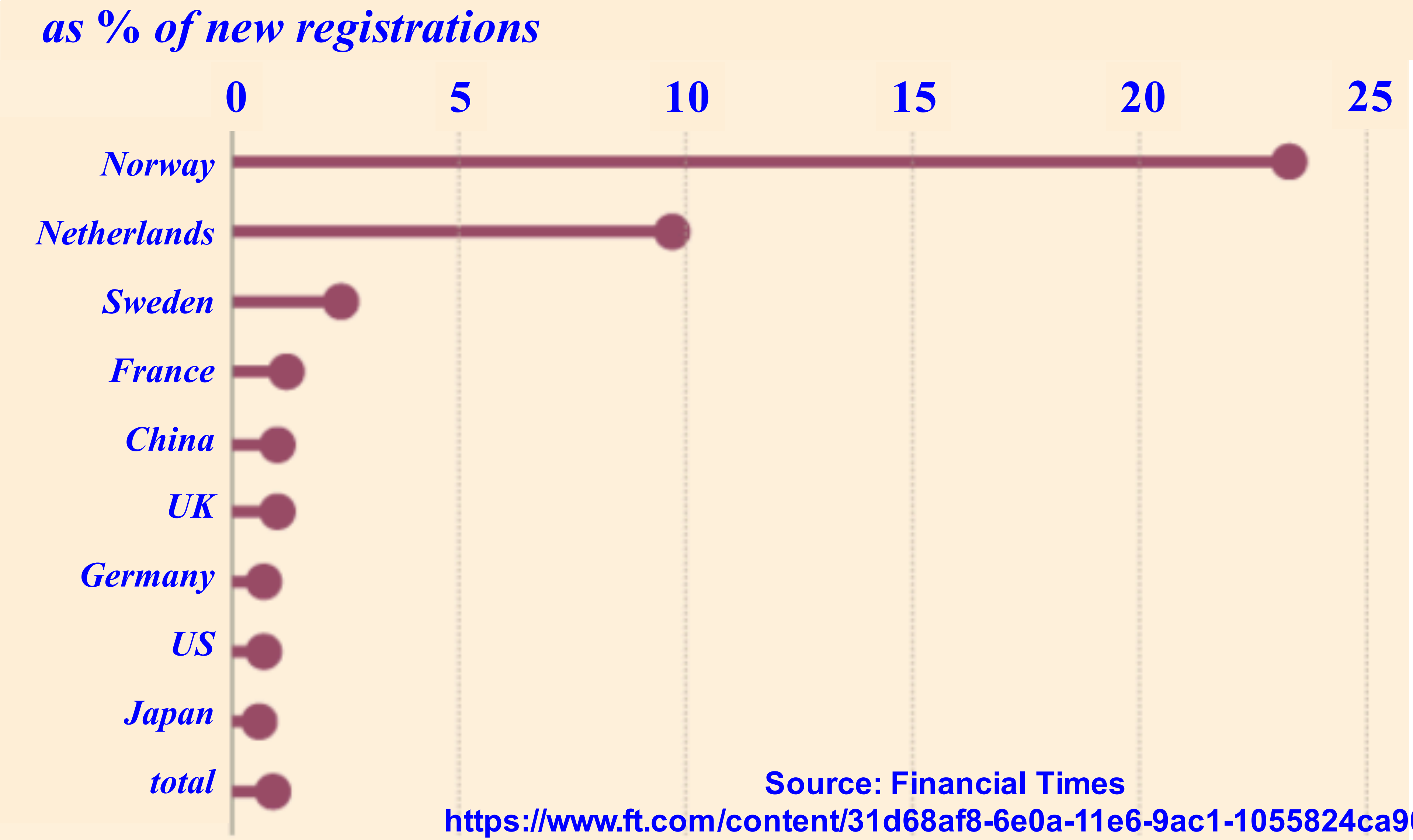
- Reduction in CO_2 emissions and energy security are the key drivers of initiatives aimed to promote the electrification of the transportation sector
- As a consequence of these efforts, the past decade has seen increased sales of *BV*s – *electric vehicles* (*EV*s), *hybrid electric vehicles* (*HEV*s) and *plug–in hybrid electric vehicles* (*PHEV*s) – that are fully or partially powered by batteries

*EV*s ON THE ROAD

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



SALES OF NEW *EVs*



Source: Financial Times
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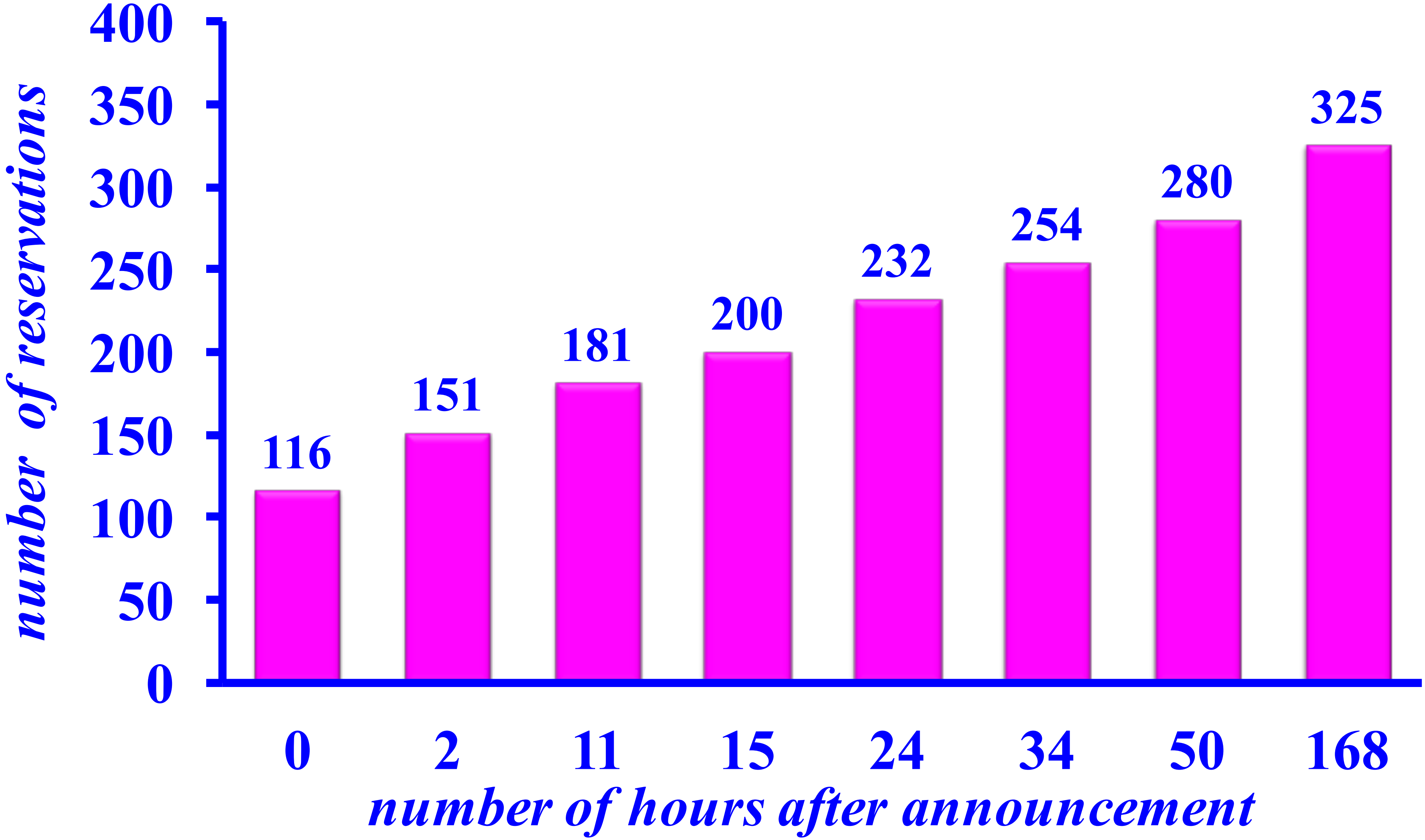
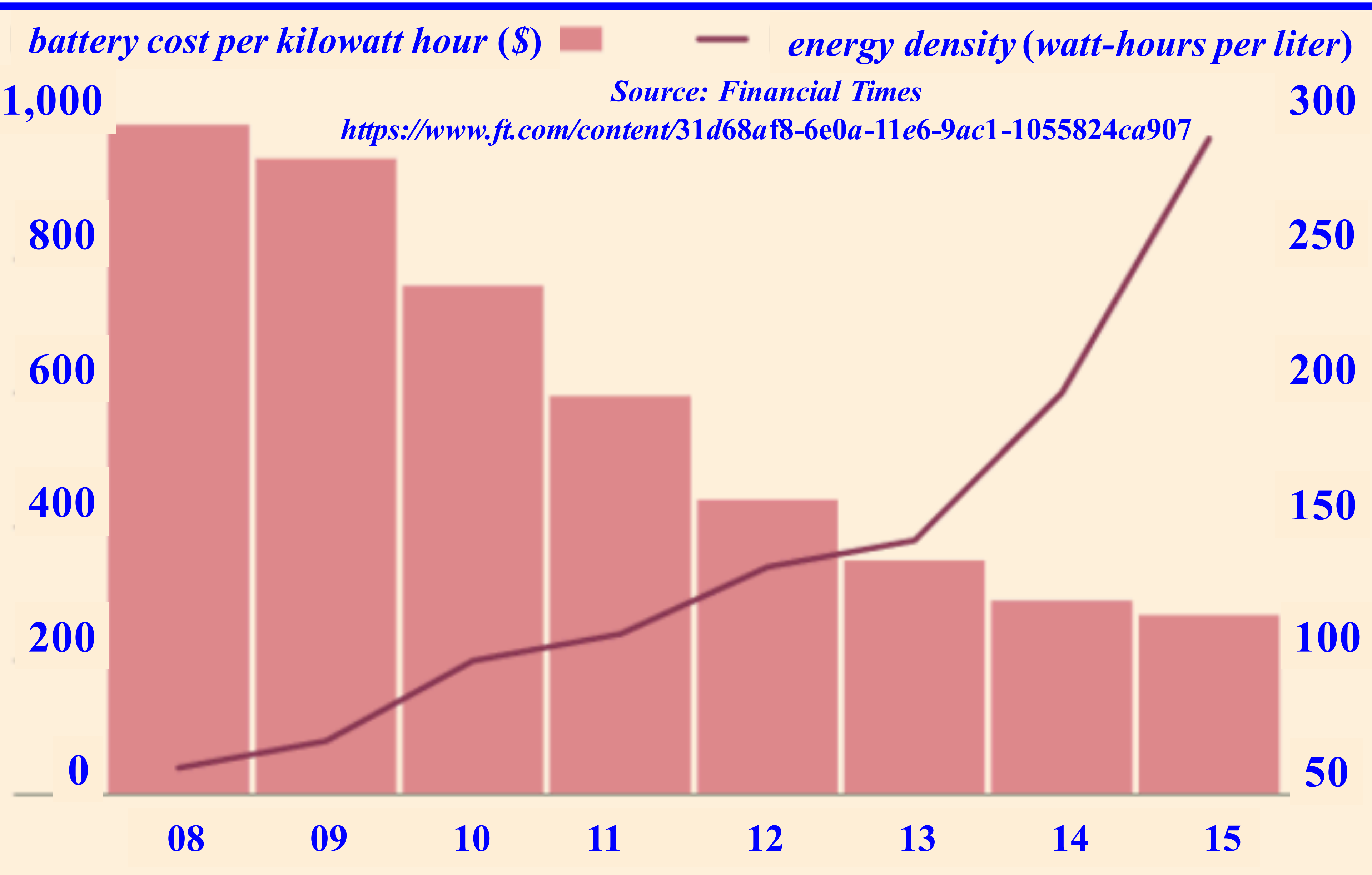
TESLA MODEL 3 RESERVATIONS



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

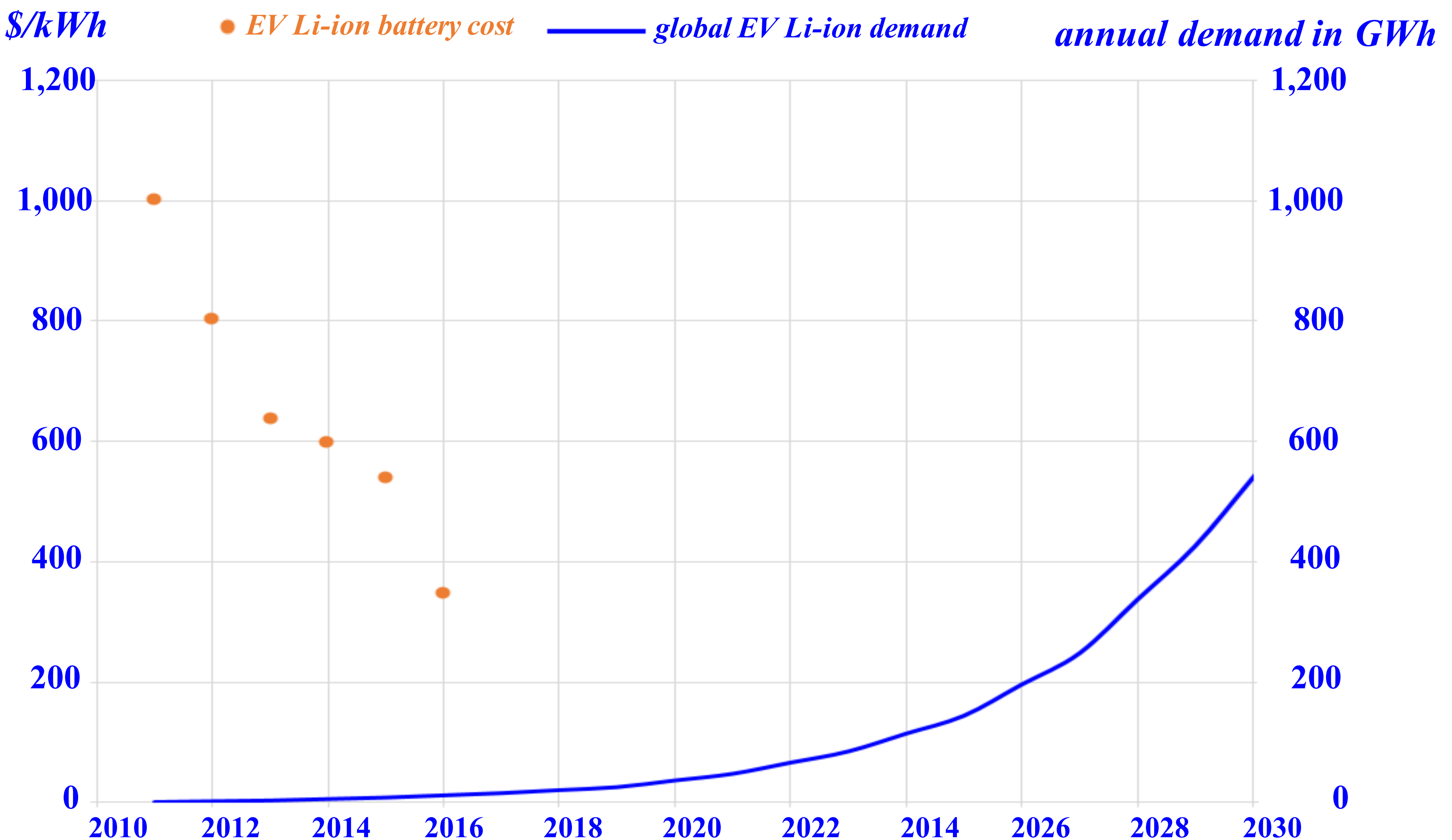
EVOLUTION OF *LI–ION EV* BATTERIES



THE VEHICLE–TO–GRID (*V2G*) FRAMEWORK AS AN *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

EV LI–ION BATTERY PACKS: 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

THE *TESLA POWERPACK*

Source: https://www.teslamotors.com/powerpack

THE *TESLA POWERPACK*

- The *Tesla Powerpack* is 200–*kWh* battery for utility and industrial–scale storage applications
- The scalable *Powerpack* unit is capable to provide different combinations of storage system with up to 5.4 *MWh* capability and up to 2.5 *MW* capacity

SOUTH AUSTRALIA'S *TESLA* BATTERY

- On November 30, 2017, the world's largest capacity battery became operational in South Australia
- The Tesla-manufactured 100–*MW Li–ion* battery has a 129–*MWh* storage capability, which enables it to supply the energy consumption of 30,000 homes for one hour

SOUTH AUSTRALIA'S *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 had said Tesla will have the battery in place within 100 days or it would be free

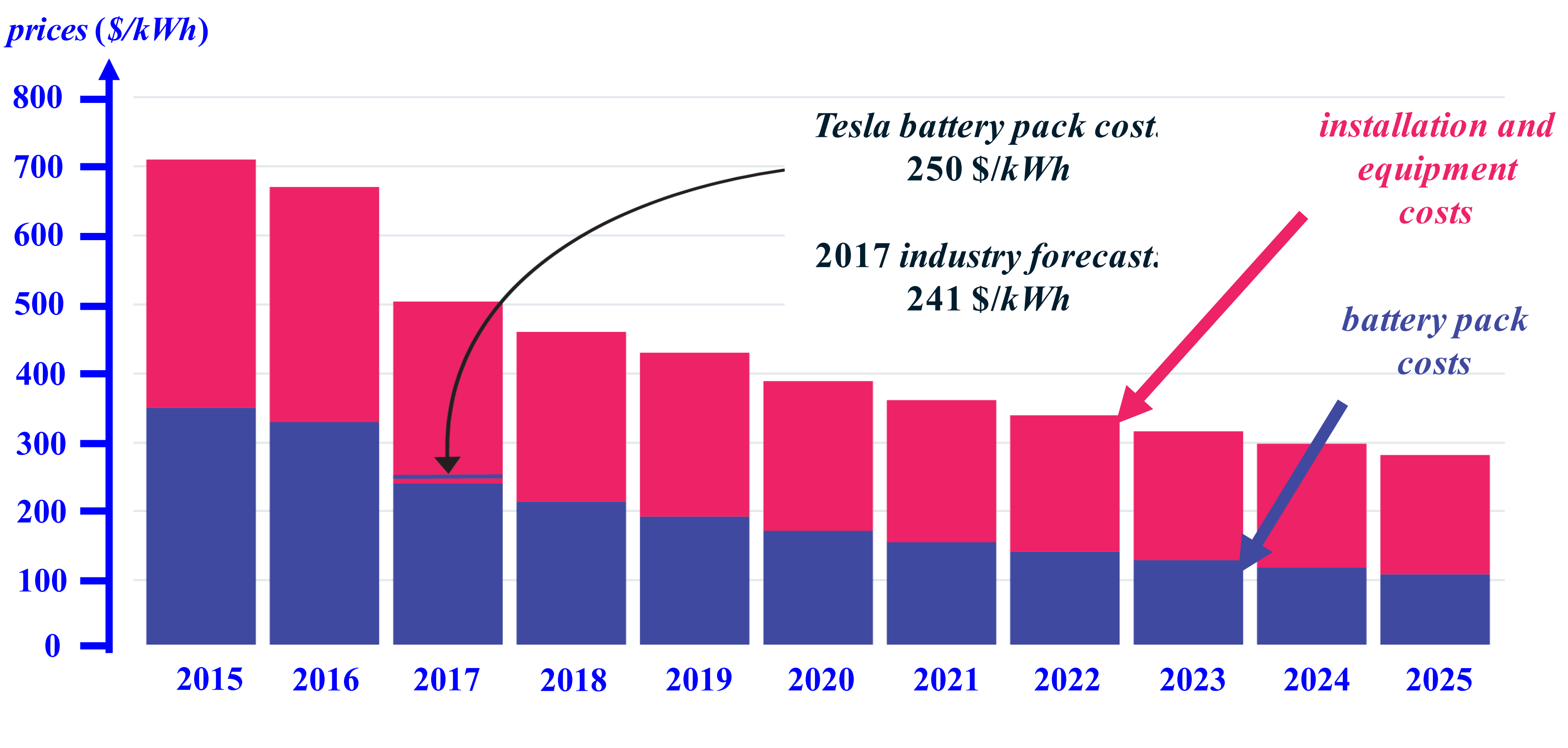
SOUTH AUSTRALIA'S *TESLA* BATTERY

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

SOUTH AUSTRALIA'S *TESLA* BATTERY

- ***South Australian*** **taxpayers will be subsidizing 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**

BATTERY COSTS

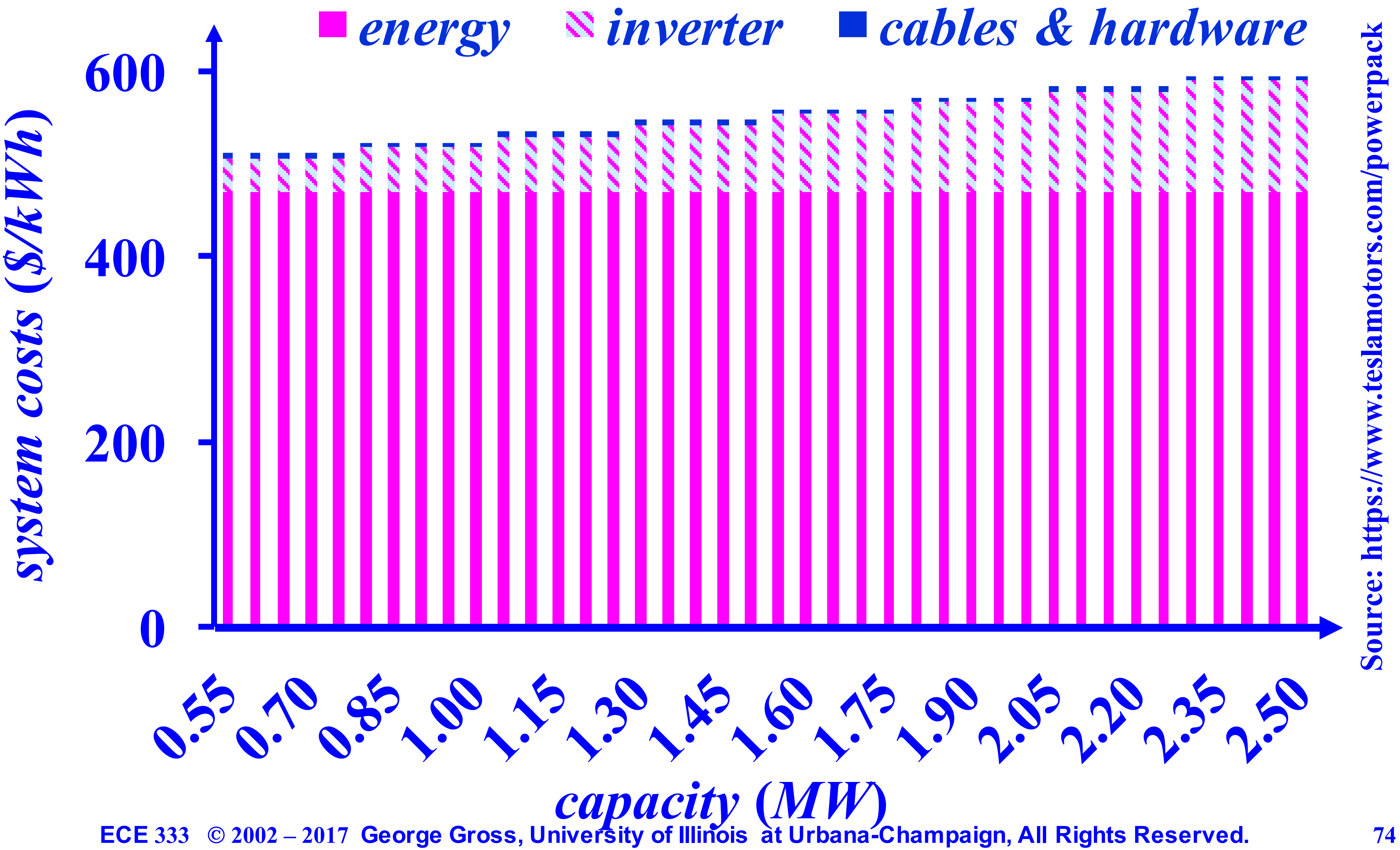


Source: Bloomberg New Energy Finance, Tesla

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

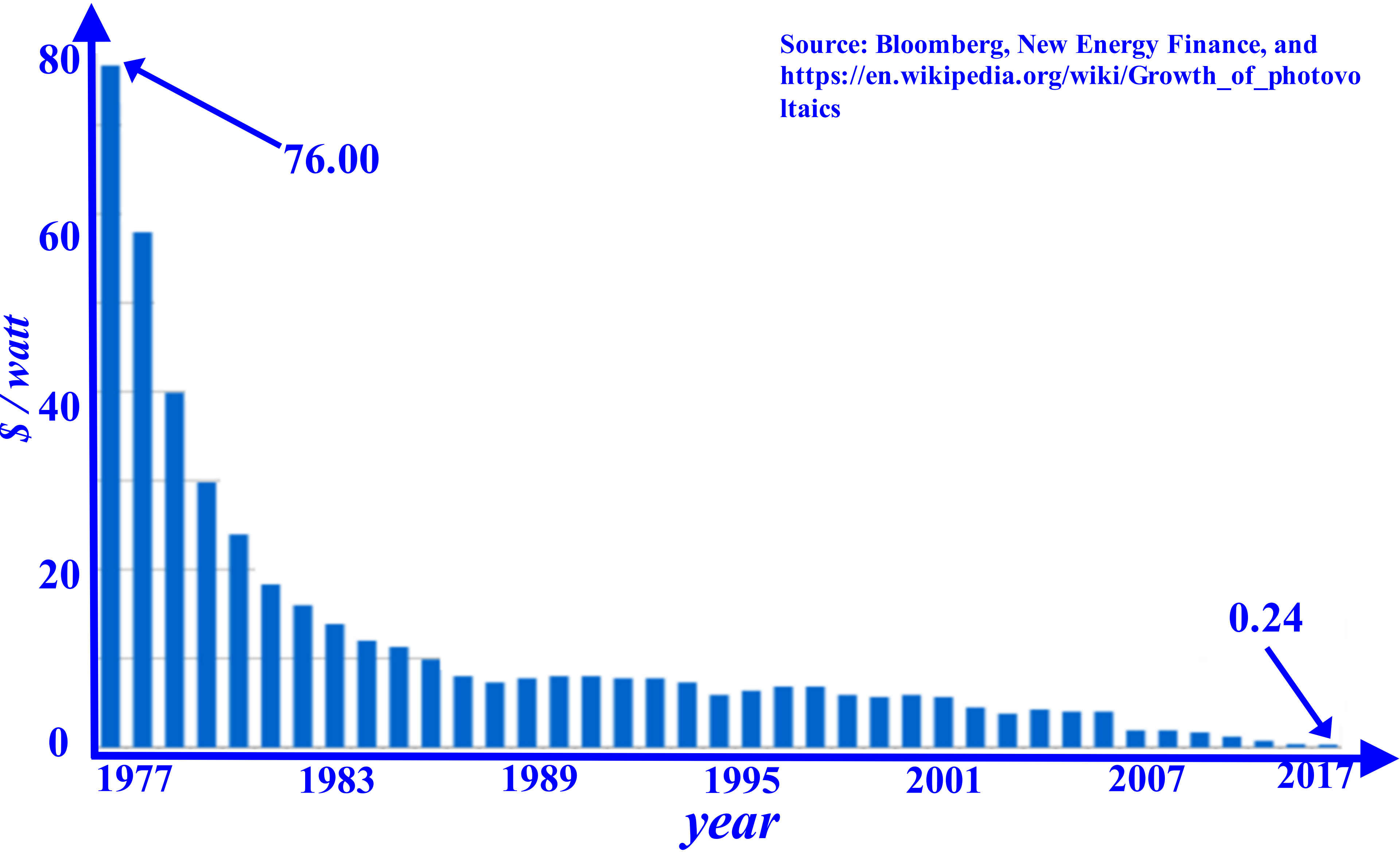
5.4 – *MWh TESLA POWERPACK* SYSTEM COSTS



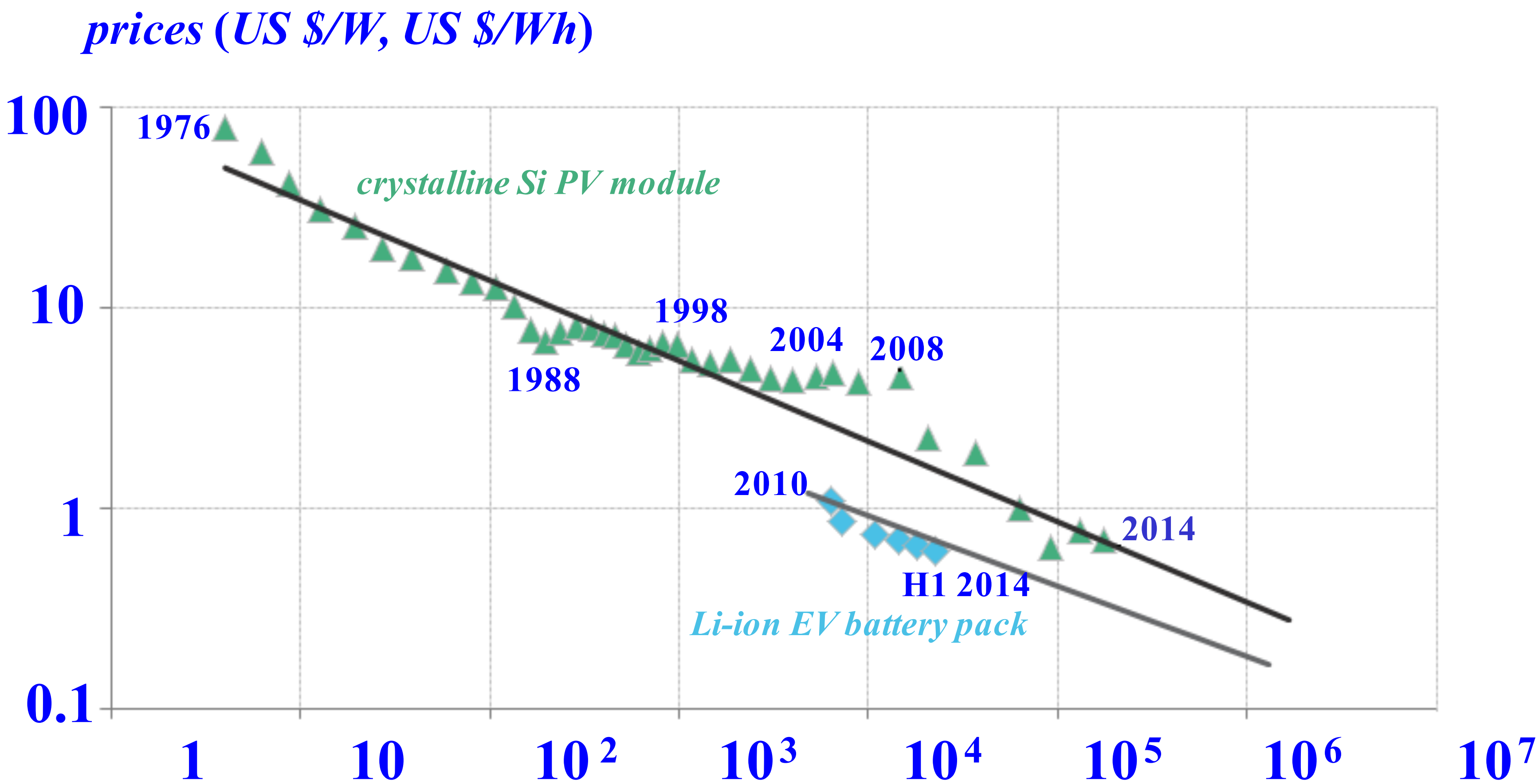
THE *TESLA POWERPACK* FALLS SHORT OF EXPECTATION

- The fixed costs of *Powerpack* unit is 470 *$/kWh*, which is nearly the double of the price that was expected earlier (250 *$/kWh*)
- This cost increase results in a range from 600 to 800 *$/kWh* with the costs of the inverter and installation taken into account
- Reductions in costs are expected to be similar to those of *PV* solar capacity price declines and such reductions can bring about the breakthrough in the wider deployment of *ESR*s

PV SOLAR CAPACITY PRICE DECLINE

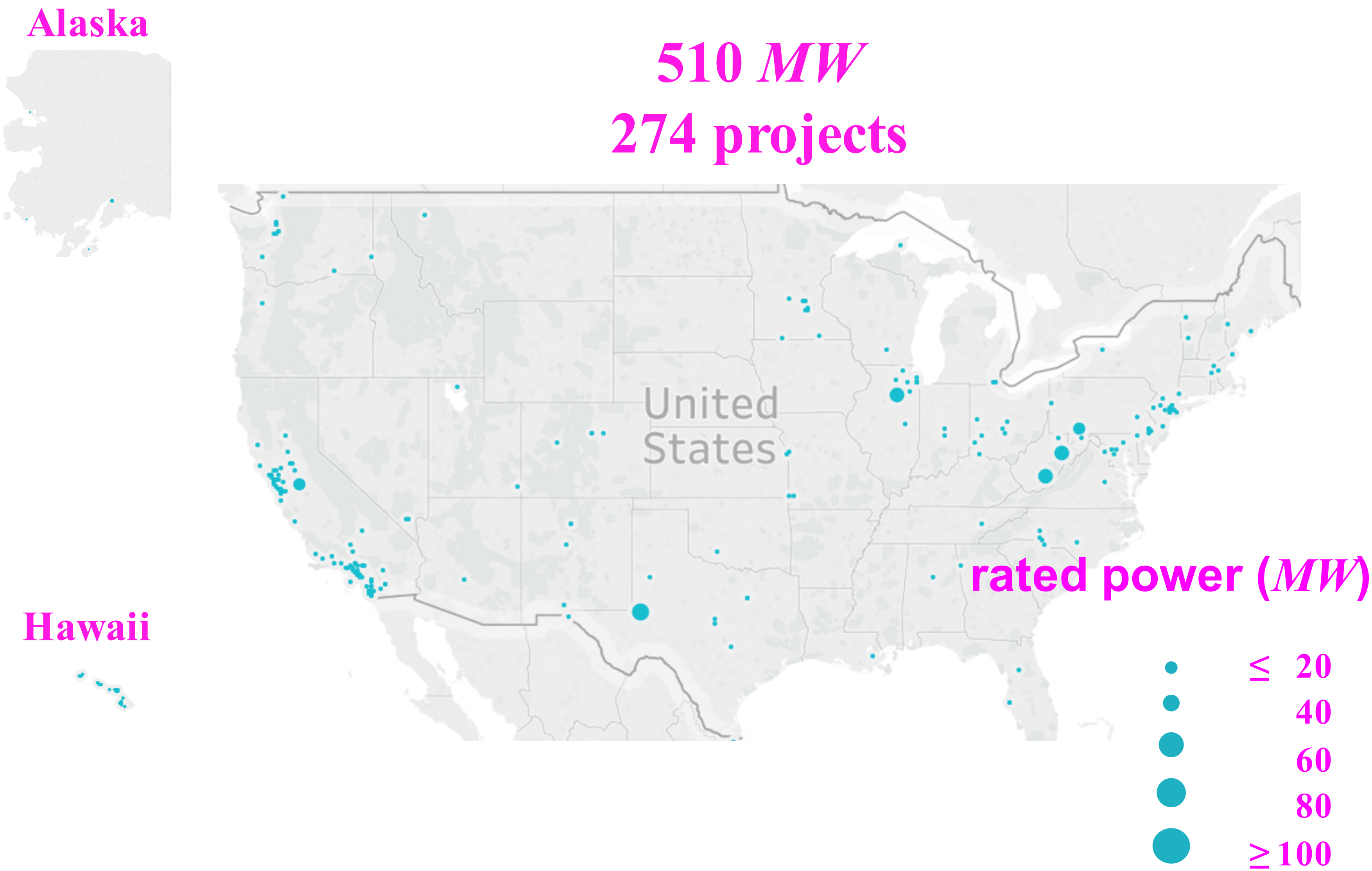


LI – ION EV BATTERY AND SOLAR *PV* PRICE CURVES



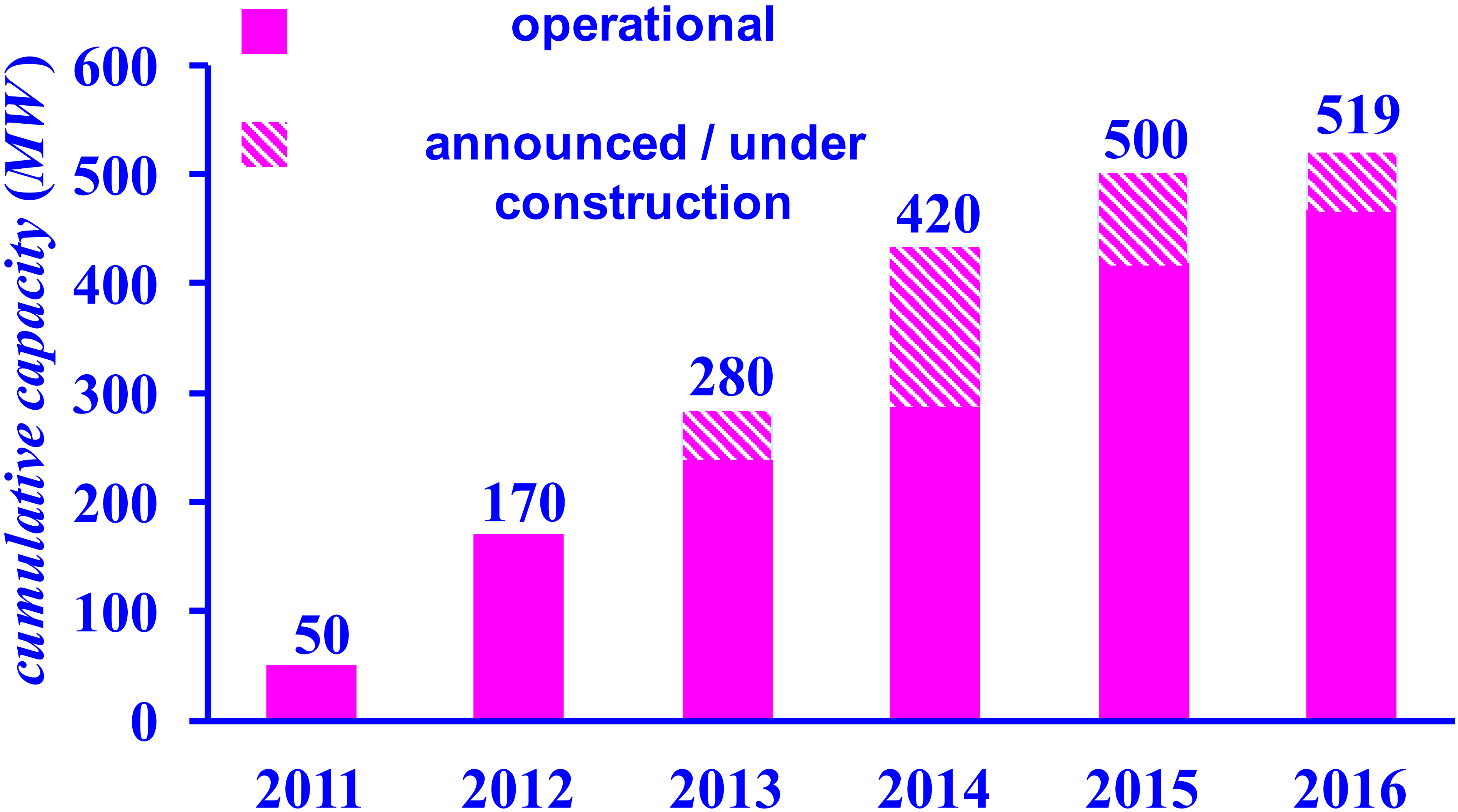
Source: Bloomberg New Energy Finance, Maycock, Battery University, MIT

THE *US BESS* PROJECTS



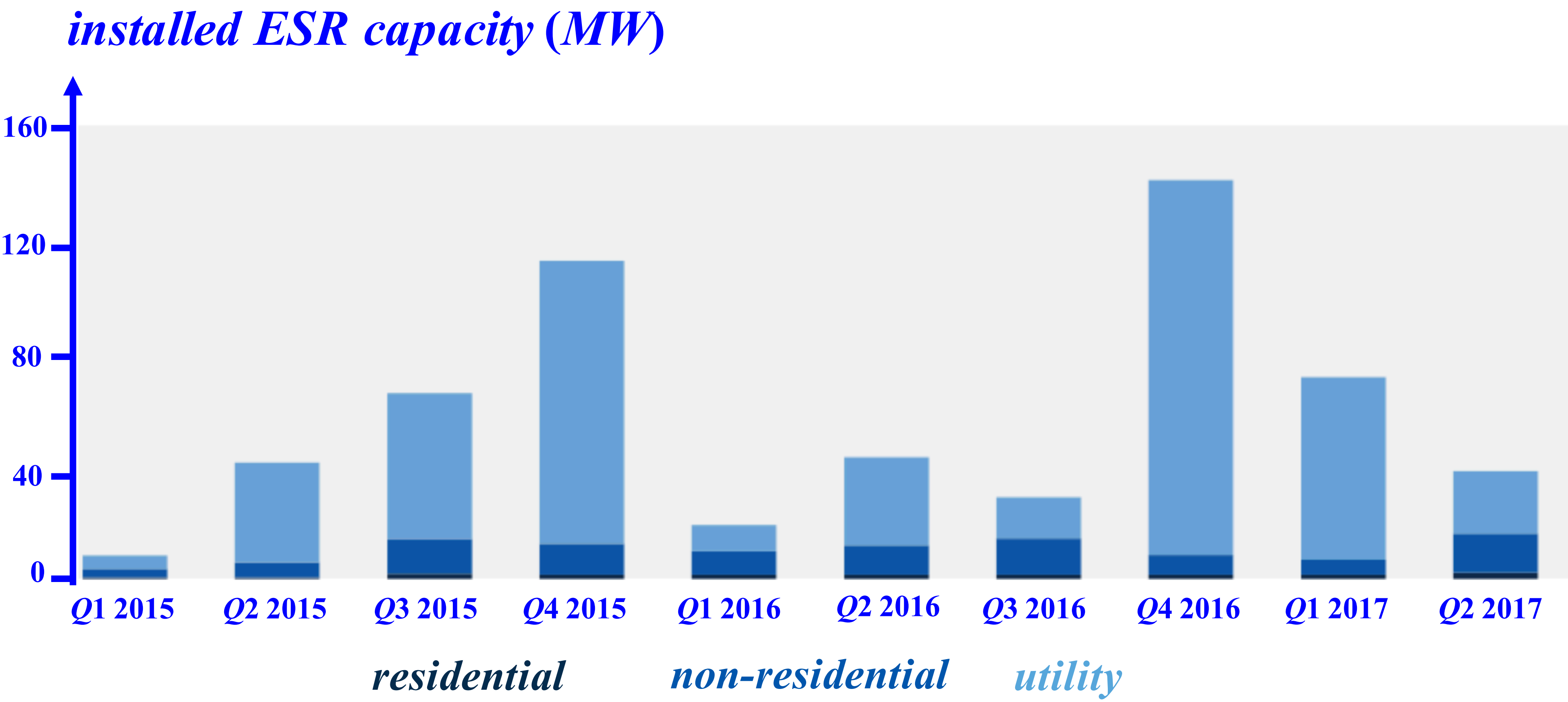
Source: http://www.energystorageexchange.org/projects

BESS PROJECT IMPLEMENTATION IN THE *US* : 2011 – 2016



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

US ADDITIONS OF *ESR* CAPACITY



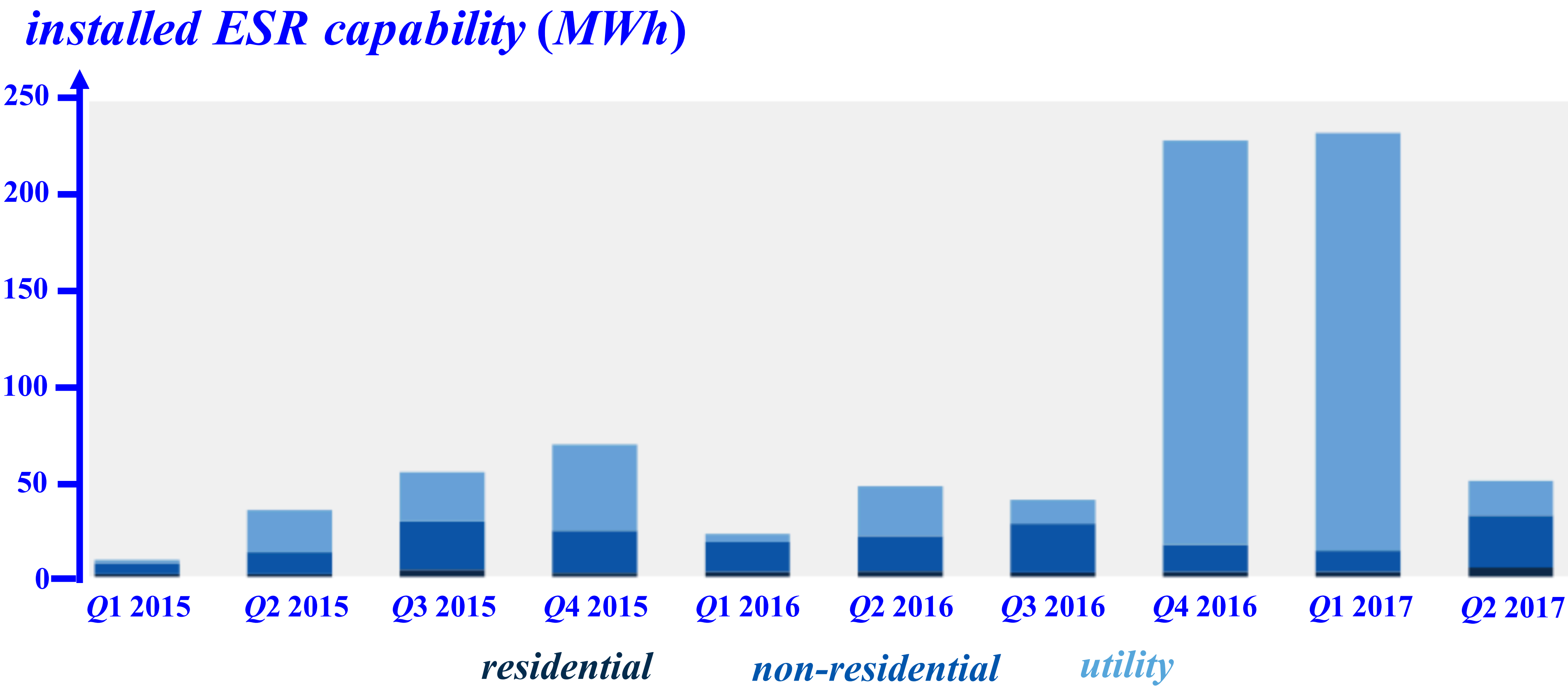
Source: GTM Research, Energy Storage Association

2017 *Q2*
US ADDITIONS OF *ESR* CAPACITY

addition type	2017 *Q2*	*% change from* 2017 *Q1*	*% change from* 2016 *Q2*
total	38 *MW*	– 47	- 11
behind–the–meter	*n/a*	– 22	+ 141
residential	*n/a*	+ 70	*n/a*
non–residential	*n/a*	+ 158	*n/a*

Source: GTM Research, Energy Storage Association

US ADDITIONS OF *ESR* CAPABILITY



Source: GTM Research, Energy Storage Association

2017 *Q2*
US ADDITIONS OF *ESR* CAPABILITY

addition type	2017 *Q2*	*% change from* 2017 *Q1*	*% change from* 2016 *Q2*
total	50.4 *MWh*	- 78	+ 6
behind-the-meter	*n/a*	+ 140	*n/a*
residential	*n/a*	+ 89	*n/a*
non-residential	*n/a*	+ 151	*n/a*

Source: GTM Research, Energy Storage Association

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 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 recent *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 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

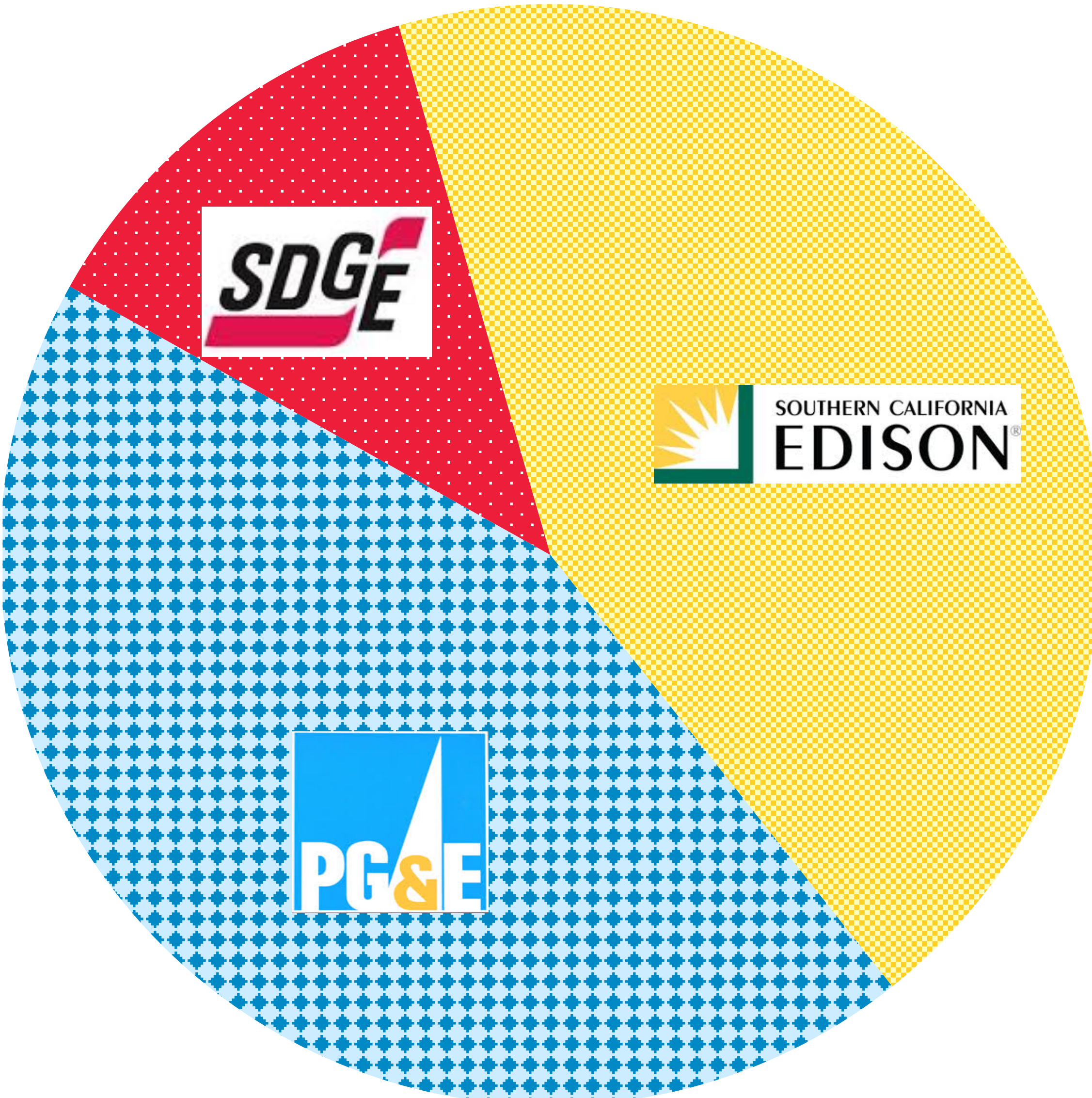
THE *CPUC* STORAGE PROCUREMENT FRAMEWORK SPECIFICATIONS

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

THE *CPUC* STORAGE PROCUREMENT FRAMEWORK SPECIFICATIONS

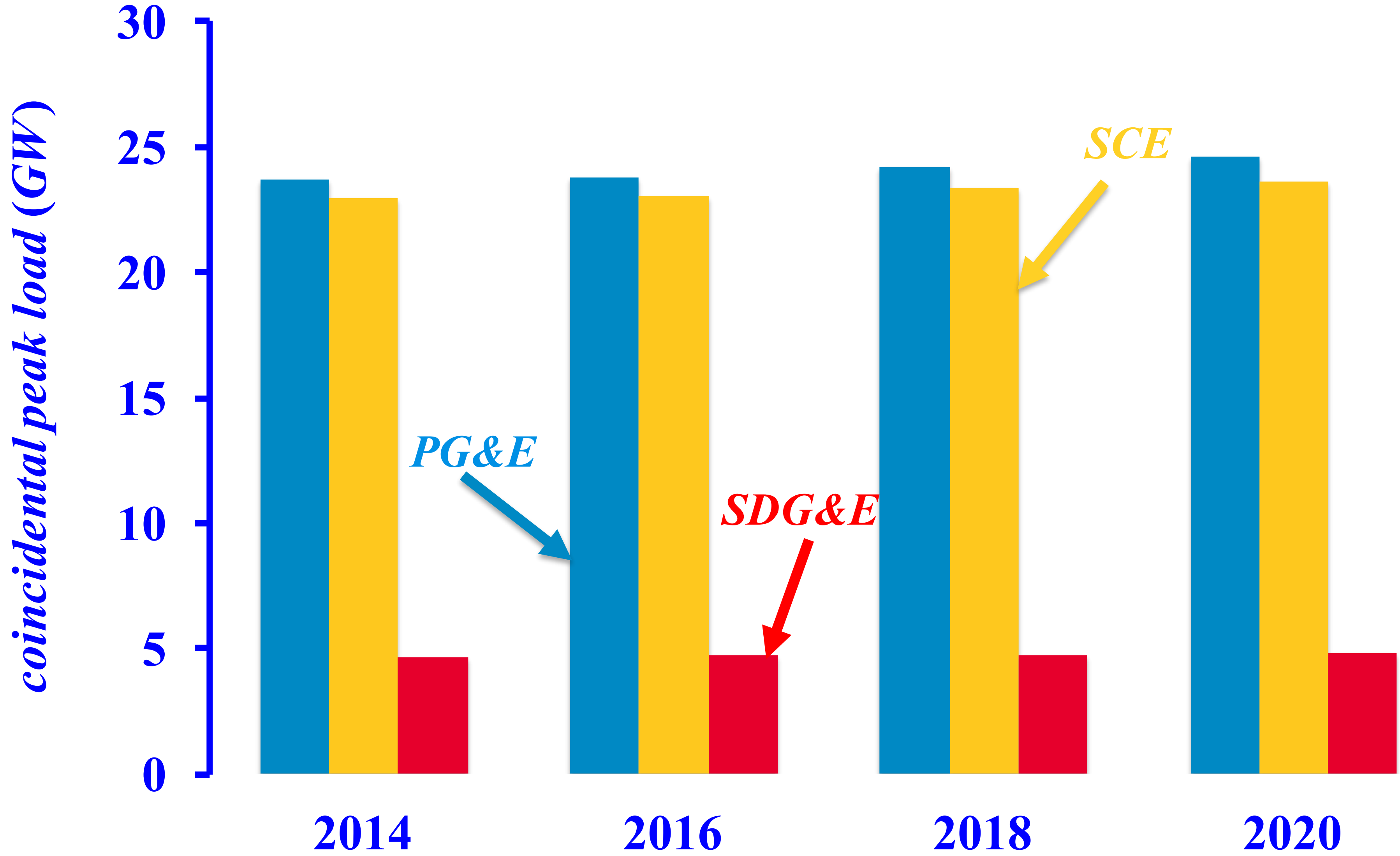
- Allowed deviations to meet the *CPUC* targets by:
  - shifting targets between grid interconnection points
  - ownership of storage resources by *IOU*s, customers and third parties
  - deferral of *IOU* targets in the *CPUC*–specified schedule

IOU STORAGE CAPACITY TARGETS



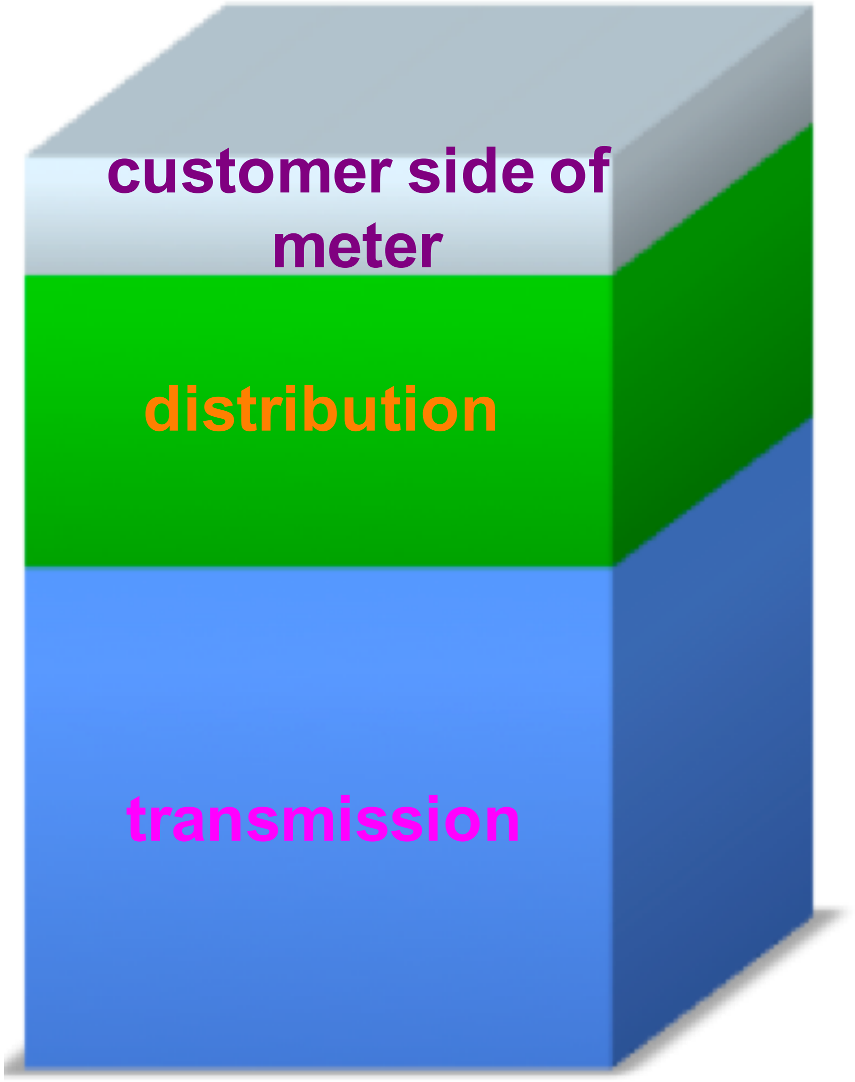
IOU	*target (MW)*	*%*
PG&E	**580**	**43.77**
SCE	**580**	**43.77**
SDG&E	**165**	**12.26**

CALIFORNIA IOUs' HISTORICAL AND FORECASTED PEAK LOADS

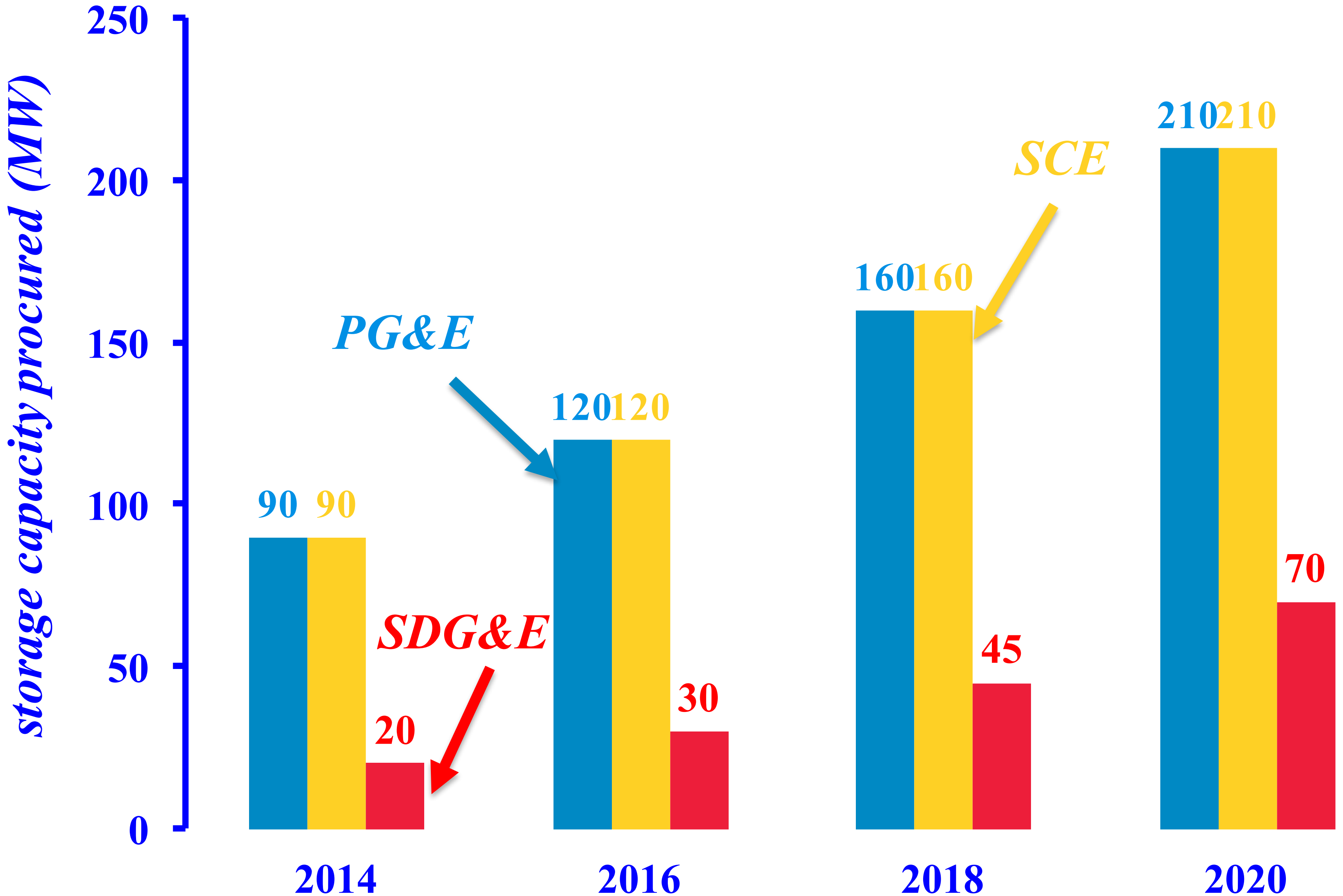


STORAGE CAPACITY TARGETS AND GRID INTERCONNECTION POINTS

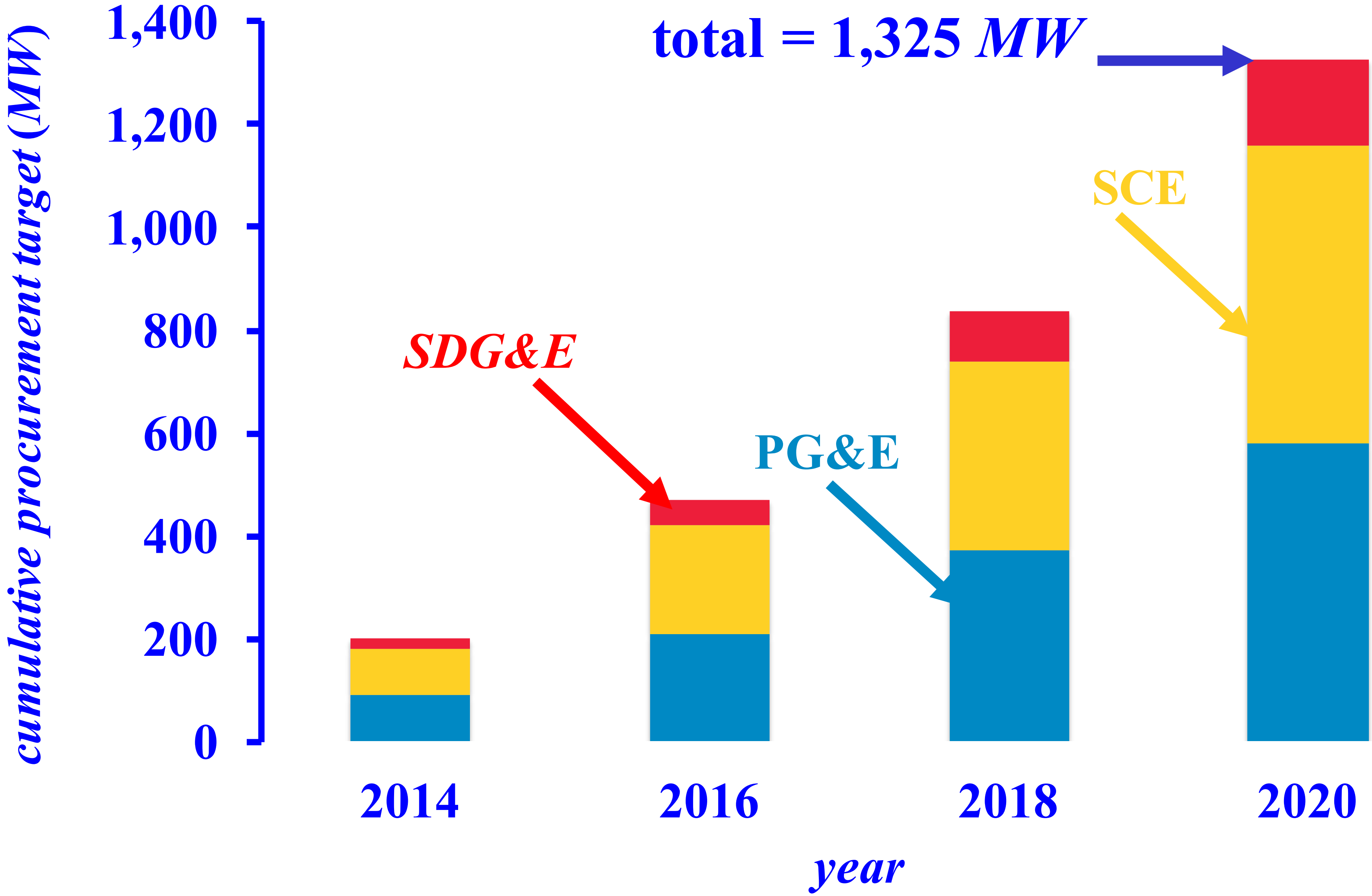
grid intercon–nection point	*target (MW)*	%
customer side of meter	200	15.09
distribution	425	32.08
transmission	700	52.83



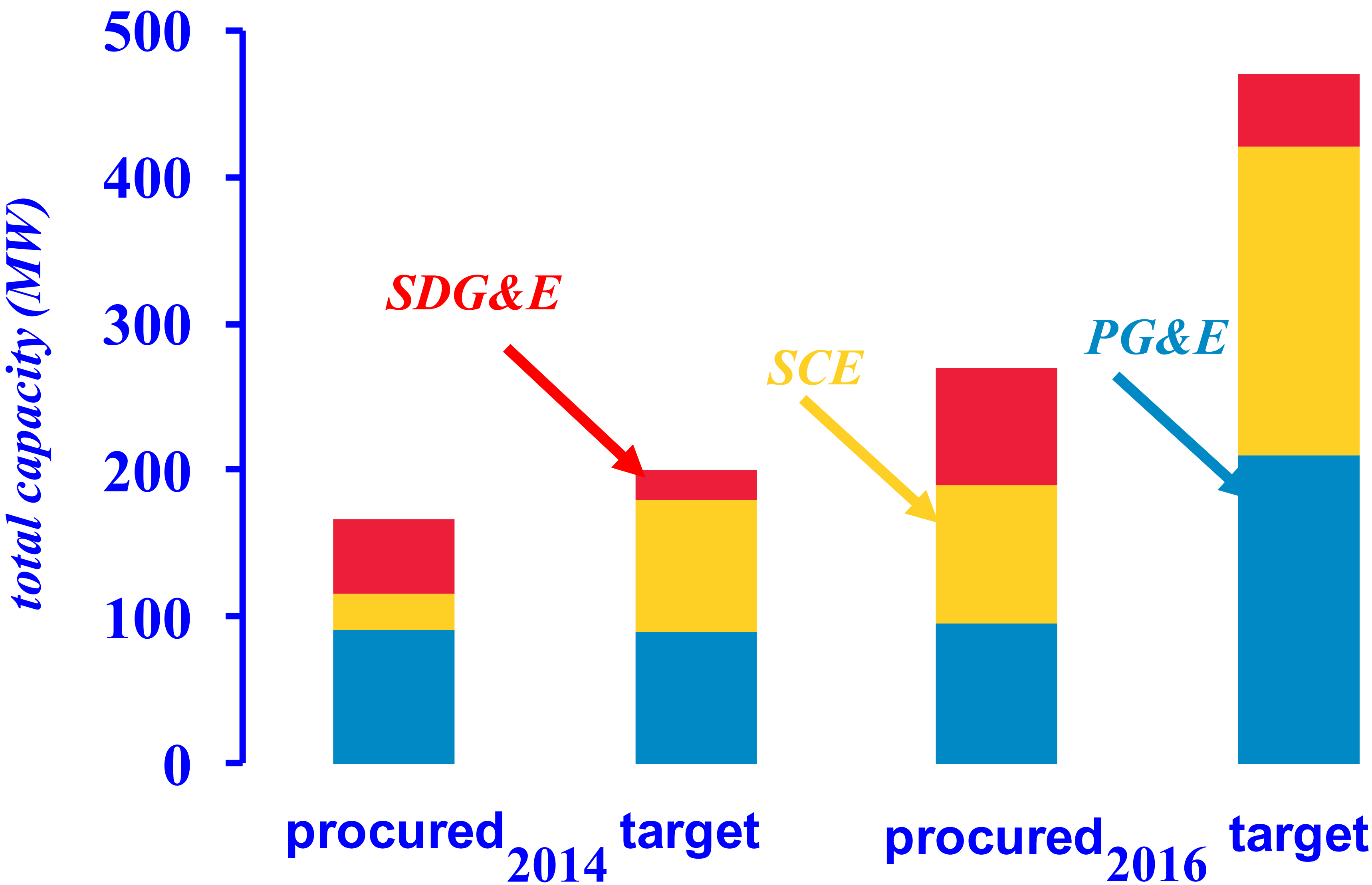
PROCUREMENT SCHEDULE



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

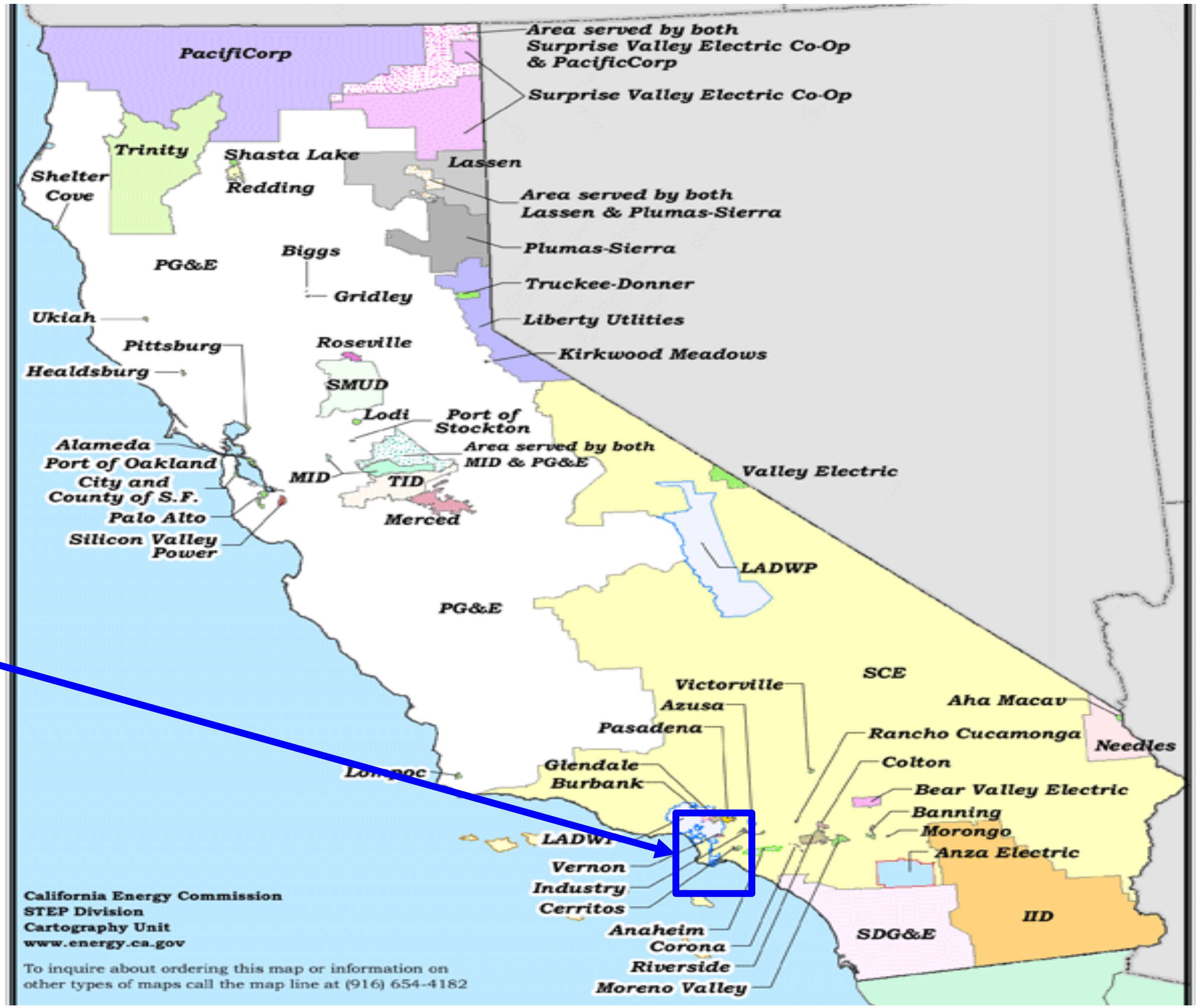
- **The *CPUC* Decision 13-10-040 also sets the energy storage procurement targets for *Community Choice Aggregators* and the *Electric Service Providers* at 1 % of their year 2020 peak loads; projects must be initiated by 2020, with installation to be completed by the end of 2024**

CPUC STORAGE PROCUREMENT FRAMEWORK FEATURES

- Over–procurement by an *IOU*, above its biennial procurement target, may reduce its next biennial target by the exceeded amount

- Southern California Edison must invest up to the 50 % level in at least 50 *MW* of energy storage to meet *L.A. Basin* local capacity requirements

CA SERVICE AREAS



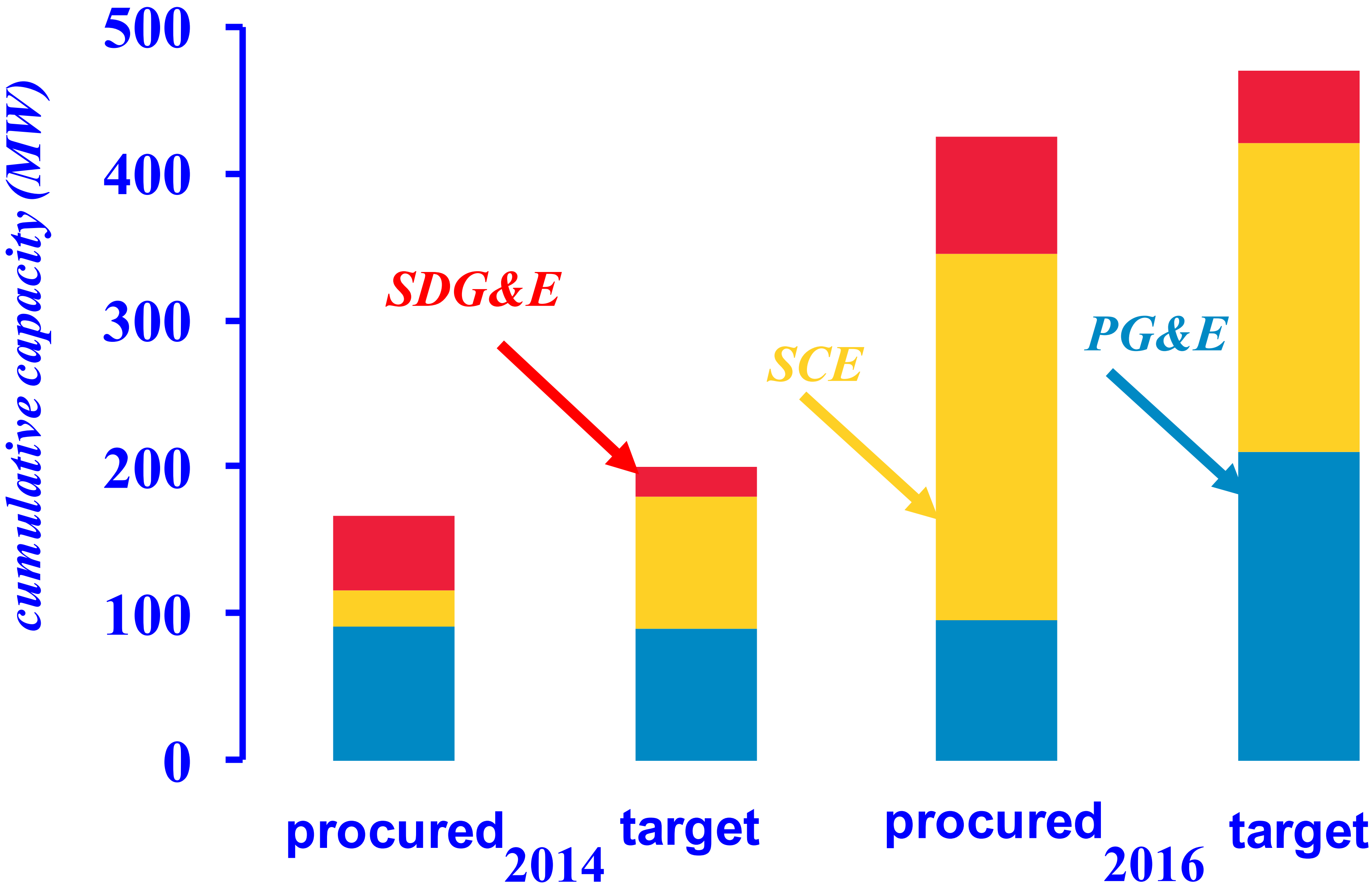
L.A.
Basin

Source : California Energy Commission

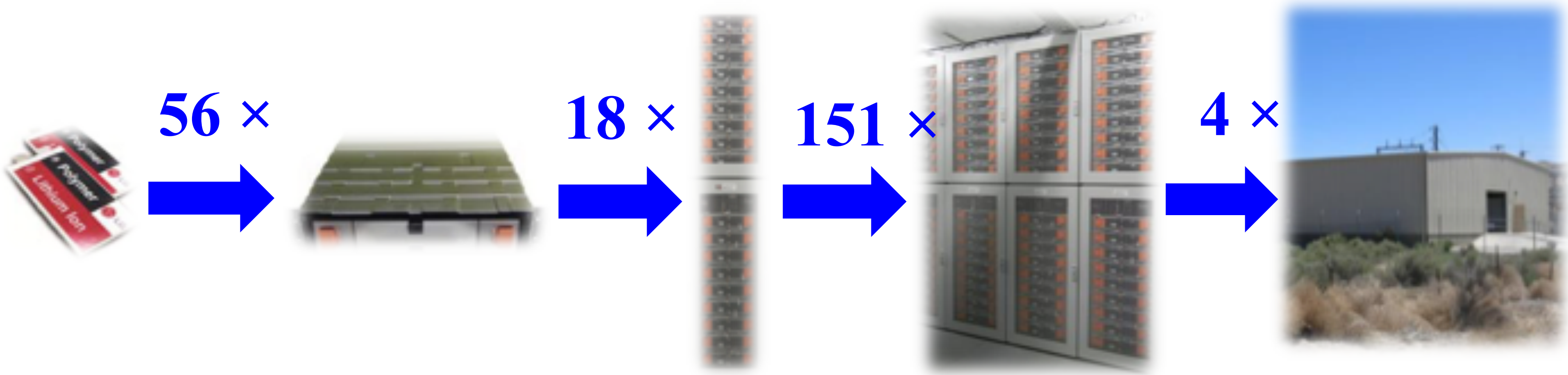
CURRENT STATUS OF ENERGY STORAGE PROCUREMENT IN *CA*

- There has been an upsurge in the customer–connected projects that have helped the *IOU*s meet some of their *T&D* storage targets in 2016
- 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*

PROCURED CUMULATIVE CAPACITY *VERSUS* TARGET CAPACITY



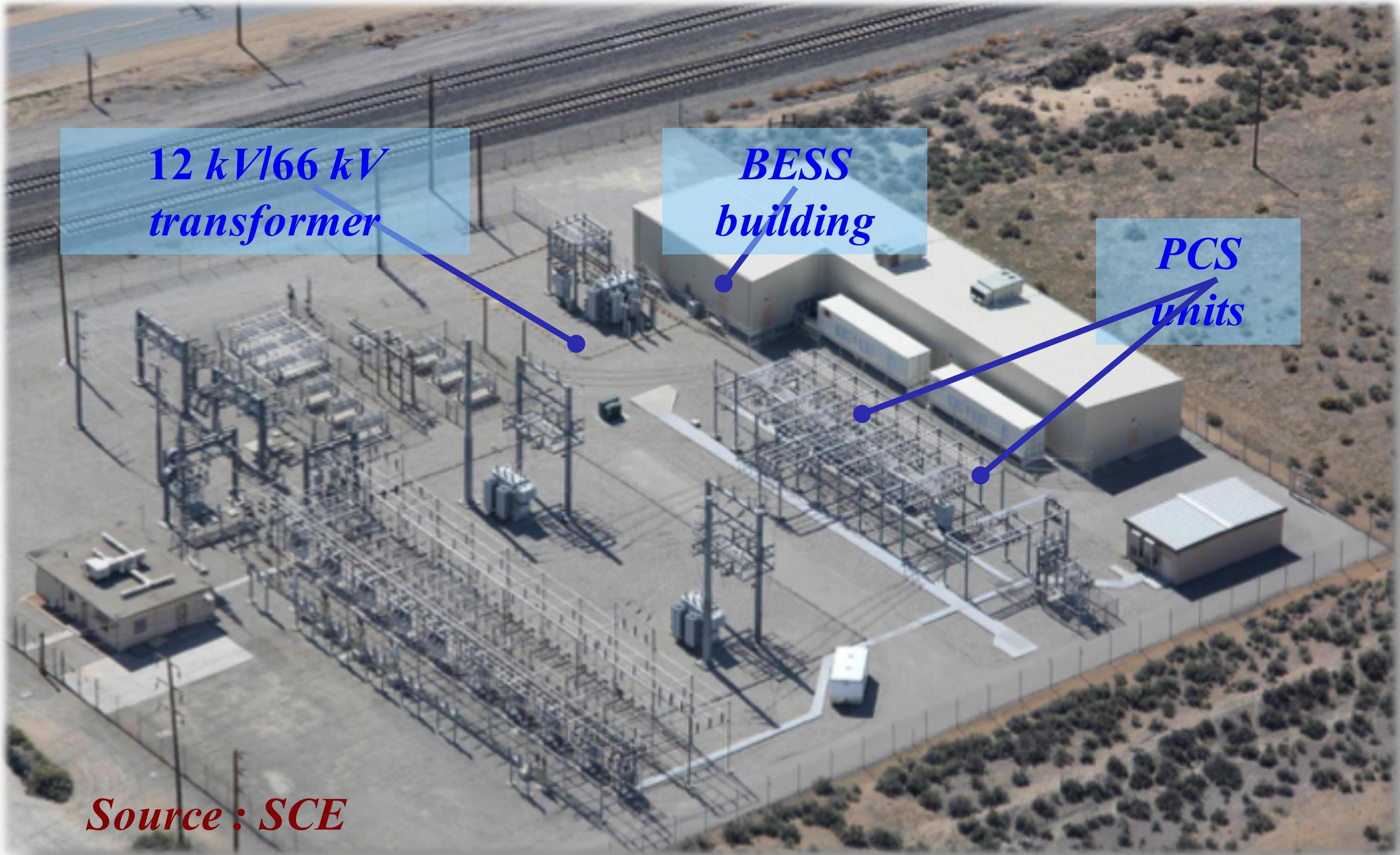
FROM 60 *Wh* BATTERY CELLS TO A LARGE–SCALE 32 *MWh ESR* (*BESS*)



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

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

LARGE – SCALE *ESR*



CURRENT STATUS OF ENERGY STORAGE PROCUREMENT IN *CA*

- In the 2016 biannual cycle, the procured total *ESR* capacity fell short by 46 *MW* of the set target
- The key barriers to procurement include the huge costs and the eligibility requirements for *ESR*s to qualify
- Unless more viable and cost–effective energy storage is procured, any shortfall in the procurement will be deferred to a future cycle

CPUC DECISION ISSUES

- The feasibility and cost–effectiveness of each energy storage project may be difficult to demonstrate without a clearly specified *CPUC* approved methodology
- While the capacity procurement targets for energy storage capacity are specified in the *CPUC* mandate, the storage capability targets are not

CPUC DECISION ISSUES

- **The quantification of the extent to which each project meets the optimization of grid services and the integration of renewables requirements represents a challenging problem**
- **Management of required permit authorization by each *IOU* within the *CPUC*–specified time frame for the planned sites**

CPUC DECISION RAMIFICATIONS

- *CPUC* specified constraint to limit pumped hydro–capacity is a key driver to spur sales of other storage technologies and reduce the dependence of drought–ridden *CA* on hydro storage
- The *CPUC Decision* stimulus to reduce the costs of *ESR*s from the increased demand is likely to be repeated by other jurisdictions so as to engender further *ESR* cost reductions

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* deployment

OPPORTUNITIES FOR LARGE–SCALE *ESRs*

- 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

CPUC ORDER FOR AN ADDITIONAL 500 *MW* *ESR* CAPACITY

- On April 27, 2017, the *CPUC* ordered each of the three *IOU*s to incorporate proposals for programs and investments to deploy 166.66 *MW* of *ESR*s – a total of 500 *MW* of *ESR* capacity – above the mandated 1,325 *MW*
- The additional 500 *MW* of *ESR*s must be connected either at the distribution system or be deployed behind-the-meter, and have a "useful life of at least 10 years"

OREGON STORAGE MANDATE

- *Oregon* was one of the first states to emulate *California* with the specification of steps to formulate a state–wide storage mandate
- *Oregon*'s *House Bill* 2193 passed in 2015, requires *Portland General Electric* and *PacifiCorp* to have a minimum of 5 *MWh* of energy storage installed and operational by January 1, 2020

Source: http://www.utilitydive.com/news/oregon-puc-release-guidelines-for-energy-storage-mandate/433462/

MASSACHUSETTS STORAGE TARGETS

- The *Massachusetts Department of Energy Resources* set 200–*MWh* energy storage target to be met by 1/1/20
- *MA* became the 3rd *US* state to set storage targets
- After the *MA* "State of Charge" report found the installation of 600–*MW ESR* capacity by 2025 would bring *$ 800 million* savings to the state's ratepayers,

MASSACHUSETTS STORAGE TARGETS

MA committed *$ 10 million* to analyze opportunities to support *MA* storage companies and develop policy options to encourage *ESR* deployment

- *MA* announced up to *$ 10 million* in additional funding for energy storage demonstration projects
- These measures constitute rather weak actions

NEW YORK ENERGY STORAGE DEPLOYMENT PROGRAM

- The *New York State Legislature* passed *Senate Bill* 5190 and *Assembly Bill* 6571 which affirms that the state's *Public Service Commission* (*PSC*) develop an energy storage deployment program
- Once the bill is signed by Gov. Andrew Cuomo, *NY* will be the 4th state to set energy storage targets
- The bill requires the *PSC* to establish storage targets by January 1, 2018 to be met by 2030

Source: http://www.utilitydive.com/news/new-york-lawmakers-clear-bill-creating-an-energy-storage-mandate/445667/

MARYLAND STORAGE TAX CREDITS

- *Maryland* provides tax credits for new storage installations to meet its aim to increase *ESR* deployment
- On April 10, The *Maryland Senate* passed a bill whose key provision is a tax credit of up to 30 % of the cost of *ESR* installations
- The tax credit can go up to *$* 5,000 for a residential system, *$* 75,000 for a commercial system, but the total awarded credits cannot exceed *$* 750,000 in a single year

Source: http://www.utilitydive.com/news/maryland-passes-30-energy-storage-tax-credit-for-residential-ci-installa/440363/

NEVADA STORAGE INCENTIVES

On June 5, *Nevada State Legislature* passed *Assembly Bill 206*, which requires that each *kWh* of energy delivered by a qualified *ESR* to be double counted for its contribution toward meeting the state's *RPS* requirements whenever

- **the *ESR* uses renewable resource outputs for charging and discharges stored energy during a peak load period; or,**
- **provides ancillary services to the grid so as to facilitate renewable resource integration**

Source:https://www.greentechmedia.com/articles/read/nevada-just-became-the-most-exciting-state-for-energy-storage-policy

TUCSON ELECTRIC POWER (*TEP*) *SOLAR* + *STORAGE* FACILITY

- ***TEP*** **signed a *PPA* with a *solar + storage NextEra Energy* project in *AZ***
- **The project consists of a a 100–*MW PV* array, and a 30–*MW* energy storage resource with a 120–*MWh* storage capability**

https://www.utilitydive.com/news/how-can-tucson-electric-get-solar-storage-for-45kwh/443715/

TUCSON ELECTRIC POWER (*TEP*) *solar + storage* FACILITY

- Although the exact pricing is not revealed, the all-in cost for the project is "significantly less than 4.5 *¢/kWh* over 20 years", which is way lower than the previous record of 11 *¢/kWh*
- *TEP* stated that the solar portion of the project at below 3 *¢/kWh*, was "the lowest price recorded in the *US*"

https://www.utilitydive.com/news/how-can-tucson-electric-get-solar-storage-for-45kwh/443715/

ARIZONA PUBLIC SERVICE (*APS*) STORAGE PROJECT

- *APS* is developing an energy storage project with a capacity of 2 *MW* and a capability of 8 *MWh* – without a statutory or regulatory mandate
- *APS* is building the project as an alternative to defer for 6 *years* the construction of a 20–*mile* long new transmission line

https://www.utilitydive.com/news/top-energy-storage-projects-driving-the-sector-in-2017/511723/

ARIZONA PUBLIC SERVICE (*APS*) STORAGE PROJECT

- *APS* has not disclosed the cost of either the storage project or the transmission lines, but estimates the batteries will enable the deferral of investment in a new transmission line for up to six years, during which the batteries will also deliver additional value by providing frequency regulation and bolstering grid reliability

https://www.utilitydive.com/news/top-energy-storage-projects-driving-the-sector-in-2017/511723/

ARIZONA PUBLIC SERVICE (*APS*) STORAGE PROJECT

- The fact that *APS* selected the implementation of a storage project instead of an investment in a transmission line due to the various benefits that an energy storage resource brings, shows the necessity of the development of new metrics for the true valuation of storage

FERC DER / ESR NOPR

- On November 17, 2016, *FERC* issued a notice of proposed rulemaking (*NOPR*), whose goal is to facilitate a more effective integration of *ESR*s and *DER*s in system and market operations
- The *NOPR* proposes to "require each *RTO/ISO* to revise its tariff to establish a participation model consisting of market rules that, recognizing the physical and operational characteristics of *ESR*s, accommodates their participation in the organized wholesale electric markets"

FERC DER / ESR NOPR

- *FERC* requirements for the participation model:
  - *ESR*s be eligible to provide all capacity, energy and ancillary services they are able to provide
  - *ISO/RTO* tariffs include bidding parameters to represent the *ESR* physical/operational limits
  - *ESR*s be able to be dispatched and set the wholesale market clearing price as both a wholesale seller and wholesale buyer

CHALLENGES TO LARGE–SCALE STORAGE DEPLOYMENT

- The deployment of large–scale *ESR*s brings many *economic, regulatory and technical challenges* that must be overcome to effectively harness the myriad benefits such resources provide
- While the implementation of large–scale storage projects is 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 far from a trivial problem

GRAND CHALLENGES

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

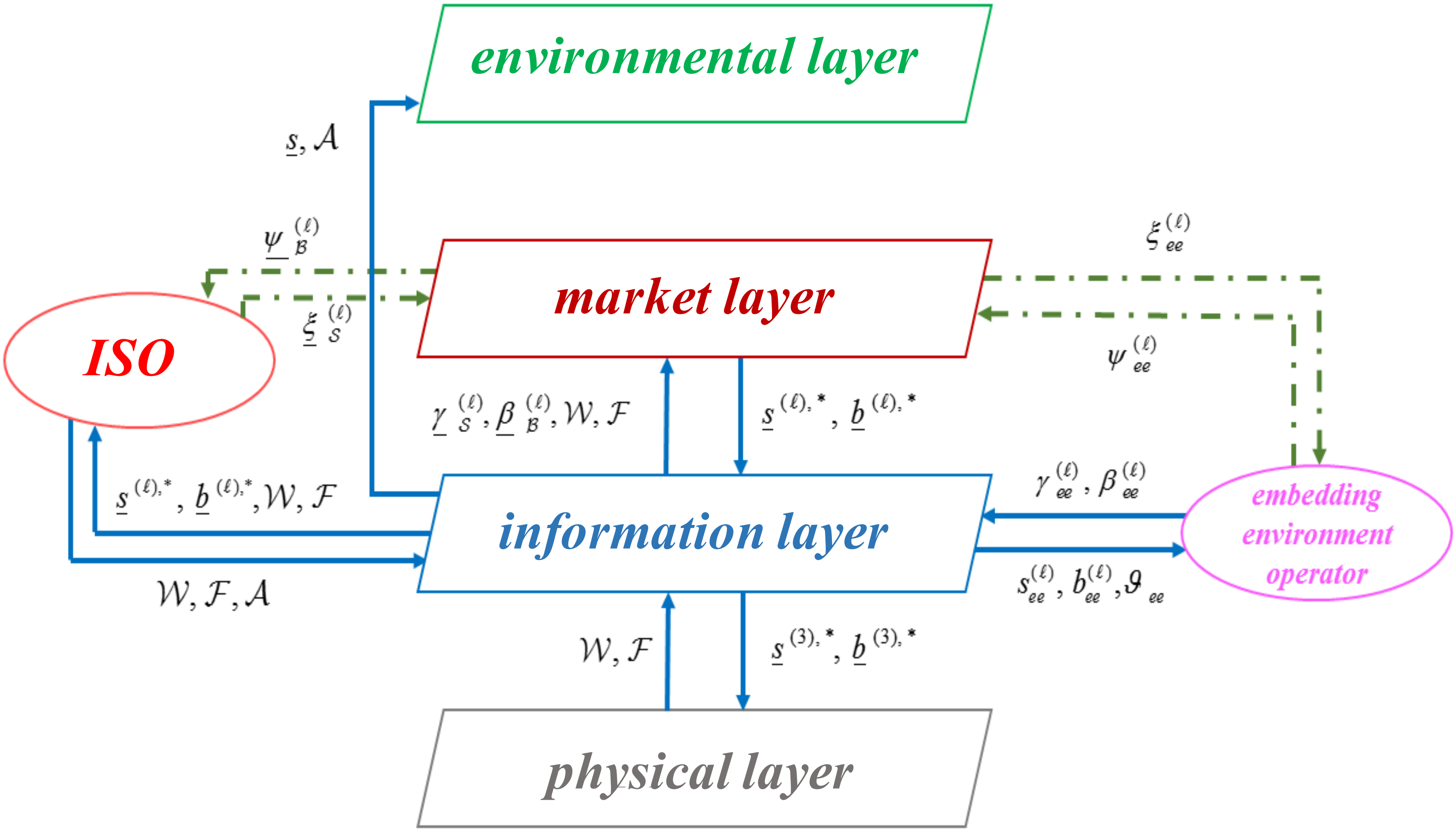
GRAND CHALLENGES

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

A KEY CHALLENGE: CONSTRUCTION OF AN ANALYTIC FRAMEWORK

- The need is for a conceptual framework to appropriately represent the unique *ESR* features and to monetize *ESR* deployment in a broad range of cases – a broad range of roles and applications
- This framework must be able to comprehensively describe all the interactions among *ESR*s and the other players/stakeholders in the grid and markets

THE FRAMEWORK DESIGN



FRAMEWORK REQUIREMENTS

- Representation of
  - the salient characteristics of each *ESR* and its operational phases
  - the interactions of the embedding environment and the grid
  - the objectives/strategy of each *ESR* entity

FRAMEWORK REQUIREMENTS

- the different roles and applications of *ESR*
- the incorporation of the business models/and the operational paradigm of different *ESR* applications
- the environmental impact of *ESR* integration
- the incorporation of relevant policy issues and appropriate policy alternatives

FRAMEWORK REQUIREMENTS

- the implementation of new market products to effectively harness *ESR* features
- the ability to incorporate new metrics and new tools for *ESR* analysis and studies
- various contractual agreements between *ESR*s and other resources via instruments such as *power purchase agreements* (*PPAs*) and *contracts for differences* (*CFDs*)

FRAMEWORK REQUIREMENTS

- Furthermore, the framework must be able to represent
  - the physical grid, the *ESR* embedding environment, if any, all resources/loads
  - the interchange of control signals, market information/forecasts/data, environmental and sensor measurements
  - the *physical/financial/information* flows between physical resources, market players, asset owners and resource and grid operators

APPLICATIONS OF THE FRAMEWORK

- Financial issue studies
  - analysis of investment alternatives
  - cost/benefit studies
  - economic impacts of policy alternatives
  - estimation of *ESR* opportunity costs
  - formulation of *ESR* offering strategies
  - justification of *ESR* investment expenses

APPLICATIONS OF THE FRAMEWORK

- **Policy issue analysis**
  - **new policies that impact *ESR* operations, such as regulatory treatment of *ESR*s, the interconnection and market participation rules and integration of *DER* aggregations**
  - **impacts of a carbon tax/price**
  - **formulation of effective strategic responses to modified *RPS* directives**

APPLICATIONS OF THE FRAMEWORK

- Operational analysis
  - side–by–side comparison of alternative *ESR* scheduling methodologies
  - assessment of forecast quality as a function of advance time
  - *robust optimization* studies to appropriately represent uncertainty impacts

APPLICATIONS OF THE FRAMEWORK

- Planning studies
  - resource mix design for grids with integrated *ESR*s
  - environmental assessment of deeper *ESR* penetrations
  - investment into dedicated *ESR*s for renewable resource projects

DEVELOPMENT OF *ESR* PERFORMANCE METRICS

- **The quantification of the *physical/information/economic interactions* between the *ESR* and all the players in the electricity markets and the grid must be performed for the spectrum of *ESR deployments* in the power grid is a big challenge**
- **A key challenge in the construction of this conceptual structure is the formulation of new, appropriate metrics**

THE FORMULATION OF APPROPRIATE METRICS

- **The replacement of the currently used *levelized costs of energy* (*LCOE*) metric by a more appropriate measure that recognizes the distinct phases of battery operation is needed**
- **New measures to indicate the performance of *ESR* on various aspects including:**

THE FORMULATION OF APPROPRIATE METRICS

- ability to act as a generator or load or be in the idle phase
- environmental impacts
- degradation effects for battery storage
- opportunity costs
- all services provided to the grid
- avoidance of investment in costly upgrades

NEED FOR APPROPRIATE TOOLS

- To take advantage of the **increased flexibility** that the grid–integrated *ESR*s provide, appropriate models, tools and policy initiatives are needed
- These needs pertain to activities that include:
  - planning and investment analysis;
  - development of additional application areas;
  - policy analysis;
  - operations; and
  - market participation and performance

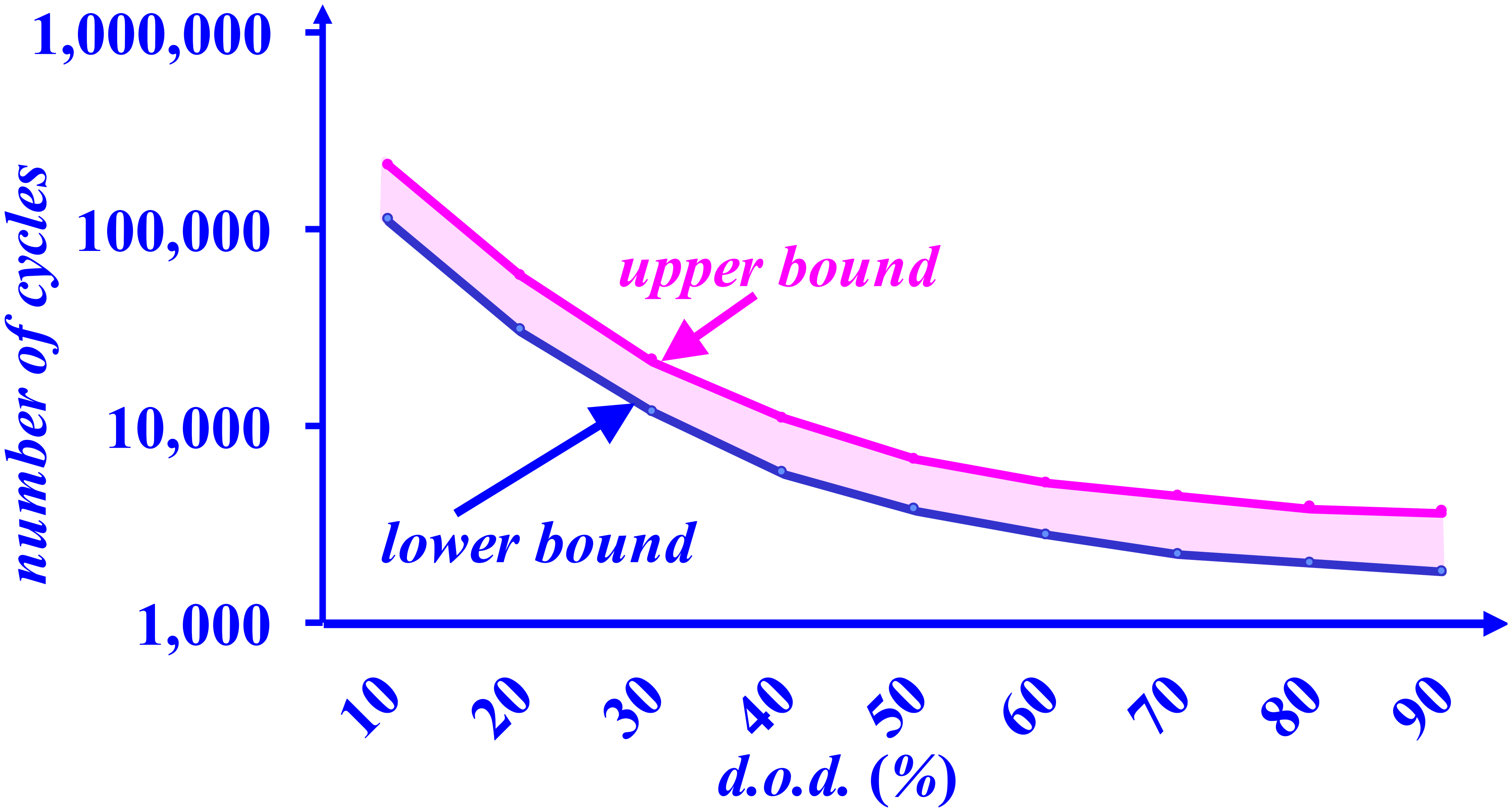
NEED FOR APPROPRIATE TOOLS

- *Energy storage* modeling, management and solution methodologies are required to:
  - allow effective *ESR* participation in markets for the provision of commodity and ancillary services
  - evaluate storage for investment decisions
  - formulate operational paradigms
  - devise new schemes to manage inventory
  - overcome scalability/tractability issues in mixed integer programming applications

BATTERY LIFE ESTIMATION

- **Battery capacity fading is a limiting factor in *BESS***
- **Better life prediction models, planning and operations tools and management schemes are required to accelerate commercial deployment of batteries in utility–scale applications**
- **Battery cycle life is defined as the number of full charge – discharge cycles a battery can perform before its nominal capability falls below 80 % of its initial rated capability**

LITHIUM – ION BATTERY LIFE DEGRADATION



Source: http://www.saftbatteries.com/force_download/li_ion_battery_life__TechnicalSheet_en_0514_Protected.pdf

REGULATORY POLICIES

- The current regulations for conventional grid assets cannot recognize the unique nature of *ESR*s and as such significantly limit the benefits that can be leveraged from these units
- The unique nature of storage raises a bevy of policy and regulatory issues regarding the ownership, control and jurisdiction of *ESR*s that need to be resolved to stimulate the continuing future investment in storage projects and to ensure the optimal operation of the storage units

ENVIRONMENTAL ASPECTS

- Environmentally sensitive means to dispose the battery solid waste after degradation–scalable for deeper penetration of large scale battery deployment
- The reduction of greenhouse gas emissions, especially in those venues in which the storage unit is charged by fossil–fuel–fired plants

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

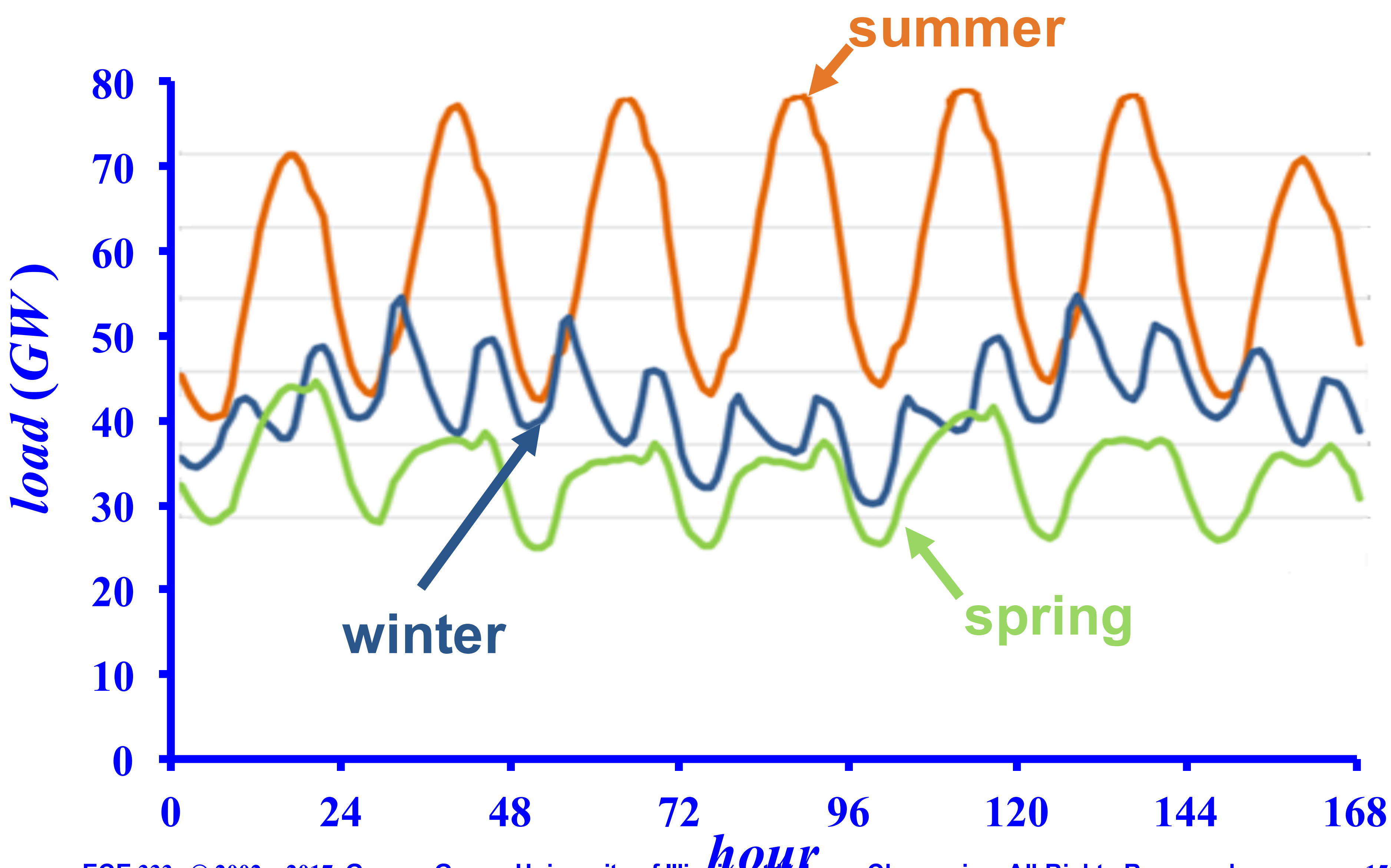
CONCLUDING REMARKS

- 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

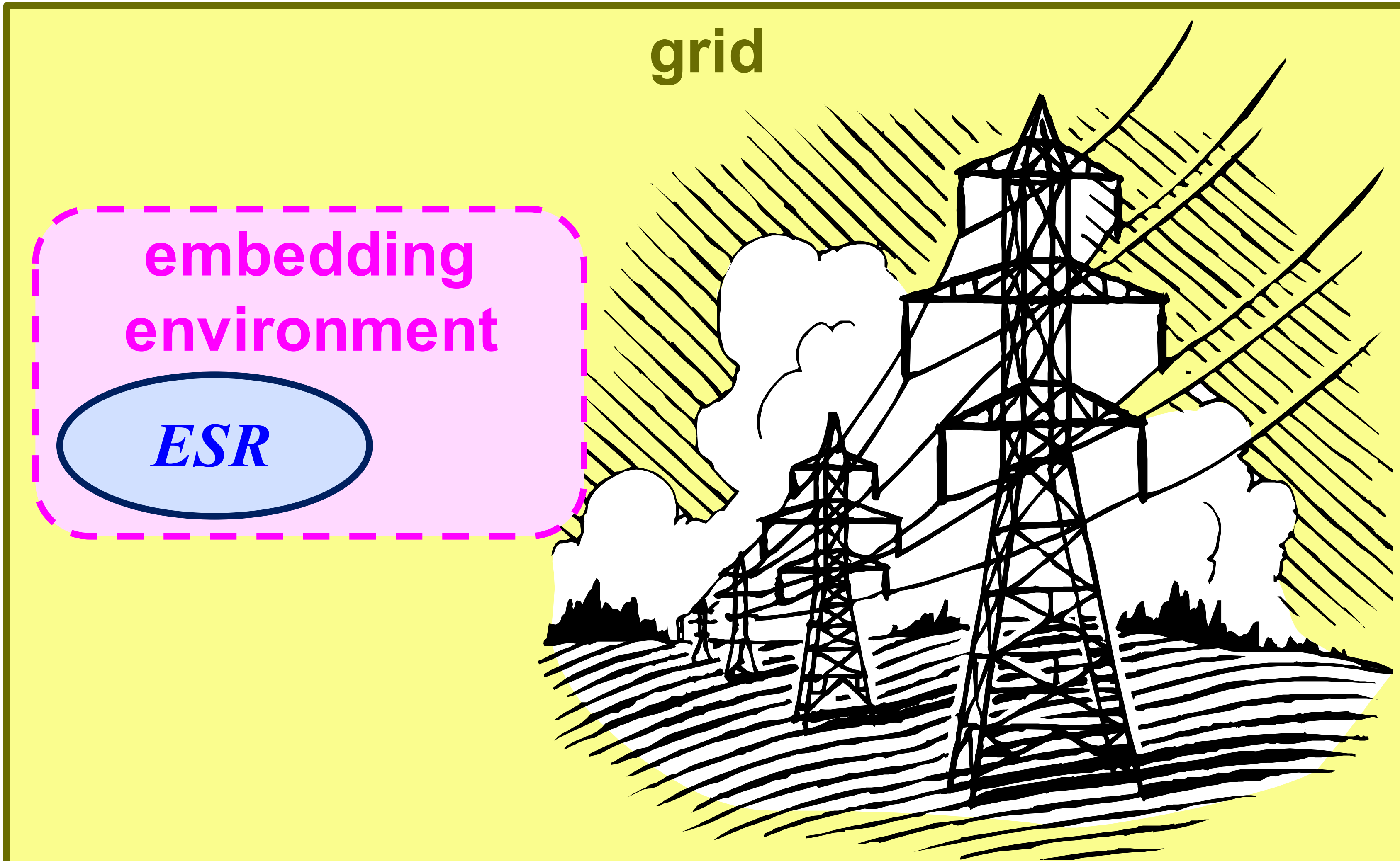
KEY BATTERY STORAGE METRICS

metrics	*measurand*
state of charge (s.o.c.)	*charge level of a battery, typically, expressed in percent*
depth of discharge (d.o.d.)	*100 % complement of the s.o.c.*
C–rate	*rate at which a battery is discharged relative to its maximum capacity*
state of health (s.o.h.)	*a combination of individual measures including the number of cycles, the internal resistance, the capability, the voltage and the current outputs*

TYPICAL SEASONAL WEEKLY LOAD PATTERNS : *ERCOT* 2005



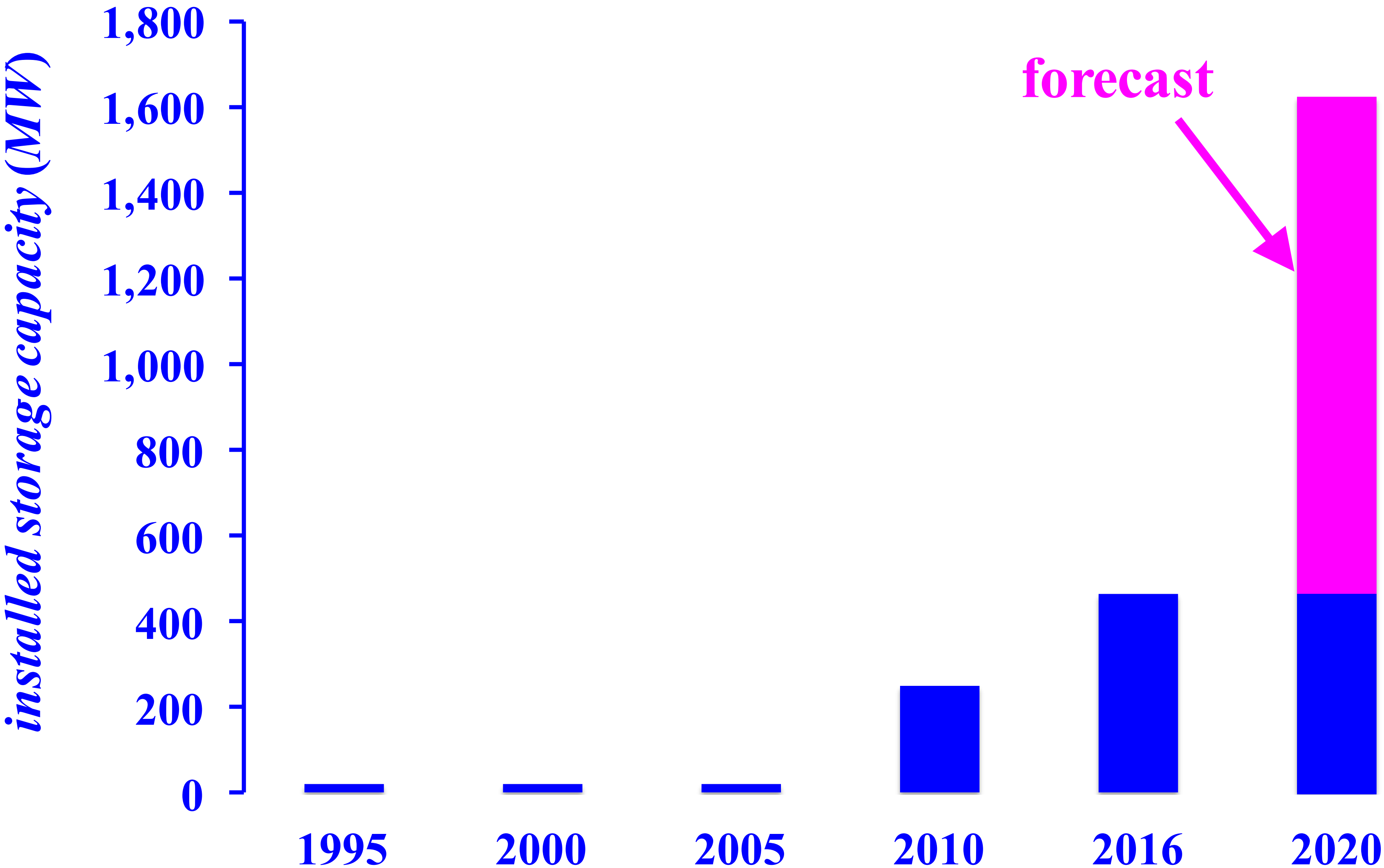
ESR EMBEDDING ENVIRONMENT



ESR EMBEDDING ENVIRONMENTS

application objective	*embedding environment*
avoid substation transformer overload	*substation*
avoid/reduce variable energy generation curtailments	*variable energy plant*
energy shift from low – to high – demand periods	*grid*
replacement of reserves requirement contribution by the units in a generation plant	*generation plant*

HISTORICAL AND PLANNED *CAISO* BATTERY CAPACITY



Source: DoE Global energy storage database

ELIGIBILITY REQUIRES EACH STORAGE PROJECT TO:

- Optimize grid operations
- Reduce *GHG* emissions
- Facilitate integration of renewable energy
- Be installed after January 1, 2010
- Be operational before December 31, 2024
- Not exceed 50 *MW* of capacity for pumped

ALLOWABLE DEVIATIONS FROM SPECIFIED TARGETS

- **Shift of target**: the *IOU*s may shift up to 80 % of the target capacity within the *T&D* domains; in 2016, the no shift of target into or out of the customer–side domain was modified to allow a shift to customer – connected projects
- **Ownership**: each utility's ownership is limited *at* 50 % of each project and its total ownership is *at most* 50 % of its procurement target
- **Recovery of investment**: approved storage asset investment may be recovered through rates

DEFERRAL IN MEETING TARGETS

Unreasonable costs/inadequate number of com–petitive bids may permit an *IOU* to request an up to 80 % deferral of its cumulative target capacity

year	*percentage of target that is deferrable*
2014	40
2016	30
2018	20
2020	20

ENEL AND *TESLA* AGREEMENT

- *ENEL Green Power S.p.A.* is a subsidiary of the generation firm *ENEL* formed in December 2008 to group all its global renewable energy interests
- *ENEL Green Power* and *Tesla* have finalized an agreement to test the integration of *Tesla*'s energy storage systems into the solar and *ENEL* assets
- The test at an initial pilot site deploys a 1.5–*MW* capacity and a 3–*MWh* energy storage capability *Tesla* battery

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

presentation by

George Gross

University of Illinois at Champaign–Urbana

at the ***IEEE EnCon Engineering Conference***

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The University of Tokyo

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IEEE DLP **presentation by**

George Gross

University of Illinois at Champaign–Urbana

at the *IEEE Montreal Section's PES, IAS and IES Chapters*

May 25, 2017, Montreal, Québec, Canada

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University of Salerno

Summer School on Smart Grid

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