THE INTEGRATION OF UTILITY – SCALE ENERGY STORAGE INTO GRIDS WITH INTEGRATED RENEWABLE ENERGY RESOURCES

presentation by

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at the iSEE Congress

Energy* 2030: *Paths to a Sustainable Future

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OUTLINE OF THE PRESENTATION

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

ESRs ARE 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)

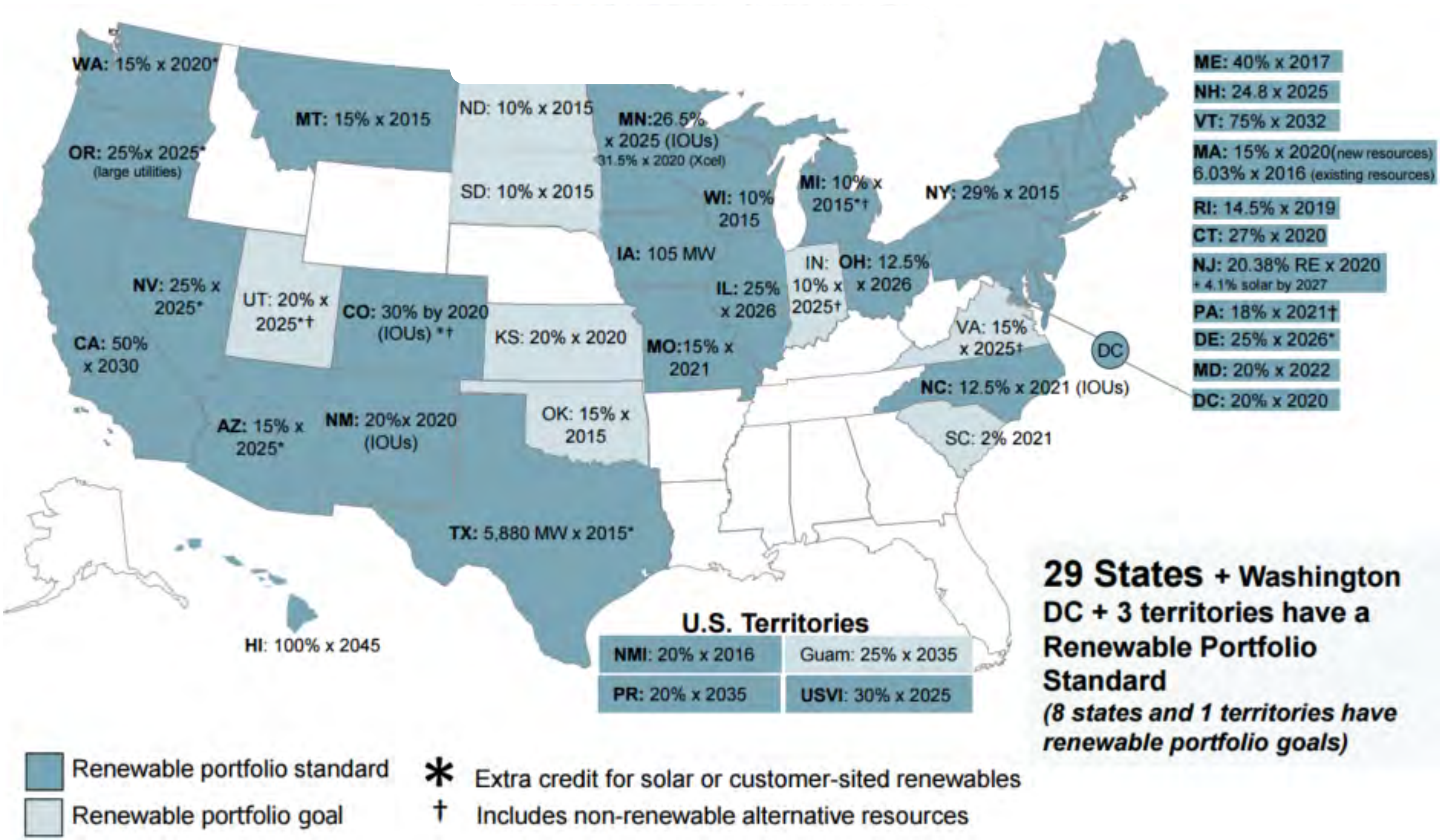
THE DIRE NEED FOR STORAGE

- 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 prototypical *just–in–time* product
- The deepening renewable resource penetrations exacerbate the challenges to maintain the *demand–supply equilibrium* at all points in time
- Storage provides flexibility to assure that demand–supply balance is maintained *around the clock*

CHANGING REALITY IN POWER SYSTEMS

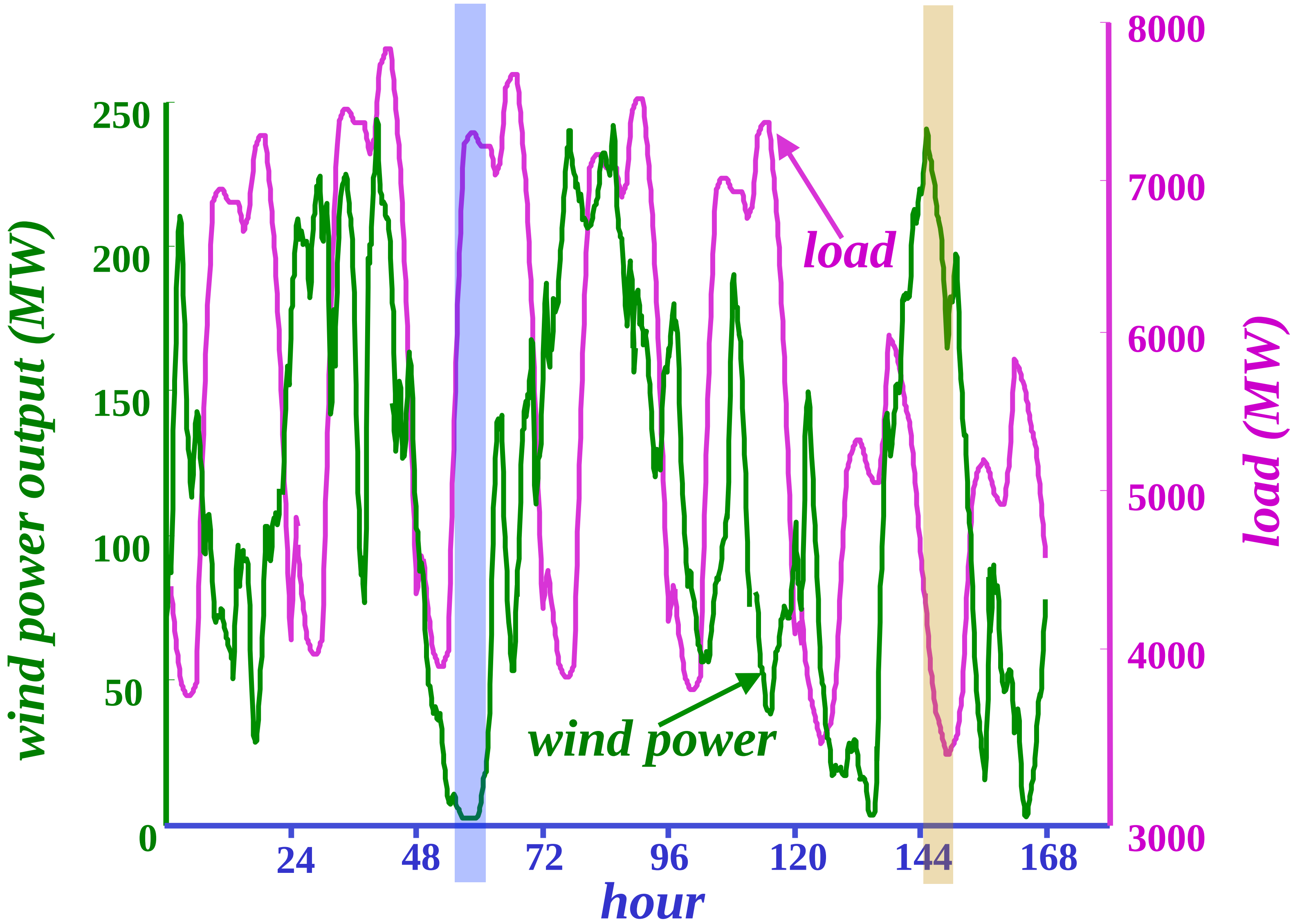
- **Climate change impacts are key drivers of the growing deployment of renewable resources to reduce CO_2 emissions**
- **In various jurisdictions, legislative/regulatory initiatives stipulate specific targets with the dates by which they must be met to result in a cleaner environment**

RENEWABLE PORTFOLIO STANDARDS

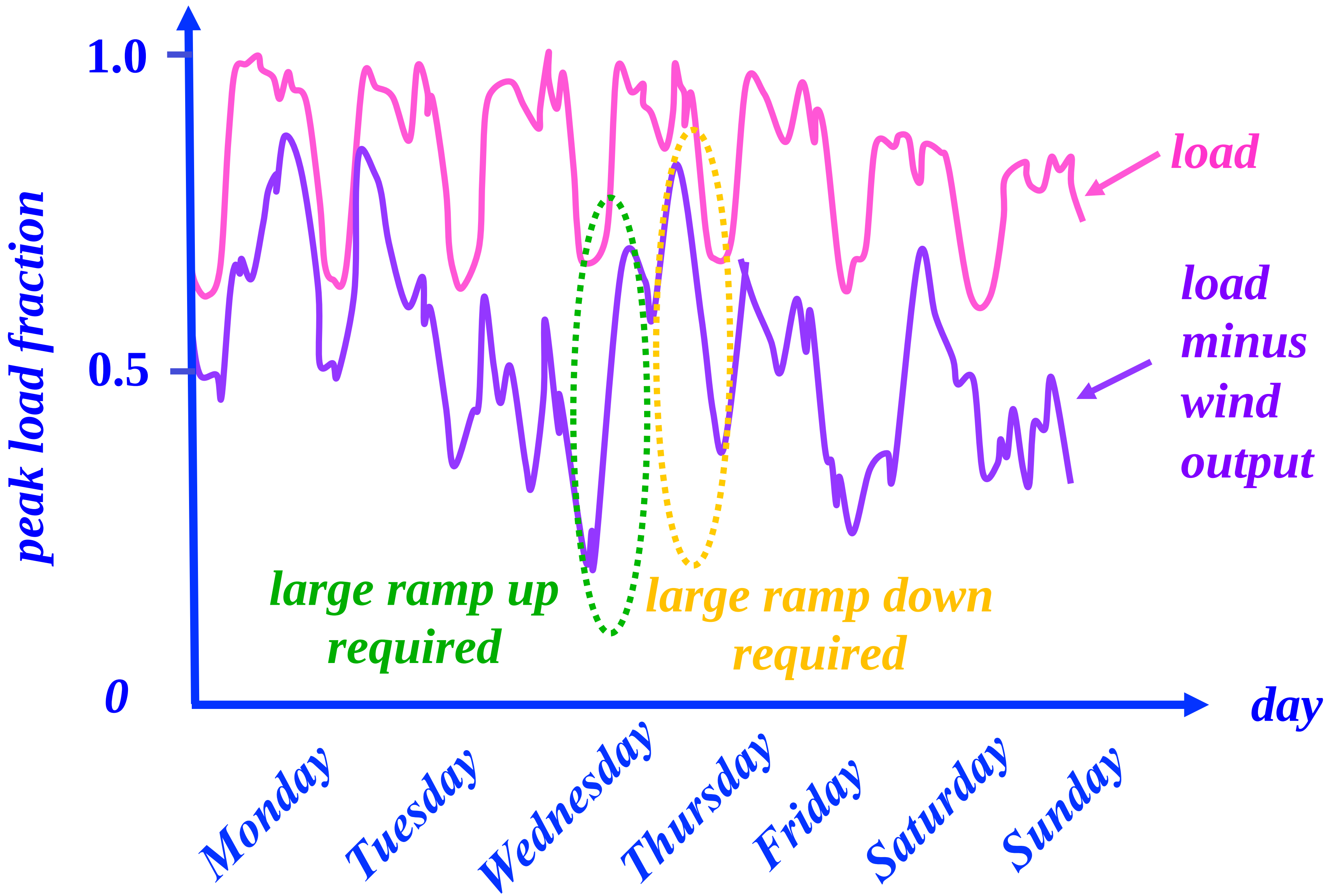


Source: www.dsireusa.org – October 2015

MISALIGNMENT OF WIND POWER OUTPUT AND LOAD

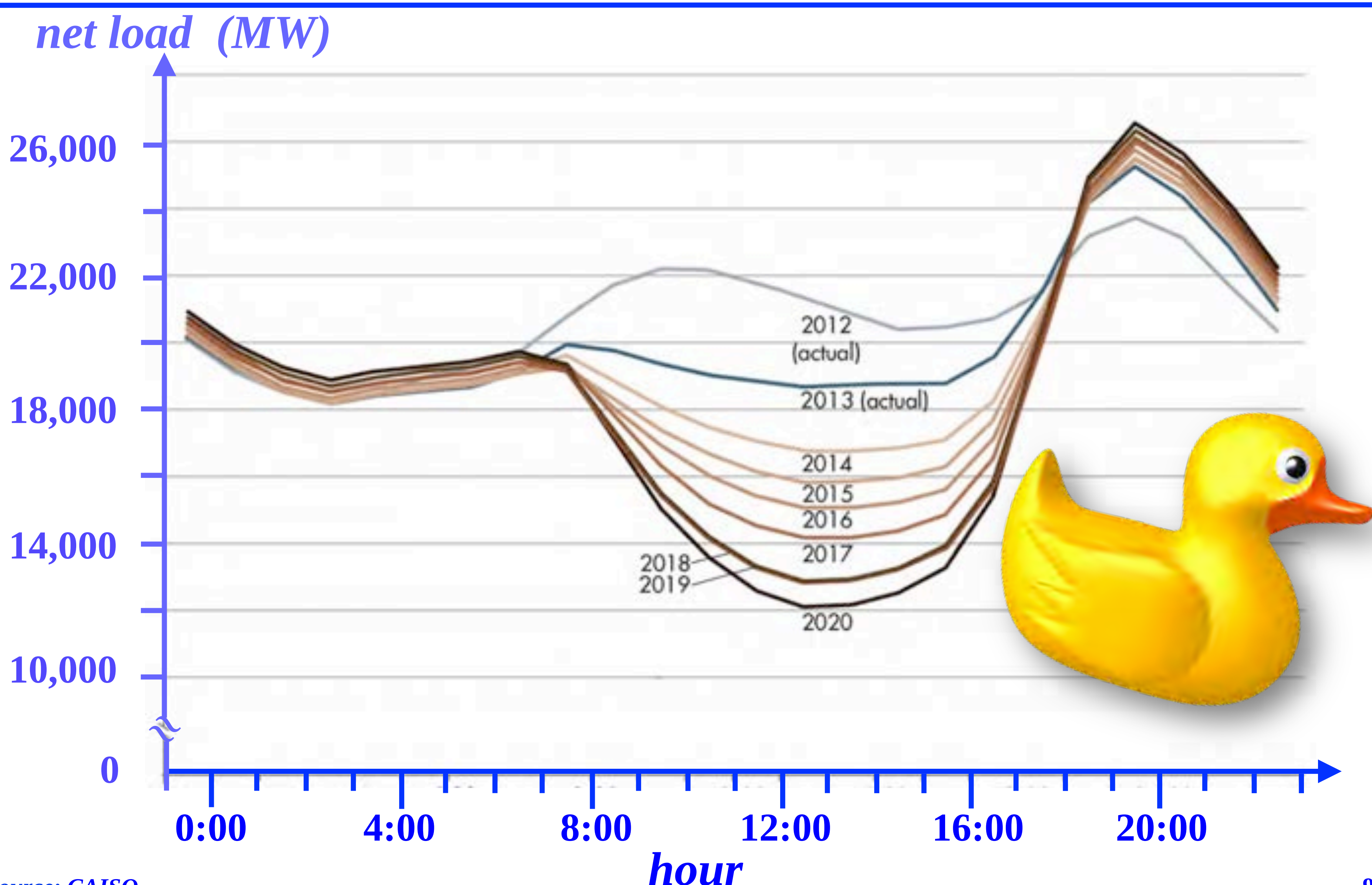


NEED FOR LARGER AND FASTER RAMPING RESERVES



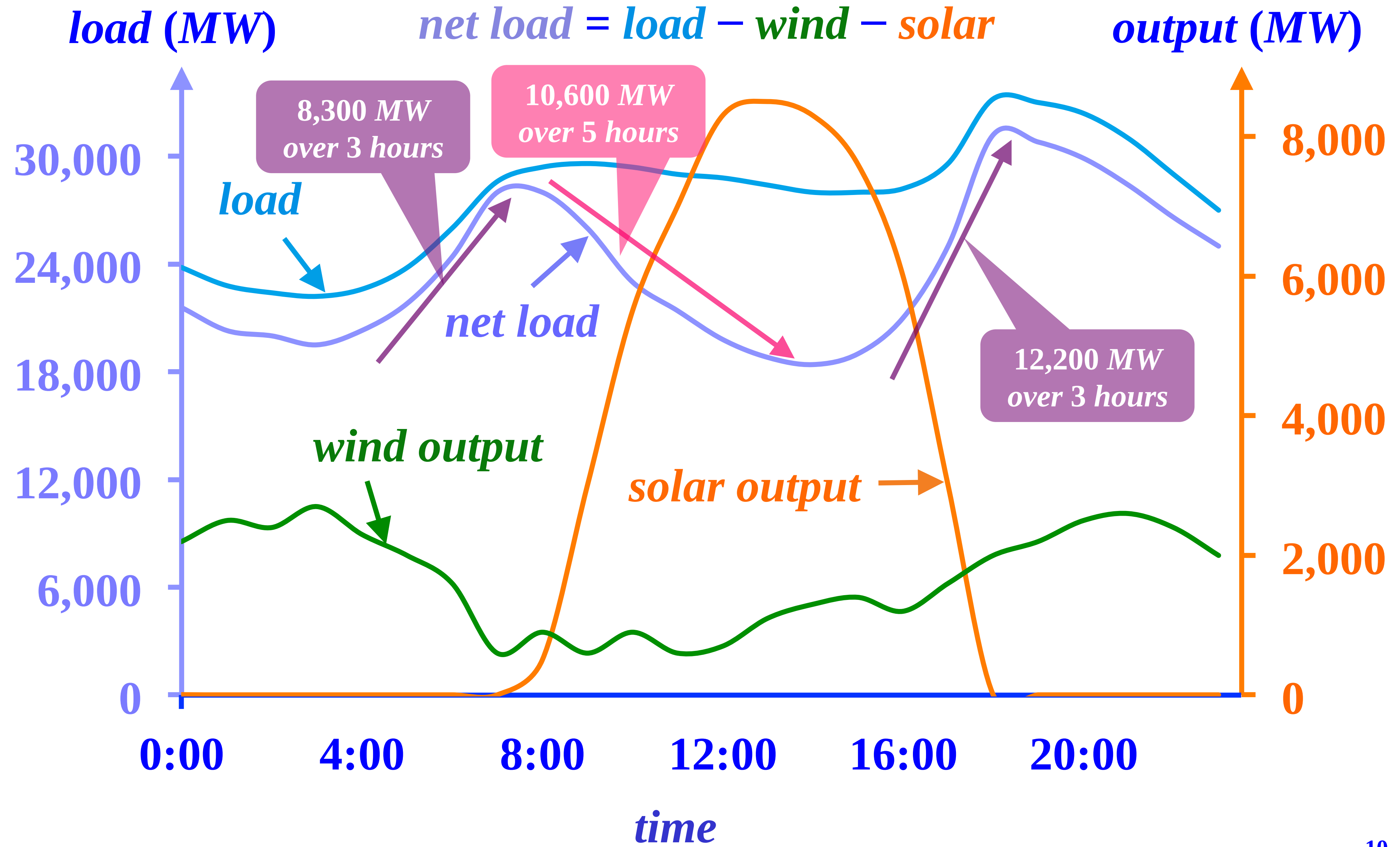
Adapted from: M. Lange & U. Focken, "Physical Approach to Short-Term Wind Power Prediction", Springer, 2006

CAISO DAILY NET LOAD CURVE UNDER DEEPENING PENETRATION

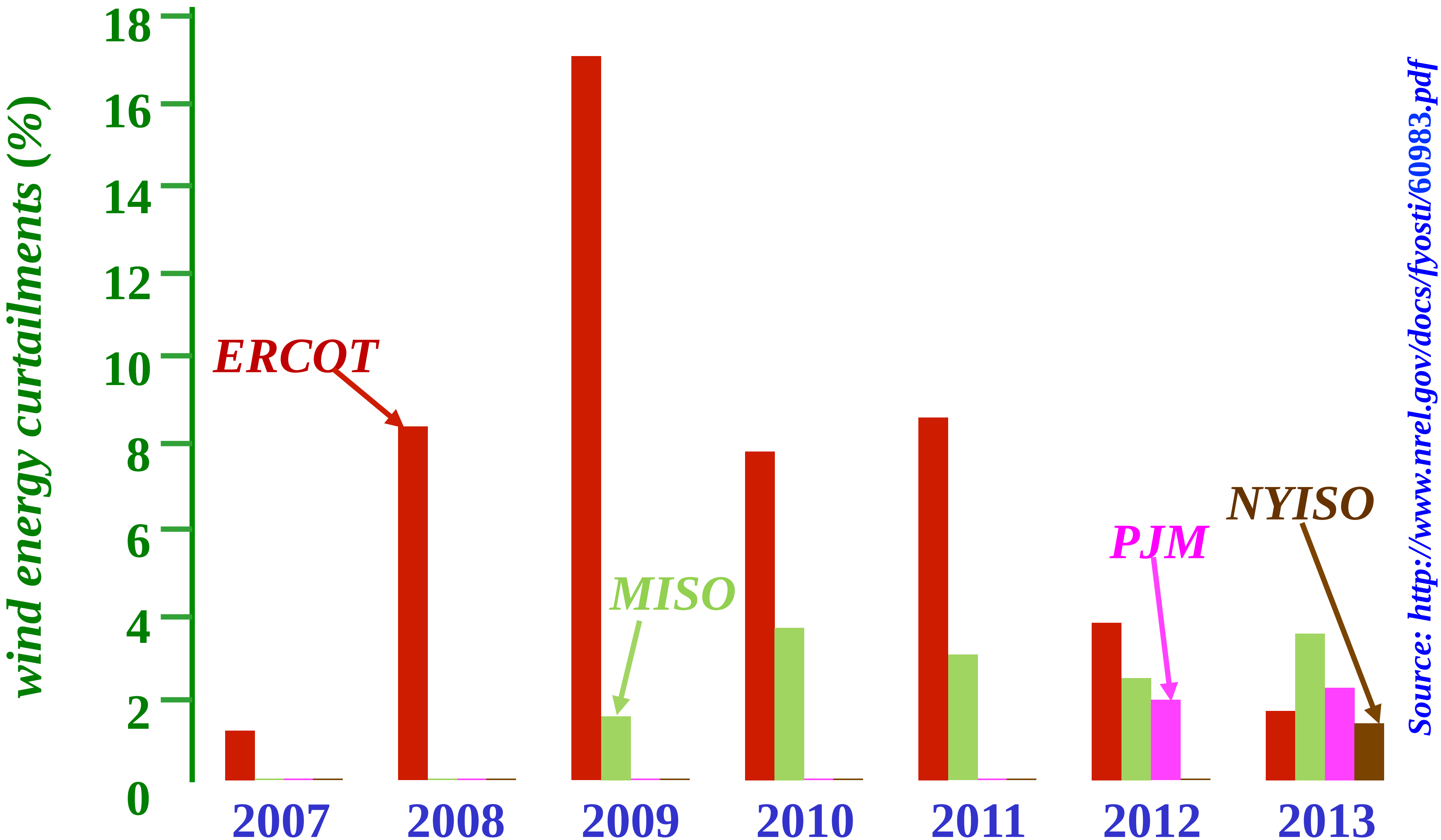


Source: CAISO

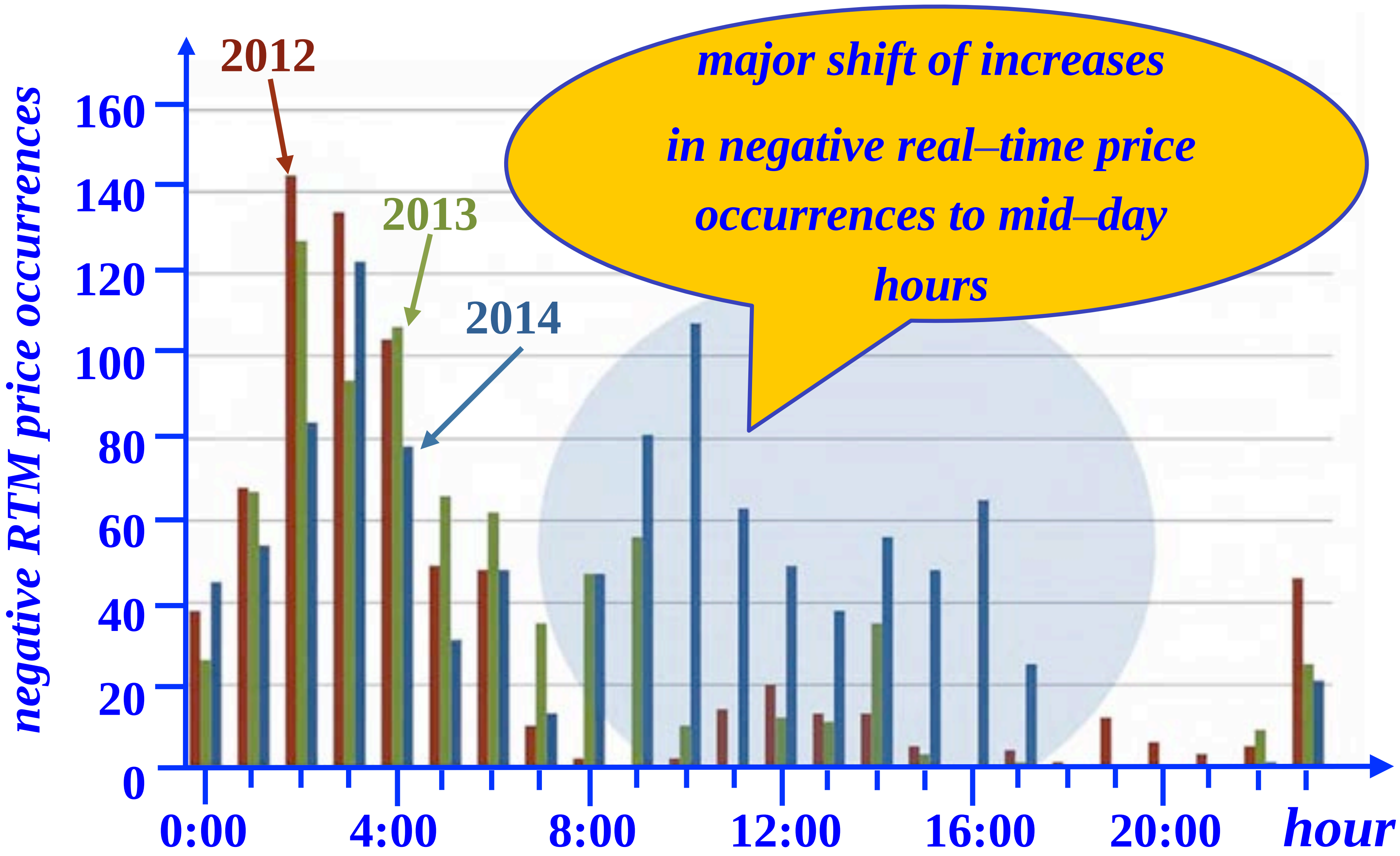
INCREASED FLEXIBILITY NEEDS



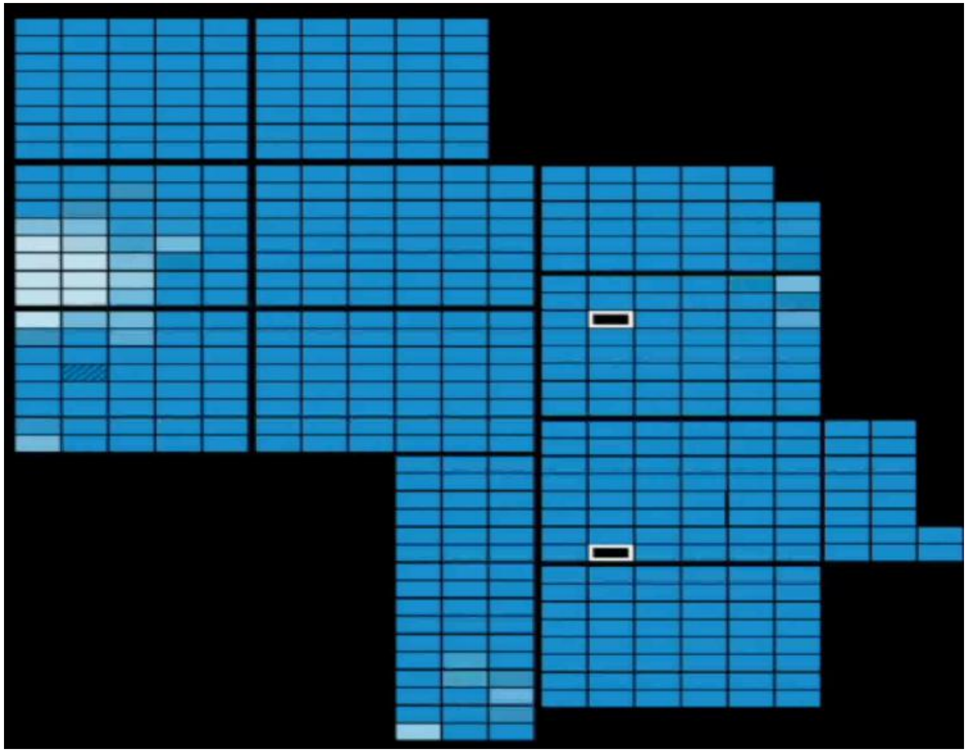
CURTAILMENT PERCENTAGES OF WIND GENERATION : 2007 – 2013

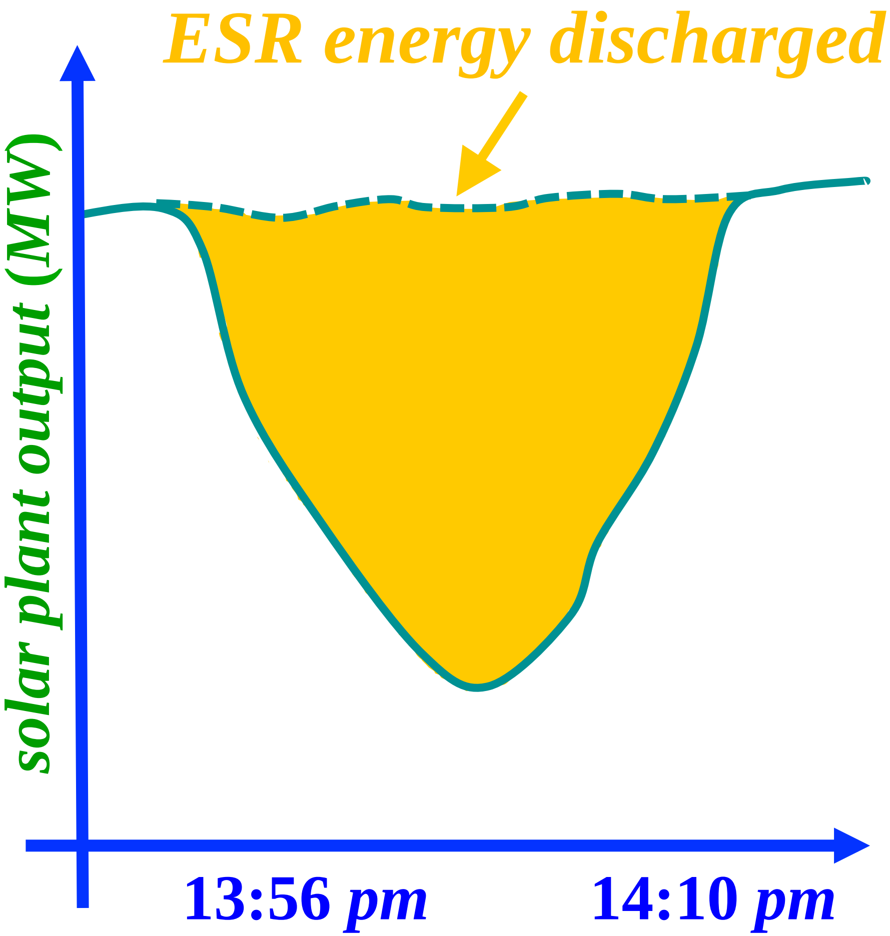


CAISO NEGATIVE *RTM* PRICES



INTEGRATION OF STORAGE WITH SOLAR RESOURCES





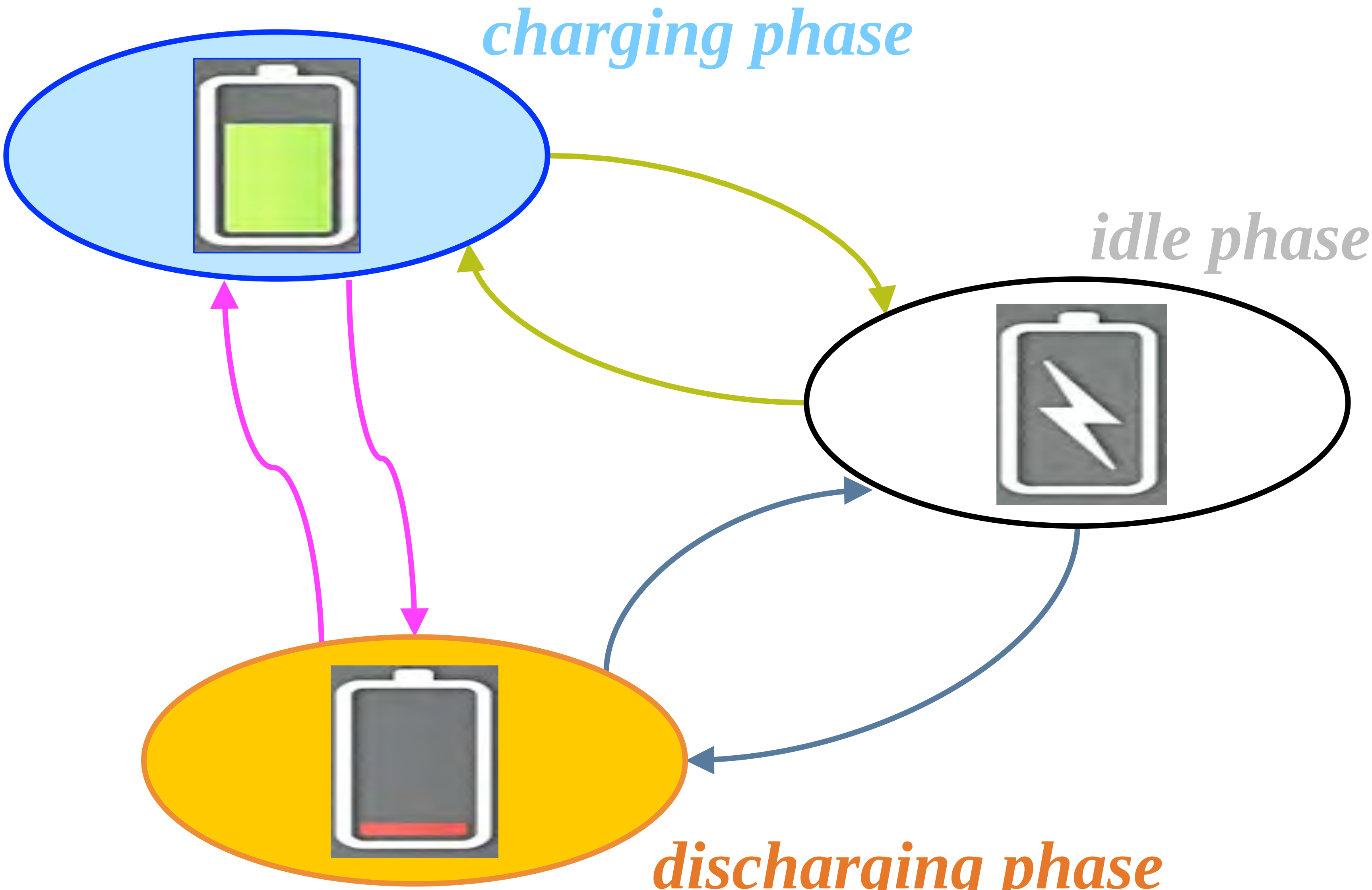
CHALLENGES THAT STORAGE CAN HELP EFFECTIVELY ADDRESS

time–dependent 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 regulation resources for flexibility in grid operations	*ESRs provide regulation with 2 – 3 times faster response times than gas turbines*

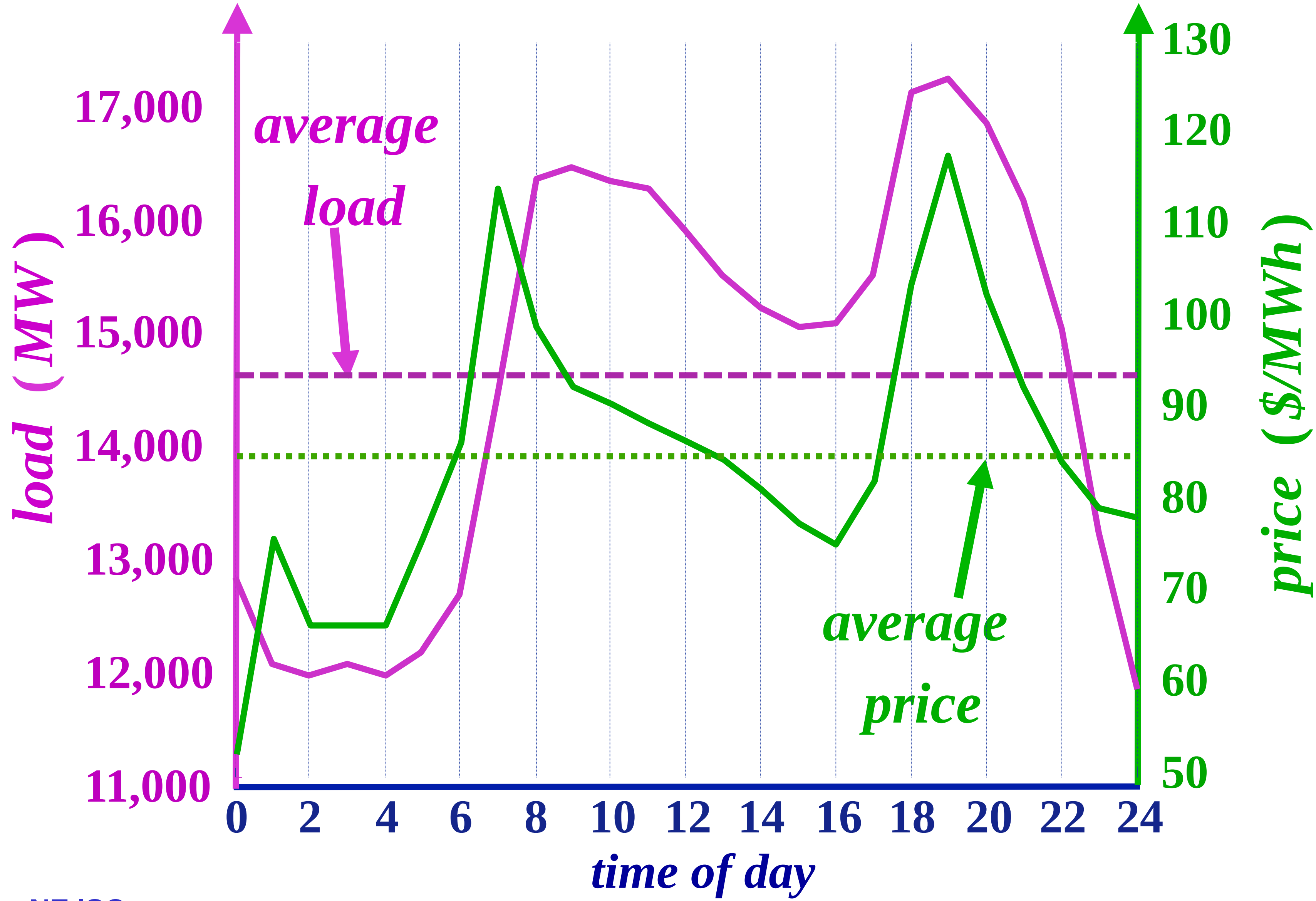
STORAGE TO THE RESCUE

today's electricity grid with limited storage capacity/capability	*future electricity grid with measurably increased storage capacity/capability*
last MWs of incremental peak demand require use of polluting and inefficient power plants	***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***

THE STORAGE RESOURCE PHASES

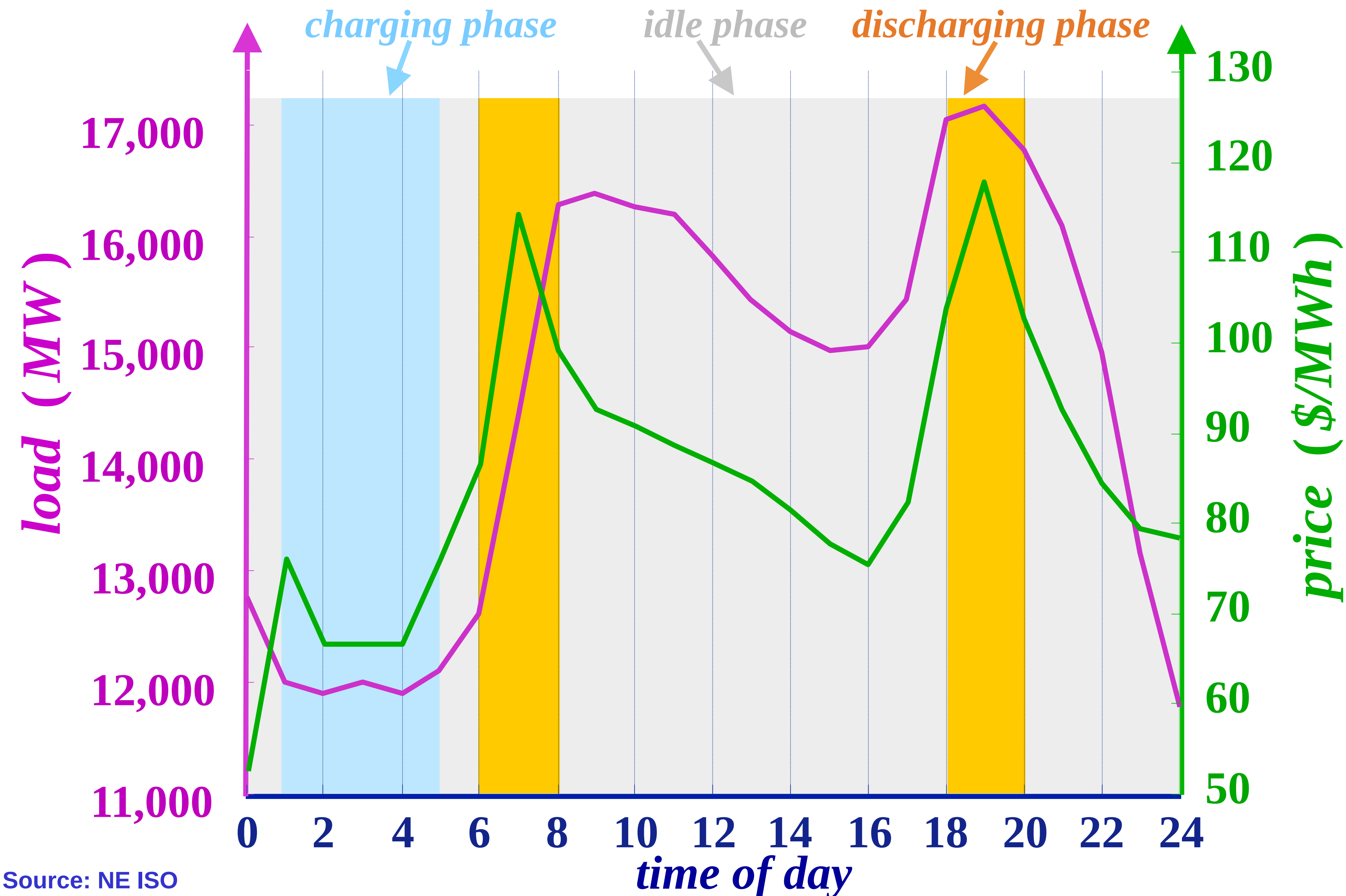


LOAD AND *LMP*



Source: NE ISO

STORAGE UTILIZATION



Source: NE ISO

KEY ROLES *ESR*s CAN PLAY

- *ESR*s enable deferral of investments in:
  - new generation resources
  - new transmission lines
  - distribution circuit upgrades
- *ESR*s are key to the development of microgrids in both grid–connected and autonomous situations

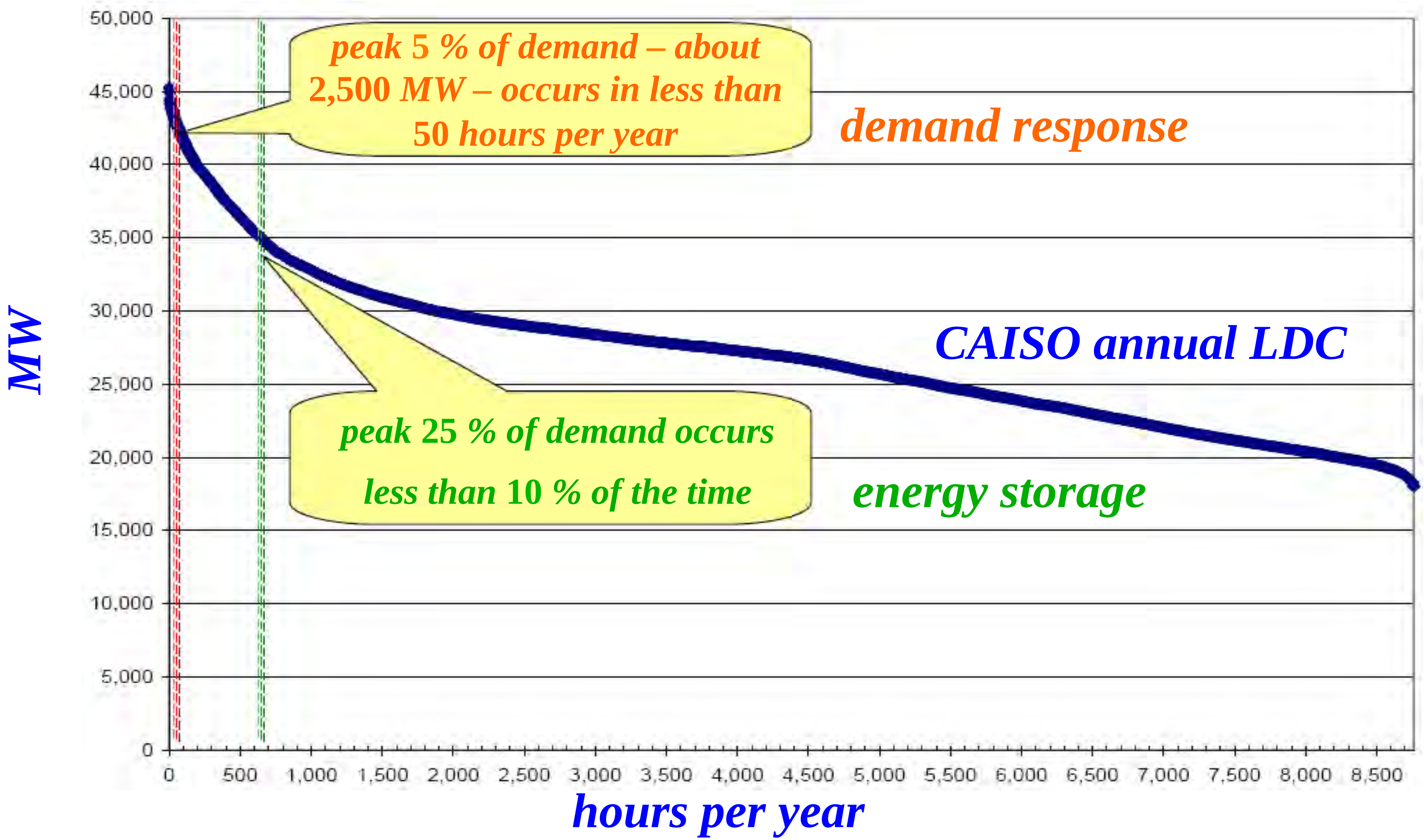
ADDITIONAL ROLES *ESR*s CAN PLAY

- **In short–term operations, *ESR*s provide:**
  - **flexibility in time of energy usage: demand shift; peak–load shaving**
  - **ability to delay the start up of cycling units**
  - **capability to provide voltage support**
  - **demand response action**
  - **reserves and frequency regulation services**
  - **levelization of substation load**
- **Storage can provide *virtual inertia service* to replace part of the missing inertia in grids with integrated renewable 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* effectively 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 further reduce both the operational costs and emissions, due to reductions in unit cycling and the deferrals in the start–up of cycling units

CAISO DRR AND *ESR* DEPLOYMENT



KEY BENEFITS OF GRID – INTEGRATED *ESR*s

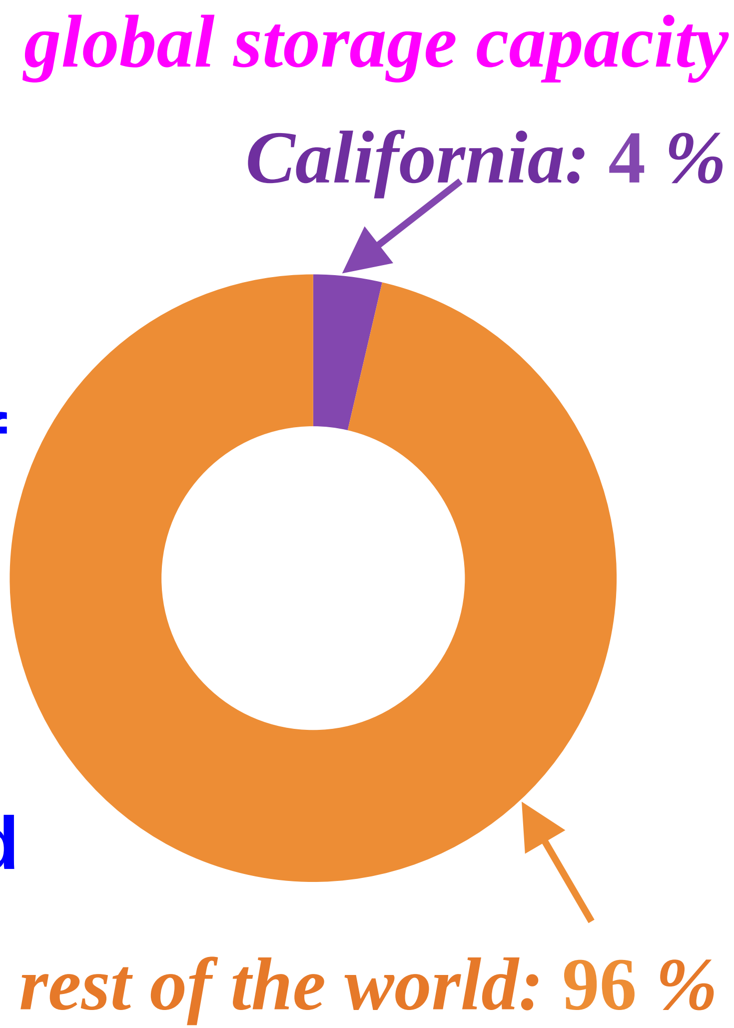
- ***ESR*** **deployment:**
  - **raises system reliability**
  - **improves operational economics**
  - **provides operators with additional flexibility to optimize grid operations and manage grid congestion**
  - **raises renewable output utilization**

KEY BENEFITS OF GRID – INTEGRATED *ESR*s

- *ESR* deployment reduces *GHG* emissions because
  - *ESR*s facilitate renewable resource integration
  - *ESR*s lower the system reserves requirements from the conventional fossil–fired resources
  - *ESR*s displace the generation of inefficient/ dirty units used to meet peak loads

CURRENT WORLD STORAGE STATUS

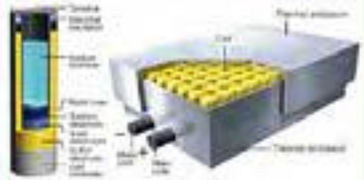
- There are currently 1,555 energy storage projects installed throughout the world with a total capacity of 188,347 *MW*
- 272 out of these projects are in California with an installed capacity of 7,392 *MW*



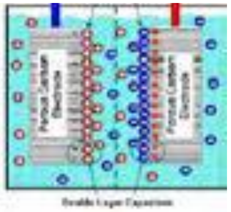
Source: ***DOE*** **Global Energy Storage Database,** ***http://www.energystorageexchange.org/projects***

ENERGY STORAGE TECHNOLOGIES

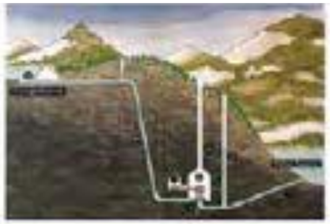
NaS battery



EC capacitor

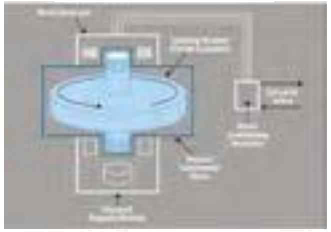


pumped storage

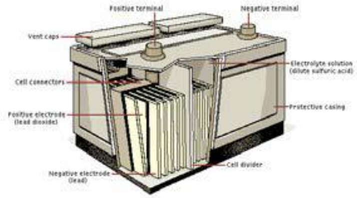


flow battery

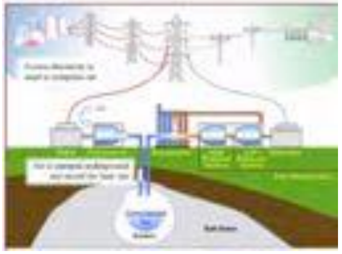
flywheel



lead–acid battery



CAES



advanced lead acid battery

Li–ion battery

Ni–Cd battery

SMES

← *increasing capability*

increasing capacity →

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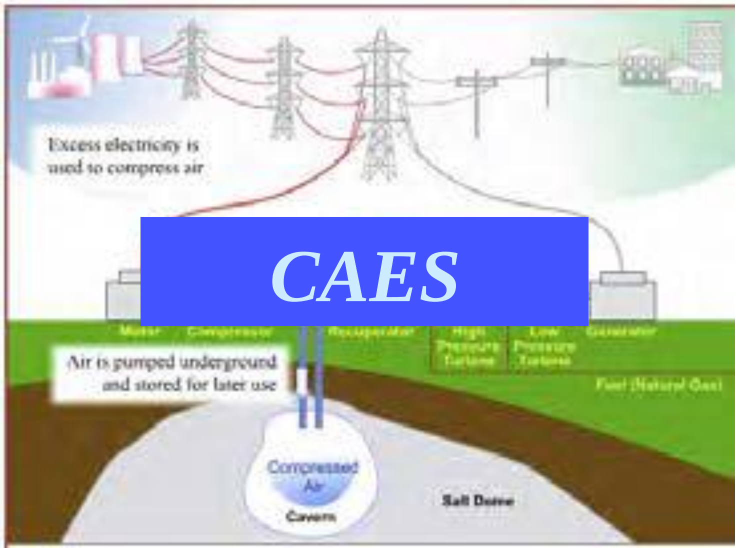
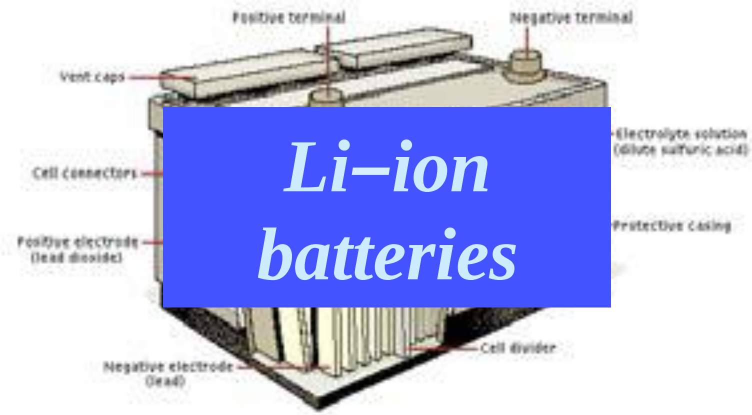
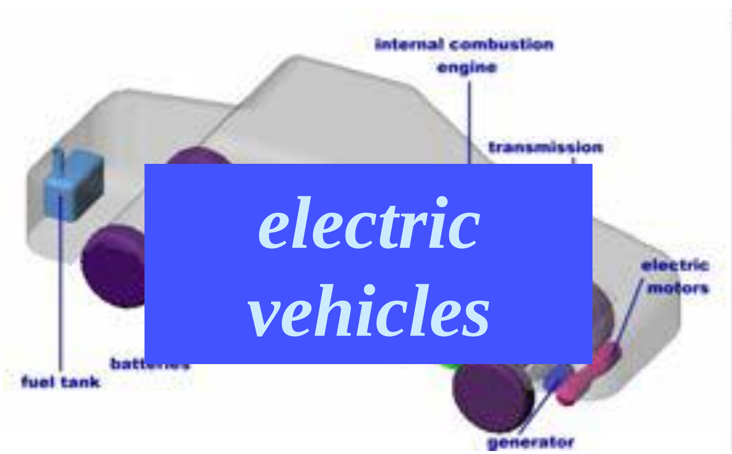
STORAGE TECHNOLOGY ADVANCES



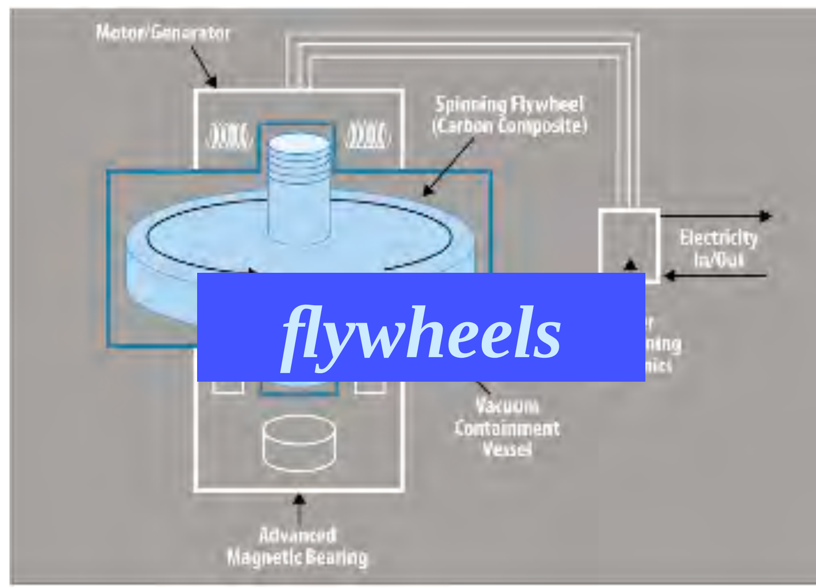
CAES



Li–ion batteries



electric vehicles



flywheels

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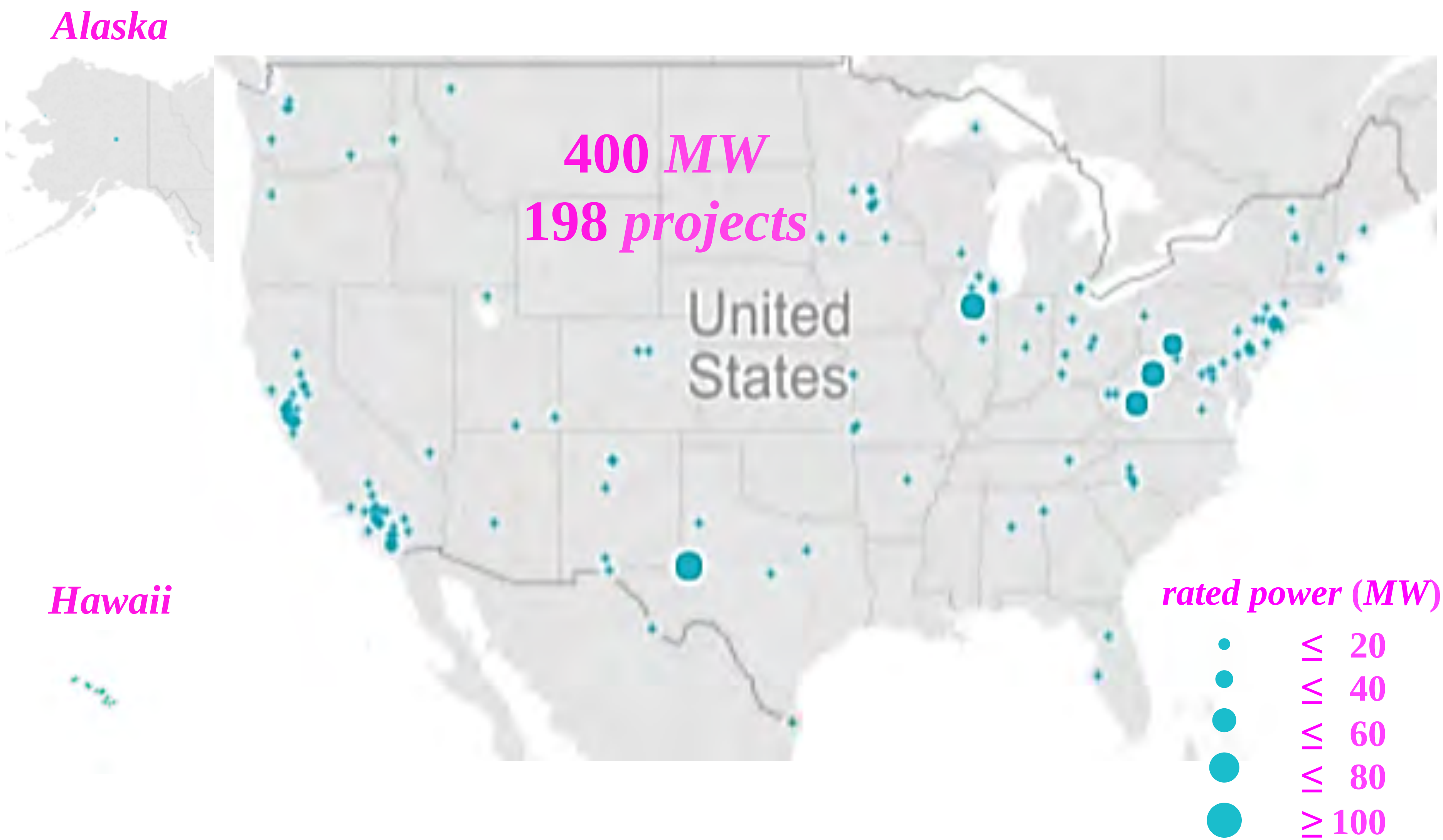
BATTERY ENERGY STORAGE SYSTEMS (*BESS*s)

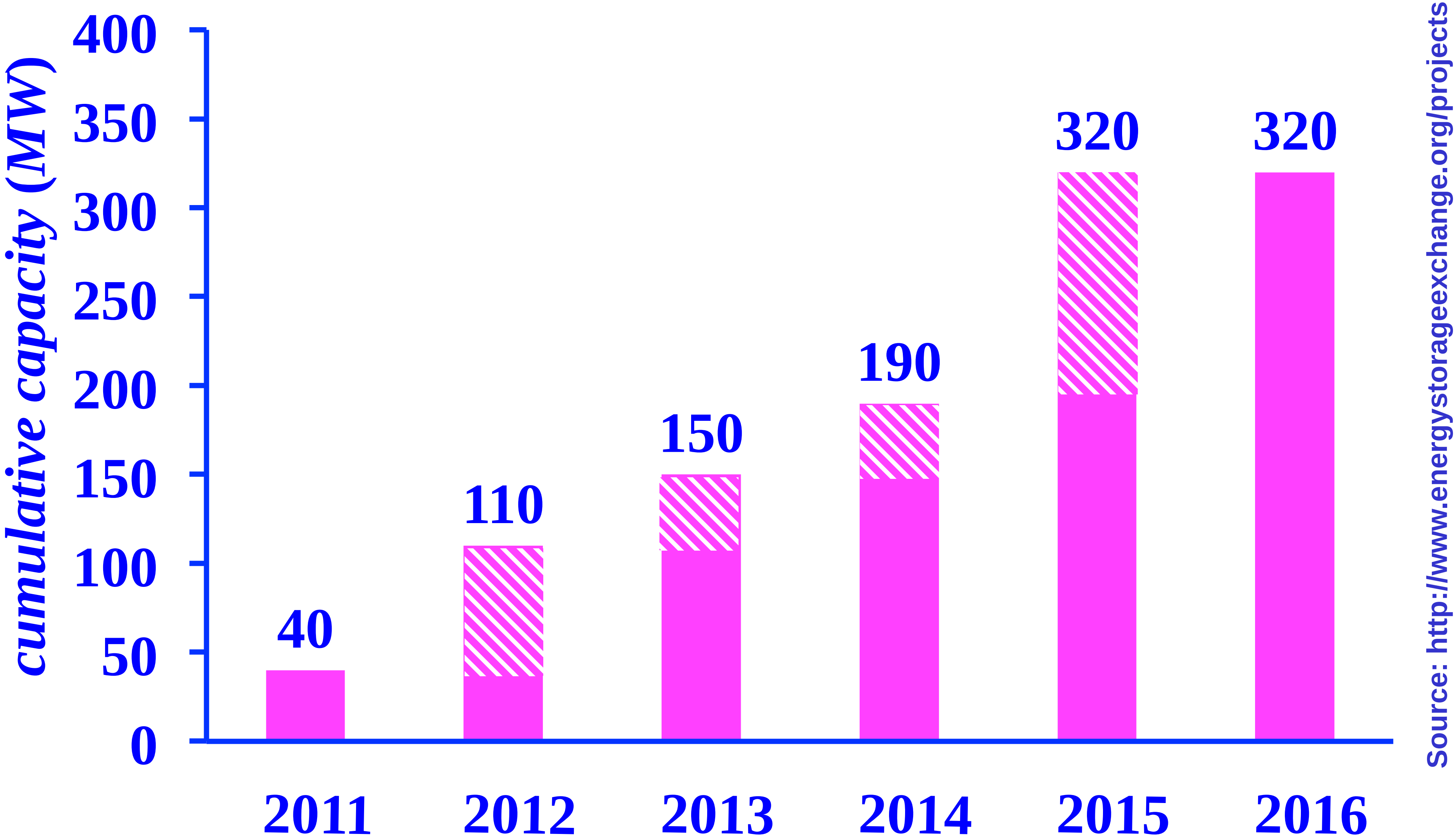
- Many practitioners consider the development of *BESS*s to most effectively address the challenges to integrate deepening penetrations of renewable resources – the *holy grail* of energy storage
- *BESS* can be highly efficient and can discharge the stored energy with high ramp rates
- The development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

BESS PROJECTS IN THE *US*



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

BESS PROJECT IMPLEMENTATION
2011 – 2016



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**

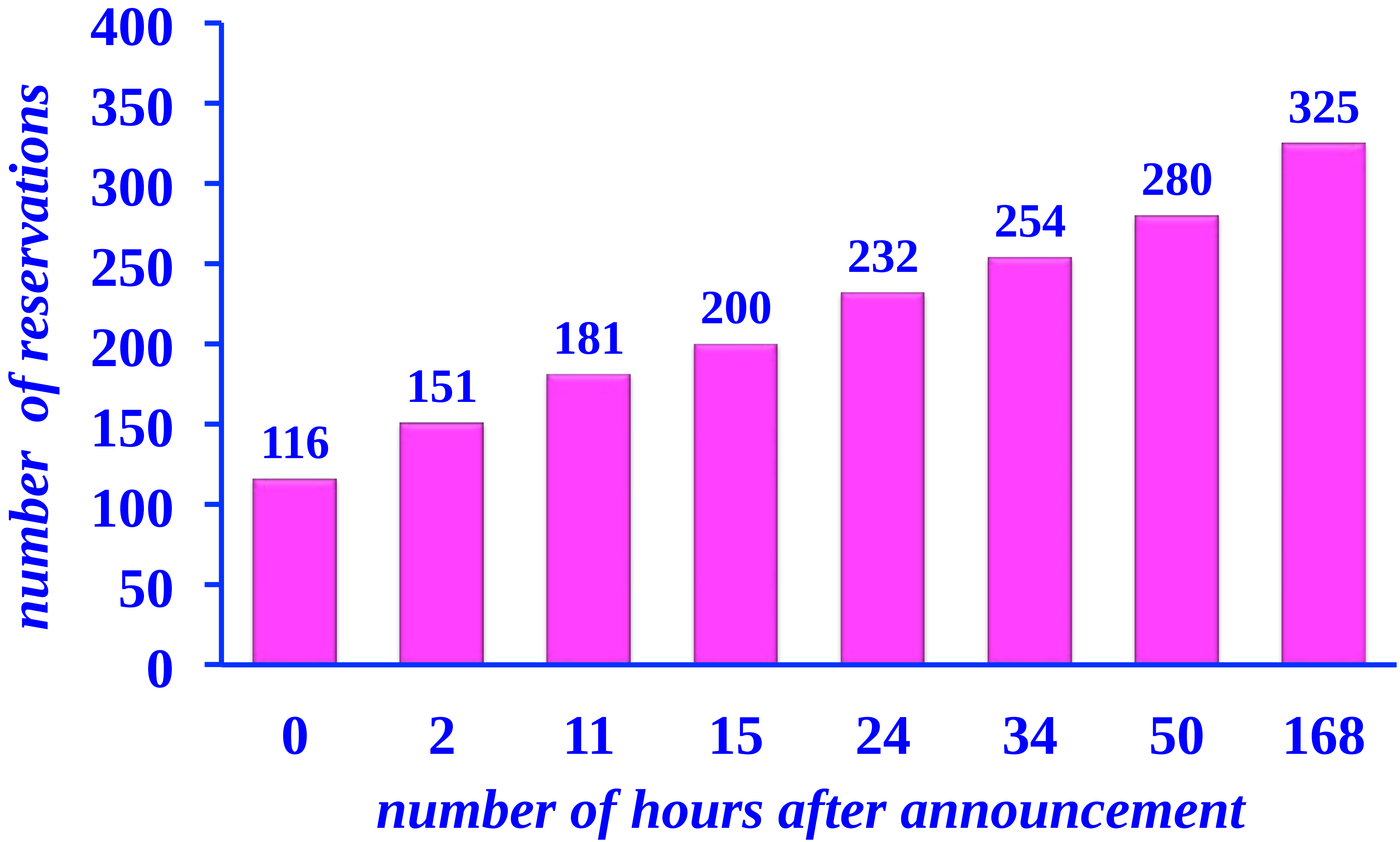
NEW PUSH IN *ESR* DEPLOYMENT

- **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* energy resource**
- **Key technological developments are in areas such as flywheels, battery vehicles (*BV*s) and utility–scale batteries**

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

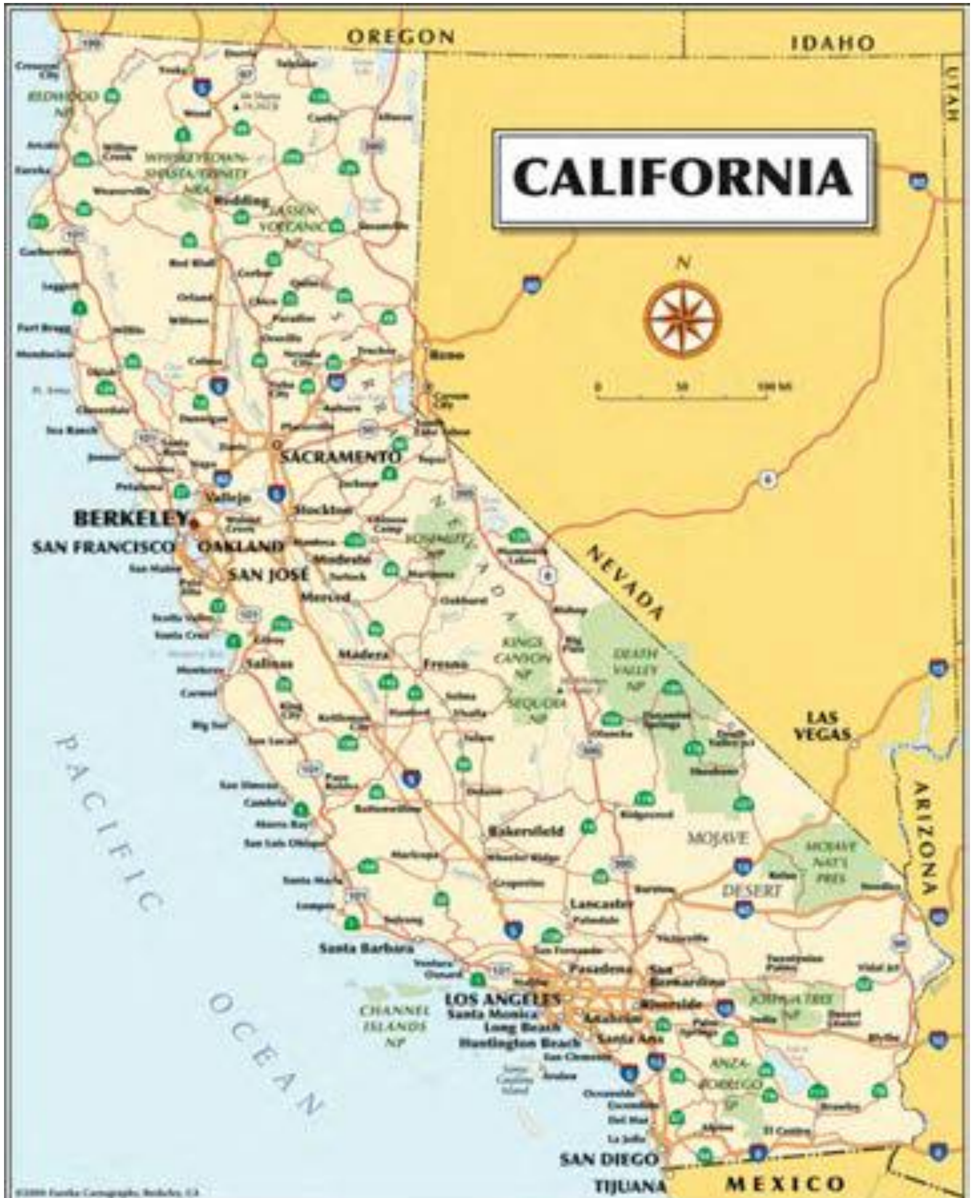
The use of bidirectional power flow interconnec–tions of the *BV*s under the *V*2*G* framework allows aggregations of *BV*s to constitute a storage project whose total capacity and capability can provide a valuable services to the grid

TESLA MODEL 3 RESERVATIONS



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

CALIFORNIA



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

38 ***million people***

electricity consum– ption is* 8 *% of the US* 293,269** ***GWh 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 recent *CPUC* mandate to deploy 1,325 *MW*s 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"**

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 procurement and deployment of the storage projects must be carried out in compliance with the specified *CPUC Decision* 13-10-040 framework

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

GUIDING PRINCIPLES

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

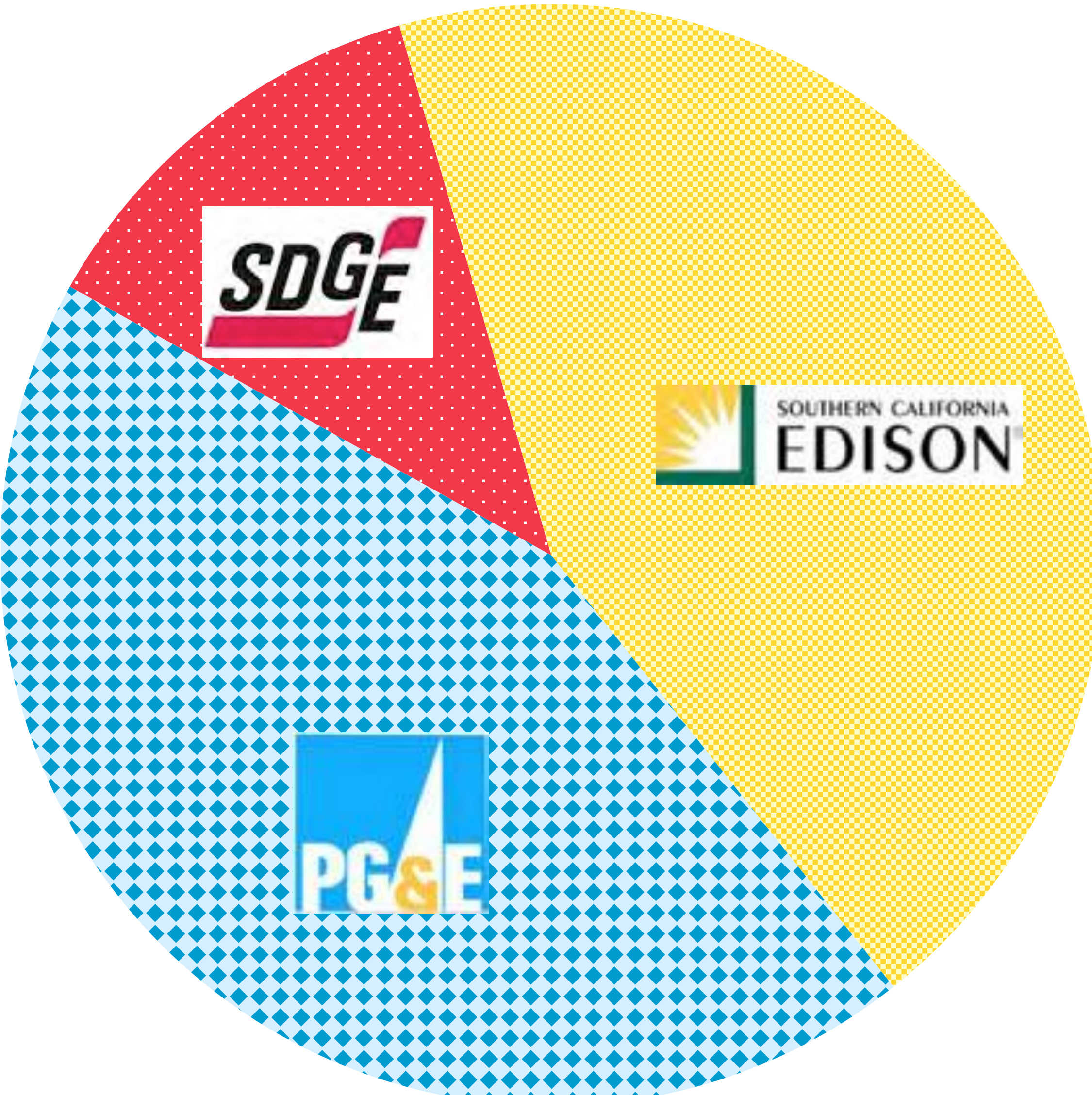
2. The integration of renewable energy; and

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

ELIGIBILITY REQUIRES EACH STORAGE PROJECT TO:

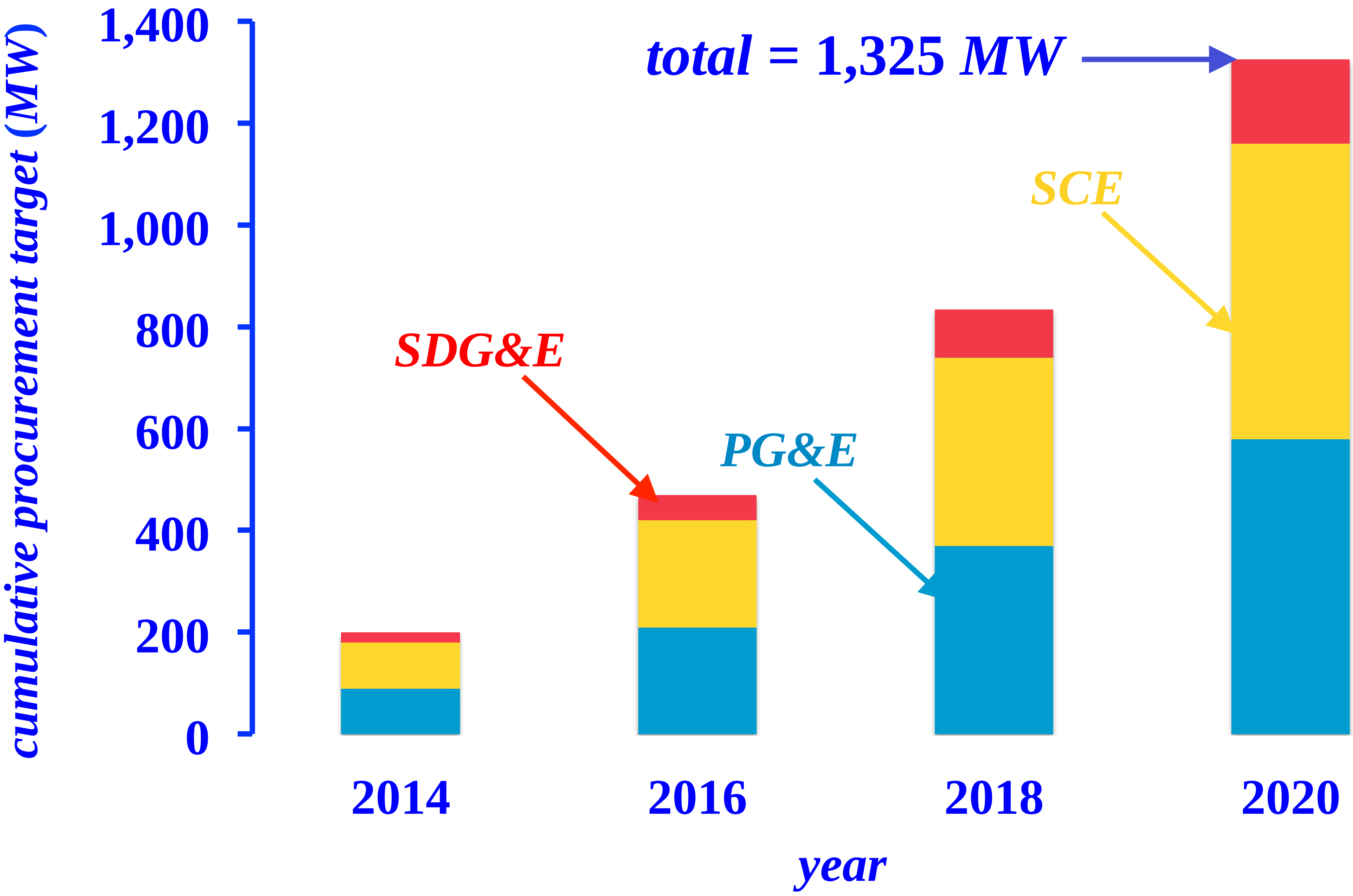
- Optimize grid operations
- Reduce *GHG* emissions
- Facilitate integration of renewable energy
- Be installed after January 1, 2010
- Be operational before December 31, 2024
- Not exceed 50 *MW* of capacity for pumped storage

IOU STORAGE CAPACITY TARGETS



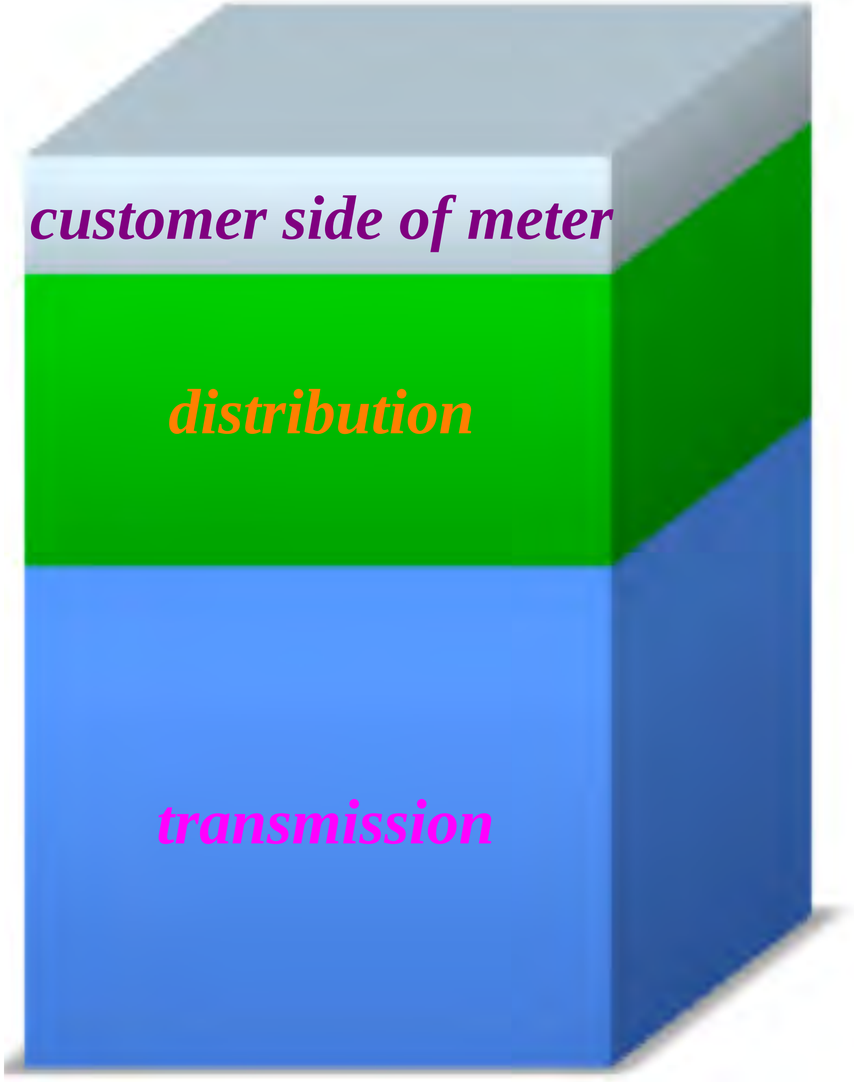
IOU	*target (MW)*	*%*
PG&E	580	43.77
SCE	580	43.77
SDG&E	165	12.26

CUMULATIVE PROCURED CAPACITY



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



CPUC STORAGE PROCUREMENT FRAMEWORK FEATURES

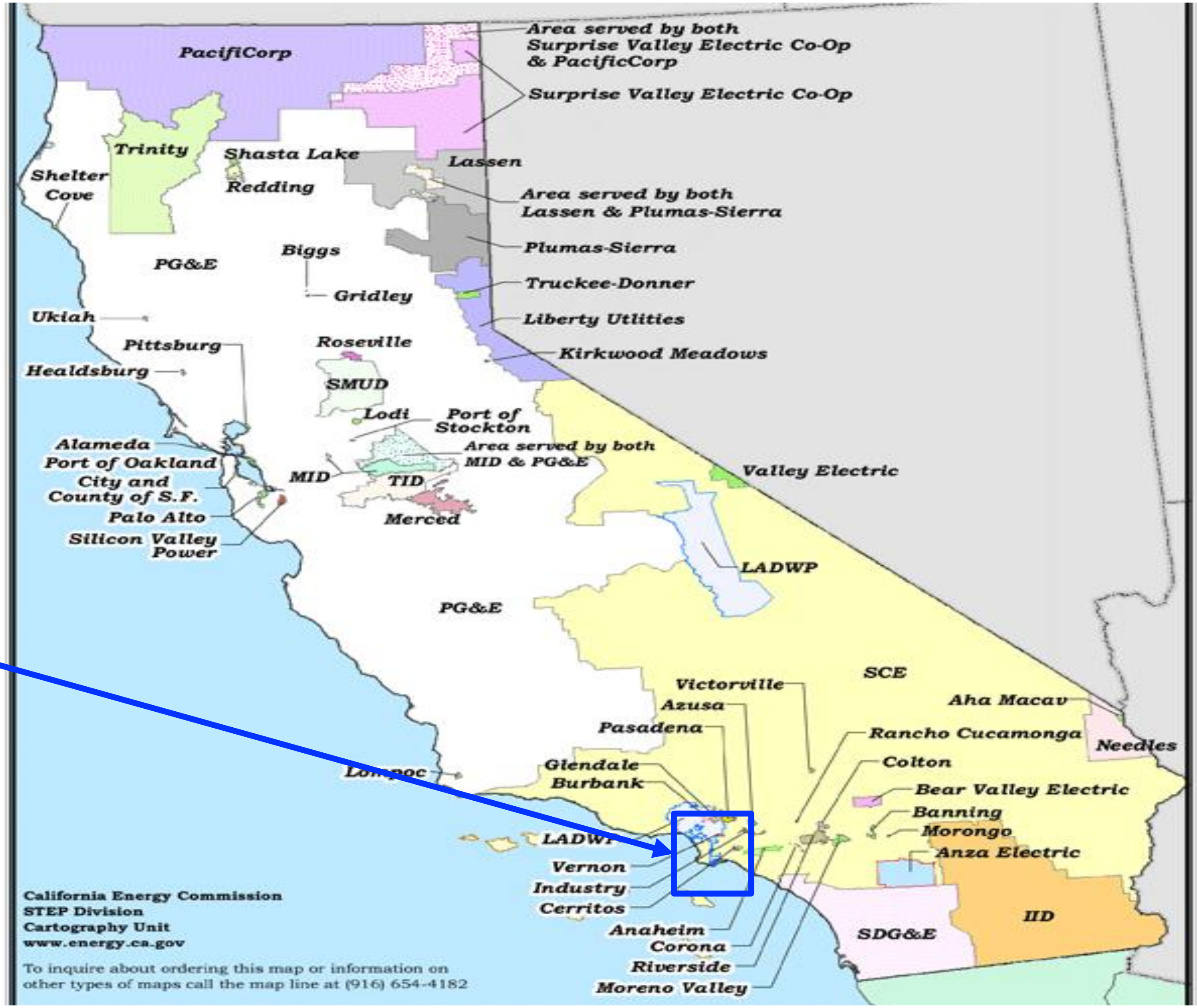
- The procurement targets are mandated for each *IOU* and may not be traded among the *IOU*s
- Biannual procurement applications are to be filed by each *IOU* by March of each applicable year
- At least 50 % of each project approved to meet the targets must be owned by third parties, customers or joint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

CPUC STORAGE PROCUREMENT FRAMEWORK FEATURES

- 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

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, but no shift of target into or out of the customer–side domain is permitted**
- **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**

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 CHALLENGES

- **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 through the increased demand is likely to spread to other regions and engender similar measures that may lead to further cost reductions

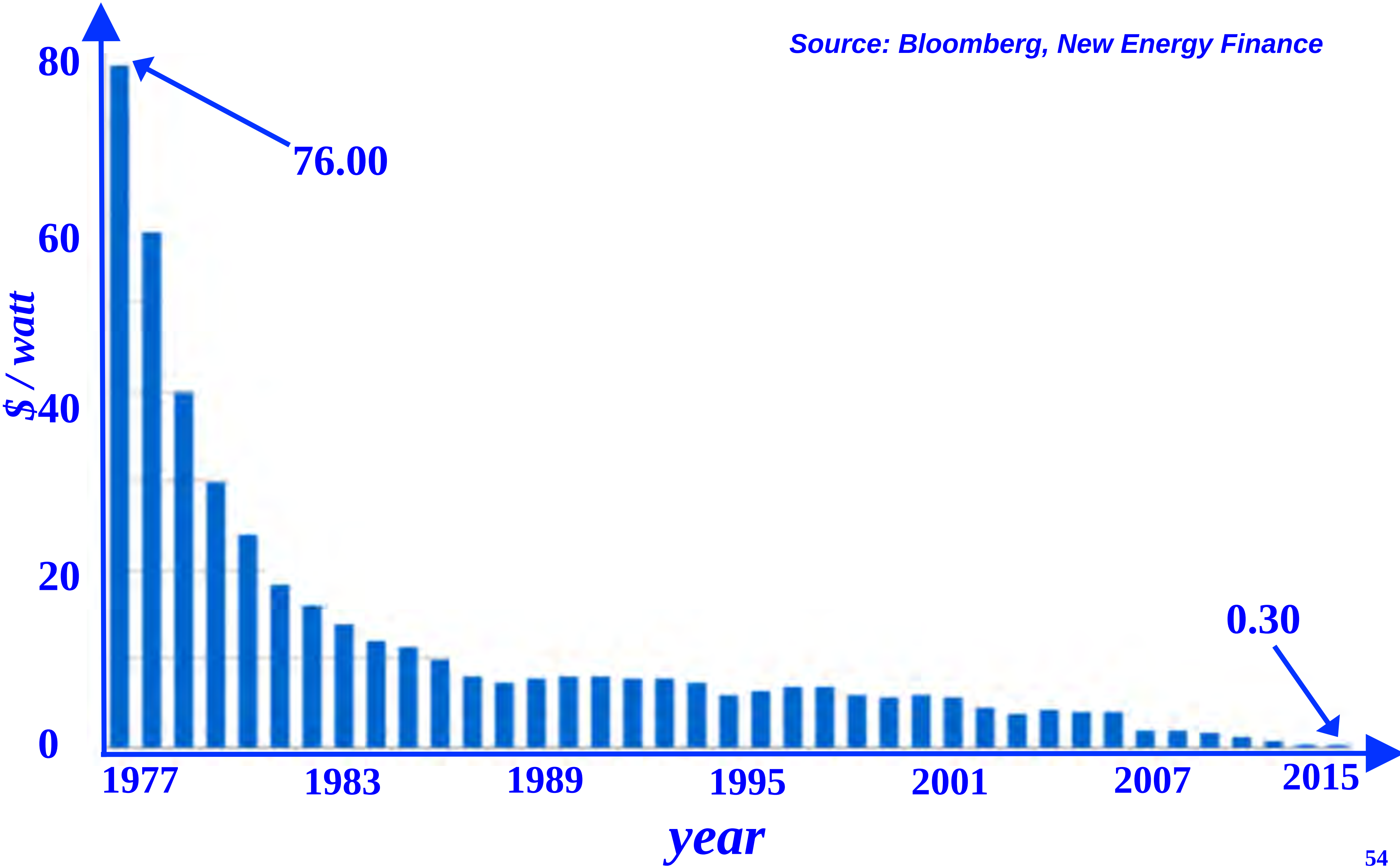
CPUC DECISION RAMIFICATIONS

- **The *CPUC Decision* is a harbinger of regulatory initiatives in the large–scale grid–connected storage domain and signals the realization by the government of the significant role of storage to further the realization of the smart grid vision**
- **The *CPUC Decision* stimulus to reduce *ESR* costs by increased demand is likely to be copied else–where and promote wider deployment of storage**

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 creates a strong push in the storage market and has considerably weakened the reluctance of investment in the storage sector**
- **A key example is the new *Gigafactory*, a large–scale plant to build commercial and residential storage batteries that *Tesla Energy* is building**

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



NEED FOR APPROPRIATE TOOLS

- To take advantage of the increased flexibility imparted by the grid–integrated ESRs, 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**

REGULATORY POLICIES

- The current regulations for conventional grid assets cannot recognize the unique nature of ESRs 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 ESRs 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 *GHG* 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 provides an 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 effectively implement *ESR* deployment in the grid

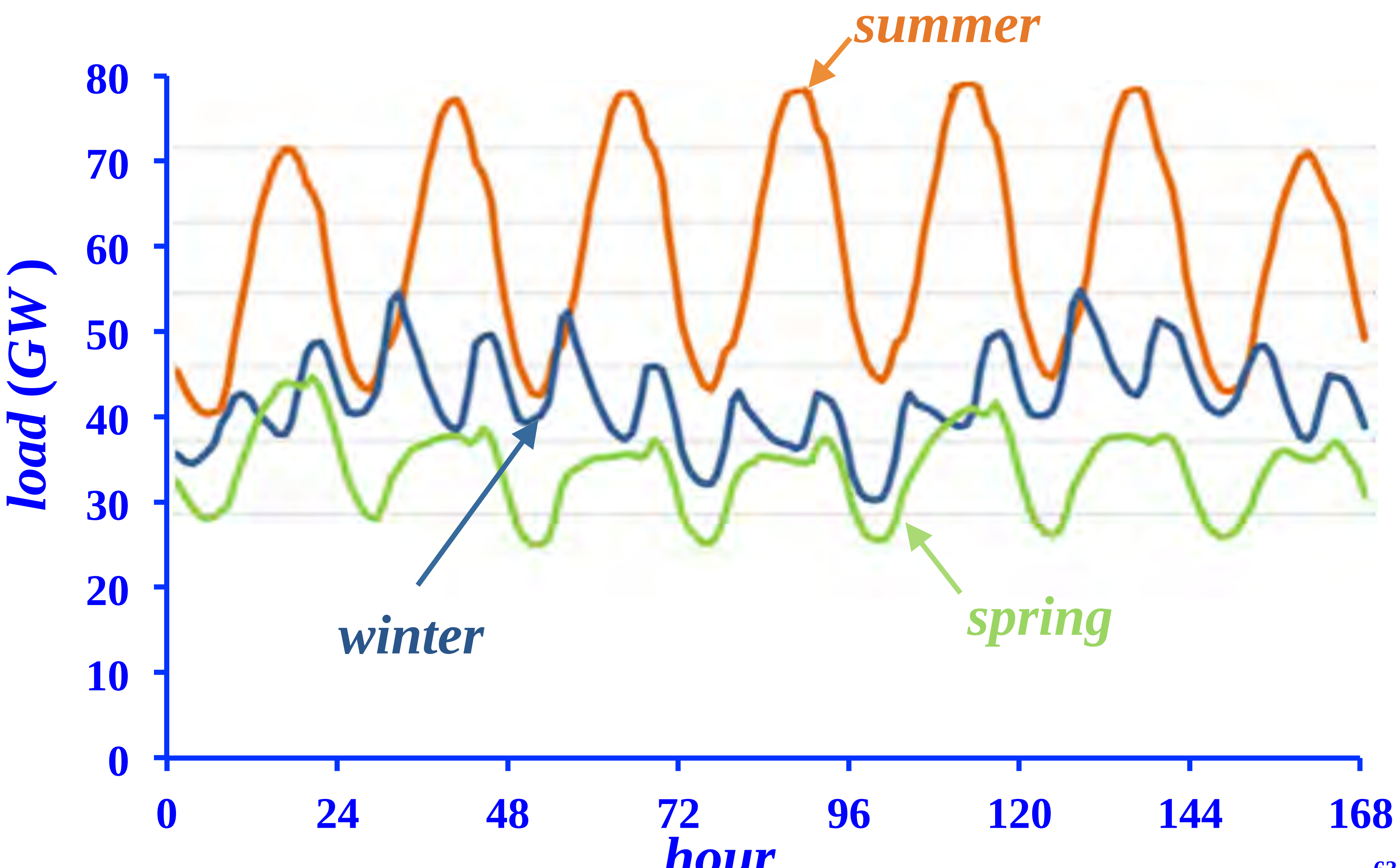
CONCLUDING REMARKS

- **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**

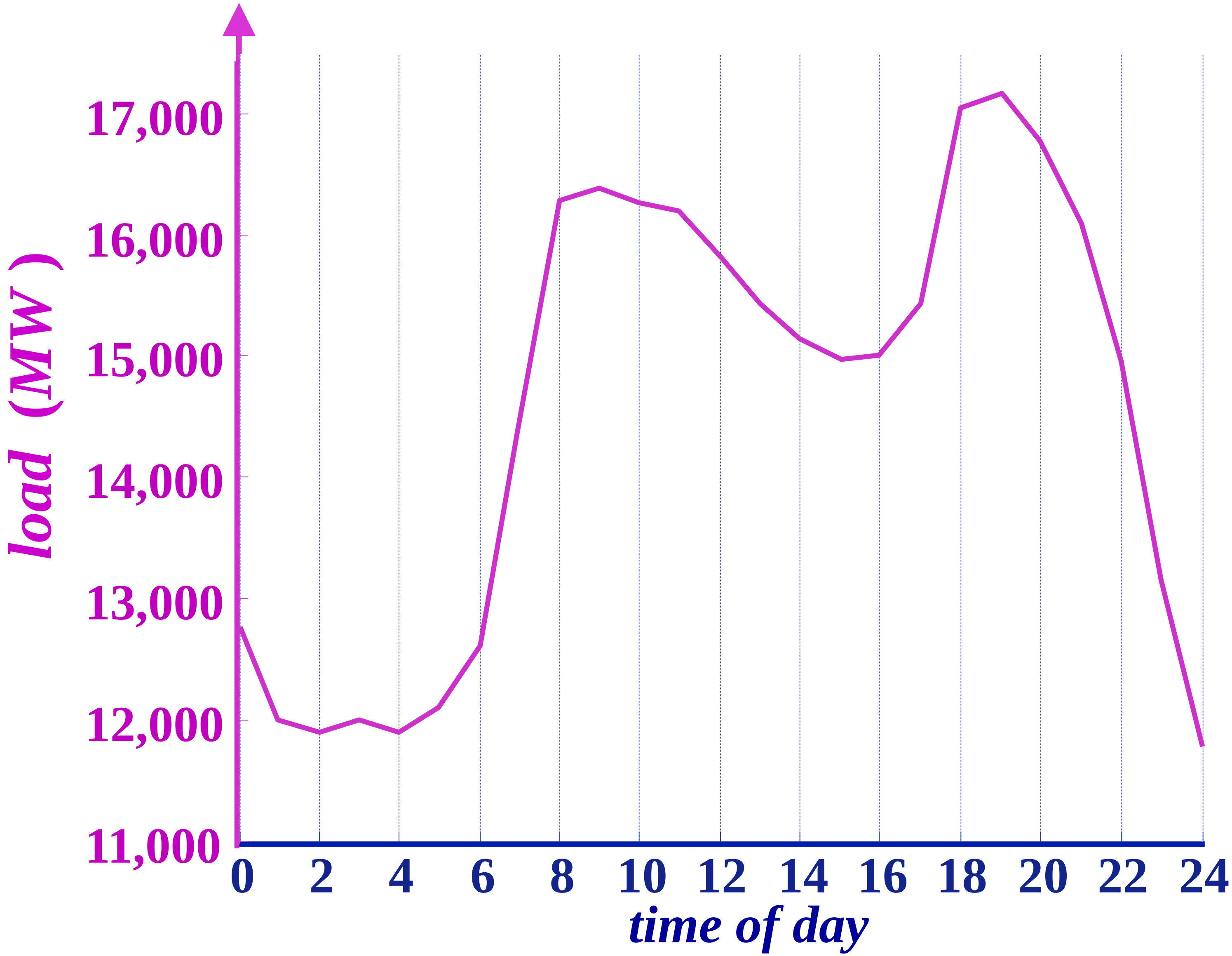
OUTLINE OF THE PRESENTATION

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

TYPICAL SEASONAL WEEKLY LOAD PATTERNS : *ERCOT* 2005

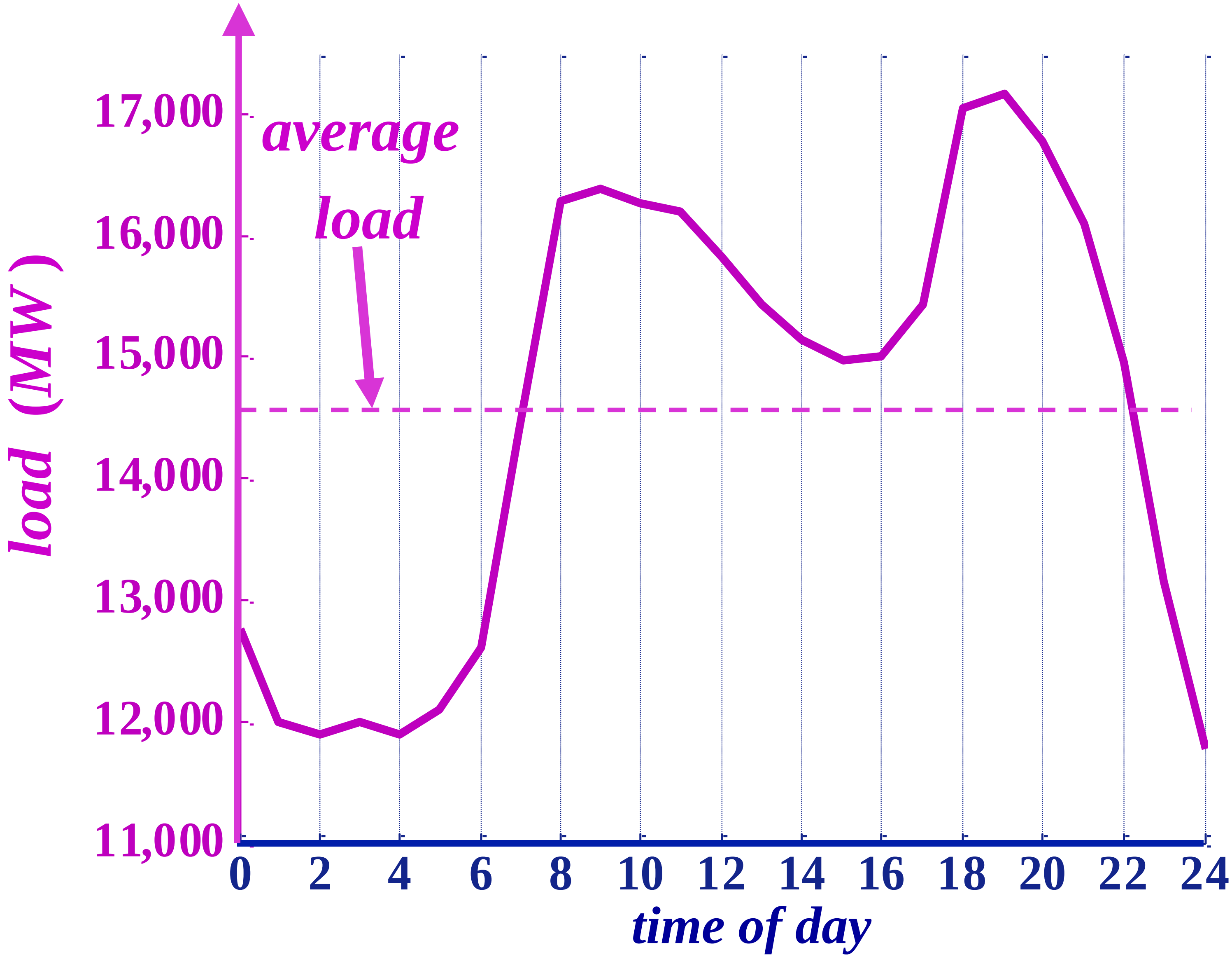


LOAD AND *LMP*



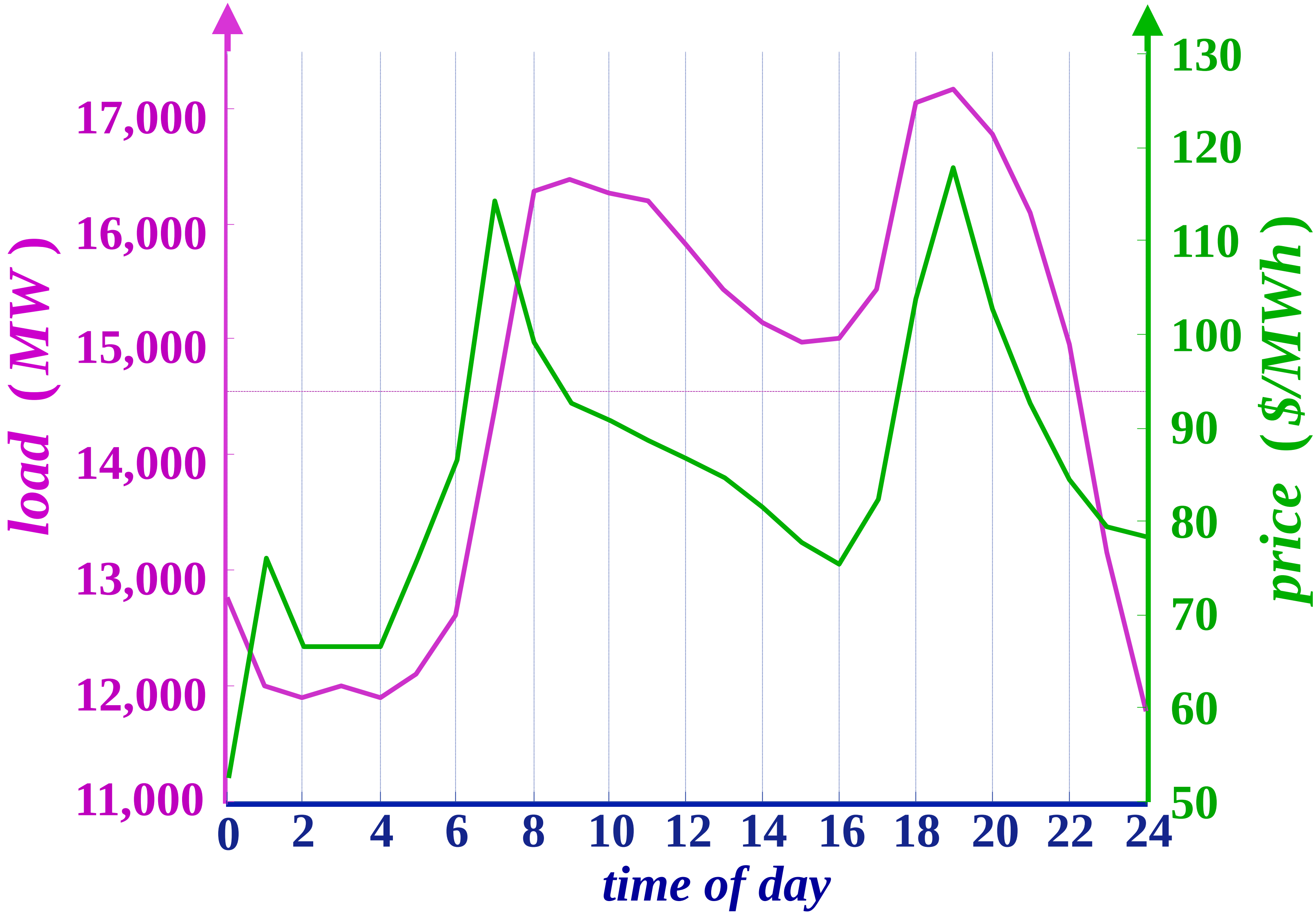
Source: NE ISO

LOAD AND *LMP*



Source: NE ISO

LOAD AND *LMP*



Source: NE ISO

OUTLINE OF THE PRESENTATION

- The critical importance of energy storage
- The storage vision
- ***ESR*** **roles and application in power system**
- The current status of storage
- The California push for storage deployment
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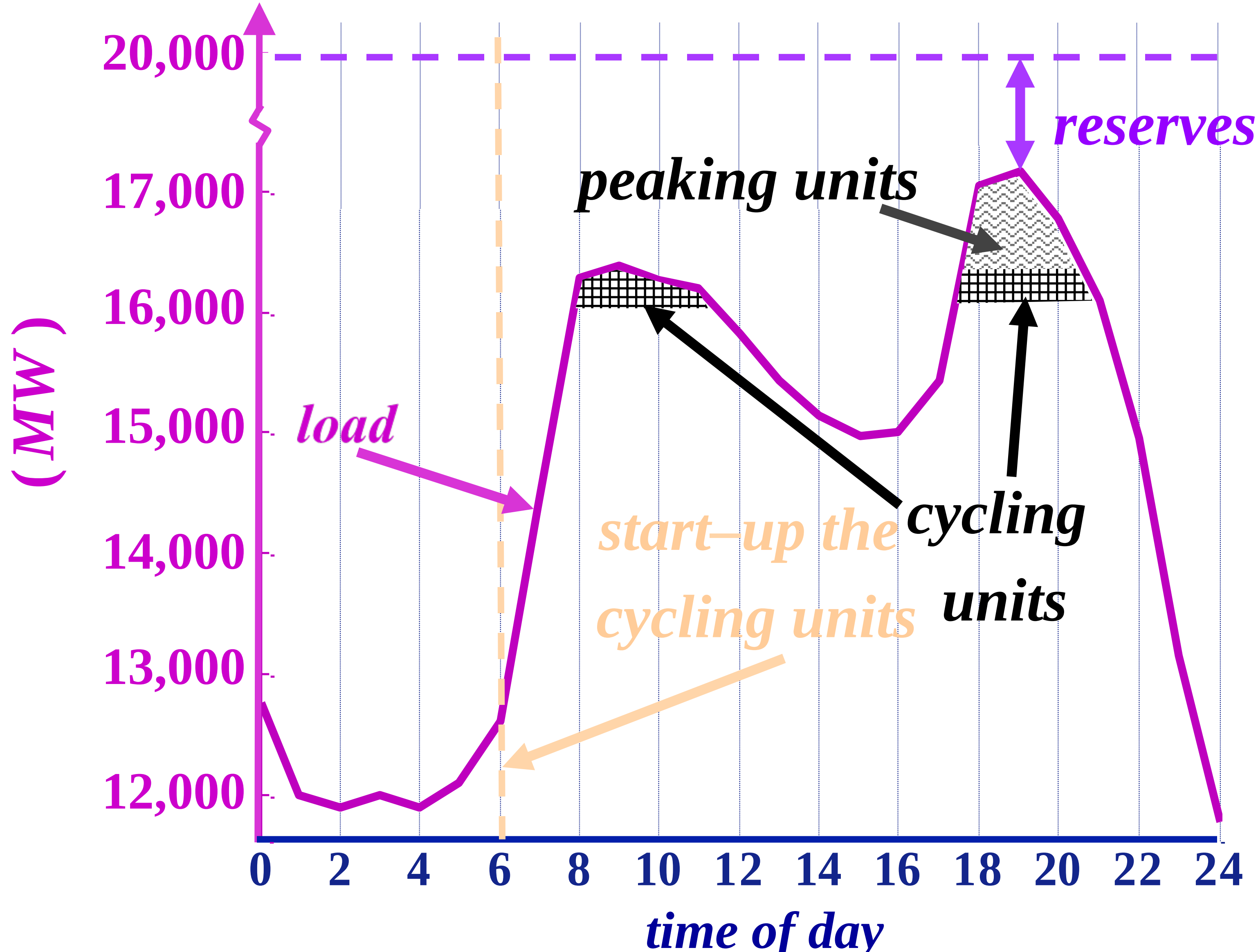
STORAGE METRICS

metrics	*measurand*
state of charge (s.o.c.)	*charge level of a battery, typically, expressed in percent*
depth of discharge (d.o.d.)	*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*

BATTERY VEHICLES (*BV*s)

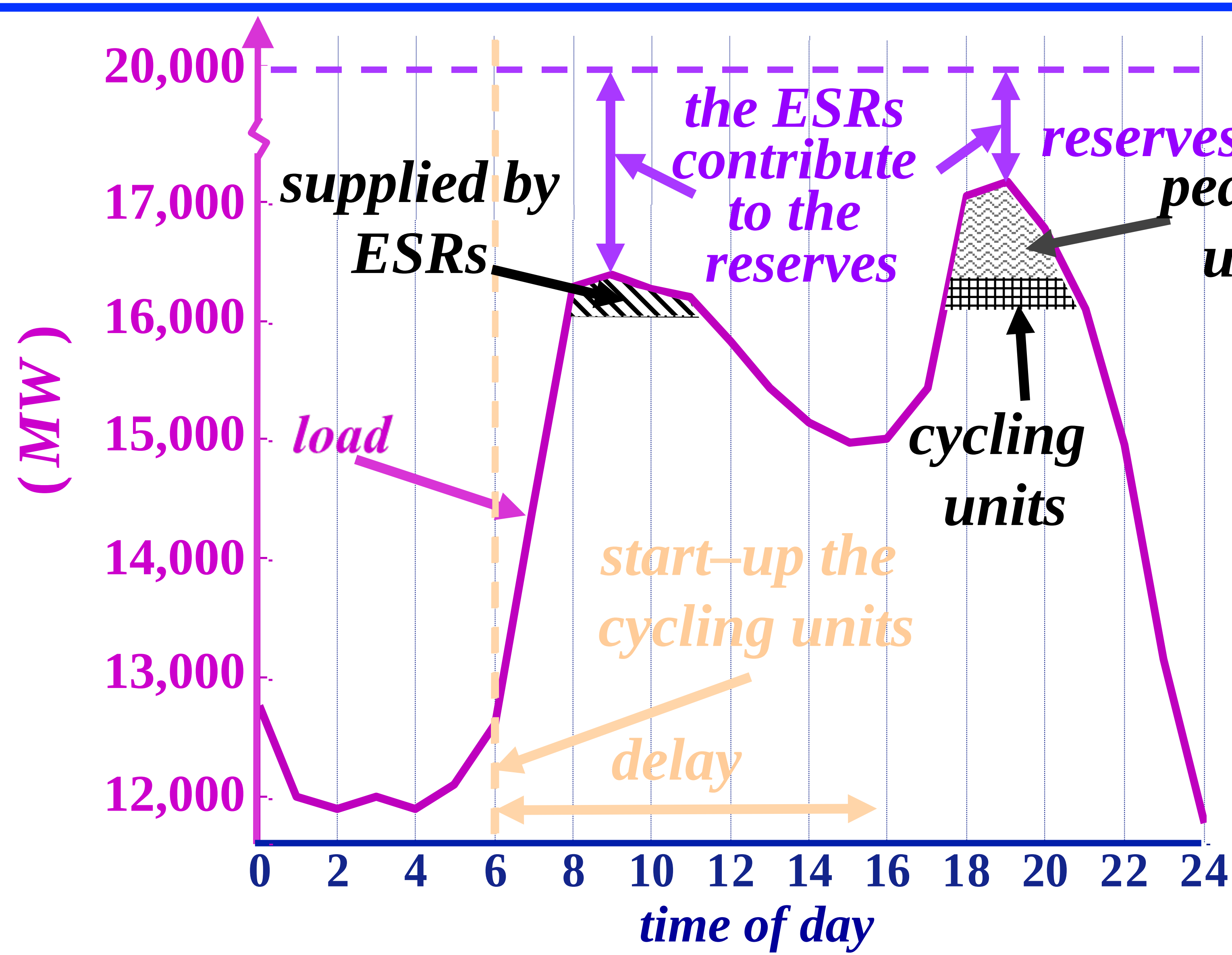
- Reduction in CO_2 emissions and energy security are the key drivers of initiatives aimed to promote the electrification of the transportation sector
- As a consequence of these efforts, the past decade has seen an increase in sales of *BV*s – *electric vehicles* (*EV*s), *hybrid electric vehicles*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

CYCLING UNITS WITHOUT *ESR*s



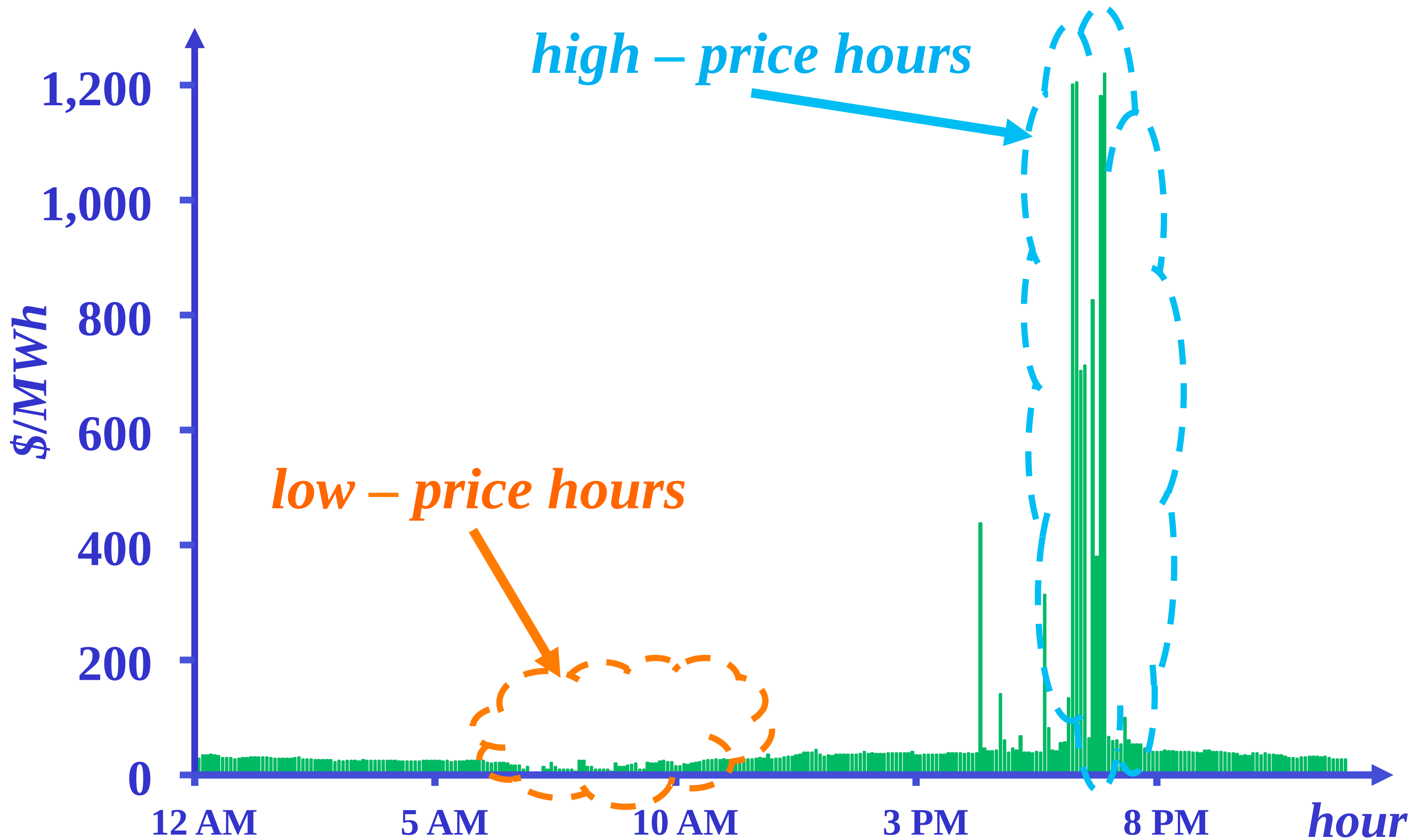
Source: ISO–NE

CYCLING UNITS WITH *ESR*s



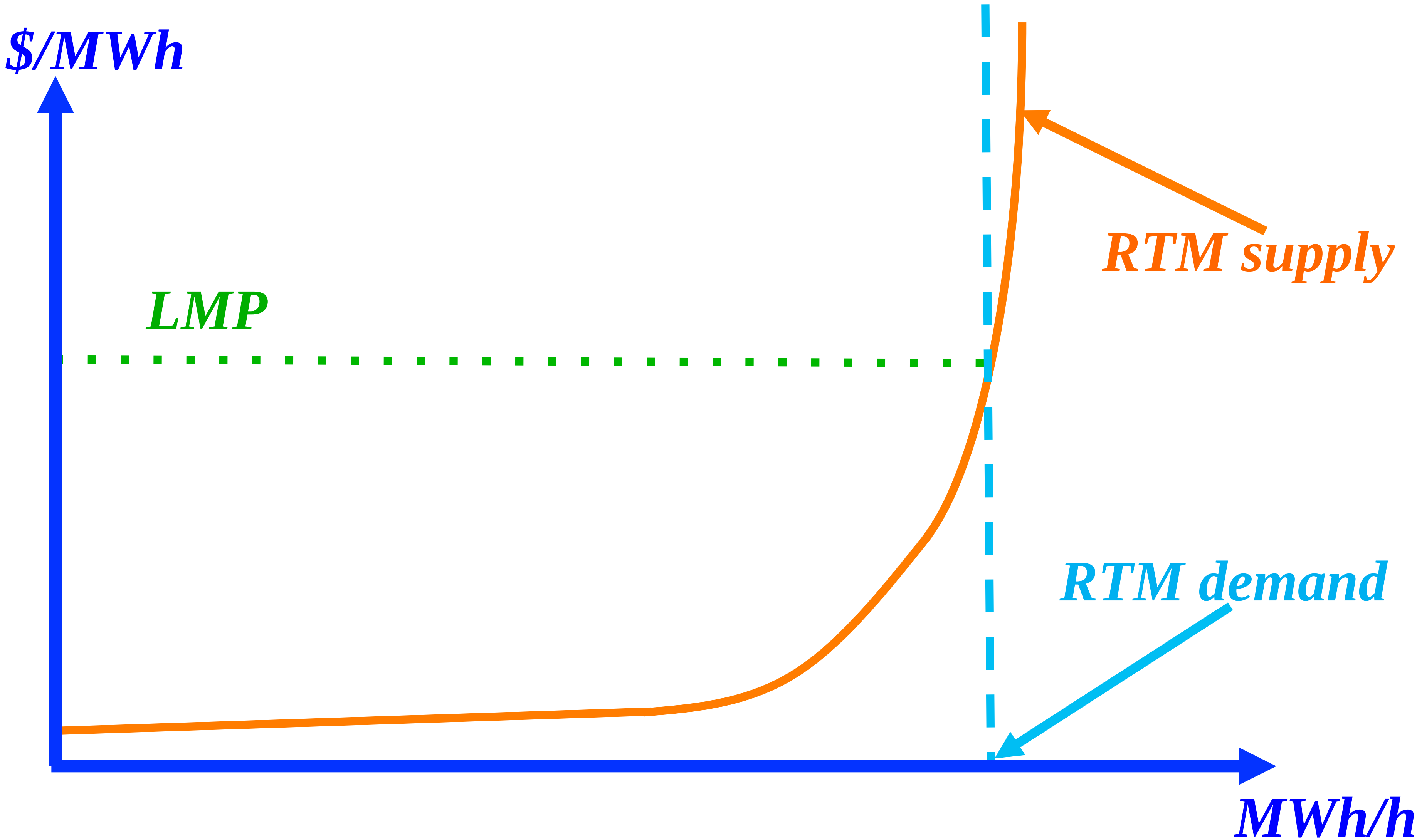
Source: ISO–NE

ESR DEPLOYMENT IN *RTM*s



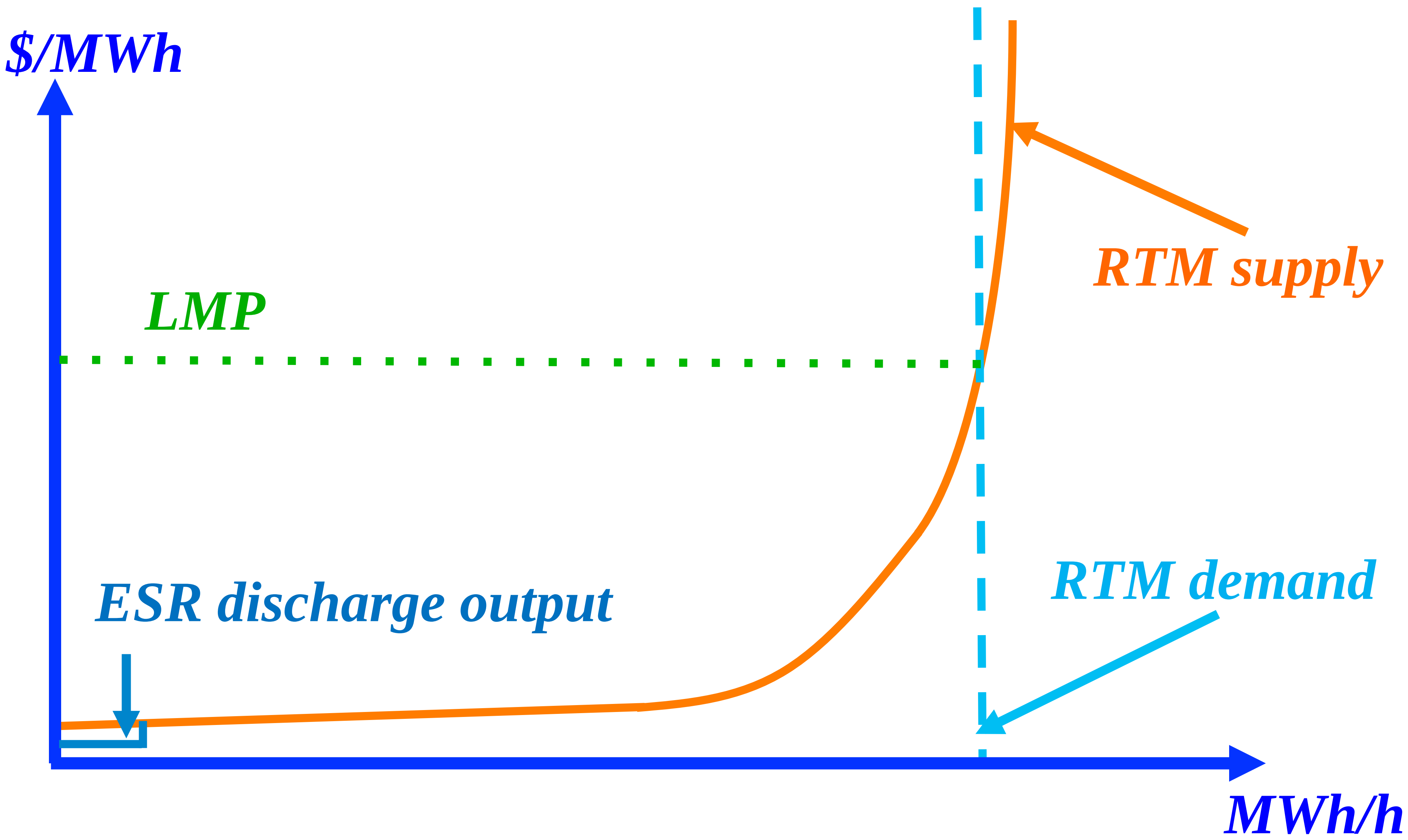
Source: http://oasis.caiso.com/, hub TH_SP15 (June 9, 2015)

LMP IN A SYSTEM WITHOUT STORAGE

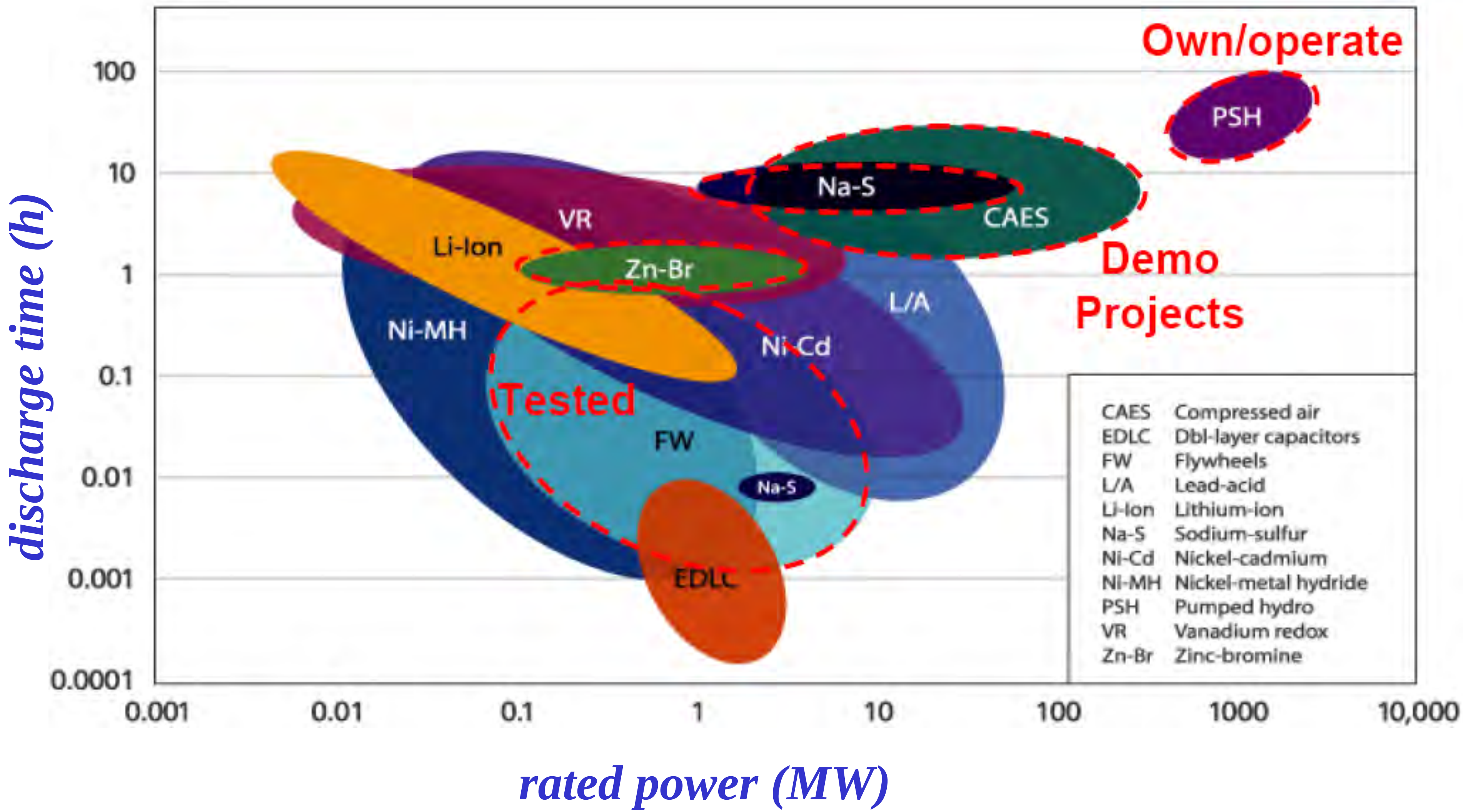


Source: http://oasis.caiso.com/, hub TH_SP15 (June 9, 2015)

ESR DEPLOYMENT IMPACT ON *LMP*



ENERGY STORAGE TECHNOLOGY CHARACTERIZATION



Source: Electricity Storage Association

OUTLINE OF THE PRESENTATION

- The critical importance of energy storage
- The storage vision
- *ESR* roles and applications to power systems
- **The current status of storage**
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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.

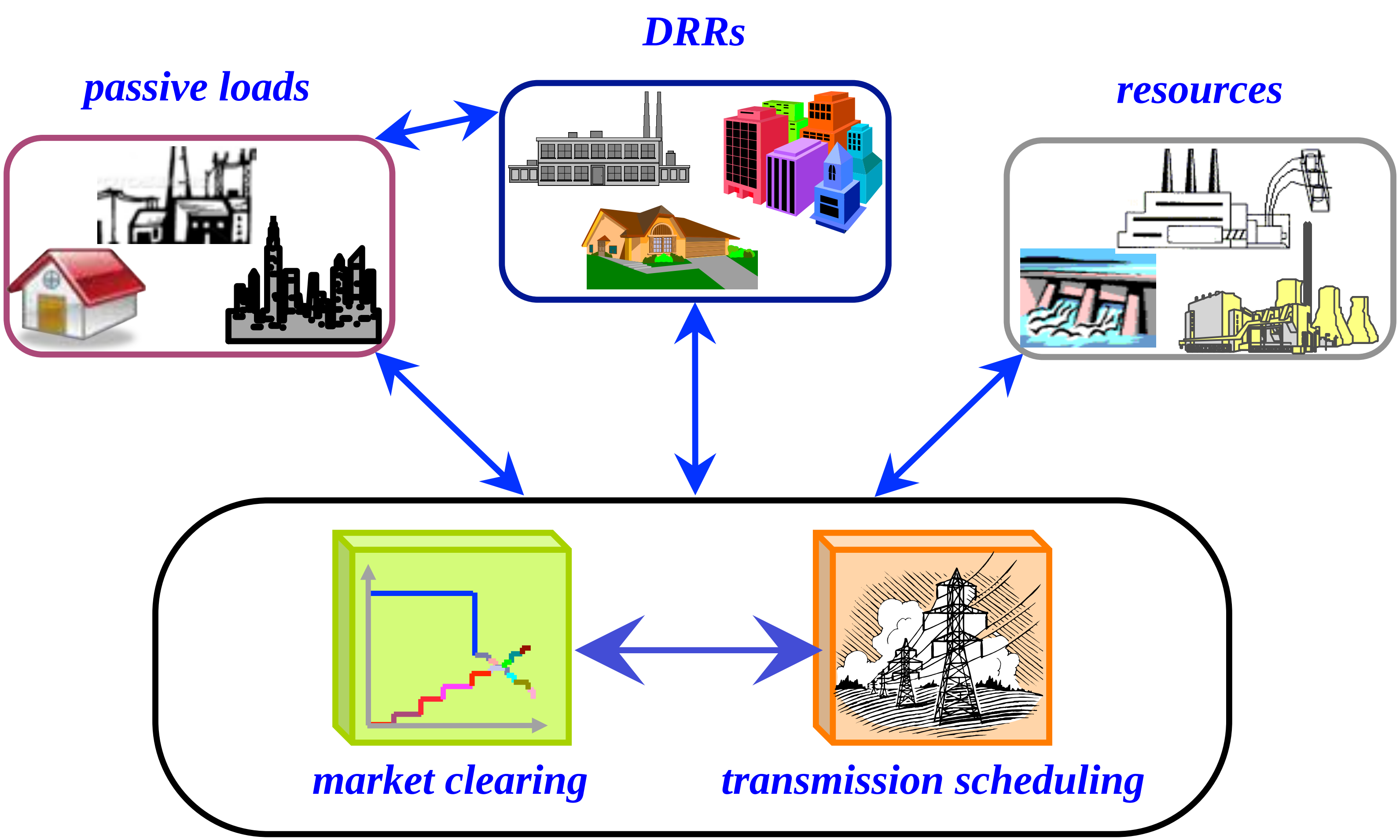
ESR APPLICATIONS IN MICROGRIDS (μgs)

- 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 element in the implementation of grid–connected, autonomous and community μgs

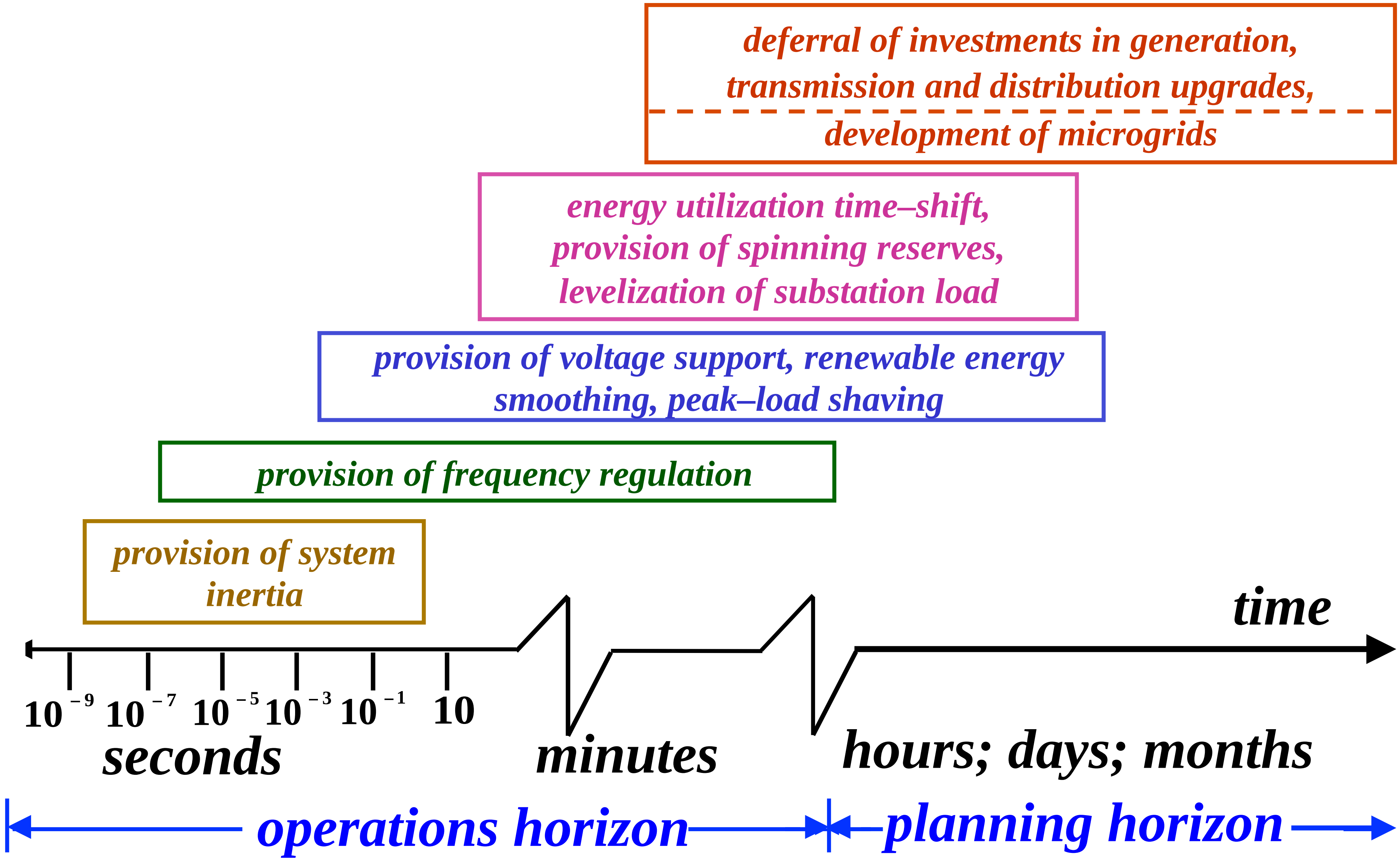
APPLICATION IN MICROGRIDS

Santa Rita Jail Microgrid

DEMAND RESPONSE RESOURCES (*DRRs*)

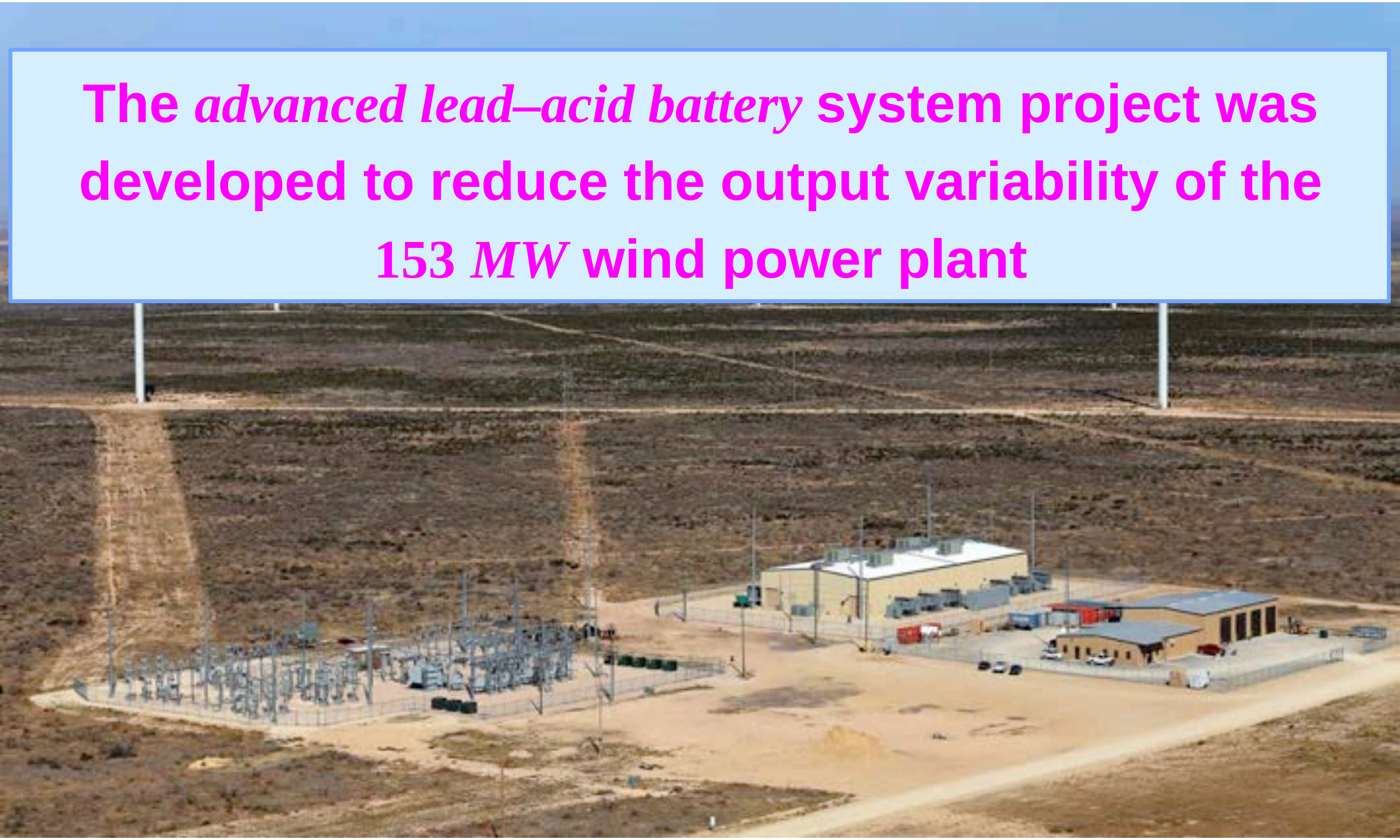


ESR APPLICATIONS



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



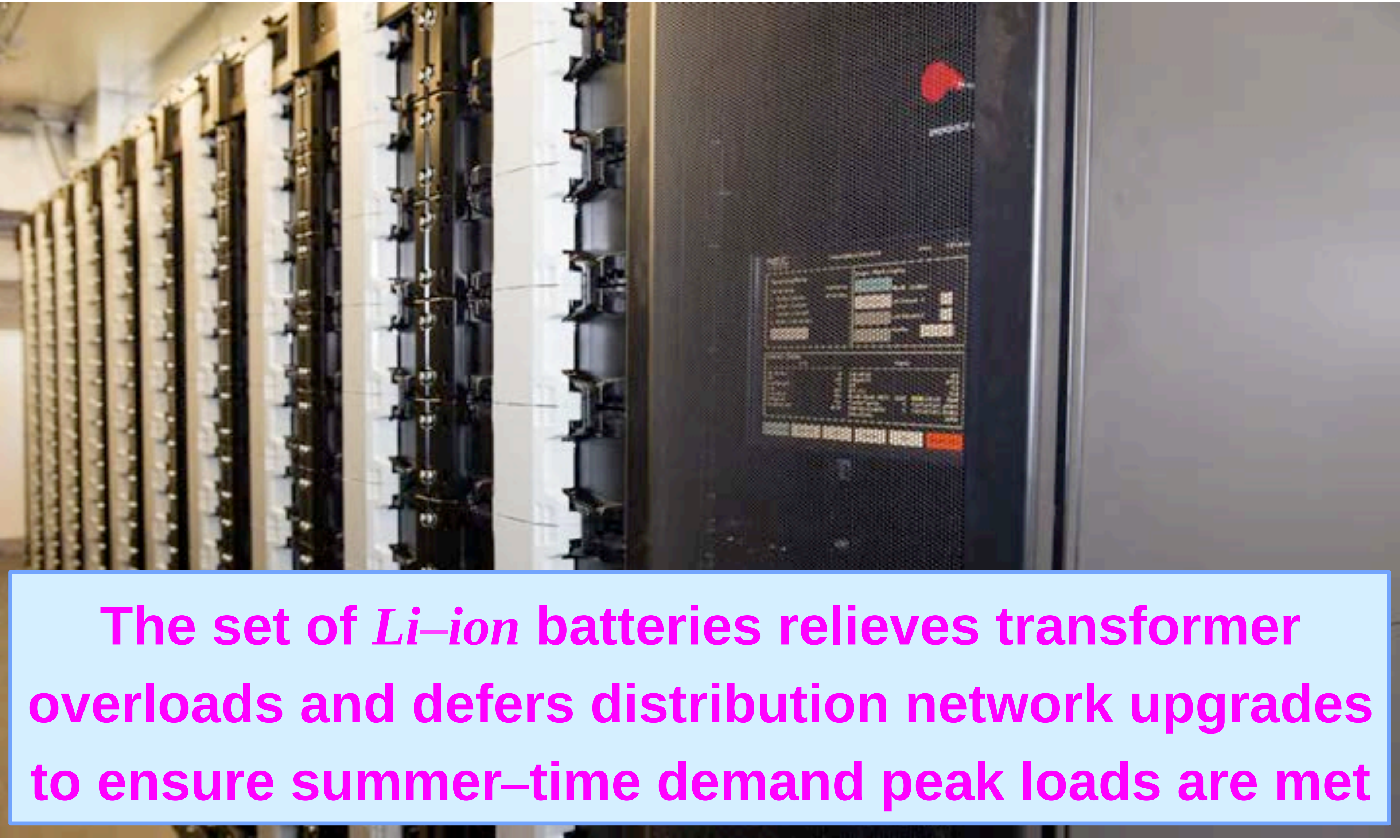
Source: http://www.energystorageexchange.org/projects

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

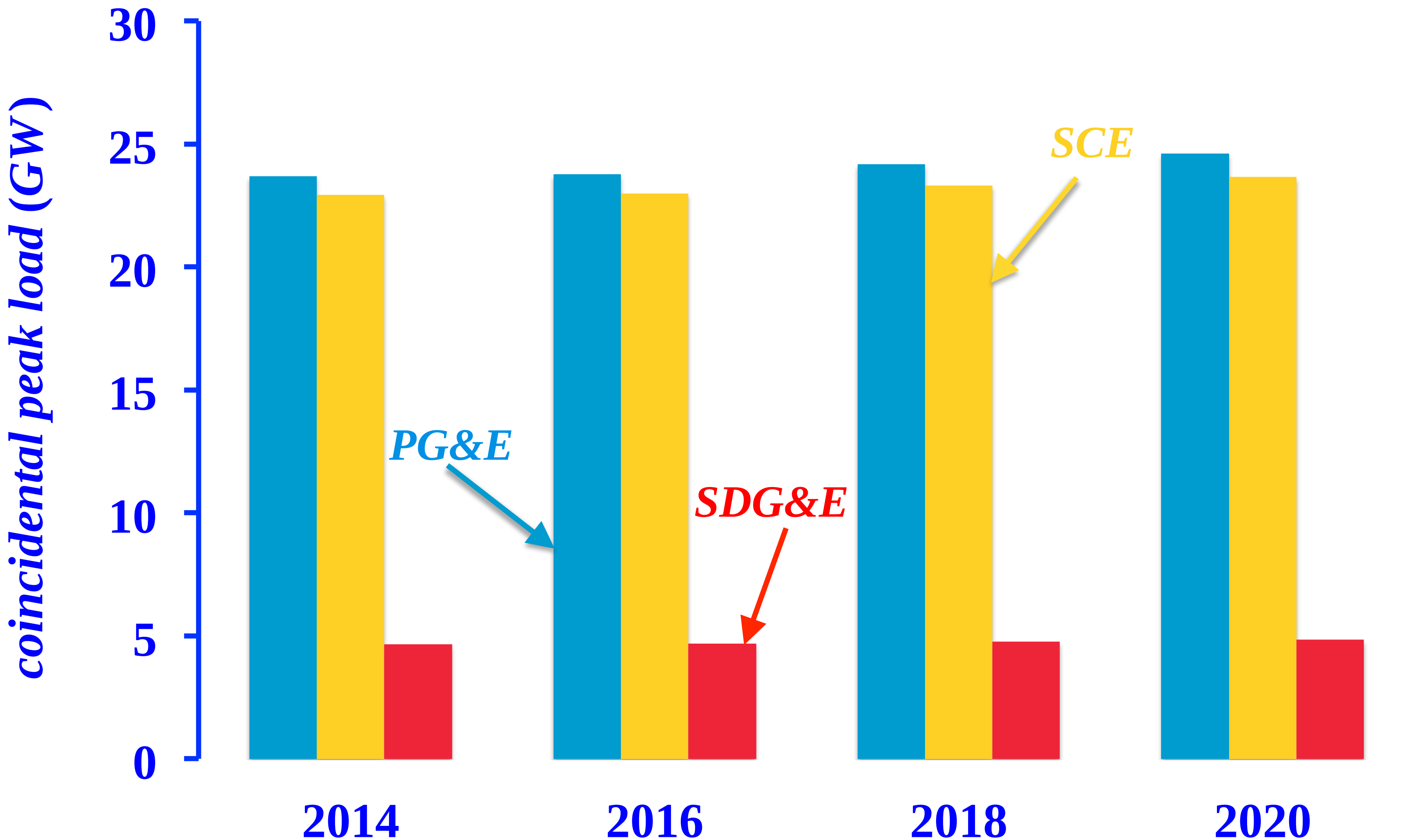
OUTLINE OF THE PRESENTATION

- ❑ The critical importance of energy storage
- ❑ Overview of *ESR* technologies
- ❑ *ESR* roles and application in power system
- ❑ The current status of storage
- ❑ **The California push for storage deployment**
- ❑ The opportunities and the challenges ahead

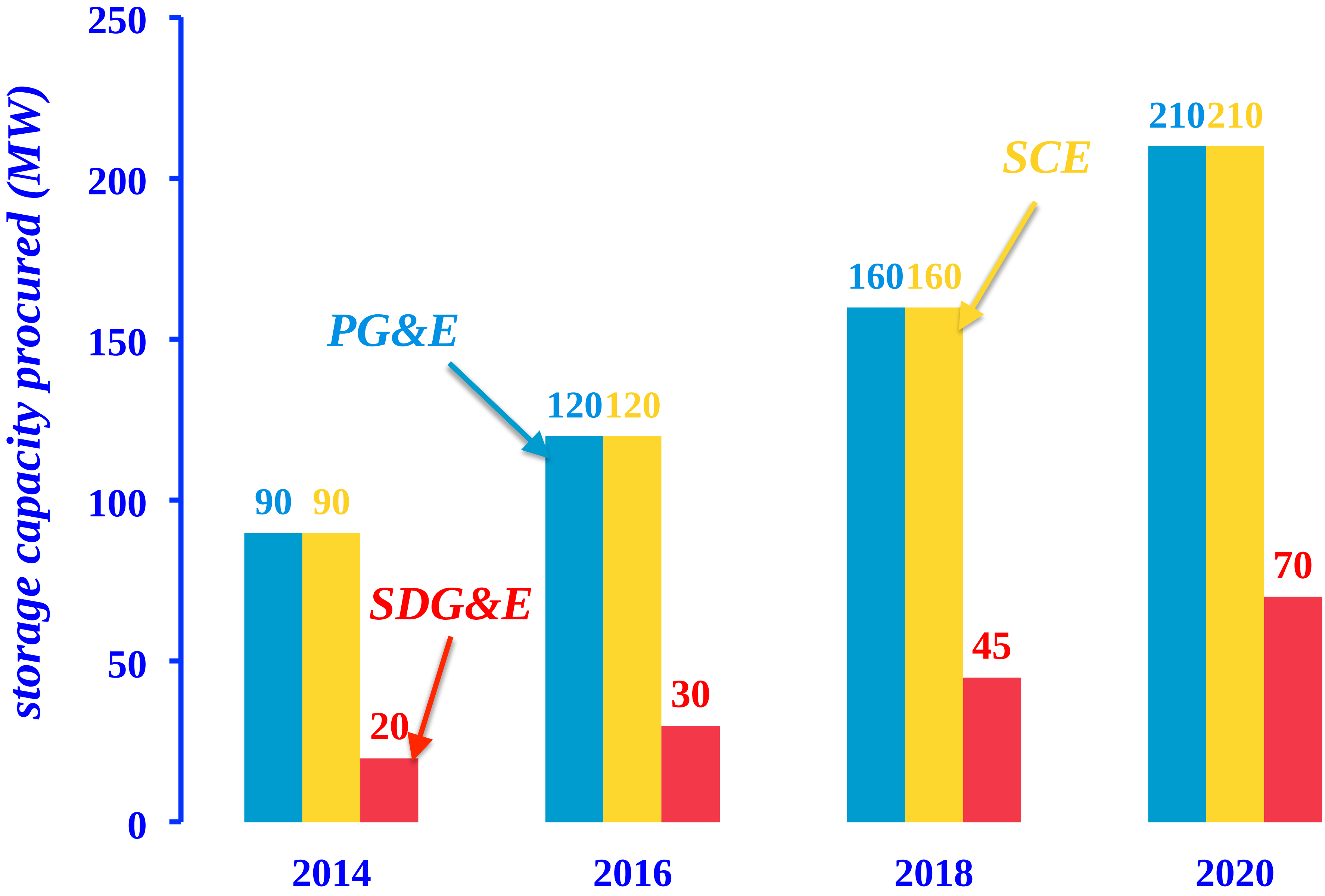
THE *CPUC* STORAGE PROCUREMENT FRAMEWORK SPECIFICATIONS

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

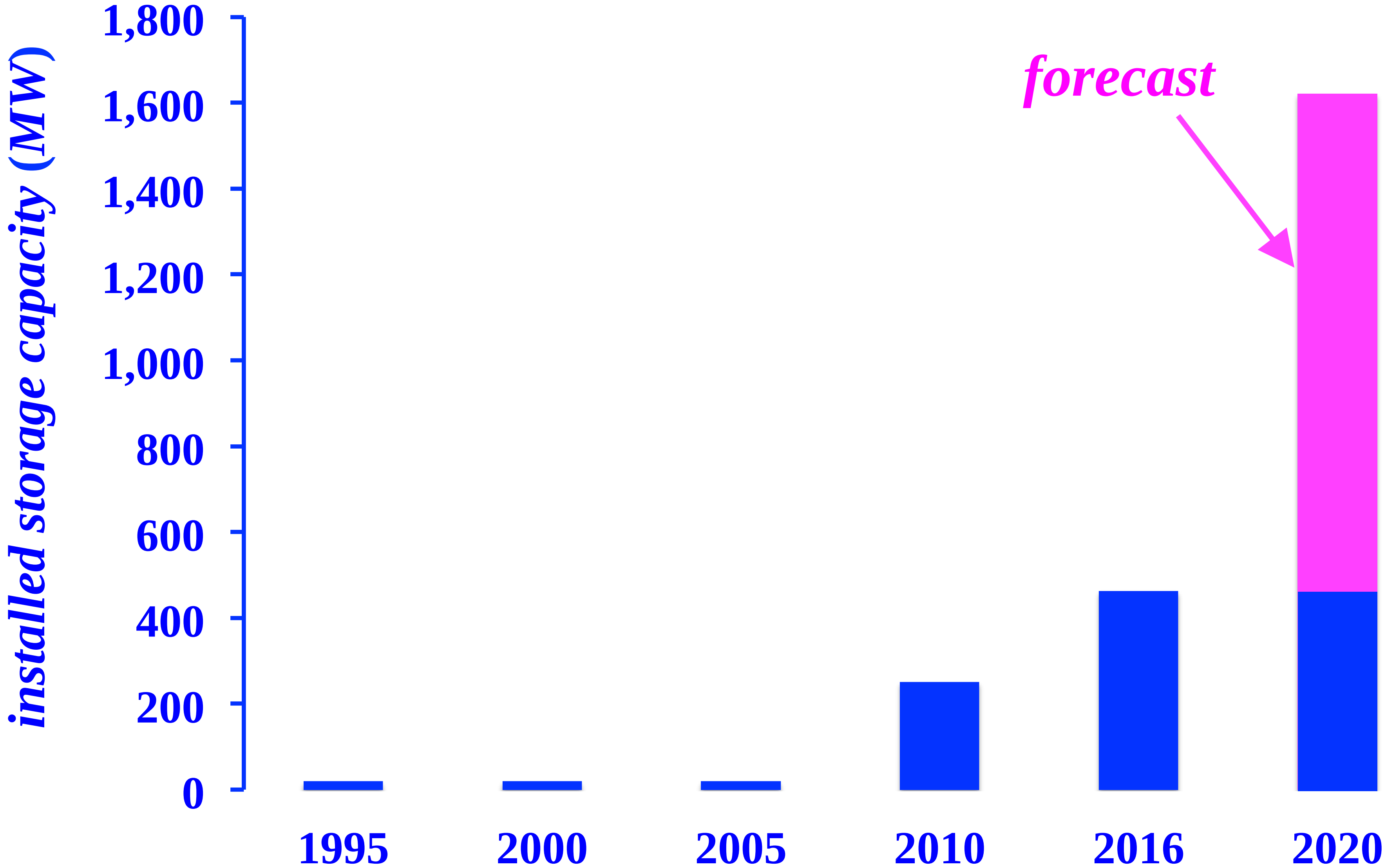
CALIFORNIA IOUs' HISTORICAL AND FORECASTED PEAK LOADS



PROCUREMENT SCHEDULE



HISTORICAL AND PLANNED *CAISO* BATTERY CAPACITY



Source: DoE Global energy storage database www.energystorageexchange.org

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

cell
(60 *Wh*)

56 ×

module
(3.2 *kWh*)

18 ×

rack
(58 *kWh*)

151 ×

section
(8.7 *MWh*)

4 ×

system
(32 *MWh*)

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

LARGE – SCALE *ESR*

Source : SCE

DEVELOPMENT OF *ESR* PERFORMANCE METRICS

- **The framework must allow the simulation of the various *ESR deployments* in the power grid and the quantification of the *physical/information/economic interactions* between the *ESR* and all the players that interact with the *ESR***
- **A key challenge in the construction of this conceptual structure is the formulation of new metrics**

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 variety 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**

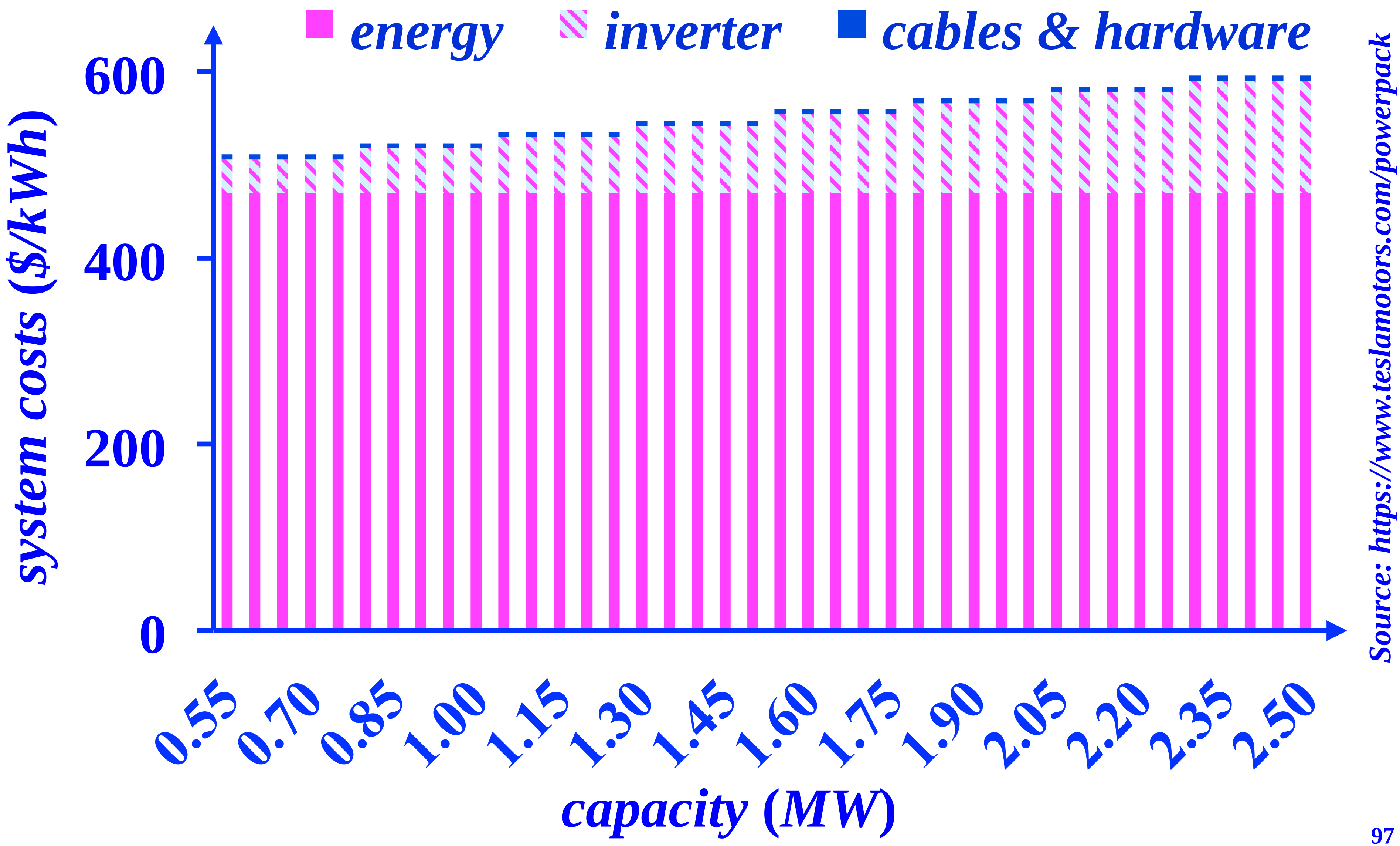
THE *TESLA POWERPACK*

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

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*)**
- **The resulting cost increase, with the costs of the inverter and installation taken into account, is in a range from 600 to 800 *$/kWh***
- **Reductions in costs are expected eventually to be similar to those of *PV* solar capacity price declines and such reductions can bring about a breakthrough in the wider deployment of *ESR*s**

CHALLENGES TO LARGE–SCALE STORAGE DEPLOYMENT

- **The deployment of large–scale *ESR*s is associated with numerous *economic, regulatory and technical challenges* that must be overcome to 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 nontrivial problem**

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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	✓	✓	✓	✓
limitation of large–scale deployment	✓	✓	✓	✓
symbiosis of ESR and DRR	✓	✓	✓	✓
environmental impacts	✓	✓	✓	✓

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 such as:**

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 investments in costly upgrades

FRAMEWORK REQUIREMENTS

- **Representation of**
  - **the salient characteristics of each *ESR* and its operational phases**
  - **the interactions of the embedding environment and the grid**
  - **the intent 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 rules for interconnection and market participation**
  - **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**

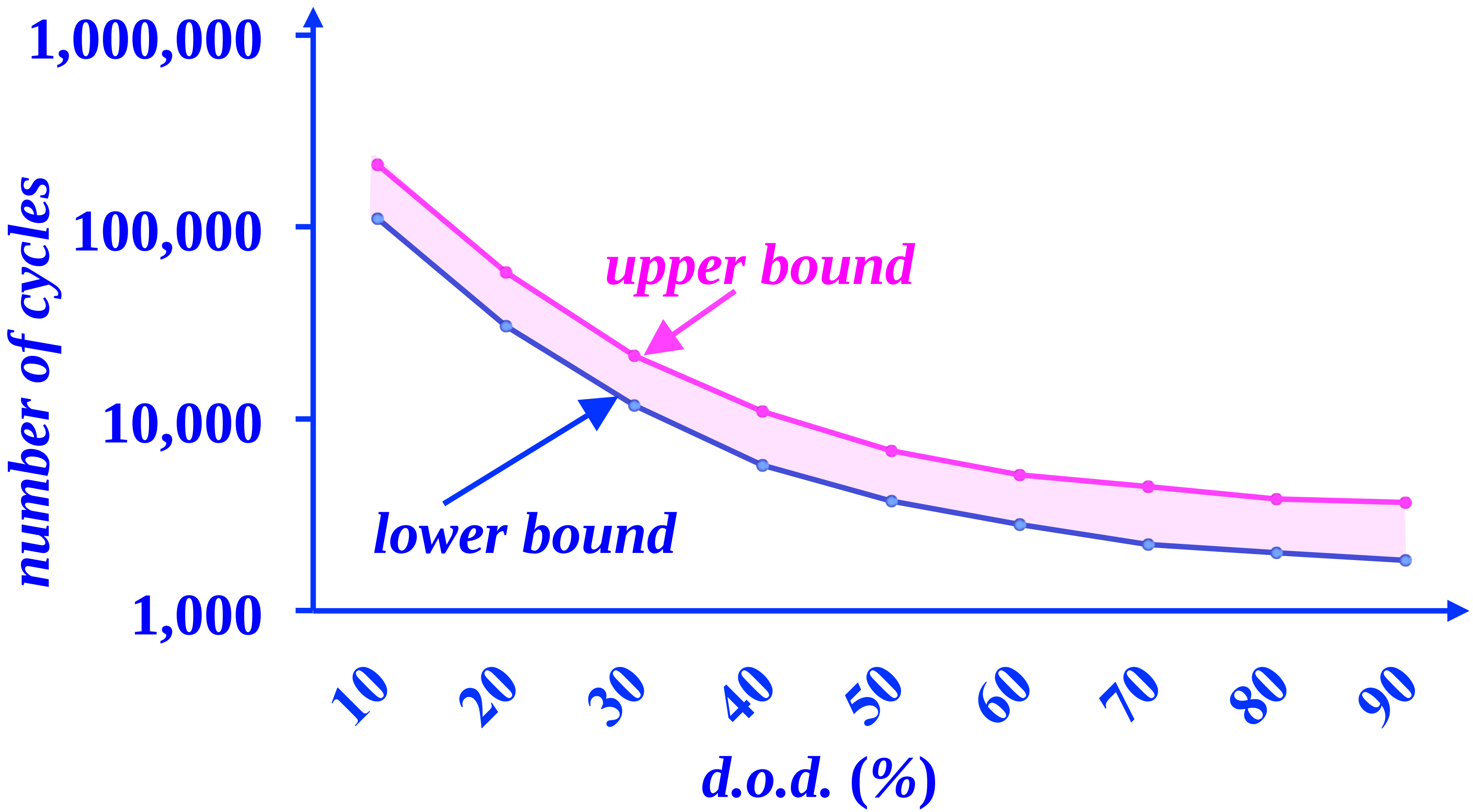
APPLICATIONS OF THE FRAMEWORK

- **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**

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

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