ECE 333 – GREEN ELECTRIC ENERGY

19. Energy Storage Resources

George Gross
Department of Electrical and Computer Engineering
University of Illinois at Urbana–Champaign
ESRs IN THE NEWS

Big Oil well placed to accelerate transition to electric vehicles
*Financial Times* (October 26, 2020)

Battery energy storage systems integrated in solar facilities to receive tax incentives
*PV magazine* (September 15, 2020)

Tesla Project to Install Another Giant Battery in Australia
*Bloomberg* (November 4, 2020)

Duke Energy to spend $500M on battery storage in next 15 years
*Utility Dive* (October 11, 2018)

Global storage heading to 741 GWh by 2030, WoodMac projects
*Utility Dive* (October 5, 2020)

California Community Choice groups seek up to 500MW of long-duration energy storage
*Energy Storage News* (October 19, 2020)

UK’s largest battery energy storage system goes live
*Power Engineering Intl.* (November 6, 2020)

LS Power Energizes World’s Biggest Battery, Just in Time for California’s Heat Wave
*Greentech Media* (August 19, 2020)
OUTLINE

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

- The *electricity business* is the only industry sector that sells a commodity *without sizeable inventory*.
- The lack of utility-scale storage in today’s power system drives electricity to be a highly *perishable commodity*.
- The deepening *renewable resource penetrations* exacerbate the challenges to maintain the *demand–supply equilibrium* at all points in time.
- Storage is a major flexibility source to maintain demand–supply balance *around the clock*.
Climate change impacts are the key drivers of the growing deployment of renewable resources to bring about $CO_2$ emission reductions.

Various jurisdictions’s legislative/regulatory initiatives stipulate specific reduction targets with the dates by which they must be met to create a greener, healthier and sustainable environment.
Many states have been active in the adoption of renewable portfolio standards (RPS) – 29 states, DC, and 3 US territories have adopted such standards.

RPS require a specified percentage or amount of renewable electricity – typically in terms of MWh – by the specified date that must be met to bring about a cleaner environment.

In addition, 8 states and a territory have voluntary goals for renewable generation implementation.
RENEWABLE PORTFOLIO STANDARDS


Notes: Target percentages represent the sum total of all RPS resource tiers, as applicable. In addition to the RPS policies shown on this map, voluntary renewable energy goals exist in a number of U.S. states, and both mandatory RPS policies and voluntary goals exist among U.S. territories (American Samoa, Guam, Puerto Rico, US Virgin Islands).
MISALIGNMENT OF WIND POWER OUTPUT AND LOAD

wind power output (MW)

load (MW)

hour

0 24 48 72 96 120 144 168

0 50 100 150 200 250 3000 4000 5000 6000 7000 8000

wind power

load
NEED FOR LARGER AND FASTER RAMPING RESERVES

load

load minus wind output

large up ramp required

large down ramp required
CAISO DAILY NET LOAD CURVE UNDER DEEPENING RER PENETRATIONS

Source: CAISO
Typical Spring Day
Net Load 9,187 MW on April 23, 2017
Actual 3-hour ramp 12,960 MW on December 18, 2016

Net Load 9,187 MW on April 23, 2017
CAISO DAILY NET LOAD CURVE UNDER DEEPER PV PENETRATION

June 10, 2018

load

solar

net load

wind
CAISO DAILY NET LOAD CURVE UNDER DEEPER PV PENETRATION

May 4, 2019

load

solar

net load

wind

MW

hours

0 8 16 24

0 5000 10000 15000 20000 25000 30000
CAISO DAILY NET LOAD CURVE UNDER DEEPER PV PENETRATION

August 15, 2019

MW

0 50000

0 8 16 24 hours

load

net load

solar

wind

MW

CAISO DAILY NET LOAD CURVE UNDER DEEPER PV PENETRATION

August 15, 2019

MW

0 50000

0 8 16 24 hours

load

net load

solar

wind

MW

CAISO DAILY NET LOAD CURVE UNDER DEEPER PV PENETRATION

August 15, 2019

MW

0 50000

0 8 16 24 hours

load

net load

solar

wind

MW

CAISO DAILY NET LOAD CURVE UNDER DEEPER PV PENETRATION

August 15, 2019

MW

0 50000

0 8 16 24 hours

load

net load

solar

wind

MW

CAISO DAILY NET LOAD CURVE UNDER DEEPER PV PENETRATION

August 15, 2019

MW

0 50000

0 8 16 24 hours

load

net load

solar

wind

MW
CAISO DAILY NET LOAD CURVE UNDER DEEPER PV PENETRATION

June 28, 2020

load

solar

net load

wind

CAISO DAILY NET LOAD CURVE UNDER DEEPER PV PENETRATION
CALIFORNIA ROOFTOP SOLAR IMPACTS: MARCH 11, 2017

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

\[ \text{net load} = \text{load} - \text{wind} - \text{solar} \]

- **Load (MW)**
- **Net Load (MW)**
- **Wind Output (MW)**
- **Solar Output (MW)**

**Graph Key:**
- **Load:** 8,300 MW over 3 hours
- **Net Load:** 10,600 MW over 5 hours
- **Solar Output:** 12,200 MW over 3 hours

**Time (0:00 to 20:00):**
- 0:00 to 4:00
- 4:00 to 8:00
- 8:00 to 12:00
- 12:00 to 16:00
- 16:00 to 20:00

**Values at Specific Times:**
- 8:00: Load 6,000 MW, Wind 2,000 MW, Solar 3,000 MW, Net Load 1,000 MW
- 12:00: Load 12,000 MW, Wind 5,000 MW, Solar 7,000 MW, Net Load 4,000 MW
- 16:00: Load 24,000 MW, Wind 10,000 MW, Solar 10,000 MW, Net Load 4,000 MW
- 20:00: Load 30,000 MW, Wind 15,000 MW, Solar 12,000 MW, Net Load 3,000 MW
NET LOAD IN CALIFORNIA IN SPRING

- Renewable energy curtailment in CAISO has increased markedly since 2017.

- CAISO mostly curtails renewable energy during the Spring, when the duck curve becomes more pronounced.

- CAISO needs to curtail the output of renewable resources to preclude overly steep net load ramps and ensure secure grid operations.
MONTHLY CAISO RENEWABLE ENERGY CURTAILMENTS


GWh

0 50 100 150 200 250

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CURTAILMENT PERCENTAGES OF WIND GENERATION: 2012 – 2019

Source: Lawrence Berkeley National Laboratory, available online at https://emp.lbl.gov/wind-technologies-market-report/
**PRINCIPAL ROLES 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 ESRs CAN PLAY

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

- demand response action
- capability to provide voltage support

- Storage can also provide *virtual inertia service* to replace part of the missing inertia in grids with integrated renewable resources – a major issue in grids with deeper levels of integrated renewable energy resources
LOADS AND LOCATIONAL MARGINAL PRICES (LMPs)

Source: NE ISO
LOADS AND *LMPs*

Source: NE ISO
LOADS AND LMPs

Source: NE ISO

[Graph showing the relationship between load (MW) and price ($/MWh) over the course of a day, with peaks during certain times of the day.]
STORAGE UTILIZATION

Source: NE ISO
LOADS AND LMPs

Source: NE ISO
THE STORAGE RESOURCE PHASES

charging phase

idle phase

discharging phase
CYCLING UNITS WITHOUT $ESRs$

Source: ISO–NE

- **load**
- **peaking units**
- **reserves**
- **start-up the cycling units**
- **cycling units**

(time of day)

(MW)
CYCLING UNITS WITH ESRs

Source: ISO–NE

supplied by ESRs

the ESRs contribute to the reserves

reserves

peaking units

cycling units

load

start-up the cycling units

delay

(MW)

0 2 4 6 8 10 12 14 16 18 20 22 24
time of day

11,000 12,000 13,000 14,000 15,000 16,000 17,000 18,000

ESRs

reserves

Source: ISO–NE

supplied by ESRs

the ESRs contribute to the reserves

reserves

peaking units

cycling units

load

start-up the cycling units

delay

(MW)

0 2 4 6 8 10 12 14 16 18 20 22 24
time of day

11,000 12,000 13,000 14,000 15,000 16,000 17,000 18,000
ESR DEPLOYMENT IN RTMs

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

$LMP$

Source: http://oasis.caiso.com/, hub TH_SP15 (June 9, 2015)
ESR DEPLOYMENT IMPACT ON LMP

$/MWh

LMP

ESR discharge output

RTM demand

RTM supply

Source: http://oasis.caiso.com/, hub TH_SP15 (June 9, 2015)
BATTERY STORAGE AND RER SYMBIOSIS

INTEGRATION OF STORAGE WITH SOLAR RESOURCES

ESR energy discharged

13:56

14:10
peak 5% – about 2,500 MW – in under 50 hours in a year

peak 25% of demand occurs less than 10% of the time

CAISO annual LDC demand response

energy storage
LEADING NATIONS’ RENEWABLE ENERGY GENERATION IN 2020


% share of total generation

- wind power
- solar PV

DK: 60%
UY: 40%
IE: 30%
DE: 20%
EL: 10%
ES: 10%
UK: 20%
PT: 10%
AU: 10%
NL: 20%
HN: 10%
SE: 10%
BE: 10%
CL: 10%
NI: 10%
IT: 10%
ANNUAL AND CUMULATIVE US ENERGY STORAGE CAPACITY

ENERGY STORAGE TECHNOLOGIES

- pumped storage
- CAES
- NaS battery
- EC capacitor
- flywheel
- lead–acid battery
- advanced lead acid battery
- Li–ion battery
- Ni–Cd battery
- SMES

increasing capacity
EFFICIENCY RANGES OF ESR TECHNOLOGIES


lower limit
upper limit

<table>
<thead>
<tr>
<th>Technology</th>
<th>Lower Limit</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCing magnets</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flywheels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supercapacitors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Li-I batteries</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Molten salt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pumped hydro</td>
<td></td>
<td></td>
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<tr>
<td>Compressed-air</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Redox flow batteries</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## ESR Interactions with the Grid

<table>
<thead>
<tr>
<th>Application</th>
<th>ESR Owner Interest</th>
<th>Grid Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substation transformer overload avoidance</td>
<td>Economic overload condition mitigation</td>
<td>Reliability improvement</td>
</tr>
<tr>
<td>Variable energy generation curtailing avoidance/reduction</td>
<td>More effective renewable energy resource harnessing</td>
<td>Increase of fraction of green energy and pollution reduction</td>
</tr>
<tr>
<td>Energy shift from low–load to high–load periods</td>
<td>Collection of arbitrage benefits</td>
<td>Low–load condition mitigation and cost reduction</td>
</tr>
<tr>
<td>Replacement of reserves requirements from the units in a generation plant</td>
<td>Relaxation of reserve requirements limits on the plant units</td>
<td>Reliability improvement</td>
</tr>
<tr>
<td>Variable Energy Resource Integration Challenge</td>
<td>The Way Storage Addresses The Challenge</td>
<td></td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>----------------------------------------</td>
<td></td>
</tr>
<tr>
<td>The pressing needs for adequate ramping capability in controllable resources</td>
<td>Fast ms–order ESR response times can meet the steep raise/lower ramping requirements</td>
<td></td>
</tr>
<tr>
<td>Variability, intermittency and uncertainty associated with renewable resource outputs</td>
<td>ESRs are instrumental in smoothing renewable outputs and in higher renewable energy harnessing</td>
<td></td>
</tr>
<tr>
<td>Increased need for frequency regulation resources for flexibility in grid operations</td>
<td>ESRs provide regulation with 2 – 3 times faster response times than gas turbines</td>
<td></td>
</tr>
<tr>
<td>today’s electricity grid with limited storage capacity/capability</td>
<td>future electricity grid with measurably increased storage capacity/capability</td>
<td></td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>any increment in peak demand requires use of polluting and inefficient power plants</td>
<td>additional peak demand is met by ESRs that shift the times of energy consumption</td>
<td></td>
</tr>
<tr>
<td>reserves requirements are met by expensive and polluting fossil–fired generators</td>
<td>reserves provided by ESRs reduce dependence on the contributions to reserves by conventional units</td>
<td></td>
</tr>
<tr>
<td>renewable generation has to be “spilled” whenever the supply exceeds the demand or under congestion situations</td>
<td>clean, renewable energy is stored in ESRs during low–demand periods, leading to reduced dependence on conventional units</td>
<td></td>
</tr>
</tbody>
</table>
Deployment of ESRs:

- raises system reliability
- improves operational economics
- provides operators with the badly needed additional flexibility to optimize grid operations and manage grid congestion
- raises renewable output utilization
KEY BENEFITS OF GRID – INTEGRATED ESRs

- Deployment of ESRs can reduce GHG emissions because ESRs:
  - 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
Many practitioners consider the installation of BESSs to most effectively address the challenges to integrate deepening penetrations of renewable resources – a game changer for RER integration.

BESSs are highly efficient and can discharge their stored energy at high ramp rates.

The development of new, large-scale, highly-efficient batteries, appropriate for utility-scale storage, is becoming a huge business rather rapidly.
FROM 60 Wh BATTERY CELLS TO A LARGE–SCALE 32 MWh ESR (BESS)


56 × cell (60 Wh)

18 × module (3.2 kWh)

151 × rack (58 kWh)

4 × section (8.7 MWh)

system (32 MWh)
The advanced lead–acid battery system project was developed to reduce the output variability of the 153 MW wind power plant.
The Li–ion batteries are installed in a 98–MW wind farm to provide operating reserves and frequency regulation in the PJM system.
The set of Li–ion batteries relieves transformer overloads and defers distribution network upgrades to ensure summer–time demand peak loads are met.
The world’s largest BESS in terms of energy storage capability; serves to provide demand – supply balance.

Source: http://www.energystorageexchange.org/projects
SOUTH AUSTRALIA: TESLA BATTERY

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

- Tesla’s battery is connected to the Hornsdale wind farm, which is owned by the French company Neoen and has 99 turbines with a generation capacity of 315 MW.

- Elon Musk promised that Tesla would have the battery in place within 100 days and it did.
The battery was linked to the grid 63 days after the contract was awarded, in a deal between Tesla, Neoen, the French renewable energy company, and the South Australian government.

The estimated cost of the battery system was US $38 million (Australian $50 million).
SOUTH AUSTRALIA’S TESLA BATTERY

- *South Australian* taxpayers will subsidize the battery’s operation with up to A $50 million over the next 10 years.

- In return, the *South Australian* Government has the right to use the battery to prevent load-shedding blackouts and is able to use the battery to provide ancillary services to the grid – critically important to maintain grid integrity – and to lower the prices of such services.
In March 23, 2020, Neoen increased the installed capacity of the Hornsdale Power Reserve BESS by 150 MW.

On September 2, 2020, the BESS storage capability was expanded to 185 MWh.

The expansion was completed by Aurecon and funded by the Clean Energy Finance Corporation, a “green bank” owned by the Australian government.
NEW PUSH IN ESR DEPLOYMENT

- Advancements in storage technology, cost reductions and regulatory initiatives have invigorated the interest in large-scale, grid-connected ESRs.
- The deeper renewable resource penetrations lead to the wider deployment of storage – as both a distributed and a grid resource.
- Given the strong push to retire fossil-fired supply resources on an accelerated basis, the electricity sector is implementing broader ESR deployment.
TOTAL US GRID INSTALLED SUPPLY RESOURCE CAPACITY BY REGION


total US grid installed capacity = 1,205 GW

PJM: 18%
CAISO: 6%
ERCOT: 10%
MISO: 16%
NYISO: 4%
ISO-NE: 3%
other: 42%
other CA: 1%

ISOs/RTOs = 58%
TOTAL US LARGE – SCALE BESS CAPACITY BY REGION


US large-scale BESS capacity = 1,022 MW
TOTAL US LARGE – SCALE BESS CAPABILITY BY REGION


**total BESS storage capability** = 1,688 MWh

- **PJM**: 36%
- **CAISO**: 14%
- **ERCOT**: 11%
- **MISO**: 10%
- **ISO-NE**: 9%
- **NYISO**: 6%
- **other CA**: 2%
- **other**: AK/HI: 12%
- **other ISOs/RTOs**: 72%

NYISO: 6%

ISO-NE: 9%

MISO: 4%

ERCOT: 6%
BESS CAPACITY / STORAGE CAPABILITY BY REGION AND OWNERSHIP: 2019

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

- Municipal / Govt-owned
- Independent Power Producer
- Commercial / Industrial
- Cooperative
- Investor-owned Utility
- Utility

Power capacity (MW)

Storage capability (MWh)

- PJM
- CAISO
- ERCOT
- MISO
- ISO-NE
- NYISO
- AK/HI
- Other

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BESS CAPACITY / STORAGE CAPABILITY BY REGION: 2019

Source: EIA, Battery Storage in the United States: An Update on Market Trends, Aug 2021; p. 7
LARGE-SCALE BESS CAPACITY / STORAGE CAPABILITY BY REGION: 2010 – 2019

Source: EIA, Battery Storage in the United States: An Update on Market Trends, Aug 2021; p. 8
PJM & CAISO BESS CAPACITY / STORAGE CAPABILITY: 2019

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

PJM

302 MW
190 MWh

CAISO

201 MW
617 MWh
REST OF US BESS CAPACITY / STORAGE CAPABILITY: 2019

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

rest of US

MW

hours

0 100 200 300 400 500 550

NYISO MISO ISO-NE AK/HI other

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

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

**power capacity (MW)**

**storage capability (MWh)**

<table>
<thead>
<tr>
<th>Annual Additions</th>
<th>Cumulative Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li-ion</td>
<td>Ni-based</td>
</tr>
<tr>
<td>Na-based</td>
<td>Flow</td>
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<tr>
<td>Other</td>
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<tr>
<td>Other</td>
<td></td>
</tr>
</tbody>
</table>
US BESS REGIONAL DEPLOYMENT BY CAPACITY / STORAGE CAPABILITY: 2019

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

- **power capacity (MW)**
  - installed capacity
  - frequency regulation
  - ramping/spinning reserve
  - voltage/reactive power support
  - load following
  - arbitrage
  - system peak shaving
  - load management
  - wind/solar energy storage
  - backup power
  - co-located renewable firming
  - transmission/distribution deferral

- **storage capability (MWh)**
  - ISO-NE
  - other CA
  - PJM
  - AK/HI
  - ERCOT
  - CAISO
  - other
  - NYISO

- **Regional Deployment by Capacity/Storage Capability**
  - PJM
  - CAISO
  - ERCOT
  - ISO-NE
  - AK/HI
  - NYISO
  - Other

- **Axes**
  - 0
  - 500
  - 1,000
  - 0
  - 350
  - 1,050
  - 1,750

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

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

<table>
<thead>
<tr>
<th>Sample characteristics</th>
<th>Duration in h</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>short (0.5)</td>
<td>medium (0.5 – 2)</td>
<td>longer (&gt; 2)</td>
<td></td>
</tr>
<tr>
<td>Number of BESS with reported costs</td>
<td>24</td>
<td>52</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Average nameplate power capacity (MW)</td>
<td>12.4</td>
<td>6.4</td>
<td>4.7</td>
<td></td>
</tr>
<tr>
<td>Average nameplate storage capability (MWh)</td>
<td>4.7</td>
<td>6.6</td>
<td>21.2</td>
<td></td>
</tr>
<tr>
<td>Average nameplate duration (h)</td>
<td>0.4</td>
<td>1.2</td>
<td>4.6</td>
<td></td>
</tr>
<tr>
<td>Capacity-weighted $ per unit capacity ($/kW)</td>
<td>872</td>
<td>1,224</td>
<td>2,575</td>
<td></td>
</tr>
<tr>
<td>Capacity-weighted $ per unit capability ($/kWh)</td>
<td>2,329</td>
<td>1,178</td>
<td>575</td>
<td></td>
</tr>
</tbody>
</table>

Sample characteristics include:
- Number of BESS with reported costs
- Average nameplate power capacity (MW)
- Average nameplate storage capability (MWh)
- Average nameplate duration (h)
- Capacity-weighted $ per unit capacity ($/kW)
- Capacity-weighted $ per unit capability ($/kWh)

Note: The data is sourced from EIA, Battery Storage in the United States: An Update on Market Trends, Aug 2021; p. 16.
BESS CAPACITY INSTALLATION COSTS BY DURATION: 2013 – 2019

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

Capacity costs ($/MW)

<table>
<thead>
<tr>
<th></th>
<th>shorter</th>
<th>medium-duration</th>
<th>longer</th>
<th>all</th>
</tr>
</thead>
<tbody>
<tr>
<td>75th percentile</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>capacity-weighted average</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>median</td>
<td></td>
<td></td>
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<tr>
<td>25th percentile</td>
<td></td>
<td></td>
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</table>

Capacity costs range from 0 to 3,500 $/MW, with shorter duration having the lowest costs and all duration having the highest costs.

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

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

75th percentile

energy capacity costs ($/MWh)

25th percentile

median

capacity-weighted average

shorter

medium-duration

longer

all

3,500
3,000
2,500
2,000
1,500
1,000
500
0

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BESS GENERATION AND USAGE FACTOR BY REGION: 2019

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

gross generation (MWh) usage factor %

<table>
<thead>
<tr>
<th>Region</th>
<th>Gross Generation (MWh)</th>
<th>Usage Factor %</th>
</tr>
</thead>
<tbody>
<tr>
<td>PJM</td>
<td>200,000</td>
<td>9</td>
</tr>
<tr>
<td>CAISO</td>
<td>100,000</td>
<td>6</td>
</tr>
<tr>
<td>ERCOT</td>
<td>50,000</td>
<td>4</td>
</tr>
<tr>
<td>ISO-NE</td>
<td>20,000</td>
<td>3</td>
</tr>
<tr>
<td>NYISO</td>
<td>10,000</td>
<td>2</td>
</tr>
<tr>
<td>MISO</td>
<td>5,000</td>
<td>1</td>
</tr>
<tr>
<td>Arizona</td>
<td>3,000</td>
<td></td>
</tr>
<tr>
<td>Florida</td>
<td>2,000</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>1,000</td>
<td></td>
</tr>
</tbody>
</table>

U.S. average usage factor %: 6

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CALIFORNIA STORAGE STATUS: 2019

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

share of small-scale battery storage capacity

small-scale battery storage

large-scale storage

residential  commercial  industrial  grid-connected

MW

0  400  800  1,000
ANNUAL AND COMPREHENSIVE BESS CAPACITY: 2015 – 2020

Source: EIA, Battery Storage in the United States: An Update on Market Trends, Aug 2021; p. 28
BESS & CO–LOCATED BESS CAPACITY ADDED BY REGION: 2003 - 2020

LARGE-SCALE CO-LOCATED BESS BY REGION: 2020

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

CAISO
ERCOT
NYISO
ISO-NE
PJM
SPP
MISO
other

co-located solar
co-located wind
co-located BESS
co-located fossil fuel

0
1,000
2,000 MW

MW
HYDRO PUMPED STORAGE ADDITIONS AND CUMULATIVE CAPACITY: 1960 – 2019

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

additions (GW) vs. cumulative capacity (GW)

- Before 1960
- 1960s
- 1970s
- 1980s
- 1990s
- 2000s
- 2010-2019

Source: EIA, Battery Storage in the United States: An Update on Market Trends, Aug 2021; p. 35
INSTALLED HYDRO PUMPED STORAGE AND BESS CAPACITY 2019

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

hydro pumped storage

large-scale BESS
US OPERATIONAL PUMPED STORAGE CAPACITY

Source: EIA October 31, 2019; available at https://www.eia.gov/todayinenergy/detail.php?id=41833
BARRIERS TO LARGE–SCALE STORAGE DEPLOYMENT

• The pace of energy storage deployment has been very slow in the past, mainly due to the extremely high costs of storage.

• The reductions in storage costs over the past decade have remained inadequate to stimulate the large–scale deployment of ESRs.

• The high costs of storage present a chicken and egg problem: costs remain high due to low demand and the high costs impede any growth in demand.
CALIFORNIA

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

38 million people

electricity consumption is about 8% of US total

Source: http://www.usamaps2015.xyz/california-map/
CALIFORNIA PUSH FOR STORAGE DEPLOYMENT

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

- The CPUC mandate to deploy 1,325 MW of cost-effective energy storage by 2020 in California constitutes a big push for the global storage sector.
CALIFORNIA PUSH FOR STORAGE DEPLOYMENT

The CPUC energy storage requirements arise from the 2010 Assembly Bill 2514 (AB 2514).

AB 2514 requires the CPUC to “open a proceeding to determine appropriate targets, if any, for each load-serving entity to procure viable and cost-effective energy storage systems and, by October 1, 2013, to adopt an energy storage system procurement 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 (IOUs) by 2024.

- The CPUC Decision provided the framework with whose specifications the procurement and deployment of storage projects must comply.
THE CPUC STORAGE PROCUREMENT FRAMEWORK SPECIFICATIONS

- Storage capacity targets for each of the 3 major California IOUs
- 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
Allowed deviations to meet the *CPUC* targets by:

- shifting targets among grid interconnection points
- ownership of storage resources by *IOUs*, customers and third parties
- deferral of *IOU* targets in the *CPUC*-specified schedule
The CPUC Decision is a harbinger of regulatory initiatives in the large-scale grid-connected storage domain that signals the realization by the government of the significant role storage plays to further the smart grid implementation.

The CPUC pumped-hydro-capacity constraint became a key driver to spur BESS advances and reduce the drought-ridden CA reliance on hydro.
OPPORTUNITIES FOR LARGE-SCALE ESRs

- The *CPUC Decision* has paved the way for new opportunities in the storage sector.

- The need for storage to meet the *CPUC* mandate created a strong push in the storage market and considerably weakened the reluctance to invest in the storage sector.

- A key example is the new *TESLA Gigafactory*, the large-scale *NV* plant in to manufacture storage batteries for commercial and residential uses.
CONCLUDING REMARKS

❑ In the development of sustainable paths to meet future energy needs, renewable resources must play a key role and storage is, by far, the most promising option to enable such paths

❑ The CA mandate provided the appropriate stimulus to jump start grid–connected storage deployment and to further reduce storage prices

❑ There remain daunting challenges at many levels – from science to engineering to policy – to effectively implement ESR deployment in the grid
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.