The US Energy Storage Market: Present and Future

Andrei Levin

Harvard Energy Journal Club, 3/30/18

"Lashing out the action, returning the reaction
Weak are ripped and torn away
Hypnotizing power, crushing all that cower
Battery is here to stay"

-- **Metallica**, *Battery*

Outline

(1) The Electric Grid

- Generation, Transmission, Distribution
- Electricity Markets

(2) Energy Storage

- Technologies
- Market size, Projections

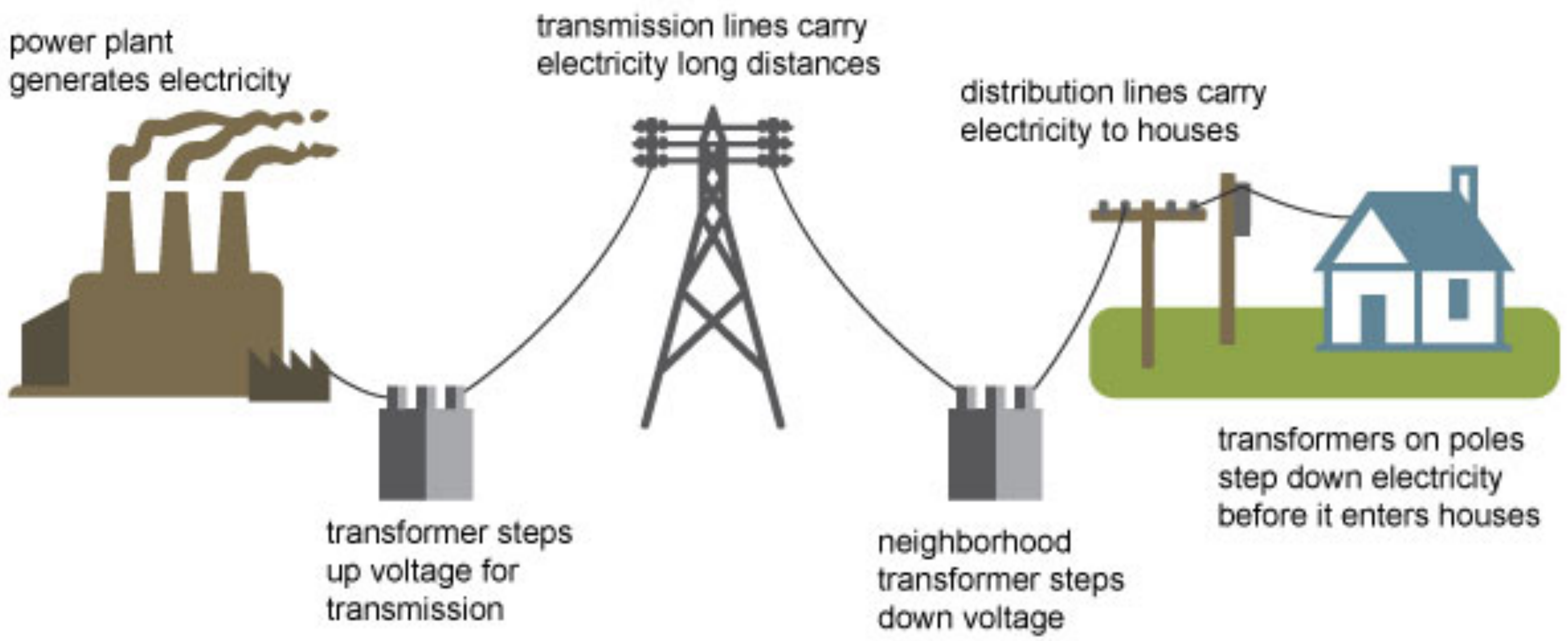
(3) Current Applications

- Backup power
- Demand charge reduction
- Frequency regulation

(4) Emerging Applications

- T&D upgrade deferral
- Time of use optimization
- On-site and distributed energy
- Peaking capacity
- Renewables integration

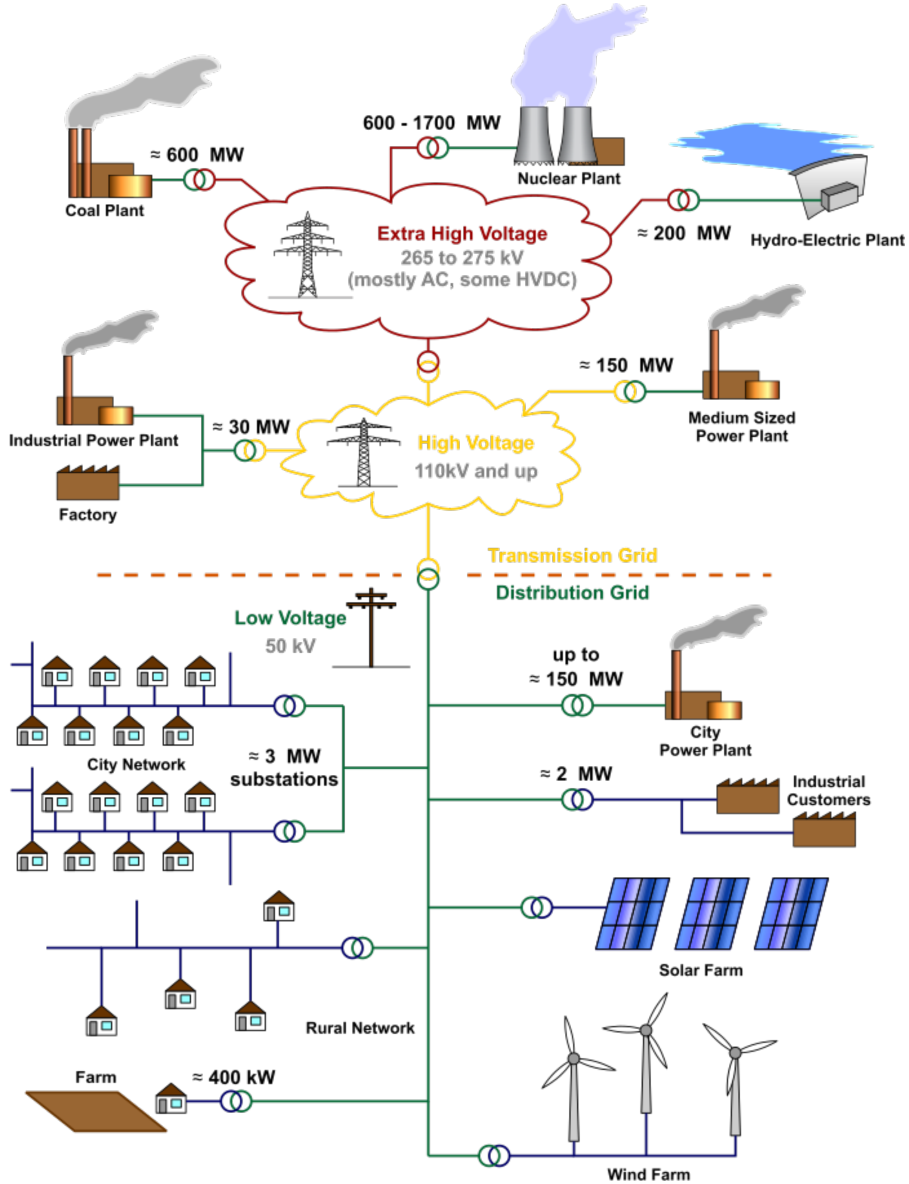
Grid 101: Generation, Transmission, Distribution



Source: Adapted from National Energy Education Development Project (public domain)

Source: National Energy Education Development Project

The Distribution Grid is More Complicated



Source: Wikipedia

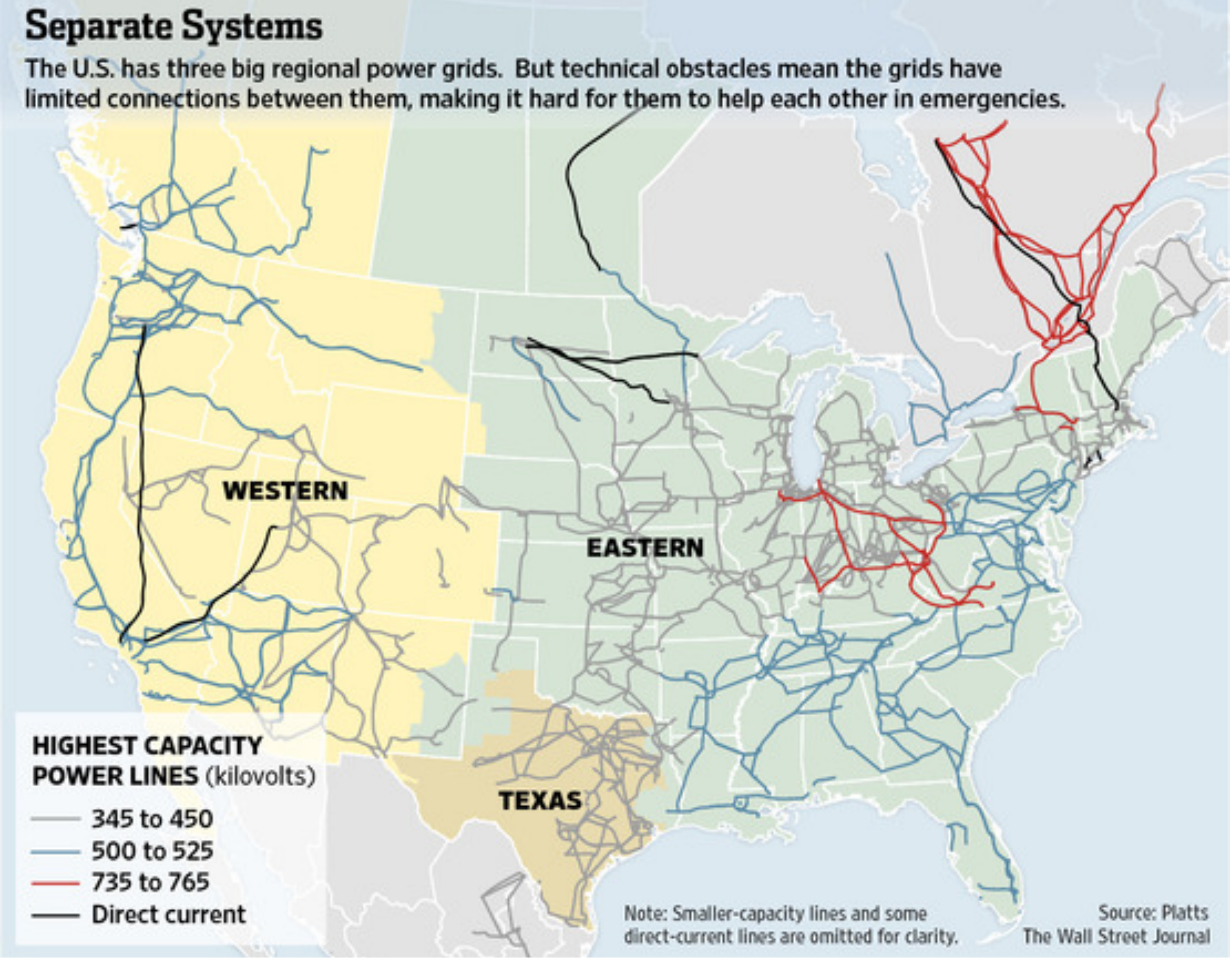
Public Utilities, Private Utilities, and IPPs

Q: Who owns the electric system?

A: The electric system, which includes generation, transmission, and distribution, is owned by a mix of entities. For example, 192 Investor-Owned Utilities (IOUs) account for a significant portion of net generation (38%), transmission (80%), and distribution (50%). About 2,900 publicly-owned utilities and cooperatives account for 15% of net generation, 12% of transmission, and nearly 50% of the nation's electric distribution lines. Approximately 2,800 independent power producers account for 40% of net generation. The Federal Government owns 9 power agencies (including 4 Power Marketing Administrations and TVA) with 7% of net generation and 8% of transmission.

Source: Energy.gov

The Transmission Grid



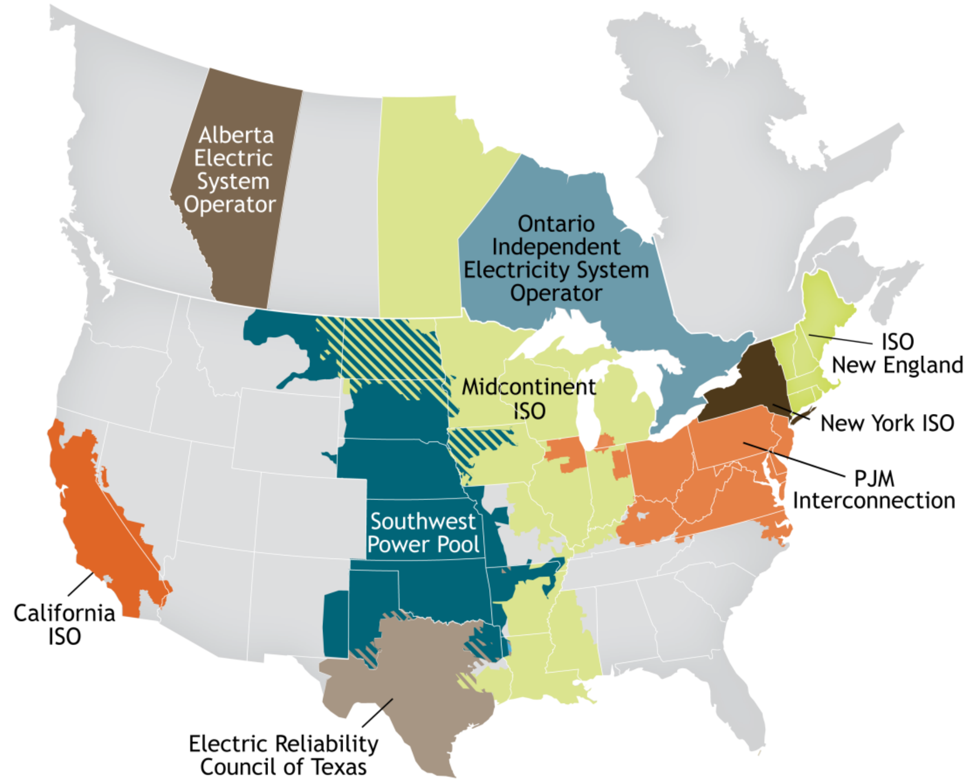
In Many Areas, ISOs and RTOs Run the Grid

- ISO: Independent System Operator
- RTO: Regional Transmission Organizations (… but they're basically the same thing)

ISOs/RTOs

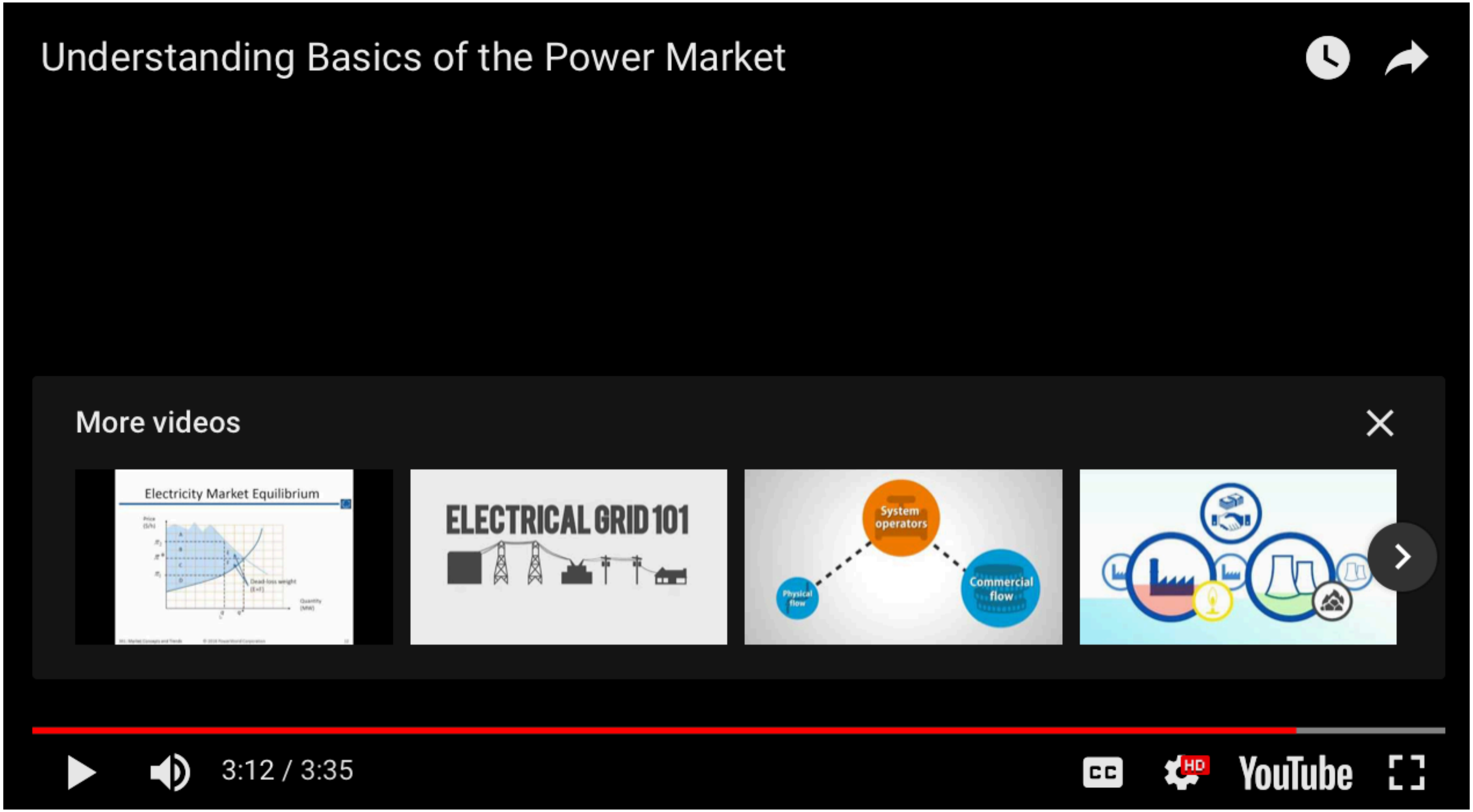
Within the three main interconnections in the United States lie regional entities called regional transmission organizations (RTOs) and independent system operators (ISOs). The formation of ISOs and RTOs comes at the direction or recommendation of the Federal Energy Regulatory Commission (FERC). The role of ISOs and RTOs are similar and may be confusing. Comparable to an RTO, ISOs either do not meet the minimum requirements specified by FERC to hold the designation of RTO or have not petitioned FERC for that status. In short, an ISO operates the region's electricity grid, administers the region's wholesale electricity markets, and provides reliability planning for the region's bulk electricity system. RTO's perform the same functions as the ISOs, but have greater responsibility for the transmission network as established by the FERC. The RTOs coordinate, control, and monitor the operation of the electric power system within their territory. They also monitor the operation of the region's transmission network by providing fair transmission access. ISOs/RTOs engage in regional planning to make sure the needs of the system are met with the appropriate infrastructure. Before ISOs/RTOs were developed, individual utilities were responsible for coordinating and developing transmission plans. Utilities in areas where there is no RTO or ISO continue to serve this function. As can be seen from the map below, there are large sections of the United States, particularly in the Southeast and the West, where there is no ISO or RTO. Electric utilities in these areas, however, are still subject to the same rules under FERC. The Electric Reliability Council of Texas (ERCOT) does not fall under interstate FERC authorities over interstate transmission and wholesale markets, but is still subject to NERC oversight and FERC regulation for reliability.

Source: energy.gov



Source: isorto.org

RTOs and ISOs Also Administer Power Markets

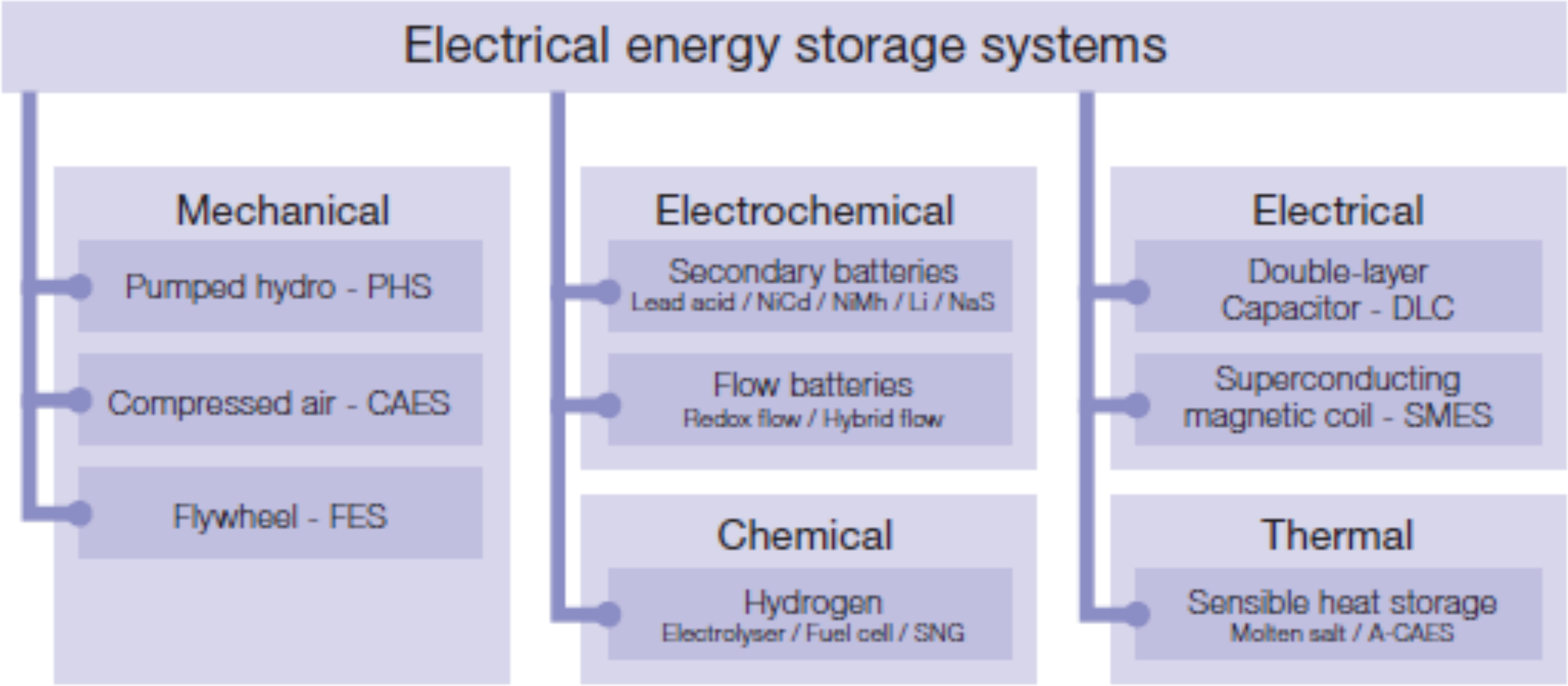


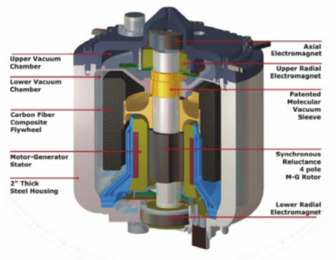
Power Markets

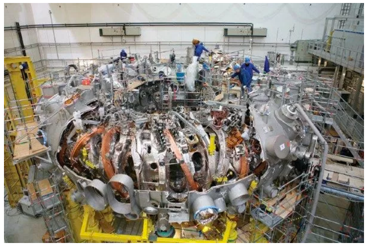
- Retail Electricity Market:
  - Gives customers some choice in generation (but not T&D)
  - Still don’t typically reflect real-time wholesale prices
- Wholesale Electricity Markets:
  - Day-Ahead (Financial)
  - Real-Time (Physical)

- Capacity Market:
  - Typically three years ahead
  - Facilitates long-term capital investment
- Ancillary Services Market:
  - Frequency regulation, Voltage control, Reserve capacity

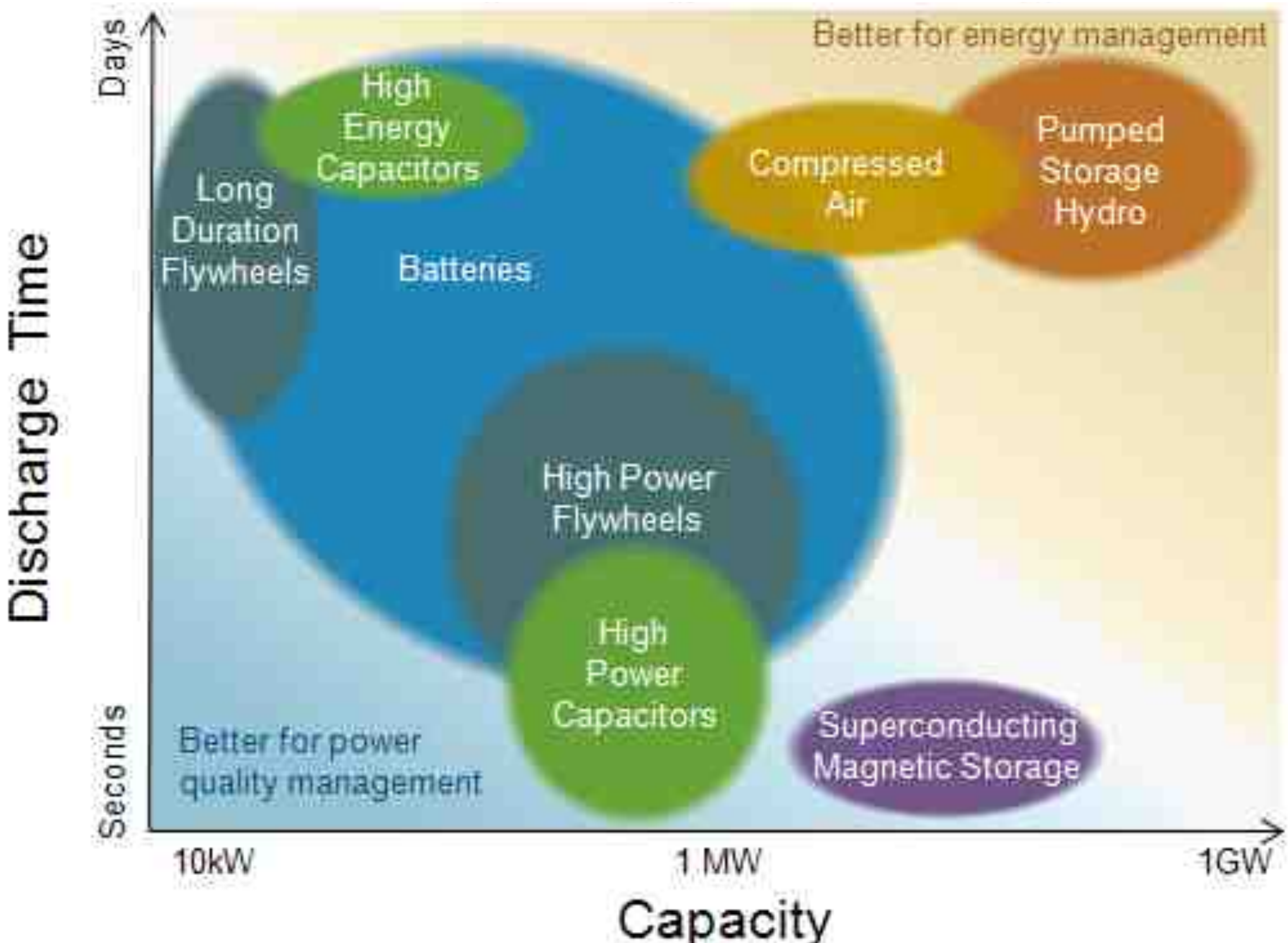
Energy Storage Technologies







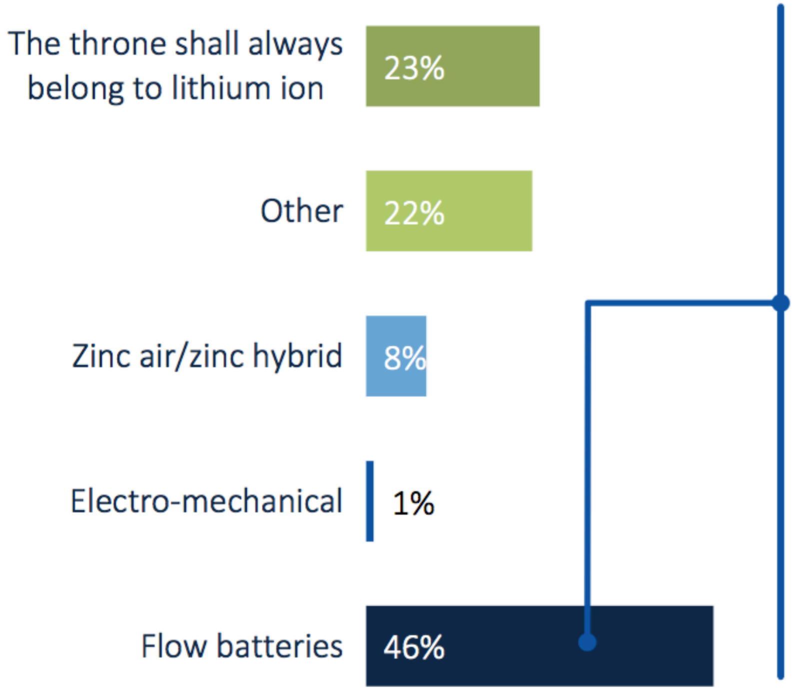
Energy Storage Technologies



Source: usgreentechnology.com

Grid-Scale Battery of the Future?

Question 3: What technology has the best chance of supplanting lithium-ion as the dominant utility-scale advanced storage technology?

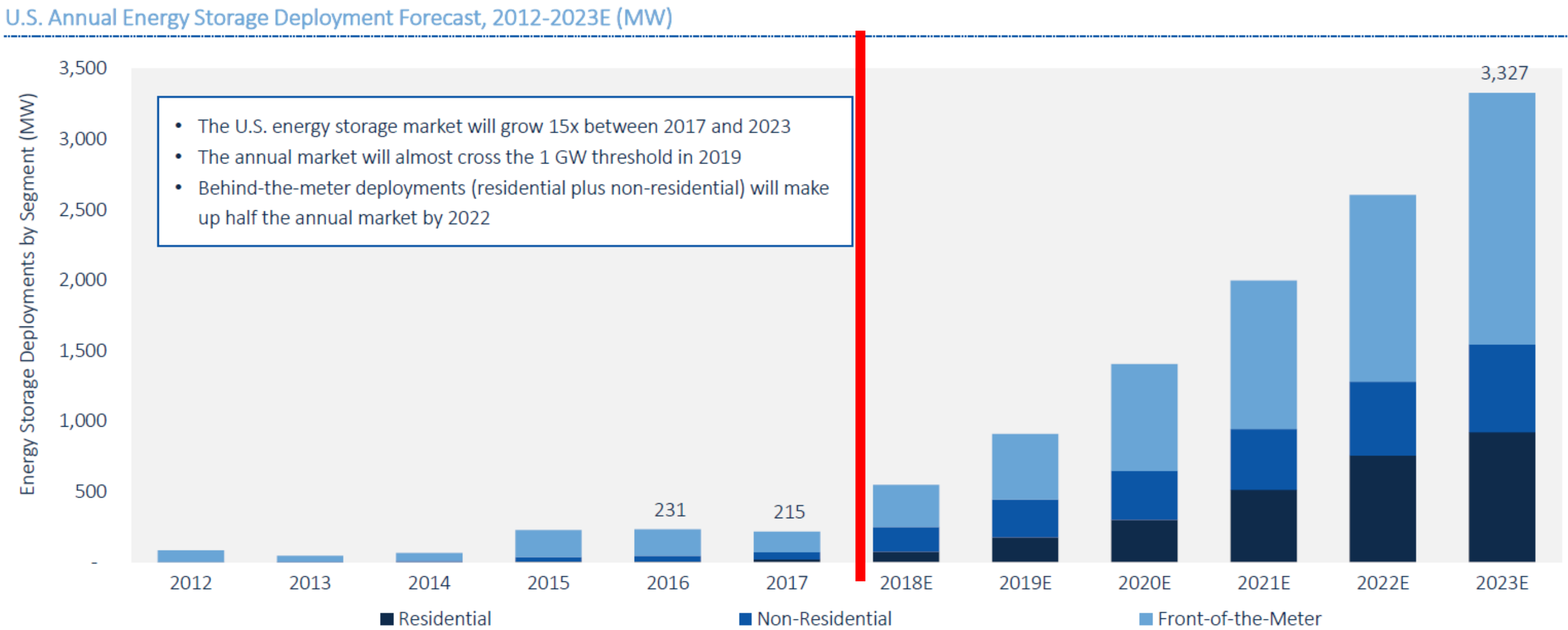


Flow batteries draw the most optimism, with nearly half of attendees citing them as the most exciting technology for utility-scale applications. As system durations continue to grow flow battery manufacturers are increasingly bullish on their pricing, claiming the high ground for 6-hour or longer duration and even eyeing the coveted 4-hour mark.

Source: Greentech Media's Energy Storage Summit, Audience Participation Poll

Source: greentechmedia.com

The Energy Storage Market

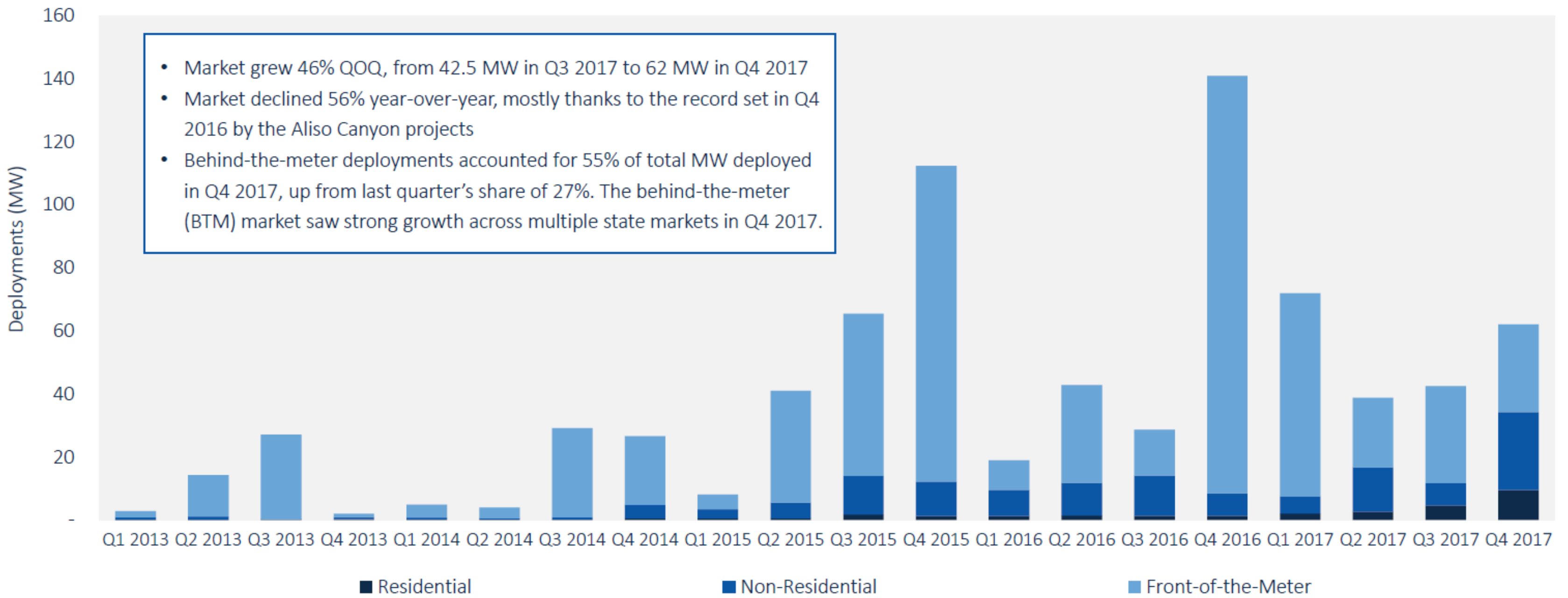


As of 2018:

- ~0.7 GW storage deployment
- ~53 GW solar deployment
- ~1100 GW total electricity generation capacity

A Quarter-by-Quarter Look

U.S. Quarterly Energy Storage Deployments by Segment (MW)



Source: GTM Research

Regulations Matter!

Quirks of Energy Storage:

- Relatively new technology
- Both consumes and delivers power
- Can be deployed both in front and behind the meter
- Many services it can provide are not easily monetizable

Prior to the passage of several key regulatory measures, most electricity markets were not structured to allow effective participation by energy storage and other small, distributed energy resources.

There is currently no location in the U.S. where an energy storage system can realize its full economic potential for the multitude of services it is capable of providing.

-- Clean Energy Group, August 2015 Report

Value stacking is key!

FERC Order 841: A Watershed Moment?

NEWS RELEASE

February 15, 2018

News Media Contact

Craig Cano | 202-502-8680

Docket No. RM16-23

Item No. E-1

FERC Issues Final Rule on Electric Storage Participation in Regional Markets

The Federal Energy Regulatory Commission (FERC) today voted to remove barriers to the participation of electric storage resources in the capacity, energy and ancillary services markets operated by Regional Transmission Organizations and Independent System Operators. This order will enhance competition and promote greater efficiency in the nation's electric wholesale markets, and will help support the resilience of the bulk power system.

In a November 2016 Notice of Proposed Rulemaking (NOPR), the Commission noted that market rules designed for traditional generation resources can create barriers to entry for emerging technologies such as electric storage resources. Today's final rule helps remove these barriers by requiring each regional grid operator to revise its tariff to establish a participation model for electric storage resources that consist of market rules that properly recognize the physical and operational characteristics of electric storage resources.

The participation model must ensure that a resource using the model is eligible to provide all capacity, energy and ancillary services that it is technically capable of providing, can be dispatched, and can set the wholesale market clearing price as both a seller and buyer consistent with existing market rules. The model also must account for the physical and operational characteristics of electric storage resources through bidding parameters or other means, and it must set a minimum size requirement that does not exceed 100 kilowatts. The final rule also requires that the sale of electric energy from the wholesale electricity market to an electric storage resource that the resource then resells back to those markets must be at the wholesale locational marginal price.

Source: ferc.gov

Current Application #1: Backup Power

$5,900	**1 Powerwall**
$700	Supporting hardware
$6,600	Total equipment cost

DuroStar
DuroStar DS4000S, 3300 Running Watts/4000 Starting Watts, Gas Powered Portable Generator
569 customer reviews
| 257 answered questions
Amazon's Choice for "backup generator"

List Price: ~~$399.99~~
Price: $269.00 FREE Shipping for Prime members
Details
You Save: $130.99 (33%)

In Stock.
Want it Thursday, March 29? Order within **10 hrs 52 mins** and choose **Standard Shipping** at checkout.
Details
Ships from and sold by Amazon.com.
Eligible for amazonsmile donation.

APC
APC 1500VA Compact UPS Battery Backup & Surge Protector, Back-UPS Pro (BX1500M)
180 customer reviews
| 85 answered questions

List Price: ~~$169.99~~
Price: $151.75 prime
You Save: $18.24 (11%)

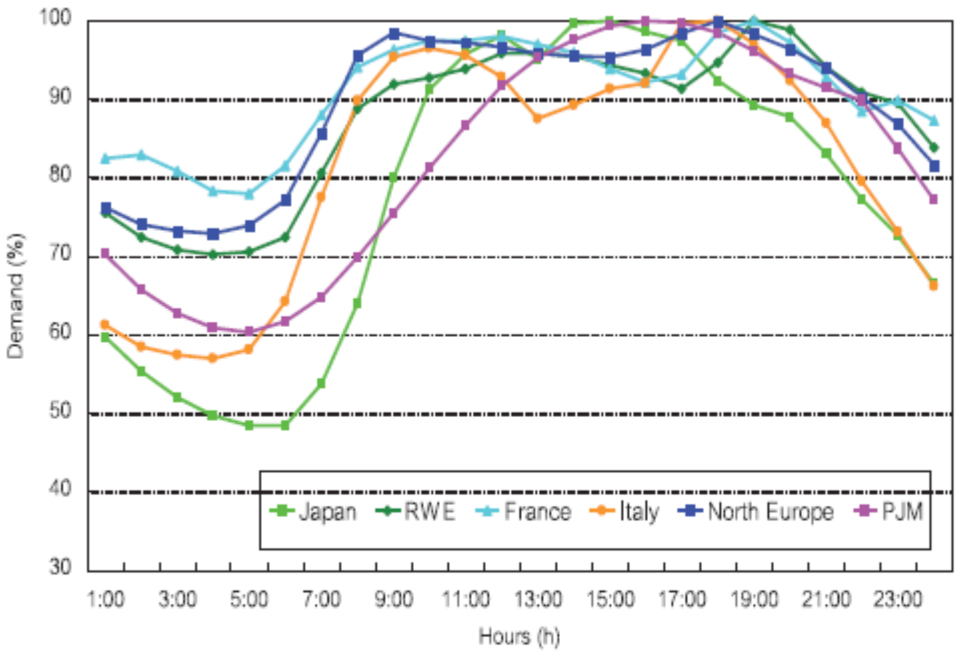
In Stock.
Want it Friday, March 23? Order within **13 hrs 45 mins** and choose **One-Day Shipping** at checkout. Details
Ships from and sold by Amazon.com. Gift-wrap available.
Eligible for amazonsmile donation.

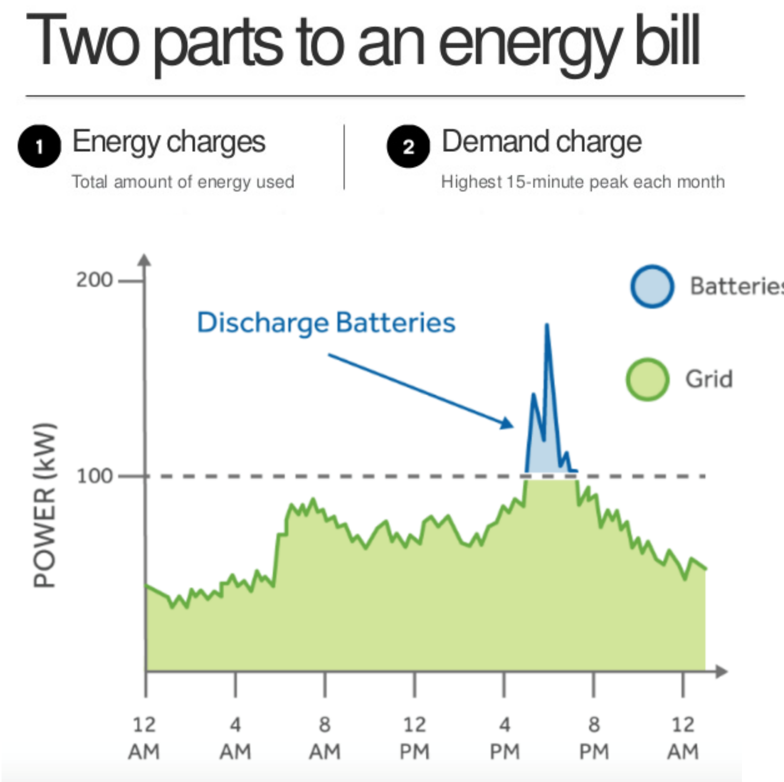
Size: **1500VA / 900W**

850VA / 510W $109.99 prime	1000VA / 600W $119.99 prime
1350VA / 810W $139.99 prime	**1500VA / 900W $151.75** prime

- Currently makes up most of **residential market**
- But… fuel generators are cheaper and longer duration
- In residential market, daily-use applications more promising

Current Application #2: Demand Charge Reduction





- Also known as "peak shaving"
- Currently makes up most of **commercial market**
- Mostly deployed in CA due to SGIP program subsidies

Example

Battery-Storage System Size (capacity in kW)	55kW
Total System Cost with Installation	$100,000
SGIP Rebate	$60,000
Net System Cost after Rebate	$40,000
Annual Utility Bill Savings from Demand Charge Reduction	$8,000
Payback on Initial Investment (assuming no Utility Demand Charge Escalator)	5 years

Source: cenergypower.com

Current Application #3: Frequency Regulation

Currently makes up most of **utility market**

- Grid frequency must be kept at 60 Hz
- Supply/Demand mismatch causes deviations:
  - Demand > Supply → Frequency decreases
  - Demand < Supply → Frequency increases

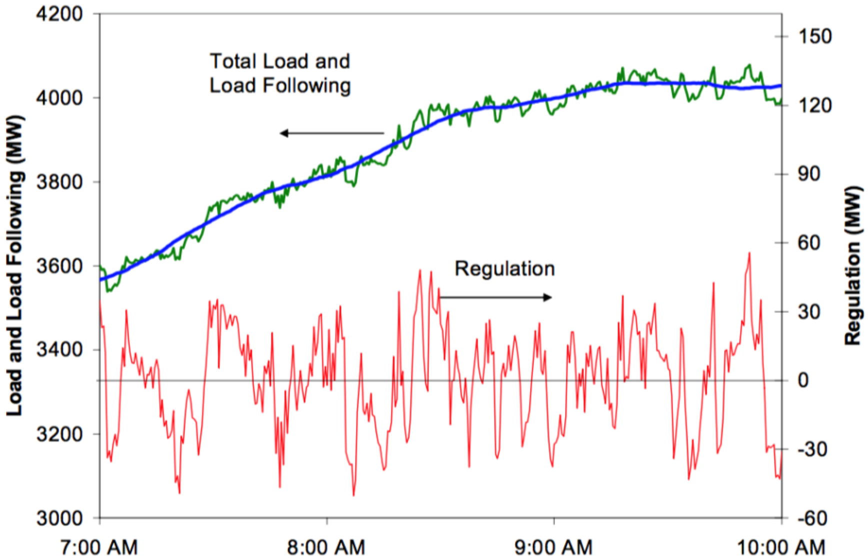


***Figure 1:** Illustration of Frequency Regulation*

Batteries have fast response
But limited duration

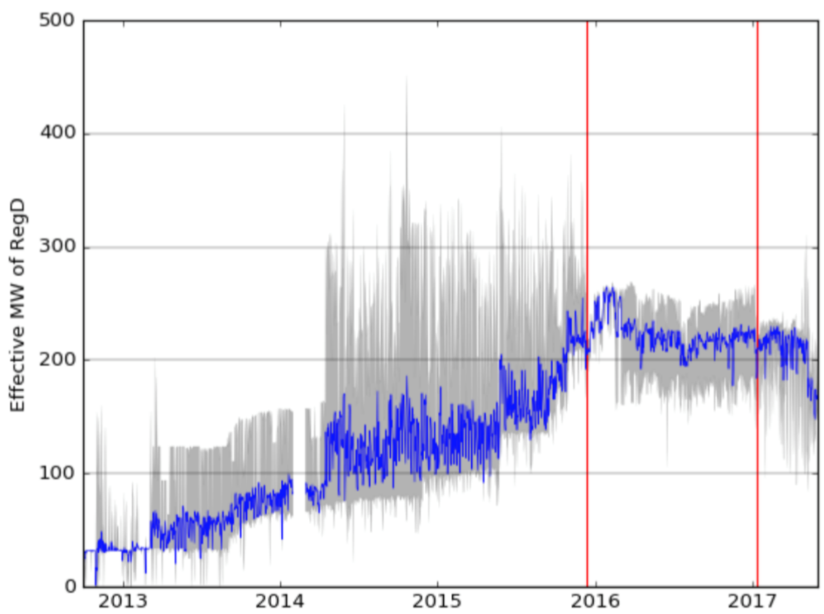
Ancillary Services	
Frequency regulation	Balancing of electricity supply and demand to keep frequency within operational bounds. Includes services for responding to both increases and decreases in system frequency.
Spinning reserve	Generation capacity that is connected to the power system but not generating electricity until needed, with the ability to respond immediately, within 10 minutes.
Non-spinning reserve	Generation capacity that is not connected to the system but can be brought online after a brief delay.
Voltage control	Similar to frequency regulation but using reactive power to maintain proper transmission system voltage.
Black start	Ability to restore power to part of the grid after failure occurs.

Case Study: Frequency Regulation in PJM

2011: FERC Order 755 establishes pay-for-performance guidelines
(quicker responding resources should get paid more)
2012: PJM Introduces new rate structure that incentivizes storage

- FR signal is split into a slow-response (RegA) and fast-response(Reg-D) signals at different rates
- Only 100 kW minimum capacity
- 15 min average energy neutrality

<<Cost and reliability problems>>

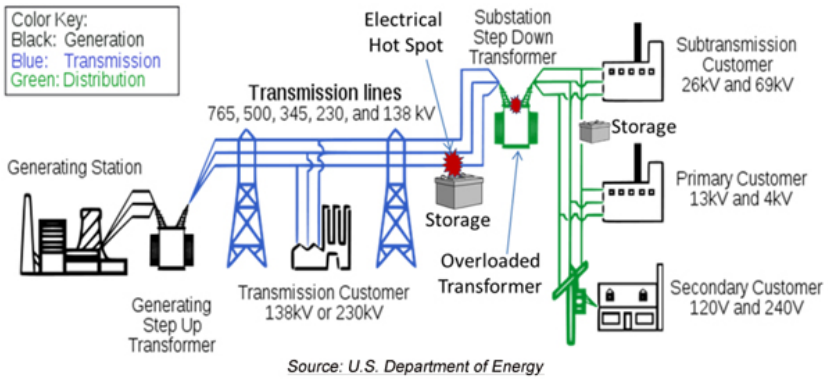


2015: PJM decreases RegD value
2017: PJM replaces neutrality with
"conditional neutrality"

<<Market for new FR dries up>>

Emerging Application #1: T&D Upgrade Deferral

- Storage strategically deployed at "hot spots" can reduce the load on congested T&D lines



- This can extend the life of existing equipment or defer the need to build new equipment to meet growing demand

Summary of T&D Challenges and ESS Benefits

T&D Challenges	ESS Benefits
Local community opposition	ESSs will have minimal impact on nearby property values, often installed at substation or existing grid facility.
Lengthy (multiyear) planning, permitting, and development process	Storage systems can be designed, built, and operational in under 6 months.
Uncertain load growth rates and demand patterns	ESS can be deployed in small modular capacity increments, avoiding oversizing and stranding assets.
Regulations across different jurisdictions	ESSs are deployed only in a single location, avoiding cross-border challenges.
Single use case of expanding grid capacity	When not needed for T&D deferral, ESS can generate revenue and grid operating cost savings by providing frequency regulation, voltage support, spinning reserves, and other services.

- Key advantage: flexibility

Source: Navigant research

Emerging Application #2: Time of Use Optimization

Residential and Commercial: Demand Response

- Financial incentives for reducing peak usage
- Voluntary or automatic control systems
- Requires dynamic rate structures

Grid-Scale: Energy Arbitrage

- Charge when prices low, discharge when prices high
- Problem: Round-trip efficiency losses

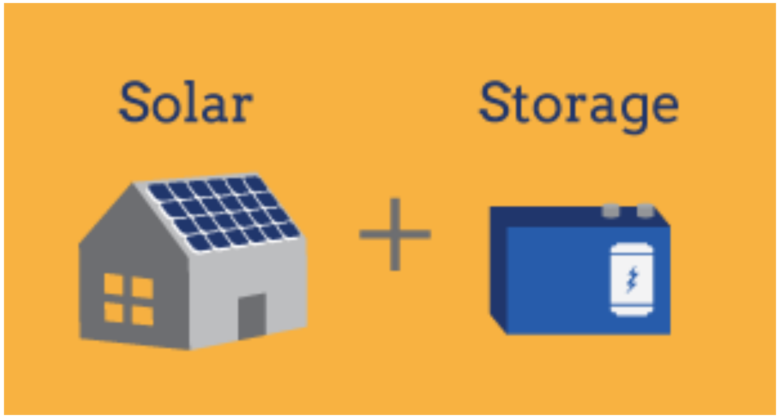
Battery Type	Efficiency (%)
Lithium-ion	95-98
Flow	65-75
Zinc-Air	70-75
Sodium Sulfur	70-75

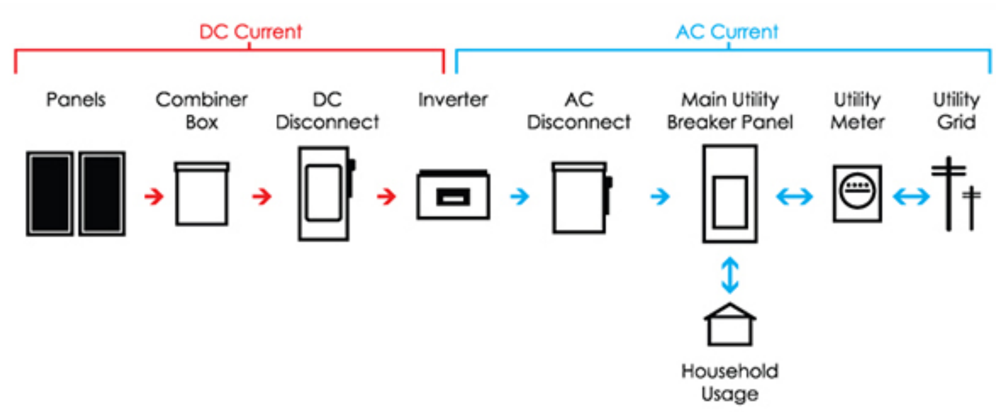
Source: energystorageconsultants.com

Emerging Application #3: On-Site and Distributed Energy

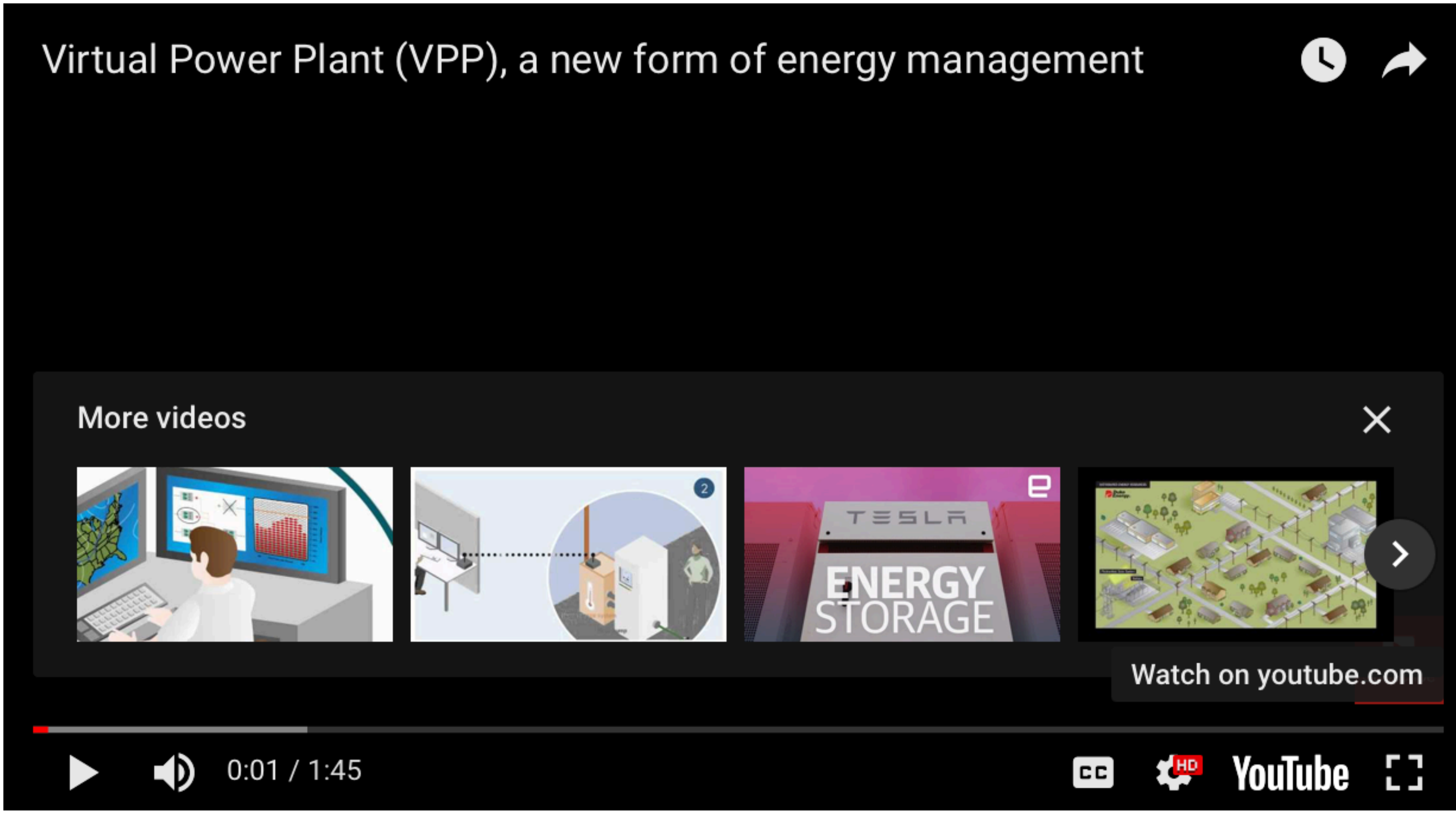
Assorted Thoughts:

- Over 1 million solar rooftop installations in the US
- Half of commercial & industrial solar installations include solar
- **Net Energy Metering** (rules allowing electricity to be sold back to the grid) could be an interesting wrench
- Utilities are concerned about partial grid defection spirals





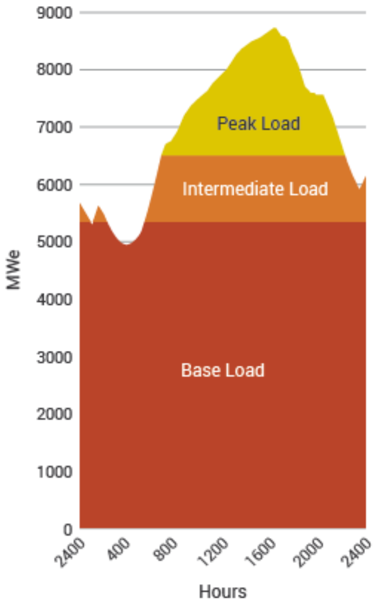
Virtual Power Plants



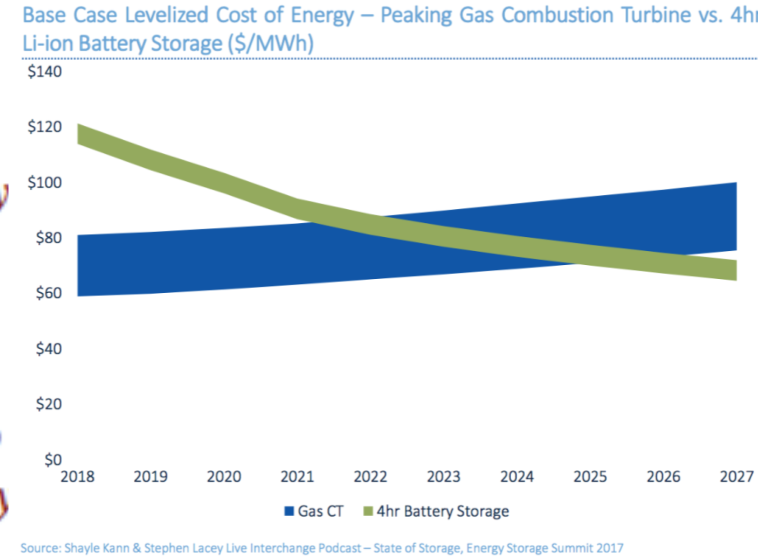
Prescott Valley Project, Arizona

- Solar plus Storage in 2900 homes
- 11.6 MW, 32 MWh
- Special deal with local utility: batteries will be used to help with load shifting and reducing peak use of grid energy
- Expected to lead to decommissioning of a coal peaker plant

Emerging Application #4: Peaking Capacity



Due to the lack of energy storage capacity available to grid operators, a delicate balance between electricity supply and consumer demand has historically been maintained almost exclusively by inefficiently ramping fossil-fuel generators up and down to meet fluctuations in electricity supply

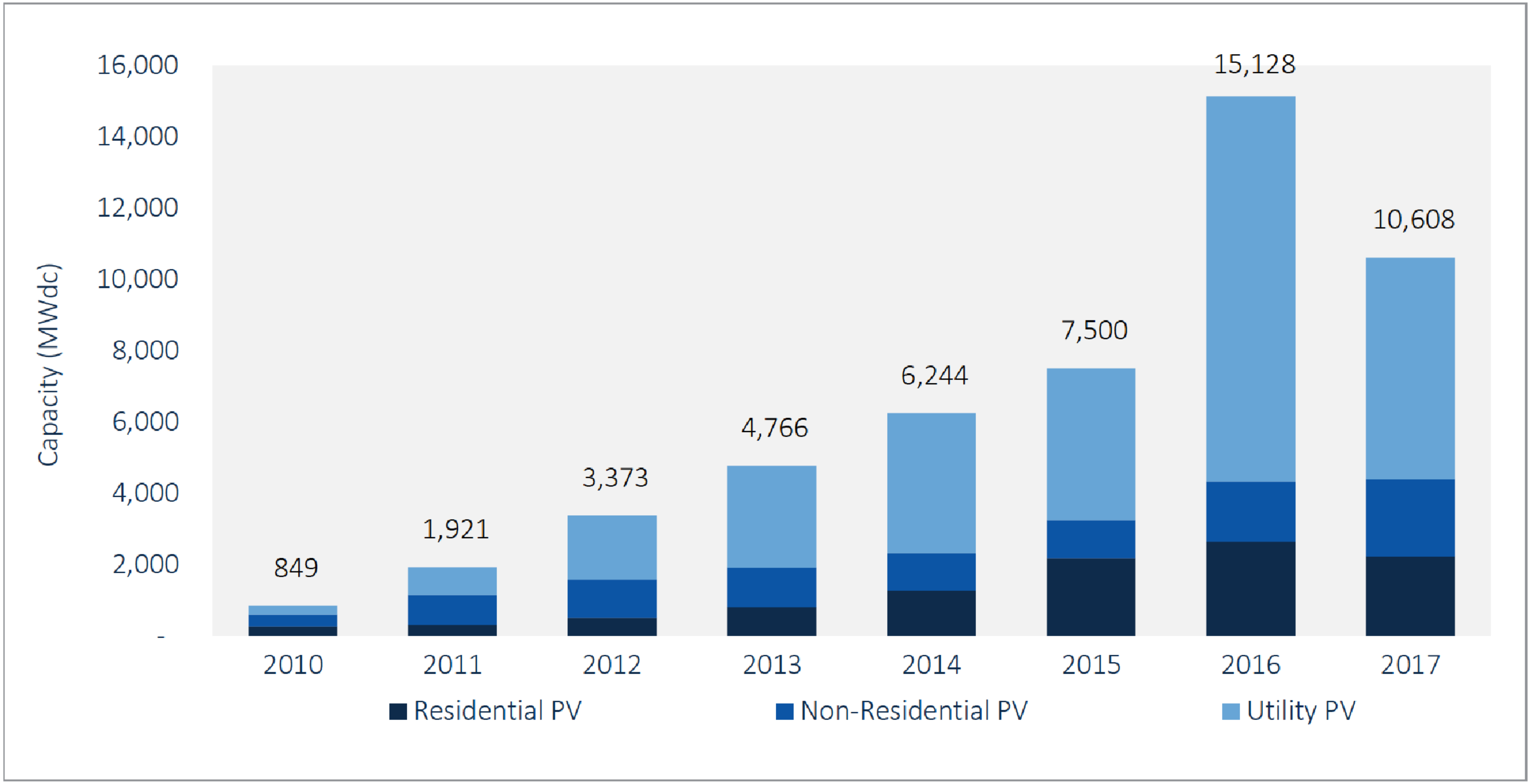


Example: Aliso Canyon Gas Leak

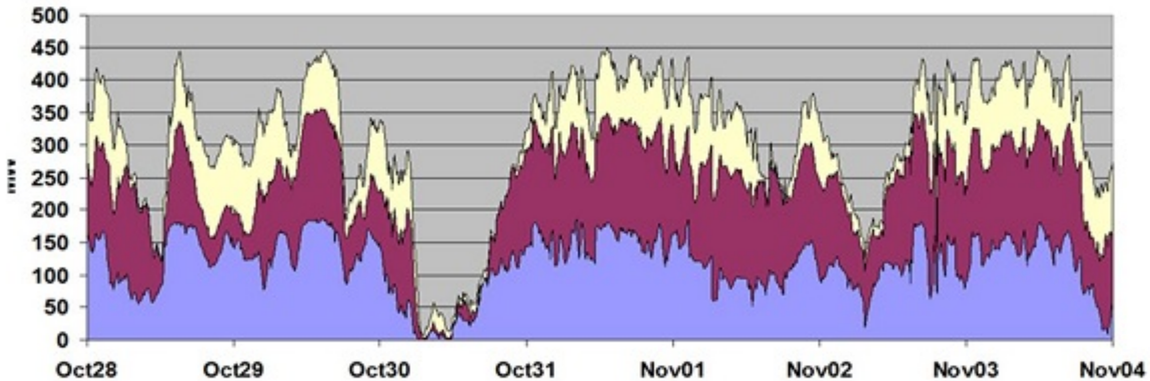
- Worst natural gas leak in US history
- Gas supply interruption to peaking plants
- Response: 100 MW of storage deployed in 6 months

Emerging Application #5: Renewables Integration

Figure 1.1 U.S. Annual PV Installations, 2010-2017

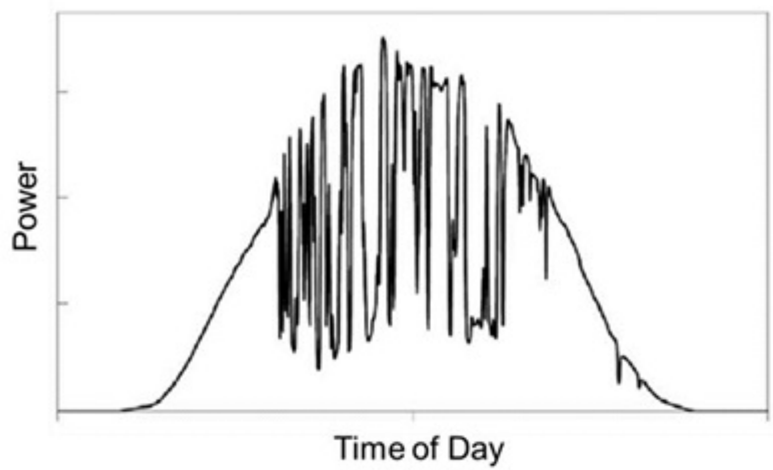


Intermittency of Wind and Solar



Source: E&I Consulting

Figure 1. Output from three adjacent wind farms over eight days.

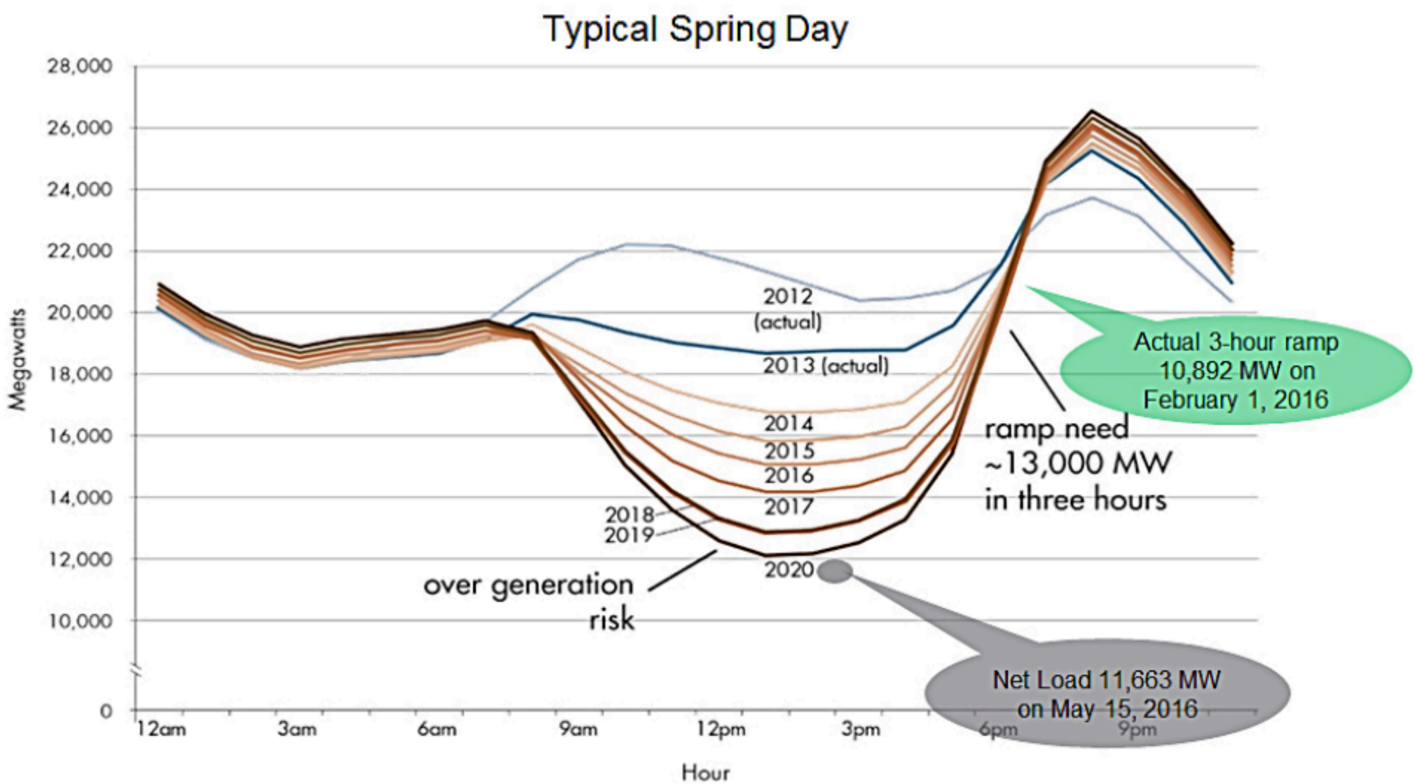


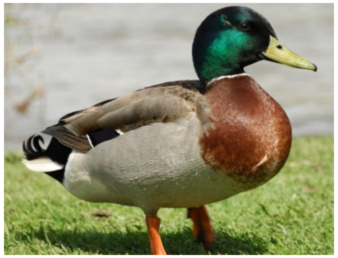
Source: E&I Consulting

Figure 2. Actual power output from photovoltaics in Texas during one summer day.

Challenges of Increased Renewable Generation

- Capacity smoothing
- Grid stability (especially managing frequency decline)
- Undesirable ramping and peaking (the "duck curve")





Source: caiso.gov

Solar First Hurts, Then Helps Storage

The Potential for Energy Storage to Provide Peaking Capacity in California under Increased Penetration of Solar Photovoltaics

Paul Denholm and Robert Margolis
National Renewable Energy Laboratory

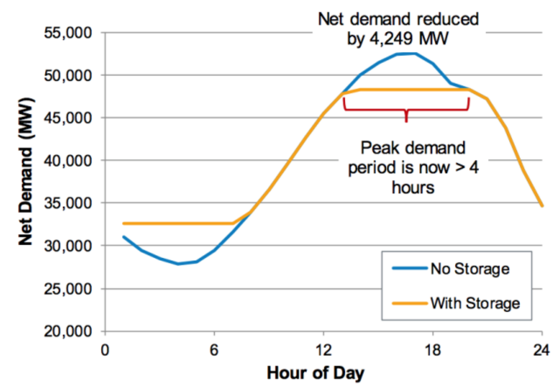


Figure 3. Impact of 4-hour storage dispatch on net load on the peak demand day in 2011

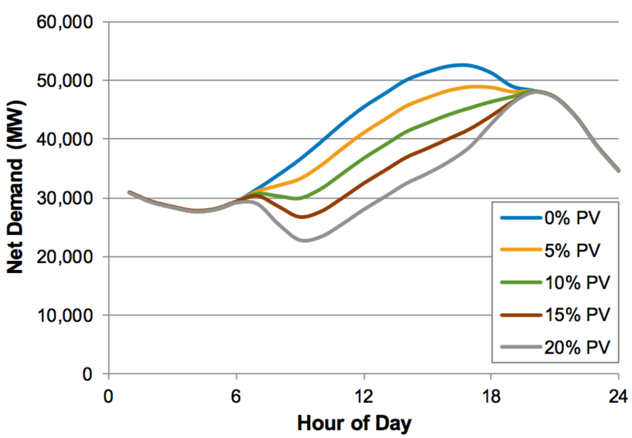


Figure 10. Change in California net load shape due to PV

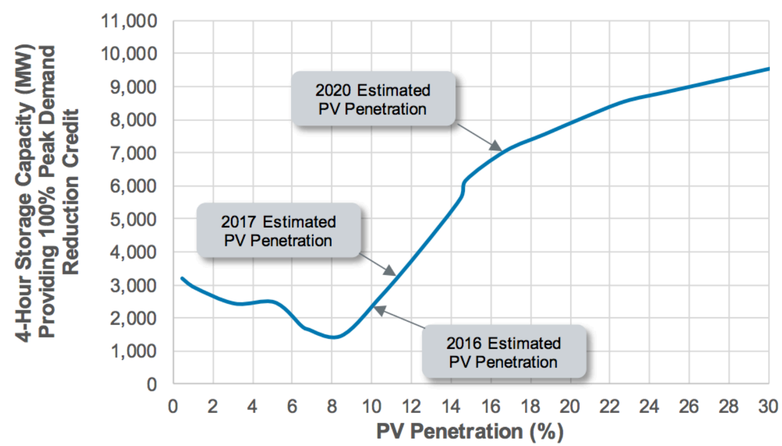
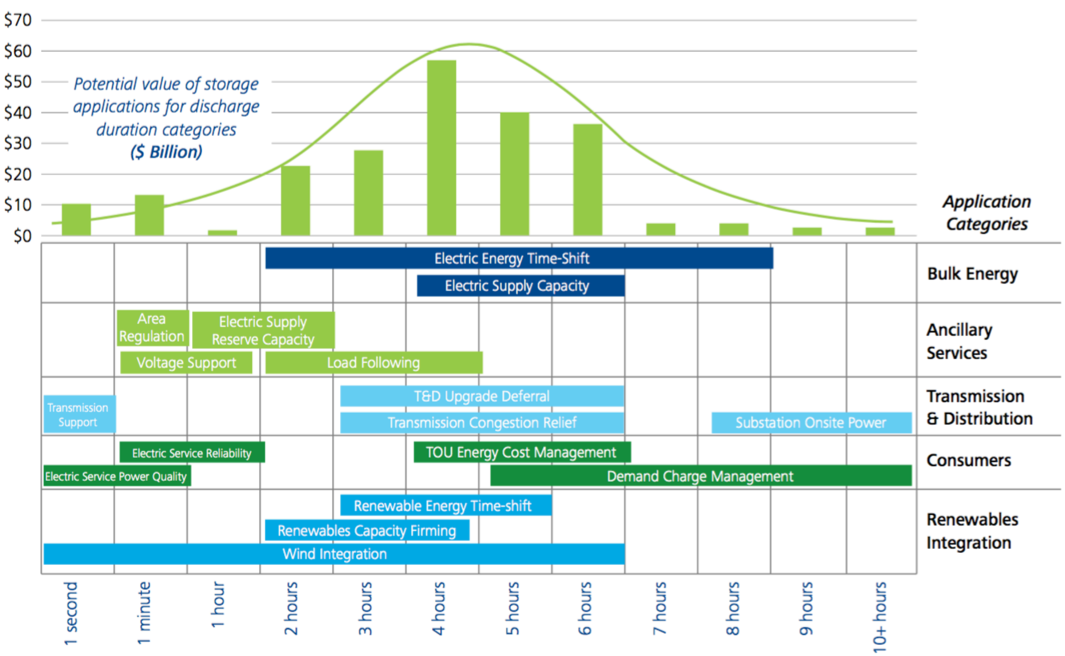


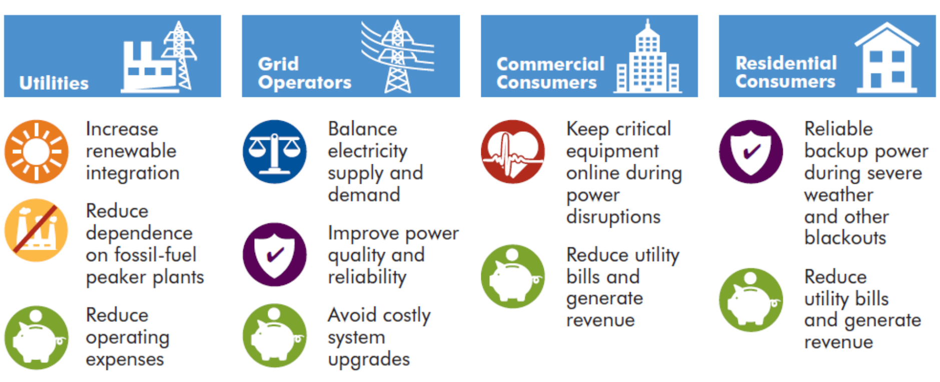
Figure 13. Threshold values for 100% peak demand reduction credit for 4-hour energy storage in 2020 (assuming a peak demand of 54 GW)

Discussion

Figure 2. Energy storage applications and corresponding value for various discharge durations[9]

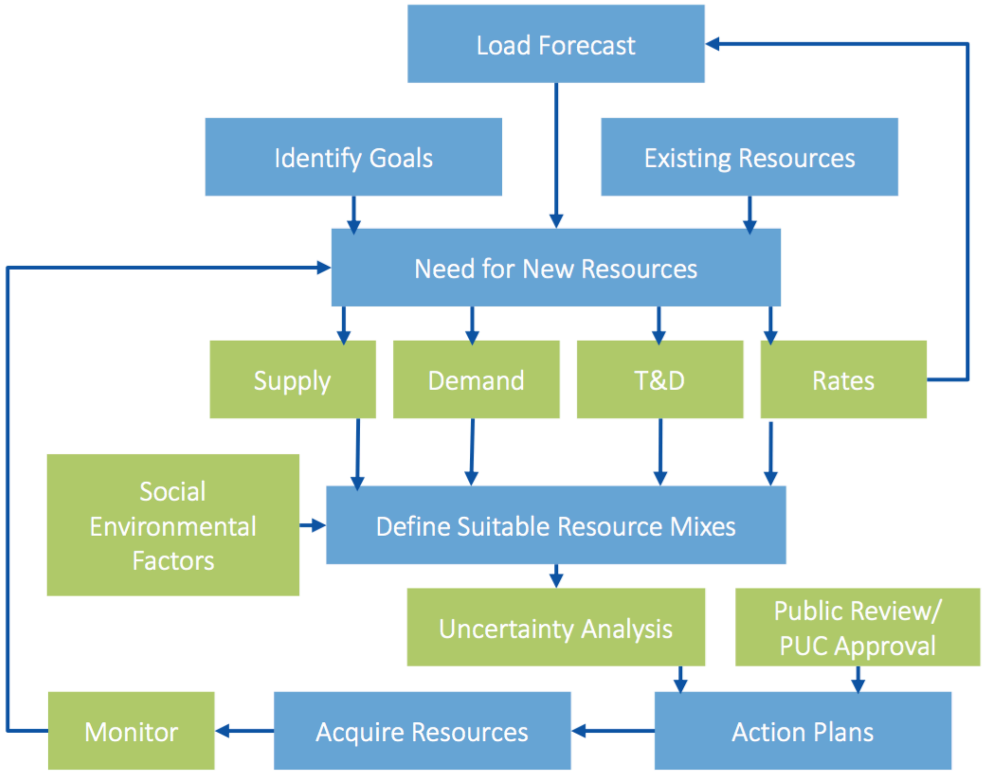


Energy storage technologies have the capacity to benefit each segment of the power system.



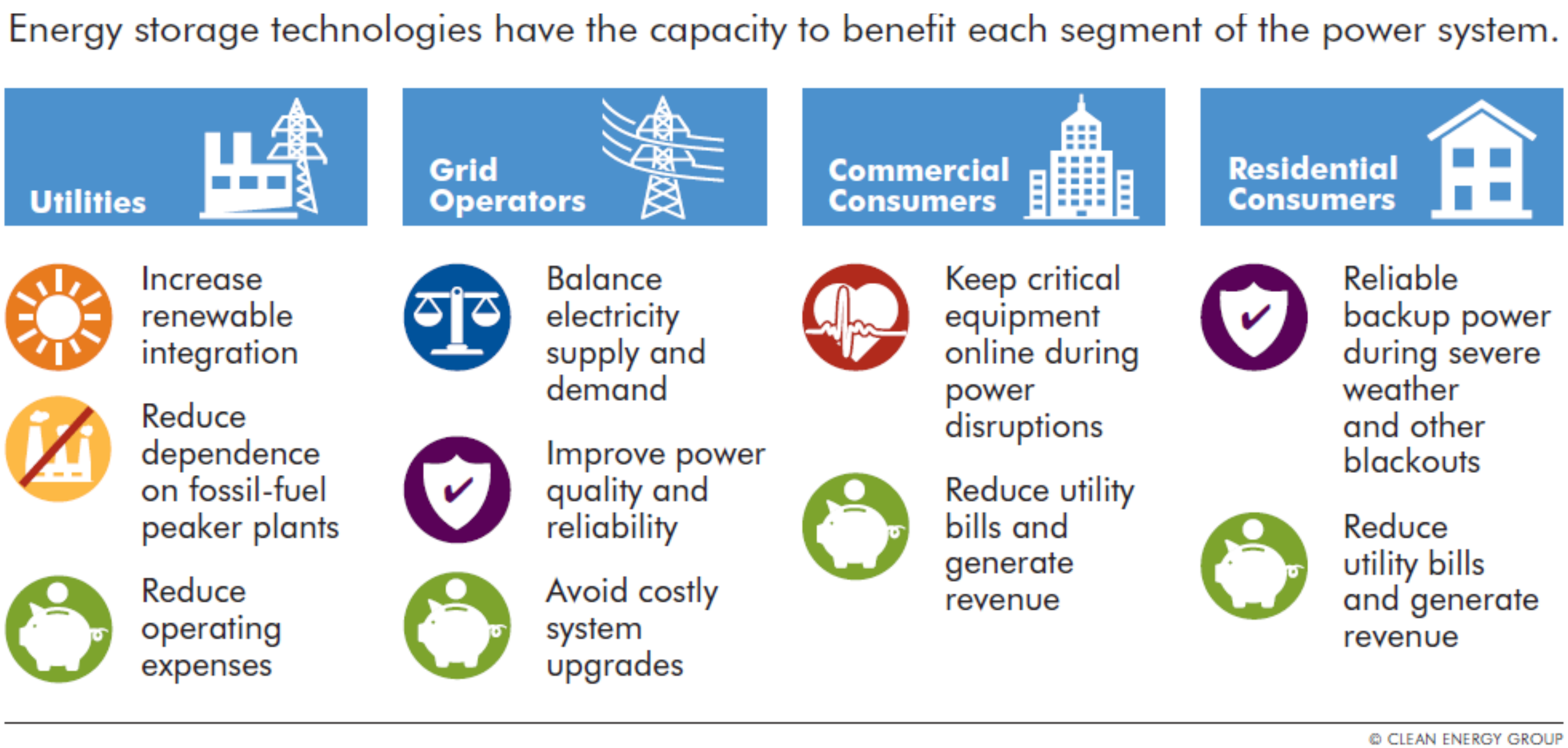
Supplementary

Flow Chart for Integrated Resource Planning



Source: Integrated Resource Planning for State Utility Regulators. Available at: http://www.raponline.org/document/download/id/817

Supplementary



Supplementary

Technologies	Power rating (MW)	Storage duration (h)	Cycling or lifetime	Self-discharge (%)	Energy density (Wh/l)	Power density (W/l)	Efficiency (%)	Response time
Super-capacitor	0.01-1	ms-min	10,000-100,000	20-40	10-20	40,000-120,000	80-98	10-20ms
SMES	0.1-1	ms-min	100,000	10-15	~6	1000-4000	80-95	< 100ms
PHS	100-1,000	4-12h	30-60 years	~0	0.2-2	0.1-0.2	70-85	sec-min
CAES	10-1,000	2-30h	20-40 years	~0	2-6	0.2-0.6	40-75	sec-min
Flywheels	0.001-1	sec-hours	20,000-100,000	1.3-100	20-80	5,000	70-95	10-20ms
NaS battery	10-100	1min-8h	2,500-4,400	0.05-20	150-300	120-160	70-90	10-20ms
Li-ion battery	0.1-100	1min-8h	1,000-10,000	0.1-0.3	200-400	1,300-10,000	85-98	10-20ms
Flow battery	01-100	1-0h	12,000-14,000	0.2	20-70	0.5-2	60-85	10-20ms
Hydrogen	0.01-1.000	min-weeks	5-30 years	0-4	600 (200 bar)	0.2-20	25-45	sec-min
SNG	50-1.000	hours-weeks	30 years	negligible	1,800 (200 bar)	0.2-2	25-50	sec-min

Electrical   Mechanical   Electrochemical   Chemical