Compressed Air Energy Storage

"CAES" Discussion

Opportunities to meet peak power needs and store excess power for later use

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Agenda

- About Kinder Morgan Storage
- Quick CAES background
- What are the power market needs
- Is anyone other than California experiencing the "duck" curve, negative pricing?
- Would utilities be interested in partnering in an multi-hour energy storage project?

Need for Peaking Power

The power industry is seeing a heightened need for peaking-capacity resources as capacity from retiring power plants is lost and higher levels of renewable generation is integrated"

Source: Baltimore (Platts), 14 Nov 2017

Battery-based demand response is "a limited resource" with "finite MWh"

Source: UtilityDive, 22 Nov 2017, Dave Margolius, Market Operations Manager for battery-based DR provider Green Charge Networks

Compressed Air Energy Storage (CAES)

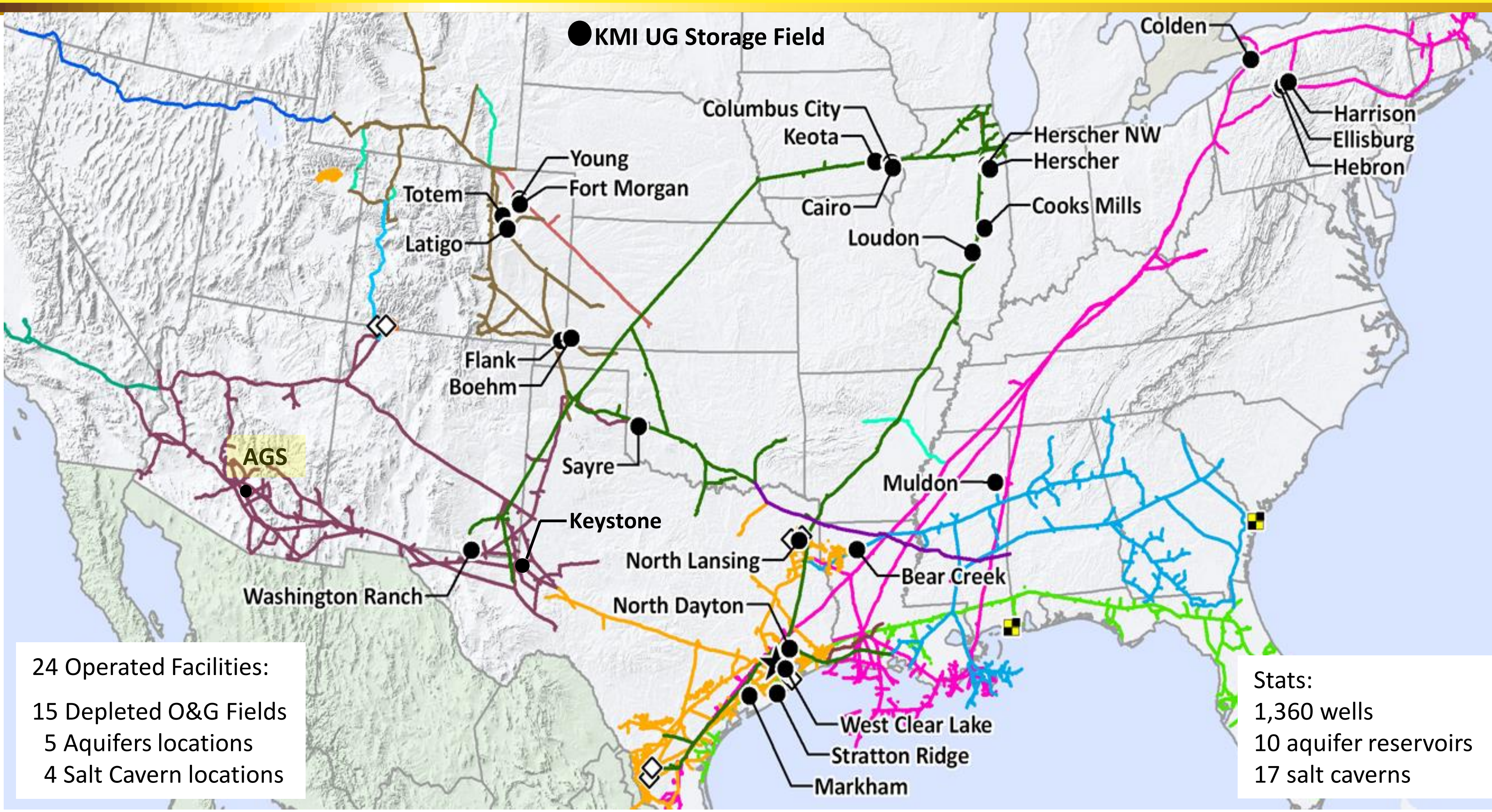
- CAES is a means of storing energy indefinitely by compressing air in an underground storage reservoir an “air battery”
- CAES economically competes with utility scale energy storage projects needing to serve loads for multiple hours and days
- Absorbs excess grid power, resulting from renewables and base sources, by pressurizing an underground storage facility with air for hours, days, or seasons
- Load shifting using off-peak power to offset peak power
- Provides reliable peak energy by allowing the air to return to the atmosphere after traveling through an expander which drives an electric generator feeding power back to the grid

CAES Benefits

- Non-explosive, non-toxic
- Two options: 1st consumes 70% less fuel than a peaking power plant and has lower O&M costs
- 30+ year service life versus 10+ for batteries
- Provides energy 7X longer than same cost lithium-ion battery bank designed for multiple hours/days
- Lowest levelized cost for energy storage*
- High reliability and Black Start capable
- Utilizes proven technology

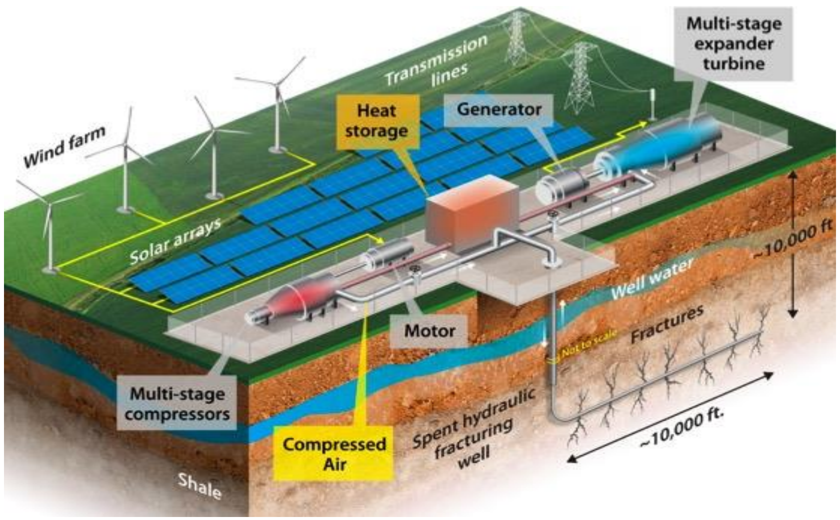
*Lazard 10.0

Kinder Morgan Natural Gas Pipelines and Underground Storage Facilities



The 2nd largest natural gas transporter and storage operator in North America with ~70,000 miles of pipelines and 660 Bcf of working gas in 10 states

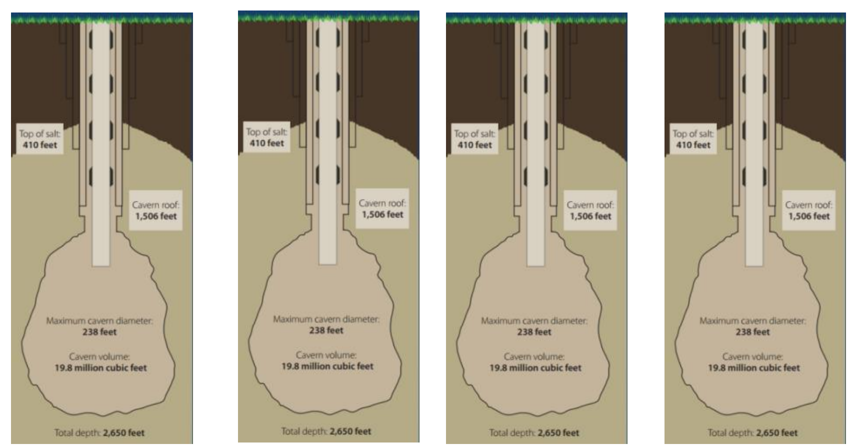
CAES Plant



Source: NREL

Source: Powersouth Alabama McIntosh 110 MW CAES

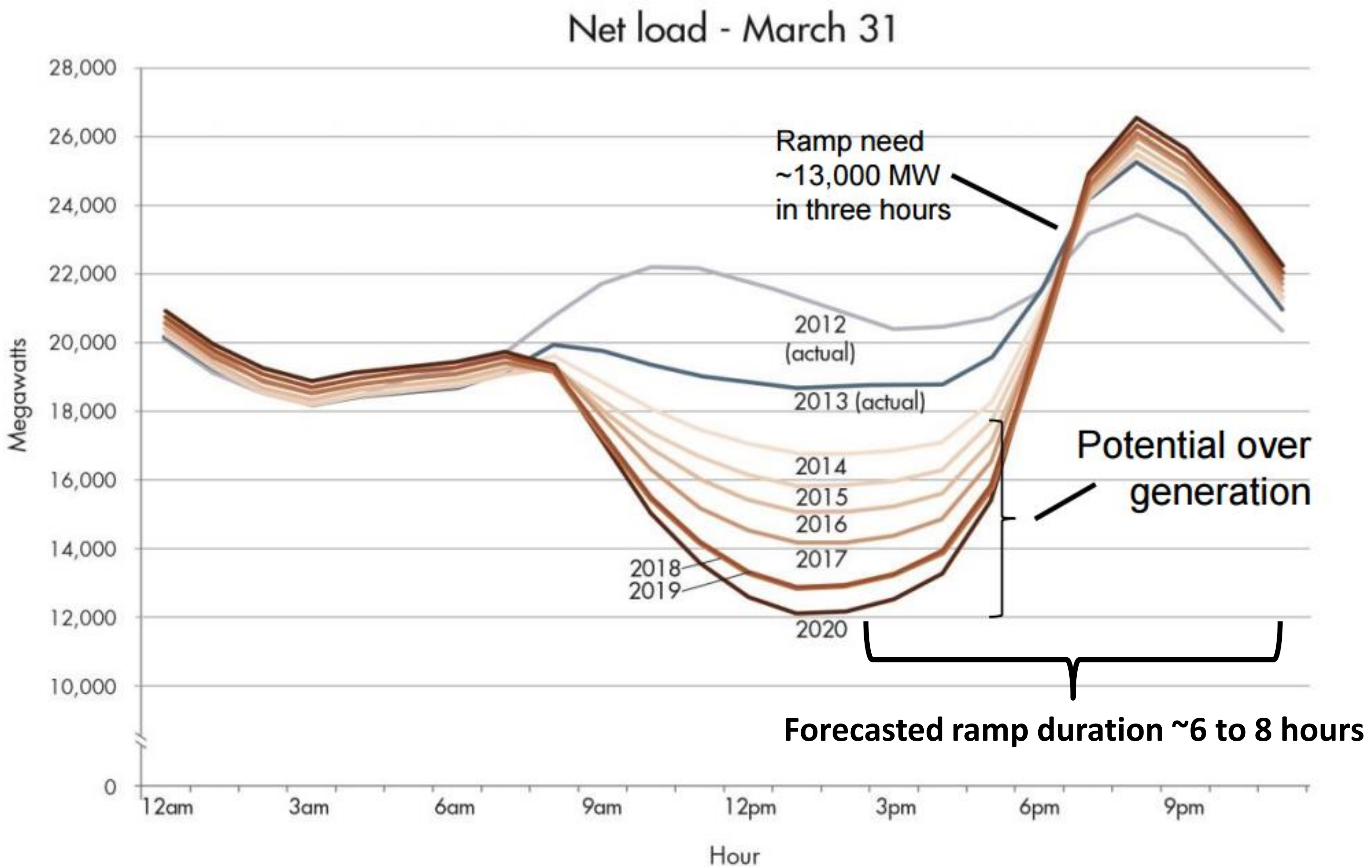
Arizona Gas Storage may use a combination of one million barrel caverns to provide 3 Bcf of gas storage and 1 Bcf of compressed air to generate 100⁺ MW for up to 40 hours. The approach leverages Kinder Morgan’s expertise in subsurface storage, compression, and adds a power generation revenue opportunity.



CAES Example

- CAES has been successfully implemented in the United States and Germany
- Excess power is taken from the grid when power prices are low, negative, to compress air
- The compressed air is expanded to meet peak power needs or high price demands
- Air can be stored indefinitely
- The “air battery” can supply power within minutes and can last for days unlike utility scale batteries which are currently limited to a few hours and have a useful life <10 years

California ISO "Duck Curve"



The ramp in gas fired generation due to renewables drives greater need for pipeline deliverability (peaking)

Natural Gas Deliverability is the ability to deliver gas at the required location, time, pressure and quantity

Source: CAISO

100 MW Peak Energy Options

1 hour peak power supply for reliability

Technology	Cost range	Life	Risk
Li-Ion Battery	\$100 - \$200 MM	10 years	Fire / short ↔
CAES	\$130 - \$230 MM	30+ years	Cavern failure ↓
Gas turbine	\$600 MM	10+ years	Fuel cost, CO_2 , stranded investment

40 hour peak power supply for reliability

Technology	Cost range	Life	Risk
Li-Ion Battery	\$1.5 B - \$2.0 B*	10 years	Fire, foot print
CAES	\$0.2 B – \$0.25 B	30+ years	Cavern failure
Gas turbine	\$0.6 B	10+ years	Fuel cost, CO_2 , overhaul stranded investment ↑

*\$250 - \$500/kWh installed

CAES Business Opportunity

Kinder Morgan Gas Storage co-located with energy markets

Goal displace batteries with longer lived lower cost assets

Utilities are investing in renewables and energy storage. Predominantly batteries to shift solar power to evening load demands.

Arizona Gas Storage

- 3rd party gas storage
- ~$190 MM for CAES in Cavern #4
- KM operates storage

Utilities may want to participate in AGS is because a CAES option replaces a similar sized battery at a fraction of the cost, and ITC possible if combined with solar/renewable

Arizona Battery Investments

- APS: 2 MW / 8 MWh
- UNS: 20 MW / 20 MWh
- SRP: 10 MW / 40 MWh

Battery installations approved in 2016/17

CAES Cavern Economics

100 MW CAES

- 1 hour of storage
  - 30 minutes of power offtake
  - 15 minutes peak delivery
- Cost ~$190 MM

Incremental Costs:

- 4 hours of storage $ 30 MM
- 40 hours of storage $ 5 MM
- 50 hours of storage $ 5 MM

Total Cost ~$ 230 MM

Expected Useful Life >30 years

100 MW Lithium Battery

- 1 hour of storage
  - 30 minutes of power offtake
  - 15 minutes peak delivery
- Cost ~$65 MM

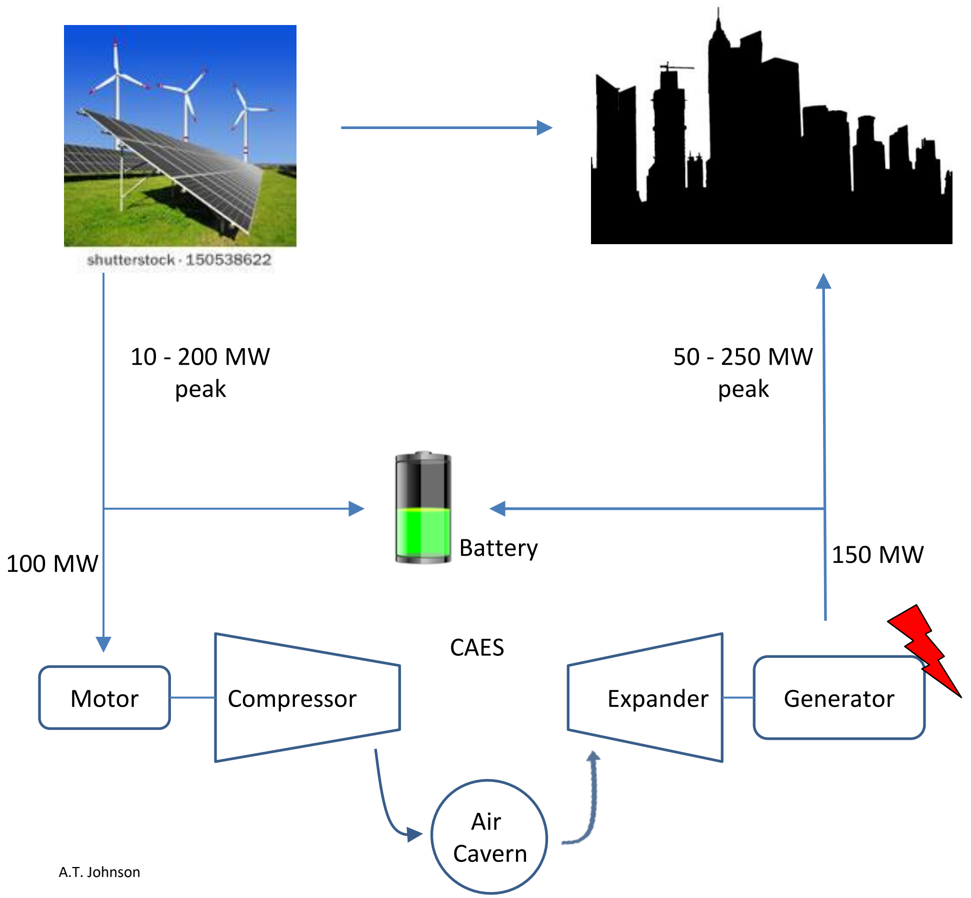
Incremental Costs:

- 4 hours of storage $ 200 MM
- 40 hours of storage $1,225 MM
- 50 hours of storage $ 250 MM

Total Cost ~$ 1,740 MM

Expected Useful Life 10 years

Hybrid CAES/Battery Energy Storage



- Hybrid CAES provides fast response (millisecond) and long term energy storage (hours up to days)
- Provides twice the power of either a standalone battery or CAES solution
- Lowest capital cost for multiple hour support

CAES Opportunities

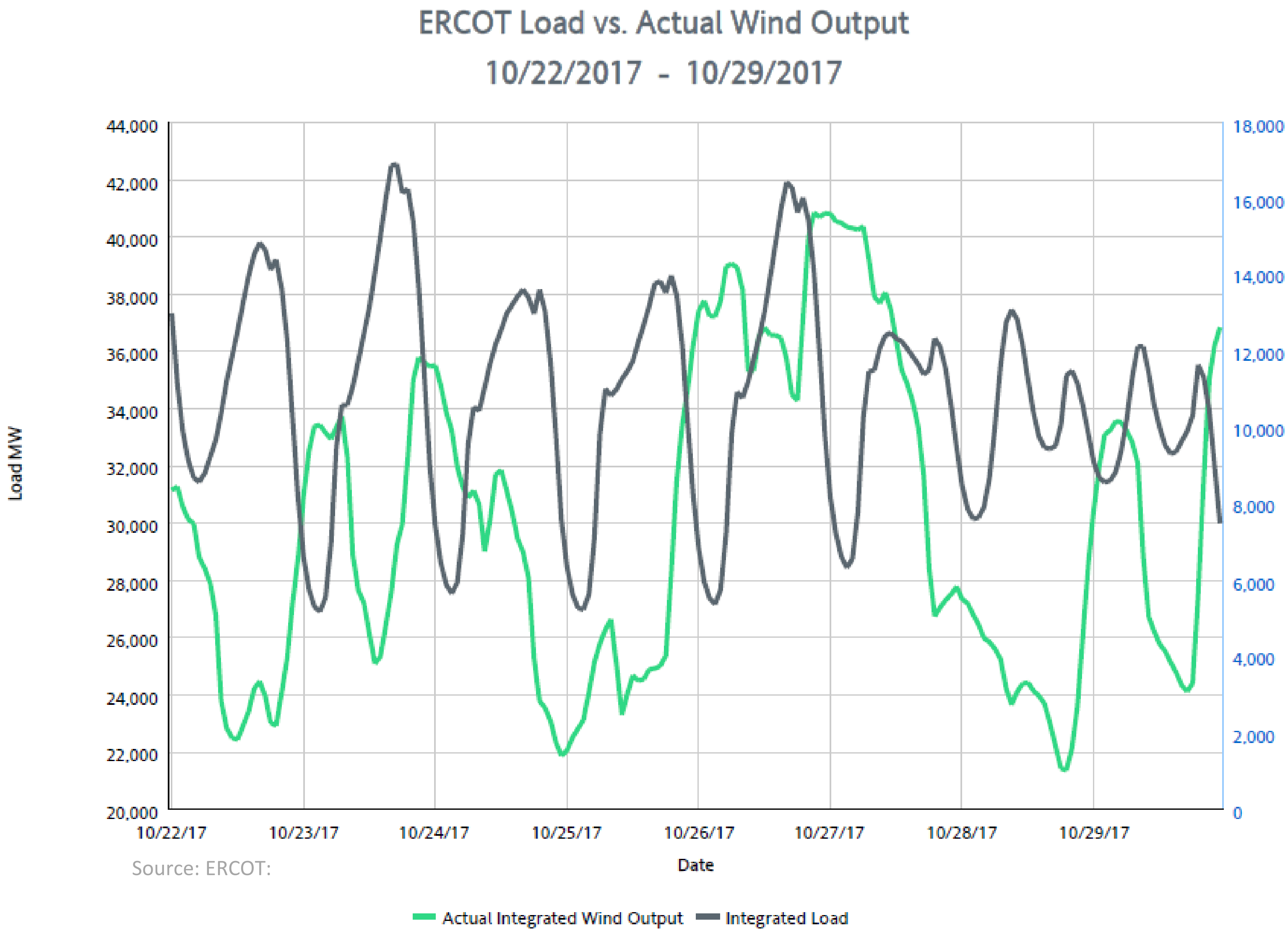
• Arizona:	Bedded salt AGS, Copper Eagle
• Colorado:	Abandoned mines, dry wells
• Illinois:	Aquifers
• Iowa:	Aquifers
• Oklahoma:	Fracked dry wells
• Texas:	Salt Caverns, fracked dry wells

- Based on the broader U.S. benefits of storage the total energy storage market opportunity is on the order of 14 GW if energy storage systems could be installed for about $700–$750/kWh and the benefits estimated could all be monetized - EPRI

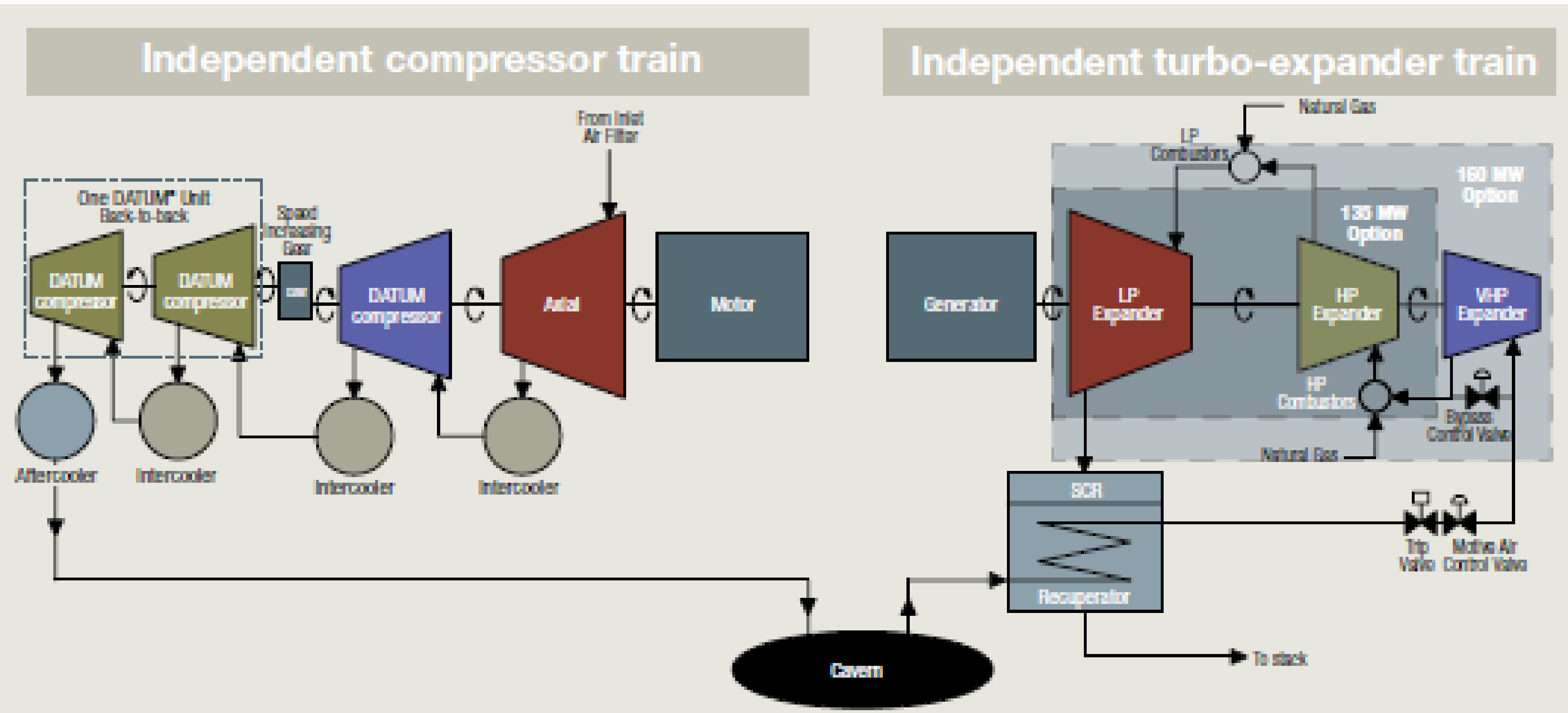
- Actual installed costs would need to be lower to accommodate life-cycle impacts and maintenance. Niche high-value market sizes were estimated to total approximately 5 GW if energy storage systems could be installed for $1400/kWh and all benefits could be monetized. - EPRI

APPENDICES

Texas Daily Load vs Wind Output

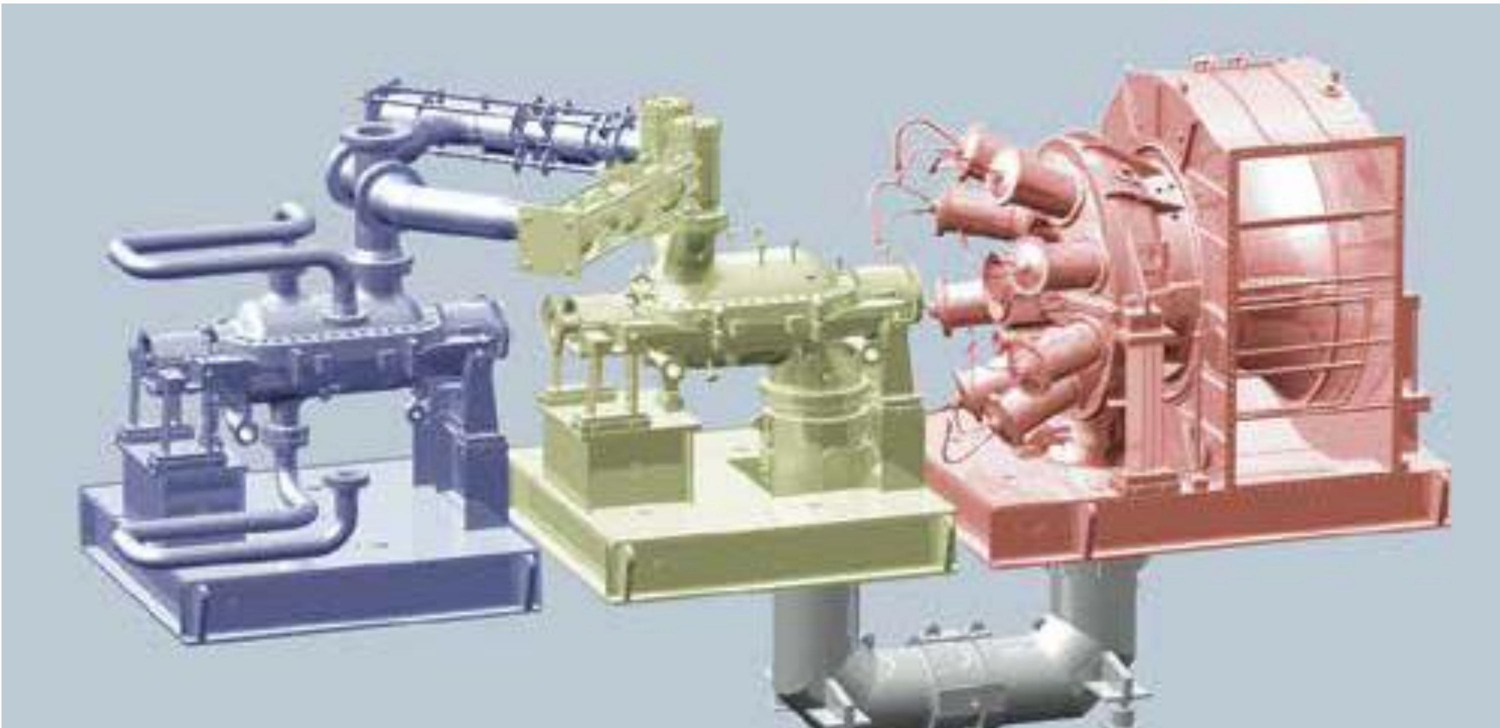


CAES: Energy Injection/Withdrawal



Source: Dresser-Rand

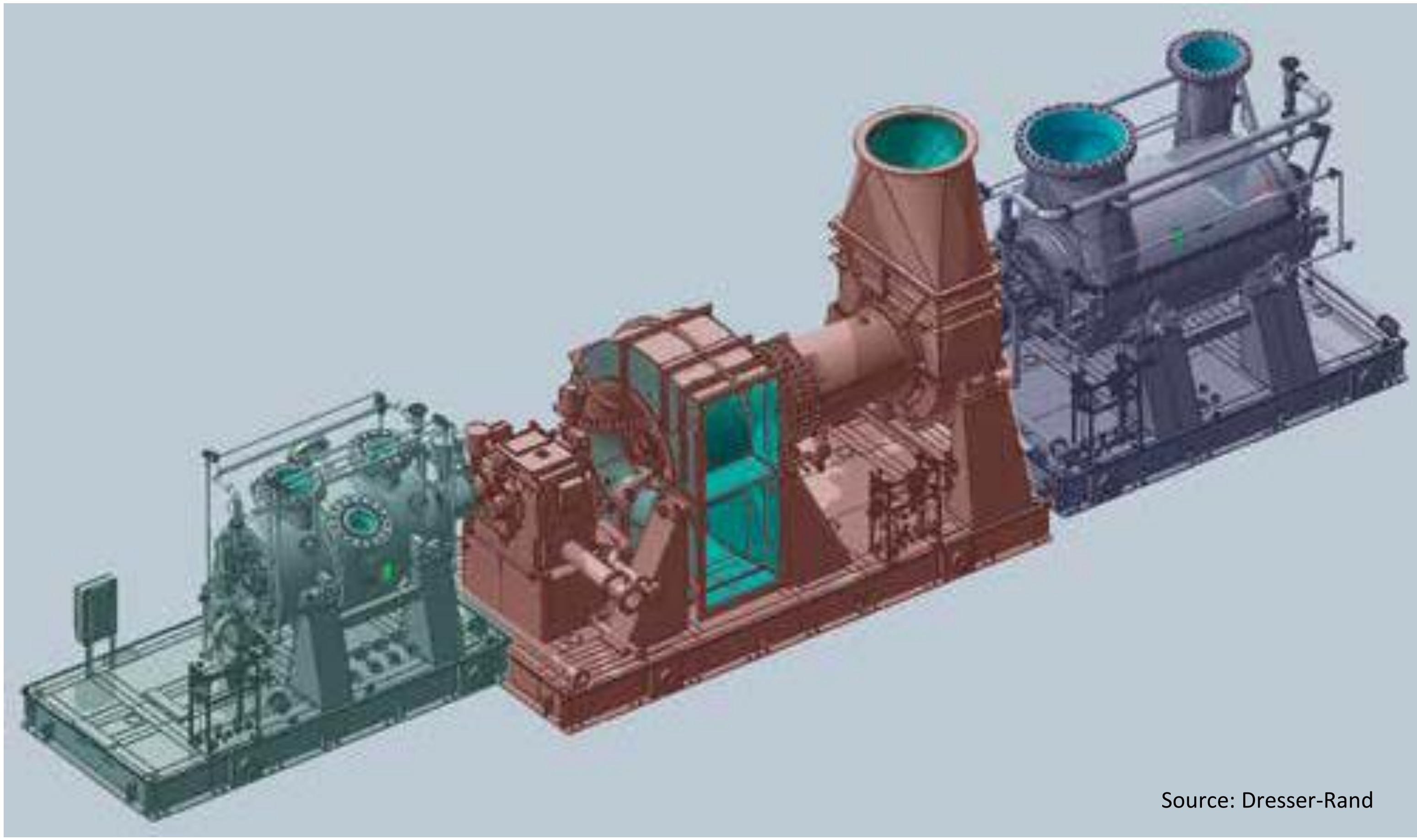
CAES Heating on Withdrawal



Source: Dresser-Rand

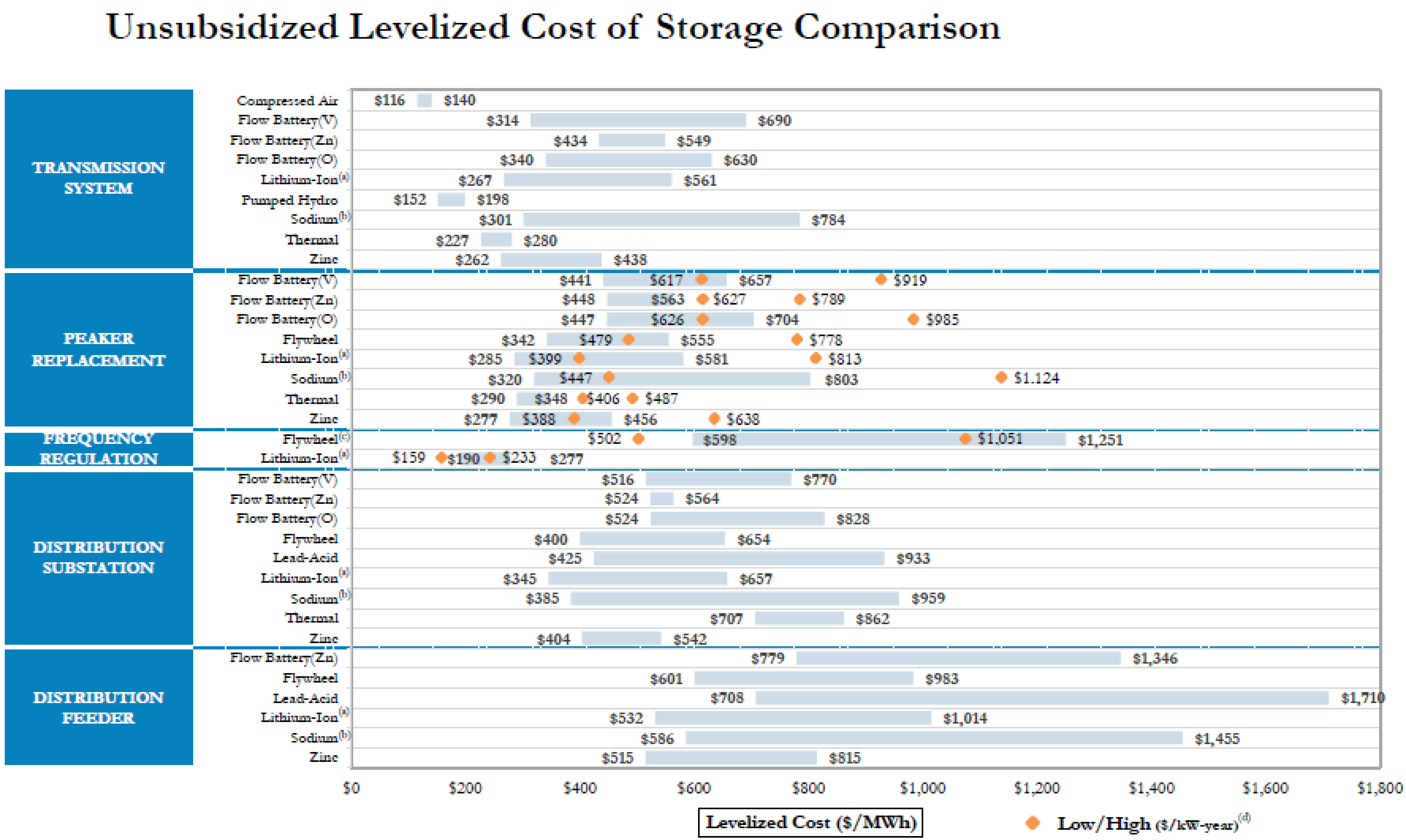
Heat compressed air prior to expansion to prevent liquids dropout and improve power generation output and efficiency

CAES Injection



Multi-stage air compressors : from atmospheric pressure to 3,000 psig

Lazard Levelized Costs



Source: Lazard

Lazard LCOE 11/2017 version 11

Renewable Energy Cost Trend ($/MWh)

Renewable Energy—Historical Cost Declines[1]

Selected Historical Mean LCOE Values[2]

Source: Lazard estimates.

Note: Reflects average of unsubsidized high and low LCOE range for given version of LCOE study.

(1) Primarily relates to North American alternative energy landscape, but reflects broader/global cost declines.

(2) Reflects total decrease in mean LCOE since the later of Lazard's LCOE—Version 3.0 or the first year Lazard has tracked the relevant technology.

(3) Reflects mean of fixed tilt (high end) and single axis tracking (low end) crystalline PV installations.

Benefits of Storage

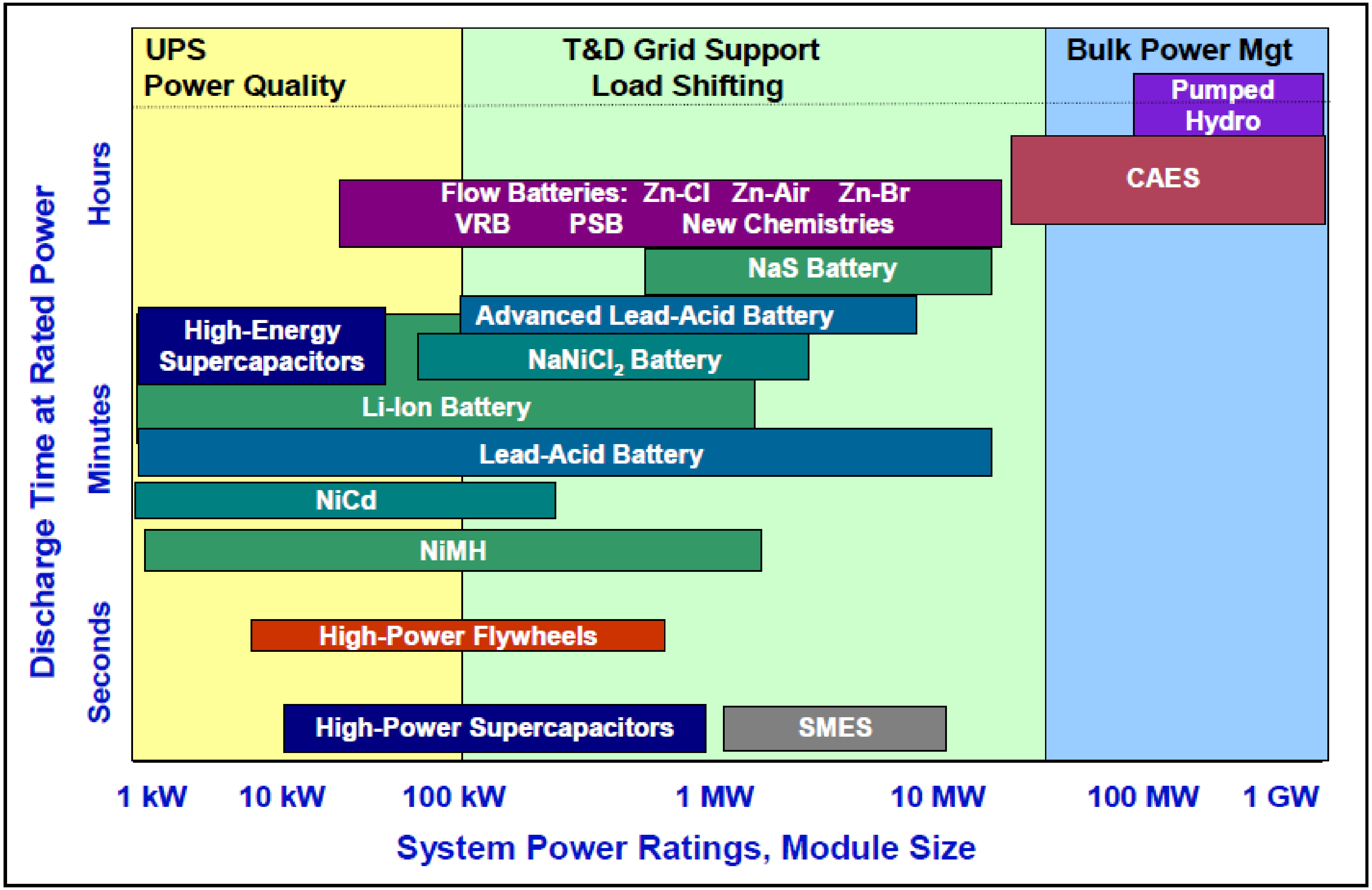
Table 4 – Electric Grid Energy Storage Services

Bulk Energy Services	
	Electric Energy Time-Shift (Arbitrage)
	Electric Supply Capacity
Ancillary Services	
	Regulation
	Spinning, Non-Spinning and Supplemental Reserves
	Voltage Support
	Black Start
	Other Related Uses

Transmission Infrastructure Services	
	Transmission Upgrade Deferral
	Transmission Congestion Relief
Distribution Infrastructure Services	
	Distribution Upgrade Deferral
	Voltage Support
Customer Energy Management Services	
	Power Quality
	Power Reliability
	Retail Electric Energy Time-Shift
	Demand Charge Management

Source: EPRI Energy Storage DEC 2013

Energy Storage Technology



Source: EPRI Energy Storage DEC 2013

Energy Storage Opportunities

Application	Description	Size	Duration	Cycles	Desired Lifetime
Wholesale Energy Services	Arbitrage	10-300 MW	2-10 hr	300-400/yr	15-20 yr
	Ancillary services [2]	See Note 2	See Note 2	See Note 2	See Note 2
	Frequency regulation	1-100 MW	15 min	>8000/yr	15 yr
	Spinning reserve	10-100 MW	1-5 hr		20 yr
Renewables Integration	Wind integration: ramp & voltage support	1-10 MW distributed 100-400 MW centralized	15 min	5000/yr 10,000 full energy cycles	20 yr
	Wind integration: off-peak storage	100-400 MW	5-10 hr	300-500/yr	20 yr
	Photovoltaic Integration: time shift, voltage sag, rapid demand support	1-2 MW	15 min-4 hr	>4000	15 yr
Stationary T&D Support	Urban and rural T&D deferral. Also ISO congestion mgt.	10-100 MW	2-6 hr	300-500/yr	15-20 yr

Implementing some of these modified rules has the potential to dramatically increase potential revenues on a $/kW-h basis from roughly $1,000/kW-h to over $6,000/kW-h in some markets.
Source: EPRI Energy Storage DEC 2013, XXi

Energy Storage Characteristics

Energy Storage Characteristics by Application *(Megawatt-scale)*

Technology Option	Maturity	Capacity (MWh)	Power (MW)	Duration (hrs)	% Efficiency (total cycles)	Total Cost ($/kW)	Cost ($/kW-h)
Bulk Energy Storage to Support System and Renewables Integration							
Pumped Hydro	Mature	1680-5300	280-530	6-10	80-82 (>13,000)	2500-4300	420-430
		5400-14,000	900-1400	6-10		1500-2700	250-270
CT-CAES (underground)	Demo	1440-3600	180	8	See note 1 (>13,000)	960	120
				20		1150	60
CAES (underground)	Commercial	1080	135	8	See note 1 (>13000)	1000	125
		2700		20		1250	60
Sodium-Sulfur	Commercial	300	50	6	75 (4500)	3100-3300	520-550
Advanced Lead-Acid	Commercial	200	50	4	85-90 (2200)	1700-1900	425-475
	Commercial	250	20-50	5	85-90 (4500)	4600-4900	920-980
	Demo	400	100	4	85-90 (4500)	2700	675
Vanadium Redox	Demo	250	50	5	65-75 (>10000)	3100-3700	620-740
Zn/Br Redox	Demo	250	50	5	60 (>10000)	1450-1750	290-350
Fe/Cr Redox	R&D	250	50	5	75 (>10000)	1800-1900	360-380
Zn/air Redox	R&D	250	50	5	75	1440-1700	290-340

Source: EPRI Energy Storage DEC 2013

Renewable Costs

- Wind and solar are the lowest cost generation resource across large swaths of the country — even without subsidies.
- Recent numbers from the investment firm Lazard show the average levelized cost of energy (LCOE) for unsubsidized wind generation fell between $32/MWh and $62/MWh, lower than the average LCOE for natural gas, which came in between $48/MWh and $78/MWh.
- Utility-scale solar was not far behind, ranging between $48/MWh and $56/MWh for thin film systems.
- Both renewable resources were shown to be cheaper than coal.

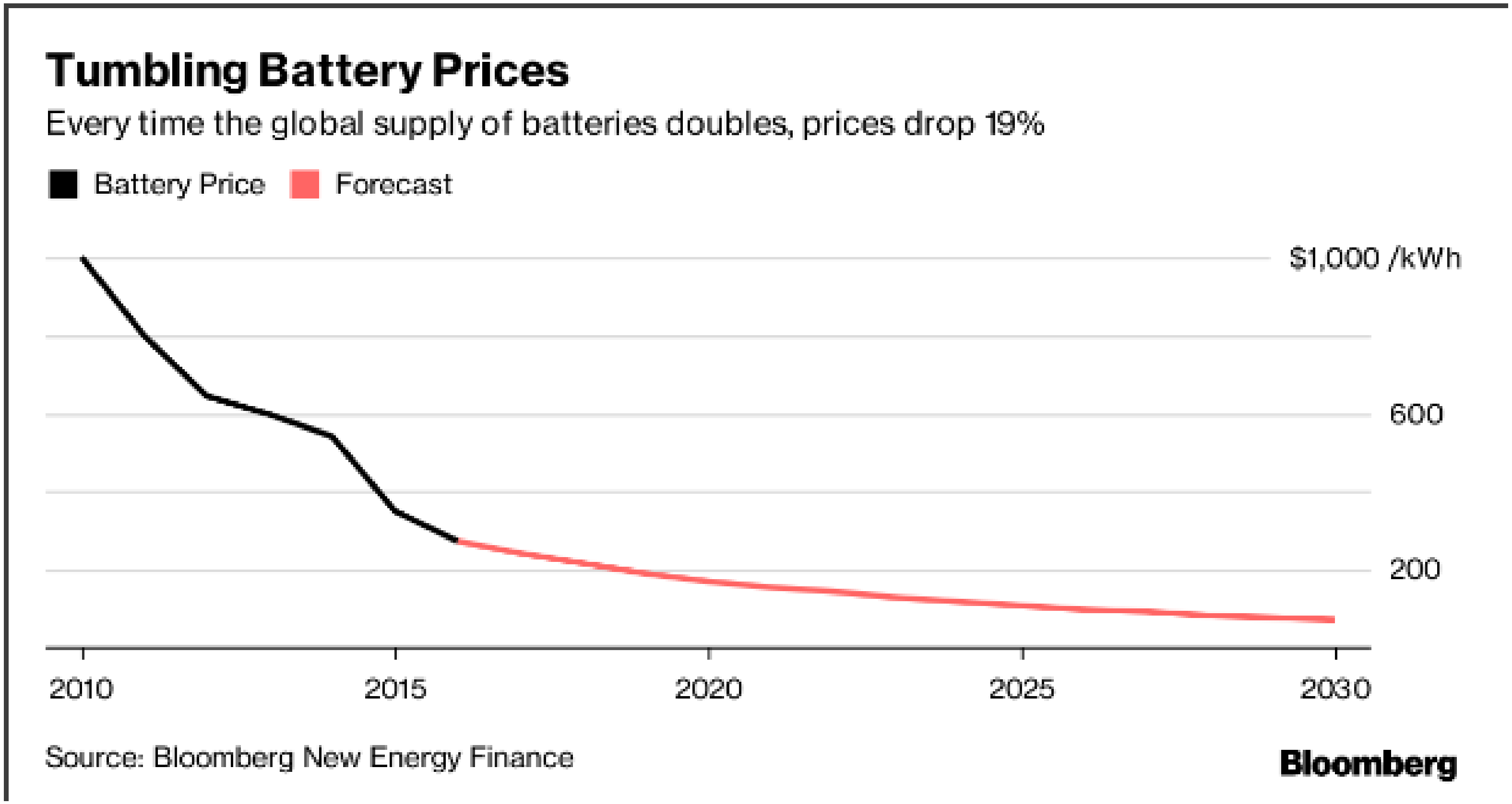
Source: Lazard 2017

Renewable Impact on Gas Equipment Suppliers

- Siemens announced last week that it will cut 6,900 jobs in its power and fossil fuel division in response to falling worldwide demand for large gas turbines.
  - Globally, production capacity for the units stands at around 400 turbines but only about 120 were sold last year and in Europe, the market is quickly disappearing.
  - About half of the job cuts will be in Germany, where the market is reportedly "hardly exits," company officials said during a conference call. Job cuts in the United States are still being planned, but could reach 1,800 by 2020.
- GE CEO John Flannery, in the company's investor update, described a strategy that includes $20 billion of divestitures, a dividend cut and refocusing on three core businesses. The plan includes the paring of several businesses, including the company's transportation sector and oil field services company Baker Hughes.
  - The company said its power sector is not the only problem, but the unit had about $39 billion in 2016 revenues and accounts for nearly one-third of overall revenues. GE's 2015 acquisition of Alstom, a major manufacturer of equipment for coal plants, has also been a trouble spot. The business is showing a "single-digit return right now, disappointing, below expectations," Flannery said
  - 2017 GE announces 1,000 employee lay-off in Europe
  - 2017 GE announces 12,000 employee lay-off world-wide in the power group

Source: Utility Dive 22 Nov 2017

Battery Costs

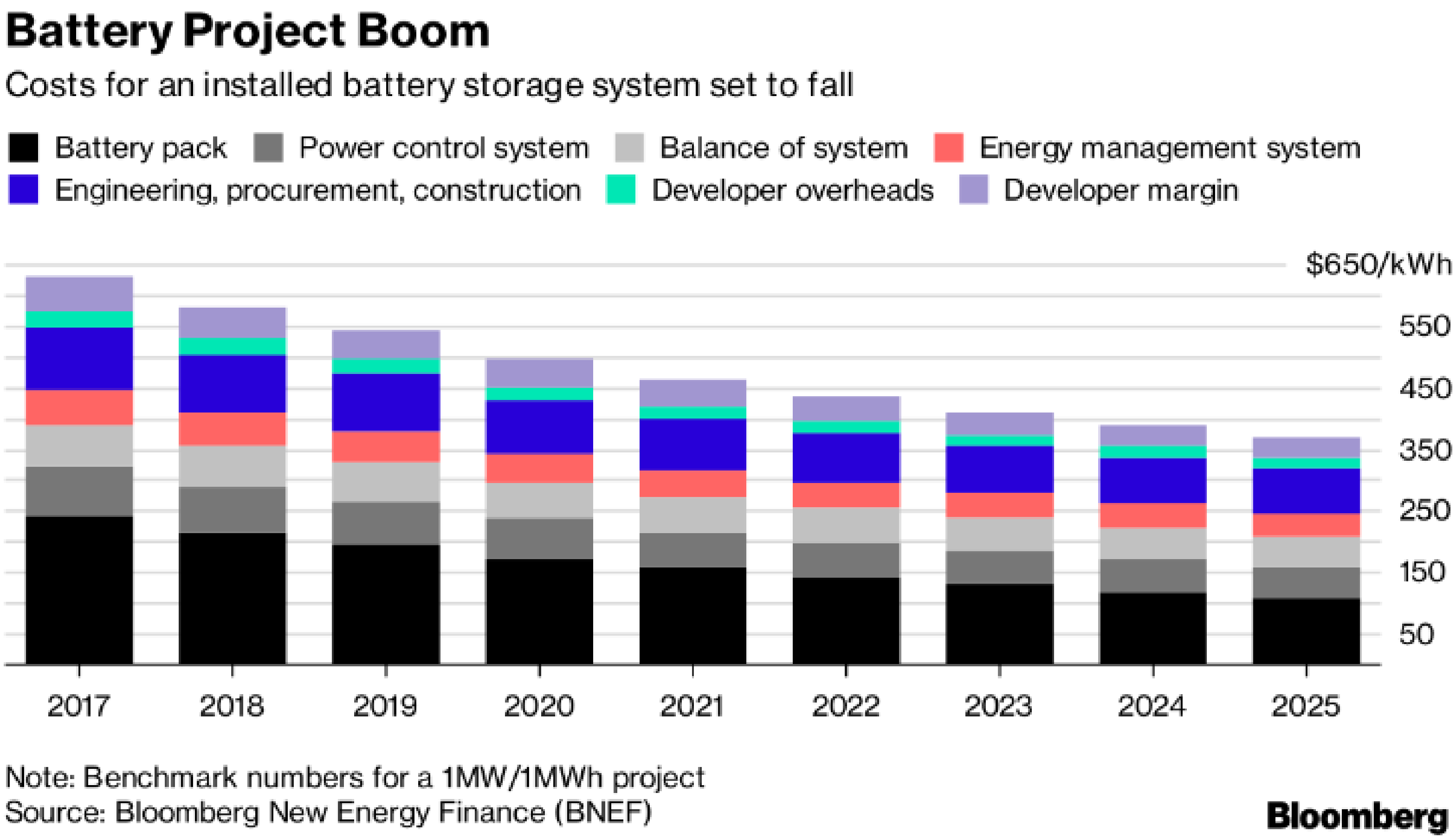


Utility Scale Battery Installations

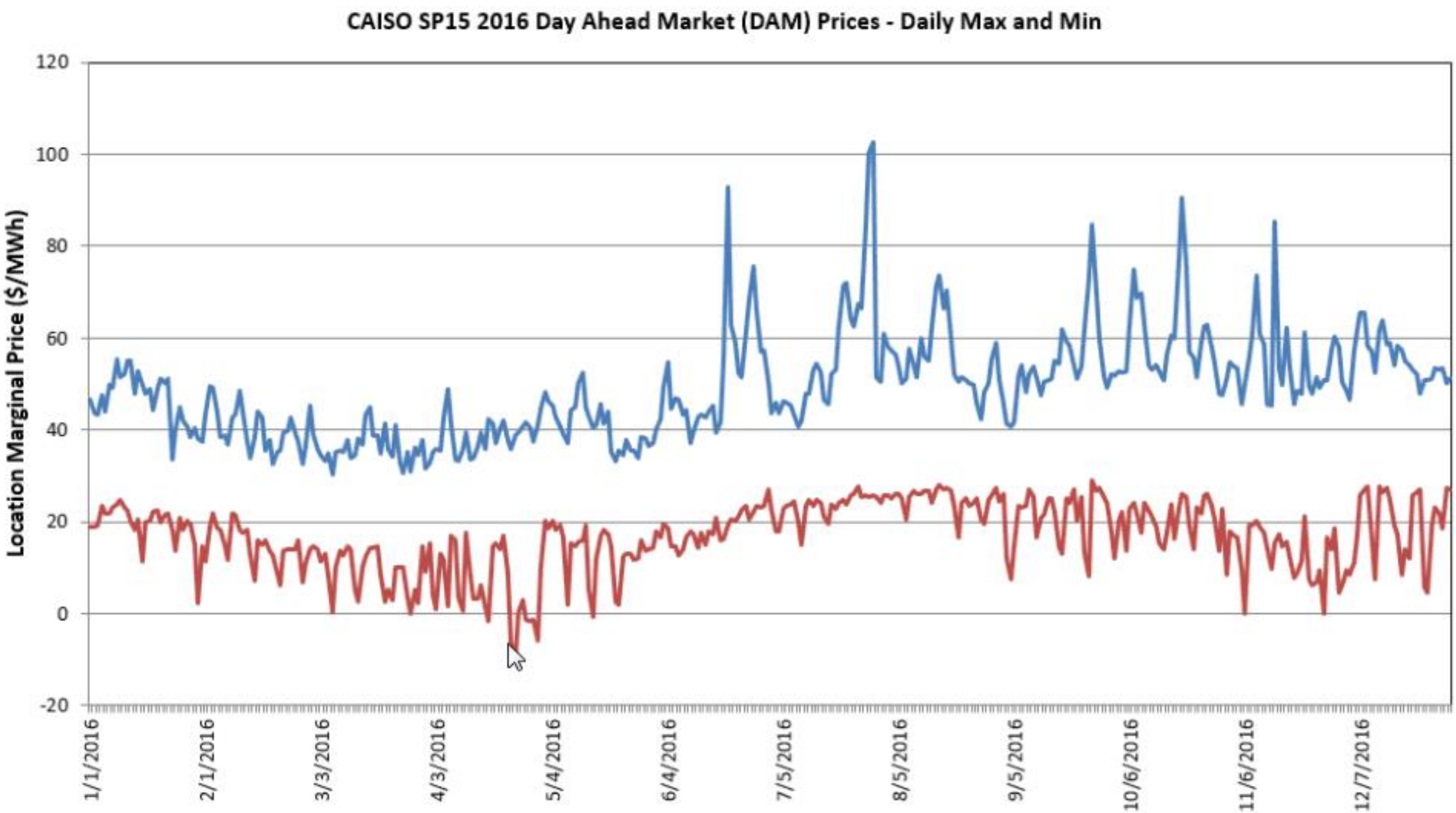
- South Korea's Hyundai Electric & Energy Systems Co. is building a 150-megawatt lithium-ion unit, 50 percent larger than Musk's, that the company says will go live in about three months in Ulsan near the southeast coast.
- With battery prices tumbling by almost half since 2014, large-scale projects are popping up around the world. Developers have announced lithium-ion battery projects with total capacity of 1,650 MWh in 2017, four times the amount for all of 2016, according to Bloomberg New Energy Finance.

https://www.bloomberg.com/news/articles/2017-11-30/musk-s-battery-boast-will-be-short-lived-as-rivals-go-bigger

Total Installed Battery Costs



Open Market Power Spread



Source CAISO / NREL C. Augustine, PhD 2017

Battery Grade Material Costs

• Cobalt	$73,000 / ton
• Graphite	$10,000 / ton
• Lithium	$14,000 / ton
• Iron	$96 / ton

Prices can vary significantly

http://www.infomine.com/investment/metal-prices Dec 11, 2017
https://oilandgas-investments.com/2017/top-stories/lithium-prices-to-stay-high-to-2024-ubs/ Jun 19, 2017