Realizing the Full Economic Potential of Storage

Physical

- Weather
- Load
- Renewables
- Congestion

Financial

- Day Ahead vs. Real Time
- Energy vs Ancillary
- Forwards & Options
- Hedge Evaluation

Allison Weis, PhD

Ascend Analytics
Better models. Better decisions.

About Ascend Analytics

- Founded in 2002 with over 50 employees in Boulder, Oakland, and Bozeman
- Seven integrated software products for operations, portfolio analytics, and planning
- Custom analytical solutions and consulting

Proven & Broadly Adopted

Differentiated Value for Enhanced Decision Analysis

BatterySimm Operations
STORAGE OPTIMIZATION

- Optimal offers to ISO
- Continuous adjust ISO offers
- Forecast probabilities of price spikes
- Event triggered over-ride of ISO
- Renewables plus storage

BatterySimm Valuation
STORAGE OPTIMIZATION

- Optimal location
- Optimal sizing for energy cycling economics
- Captures realistic revenues given imperfect foresight
- Reliability Analysis
- Renewable plus storage

PowerSimm OPS
OPERATIONAL STRATEGY

1 to 10 days

- Determine short-term operating strategies from position and financial exposure
- Forecast short-term loads and market prices with uncertainty

PowerSimm Portfolio Manager
PORTFOLIO MANAGEMENT

1 month to ≈ 5 years

- Impact of hedges on reducing cash flow uncertainty
- Portfolio management with analytics insight to manage risk (CFaR, GMaR, EaR)

PowerSimm Planner
LONG-TERM VALUATION

5 to 30 years

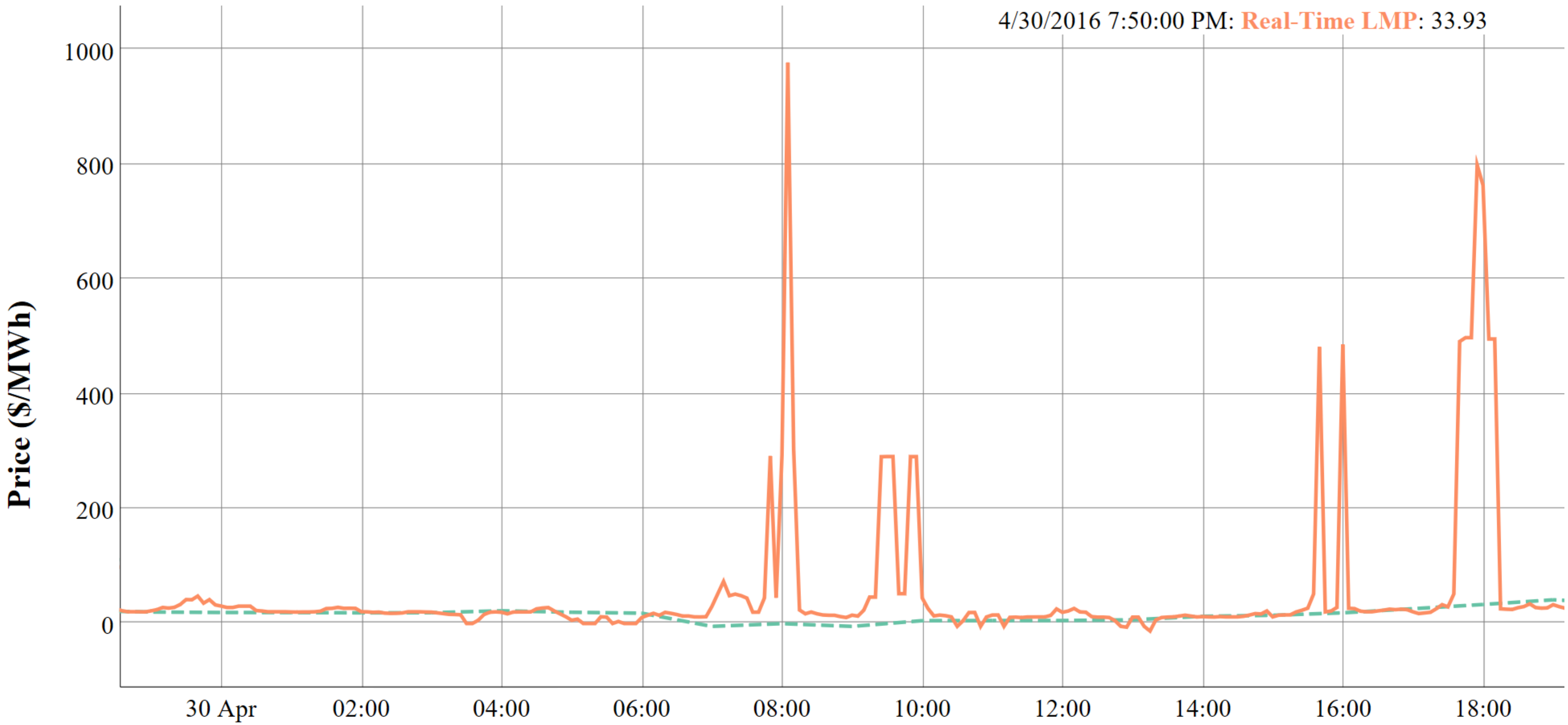
- Asset valuation
- Resource Planning
- Reliability Analysis
- Renewable Integration

Thesis of New Market Dynamics

- **Increasing renewable generation makes weather matter in determining resource value and reliability.**
- **Renewables are causing structural change in power markets with increased market volatility and declining implied HRs**
- **Realizing the value of flexible generation follows from modeling sub-hourly.**
- **Increase in price ceilings will have a pronounced effect on the value of storage in select locations.**

Revenue Opportunities: Real-Time Energy Price Spikes

CAISO
Day-ahead and Real-time Prices April 30, 2016



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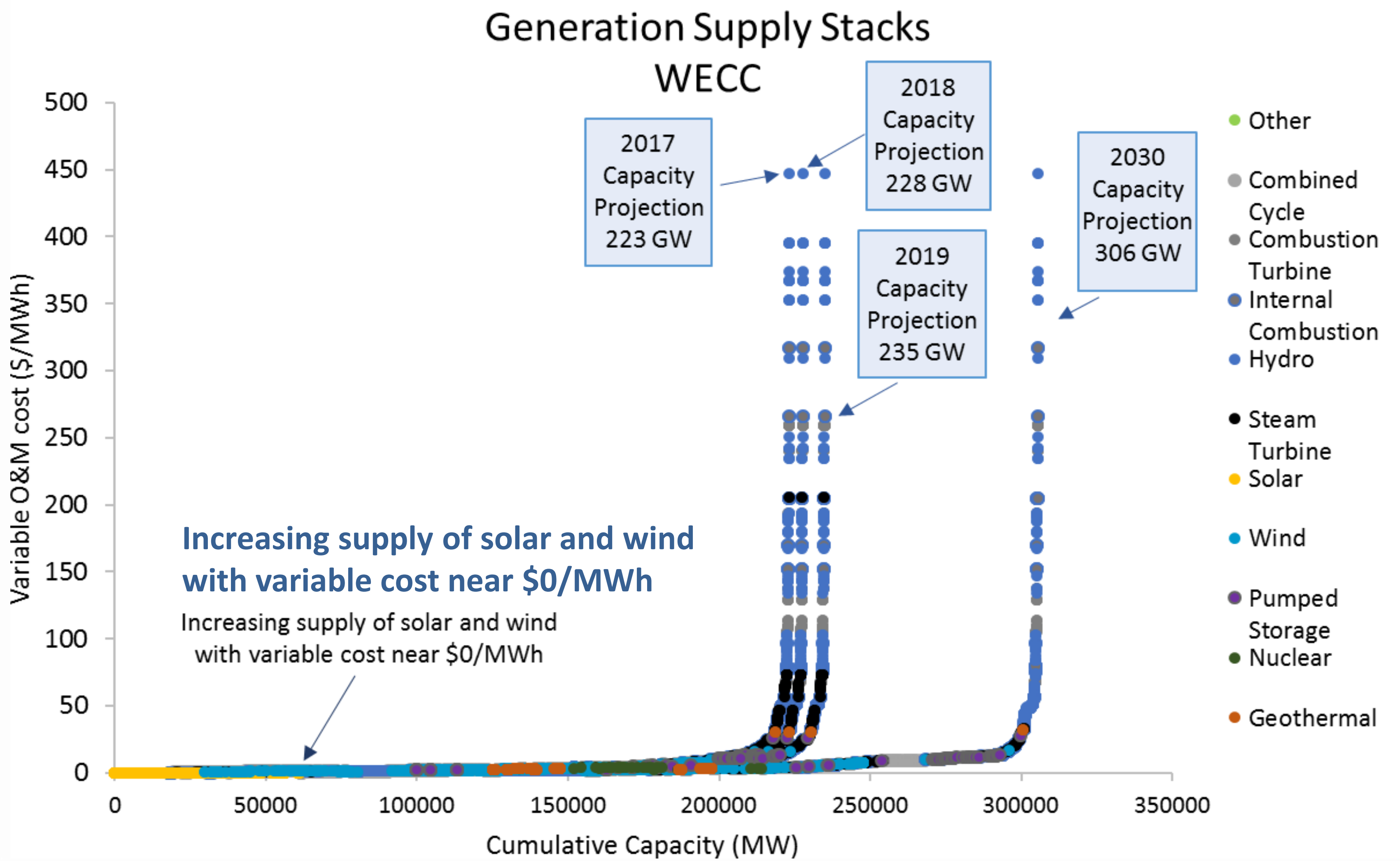
Renewables Are the New Baseload



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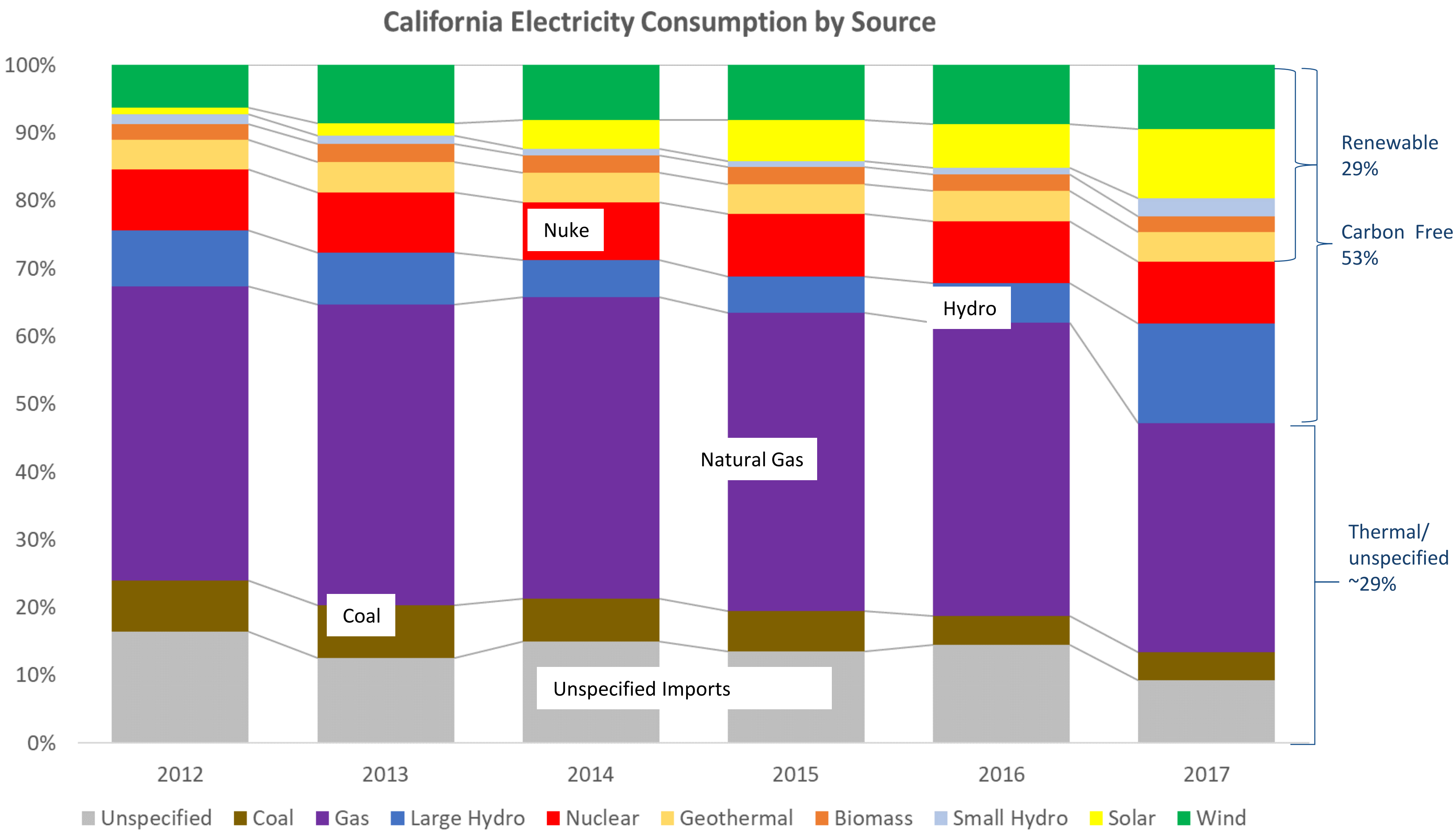
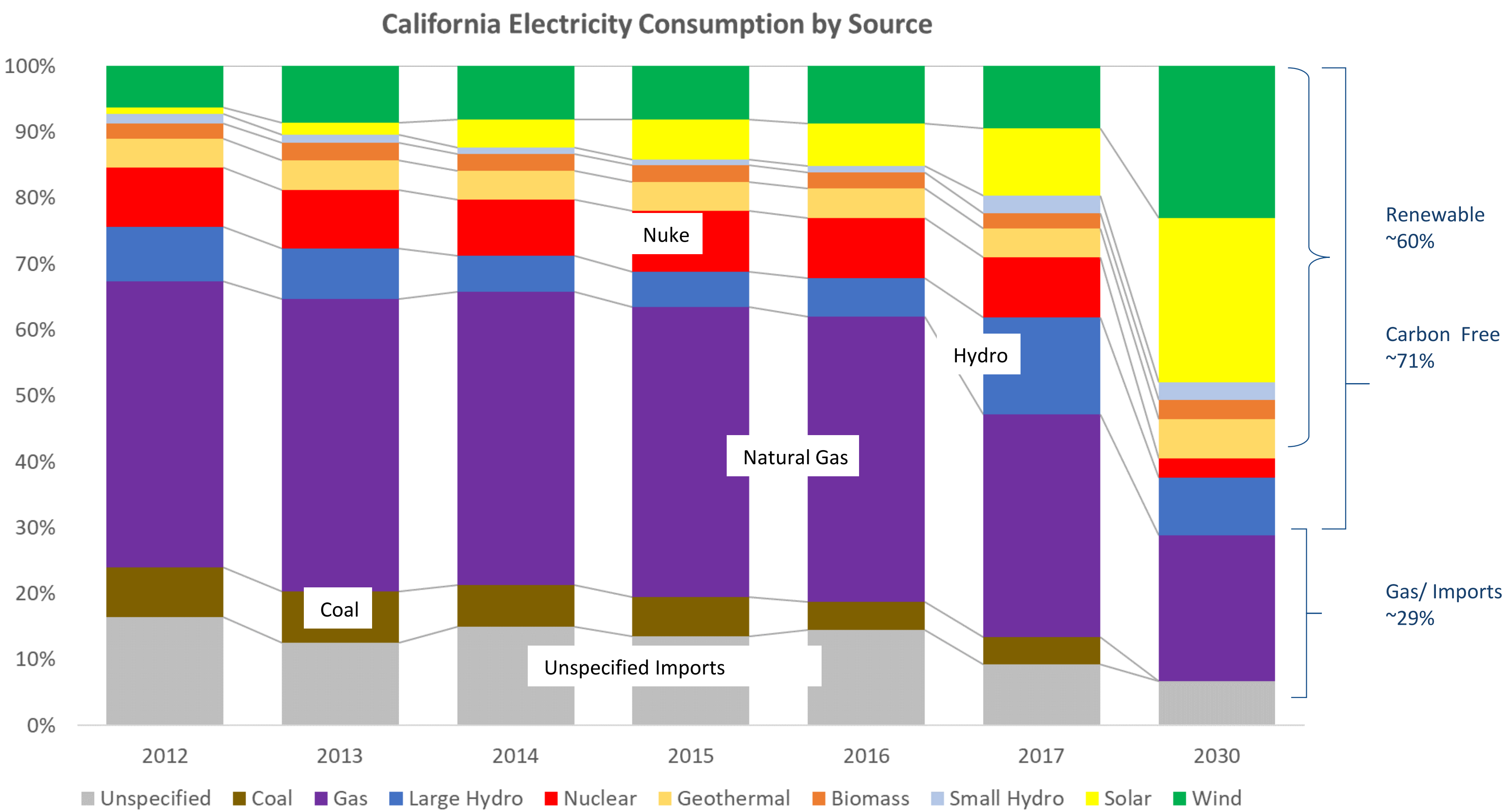
SB 350/100 Is Driving Major Changes in Energy Mix



Major Reductions In Gas Generation By 2030



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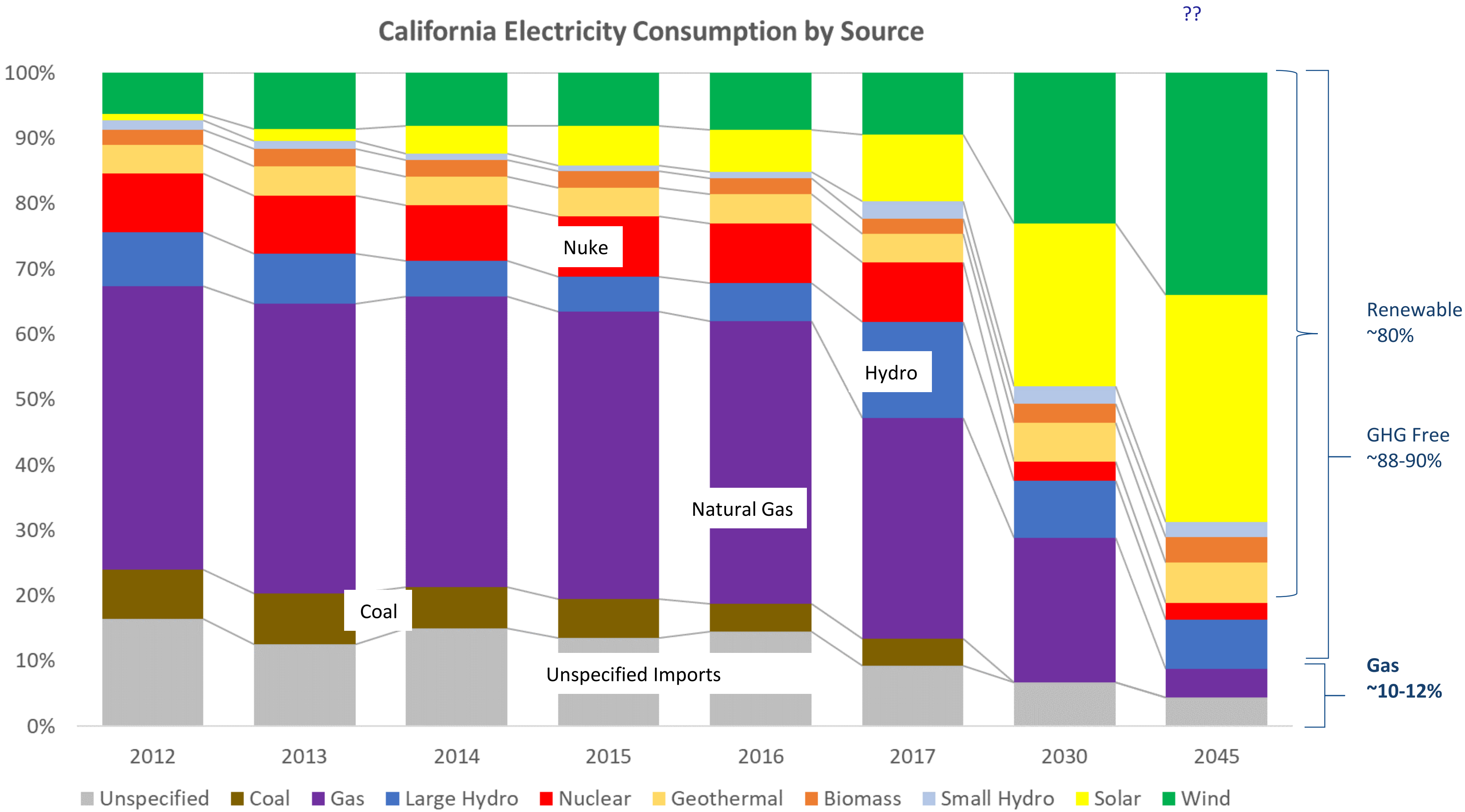
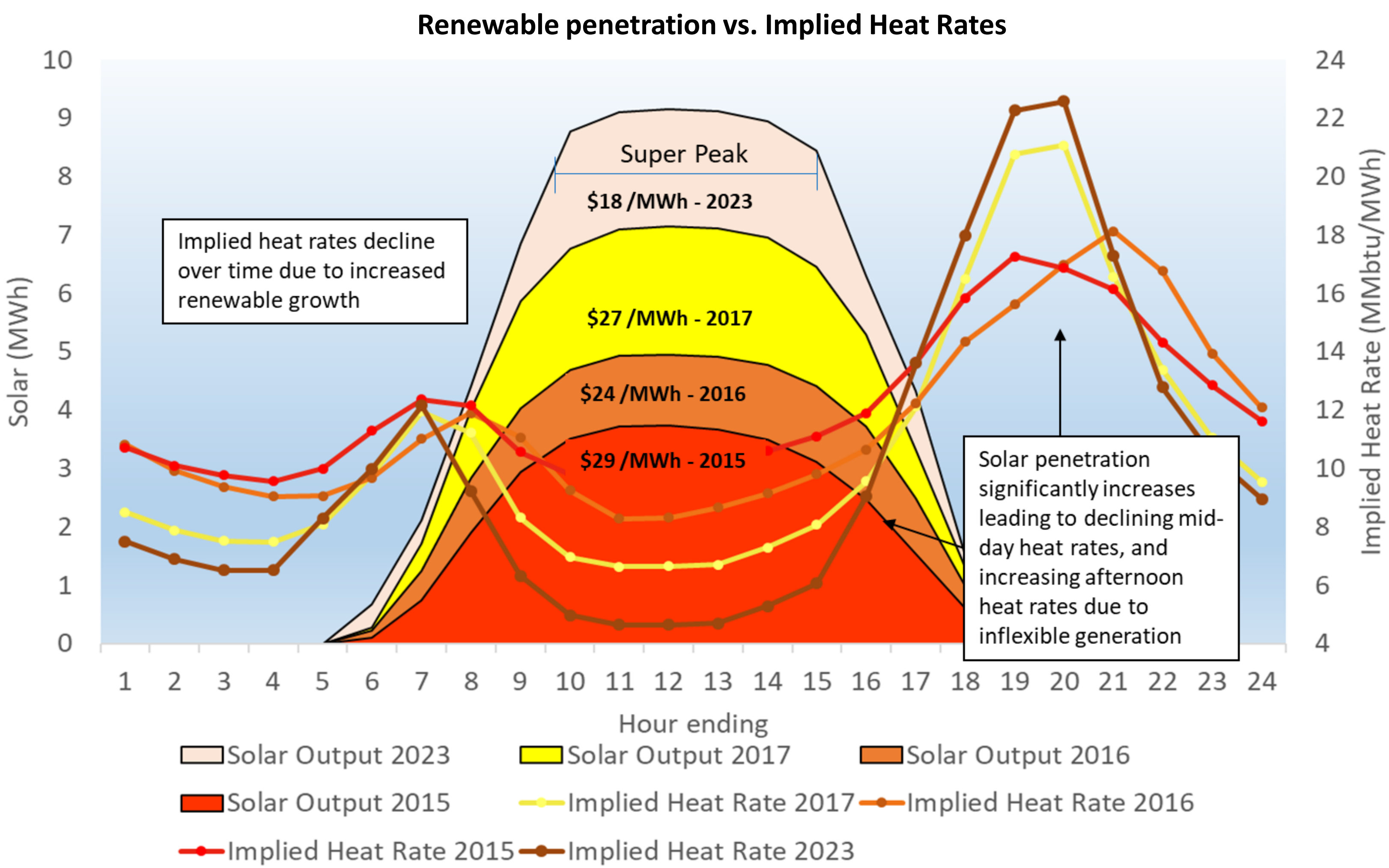
In 2045, 100% GHG Free Still Requires Flexible Gas



Renewables Drive Lower Energy Prices



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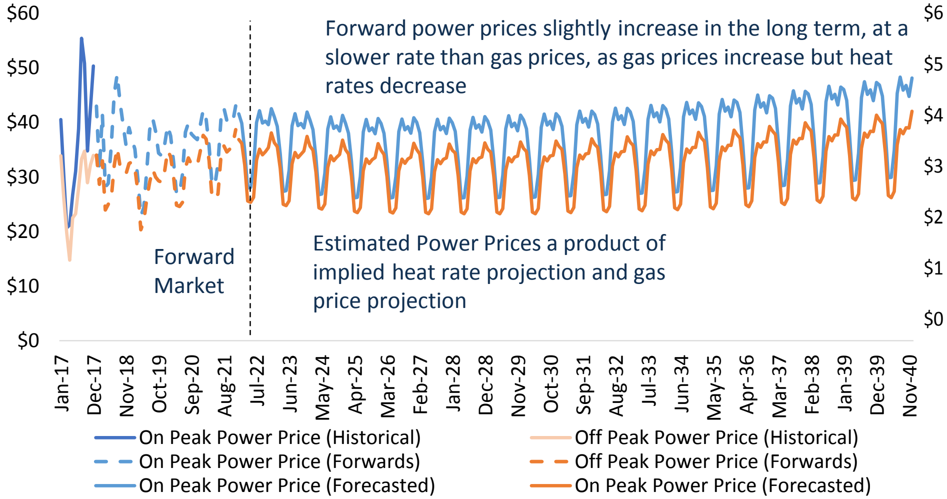
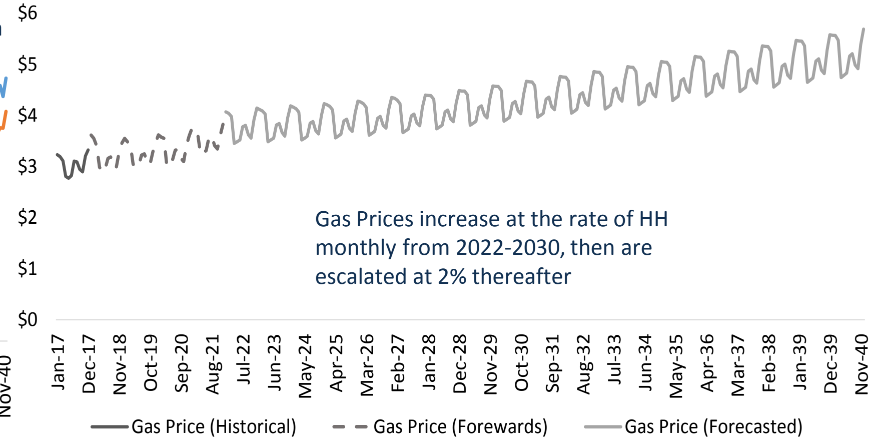
SP15 Implied Heat Rates, Forward Gas & Power Prices

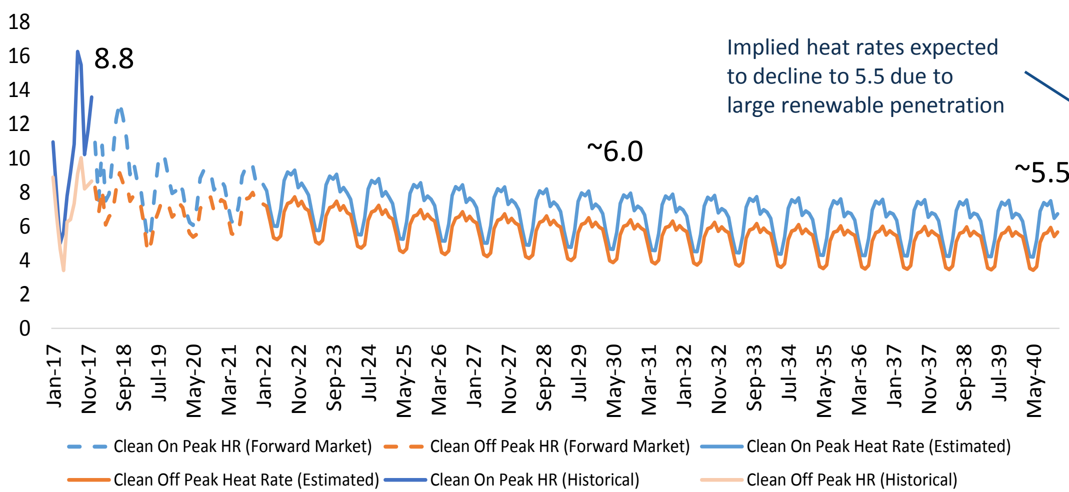
SP15 Forward Power Price ($/MWh)



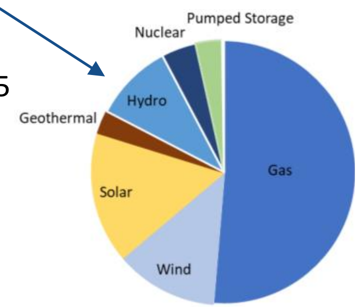
SoCal Gas Prices ($/MMBtu)



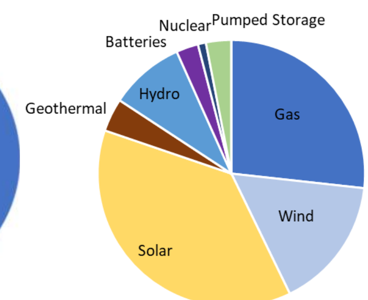
SP15 Clean Implied Heat Rates (MMBtu/MWh)



2017 Capacity Mix



2030 Projected Capacity Mix



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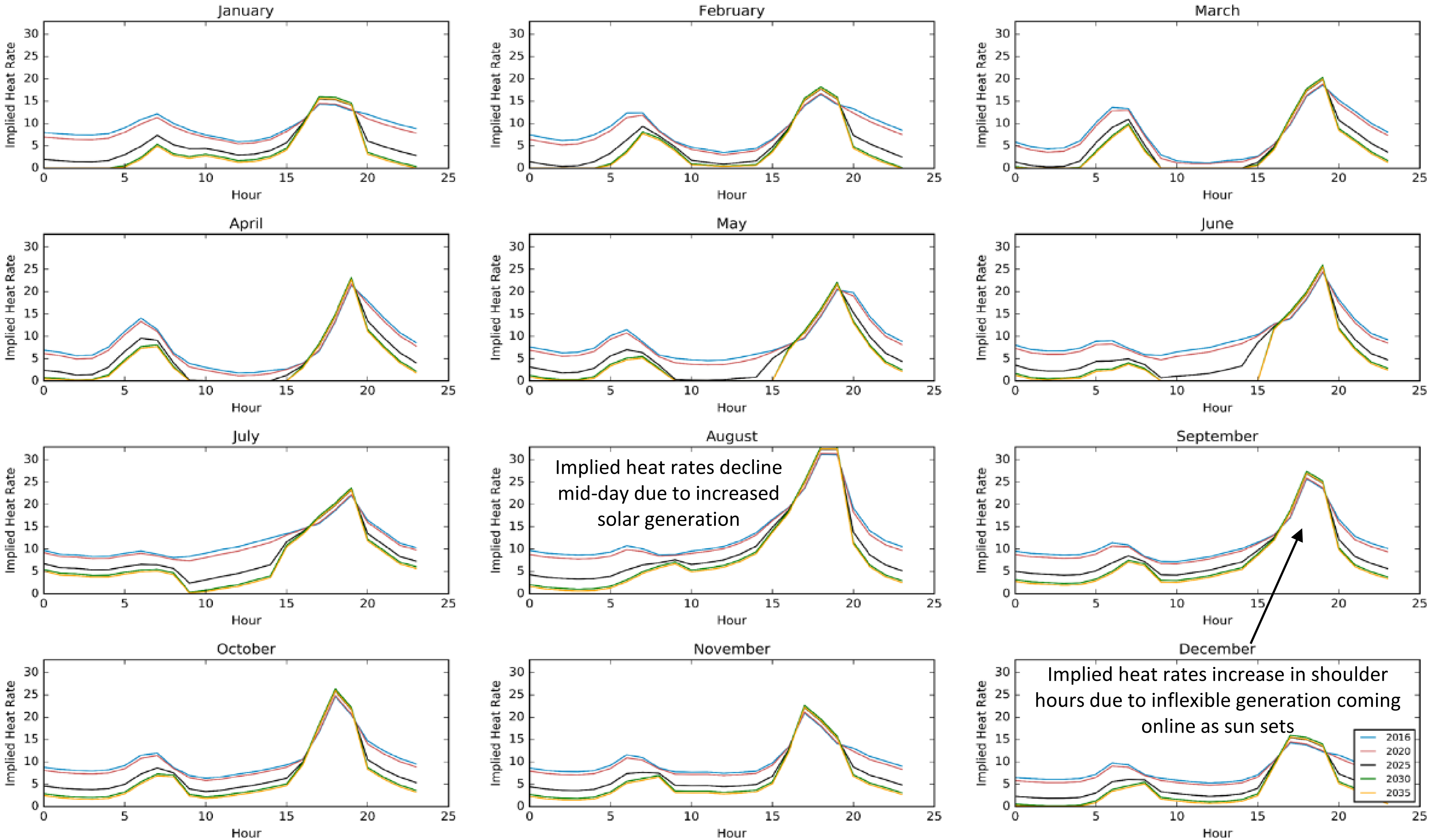
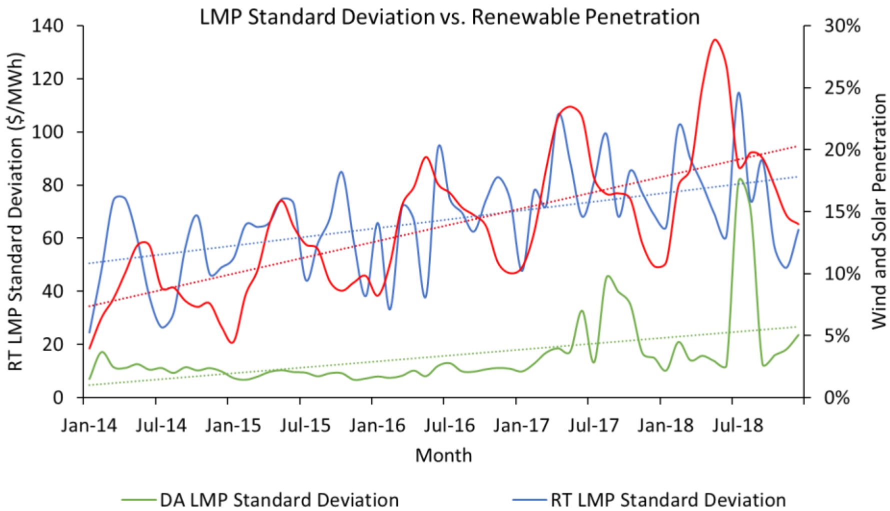
Implied Heat Rate Forecast (SP-15) Selected Years



LMP Volatility vs. Renewable Penetration (CAISO)



Year	Wind and Solar Penetration (%)	DA LMP Volatility*	RT LMP Volatility*
2014	8%	$12	$53
2015	11%	$9	$64
2016	14%	$12	$70
2017	17%	$26	$80
2018	19%	$40	$79

*Volatility = Standard deviation in prices ($/MWh)

- When renewable penetration in a system increases from 10% to 20%, volatility becomes more apparent
- High correlation between renewables and LMP volatility is more striking in the RT market as RT pricing fills the voids (discrepancies in generation between day-ahead and real-time)
- Volatility increases at a faster rate than renewable penetration in the RT market
- Volatility will increase dramatically as renewable penetration increases

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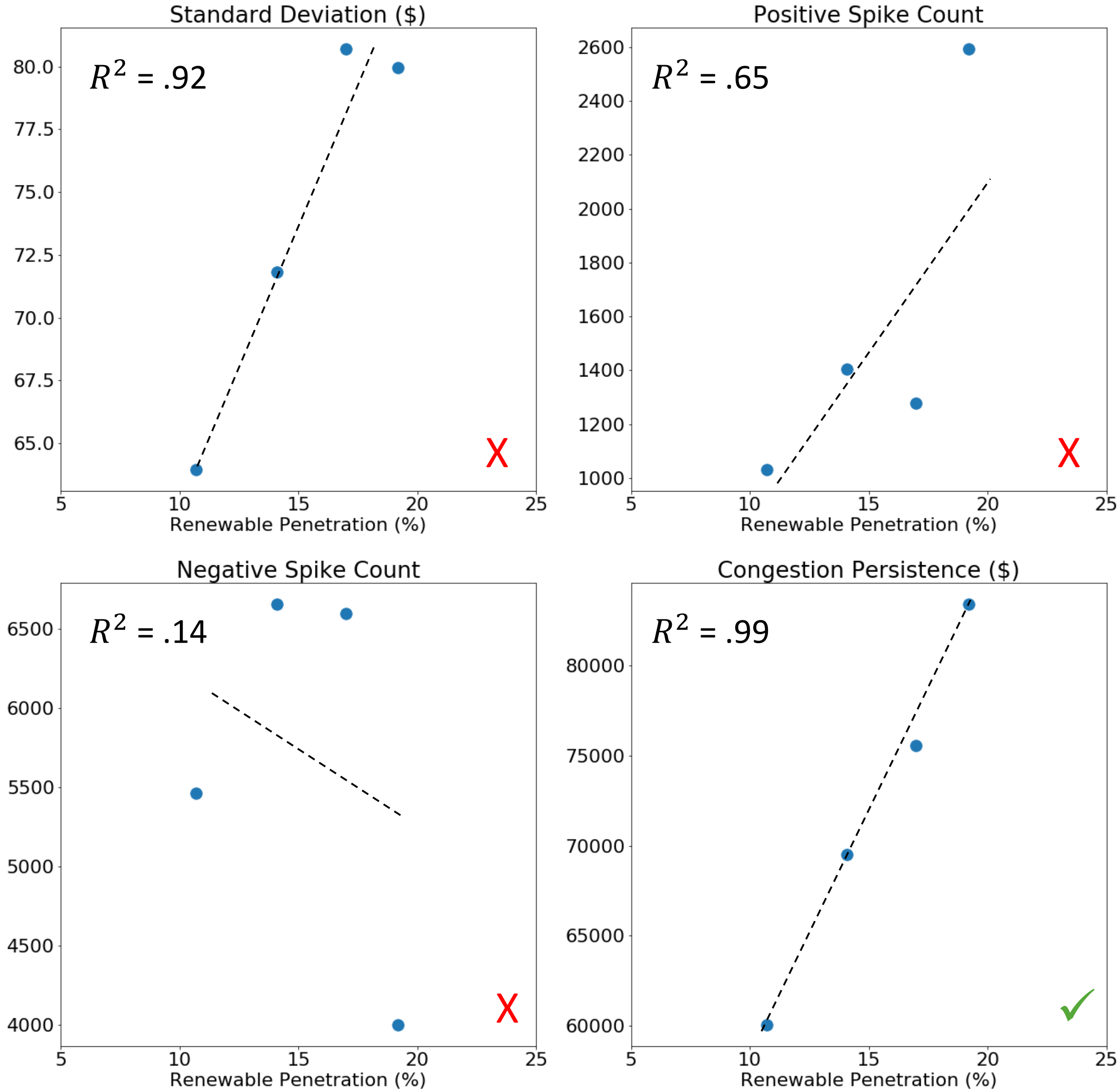
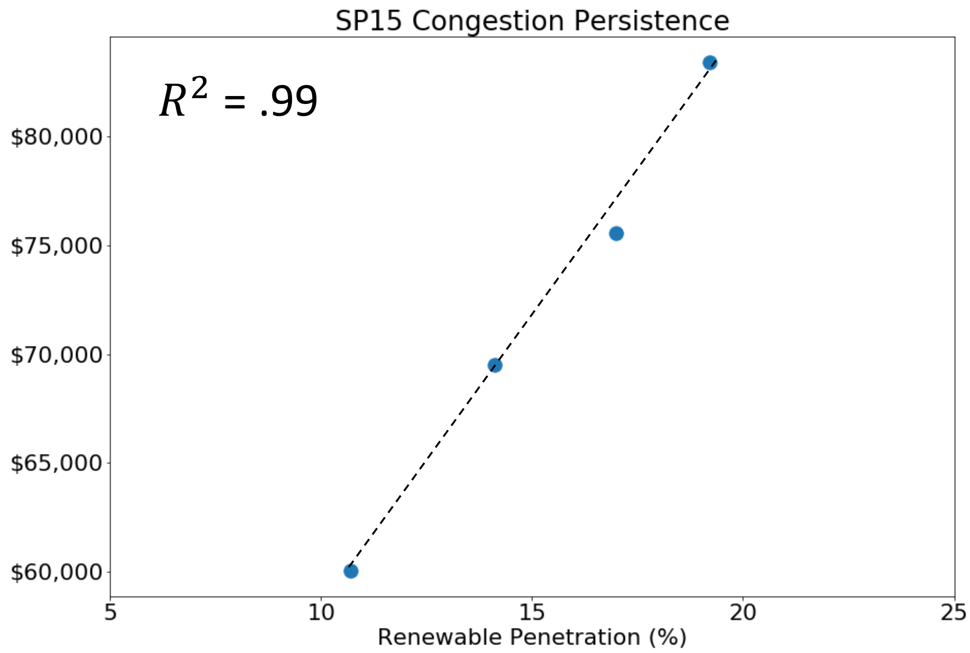
SP15: Trends vs. Renewable Penetration



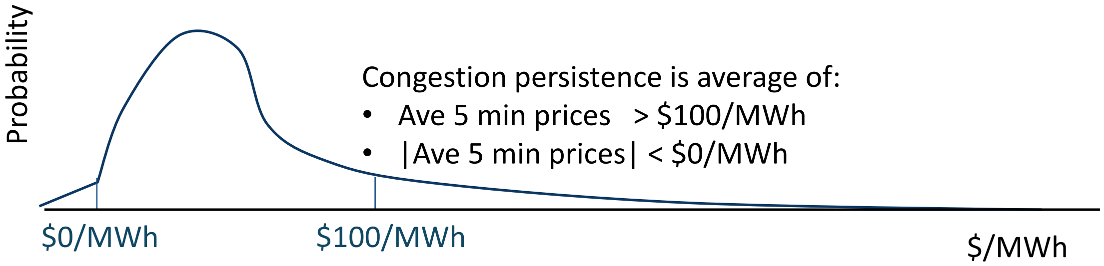
Congestion Persistence of the Real-Time Energy Prices has the strongest relationship with Renewable Penetration.

Key takeaway:
Congestion persistence explains impact of renewables on real-time market price spikes. Battery revenues will increase in future years even if volatility does not increase.

Definitions of Congestion Persistence



Key takeaway: Congestion persistence explains that real-time prices will continue to add value for storage as renewable penetration rates increase.



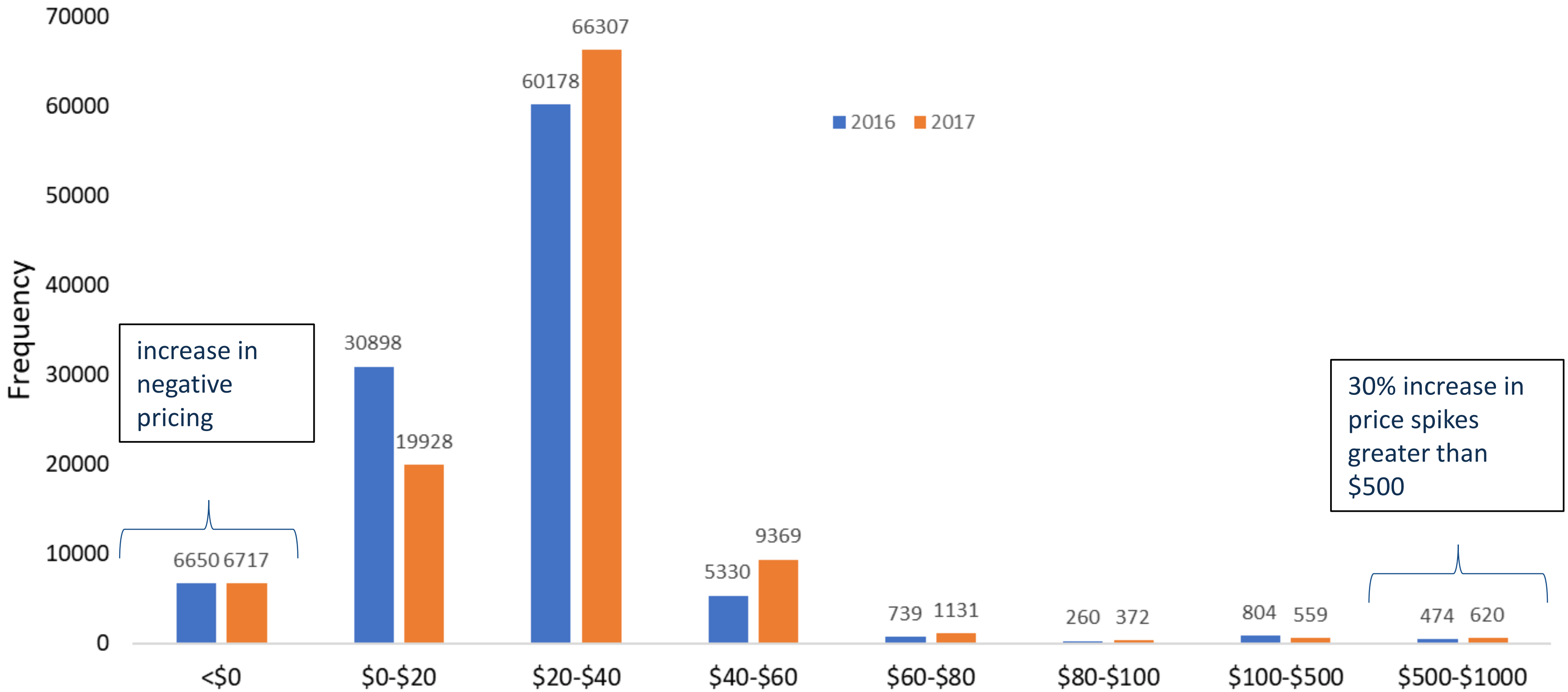
Congestion persistence is average of:

- Ave 5 min prices > $100/MWh
- |Ave 5 min prices| < $0/MWh

Congestion persistence is calculated as the sum of all prices above 100 plus the sum of all prices below 0 divided by the market timestep. It is the strongest driver of energy arbitrage opportunity, and can be interpreted as the upper bound for revenue of a BESS system with no energy constraint.

SP15 5-minute Market Price Frequencies

- Price Spikes are due to Imbalance between day-ahead and real-time prices
- Renewables combined with lack of flexible thermal generation, and congestion, both positive and negative spikes
- With more extreme pricing, volatility increases



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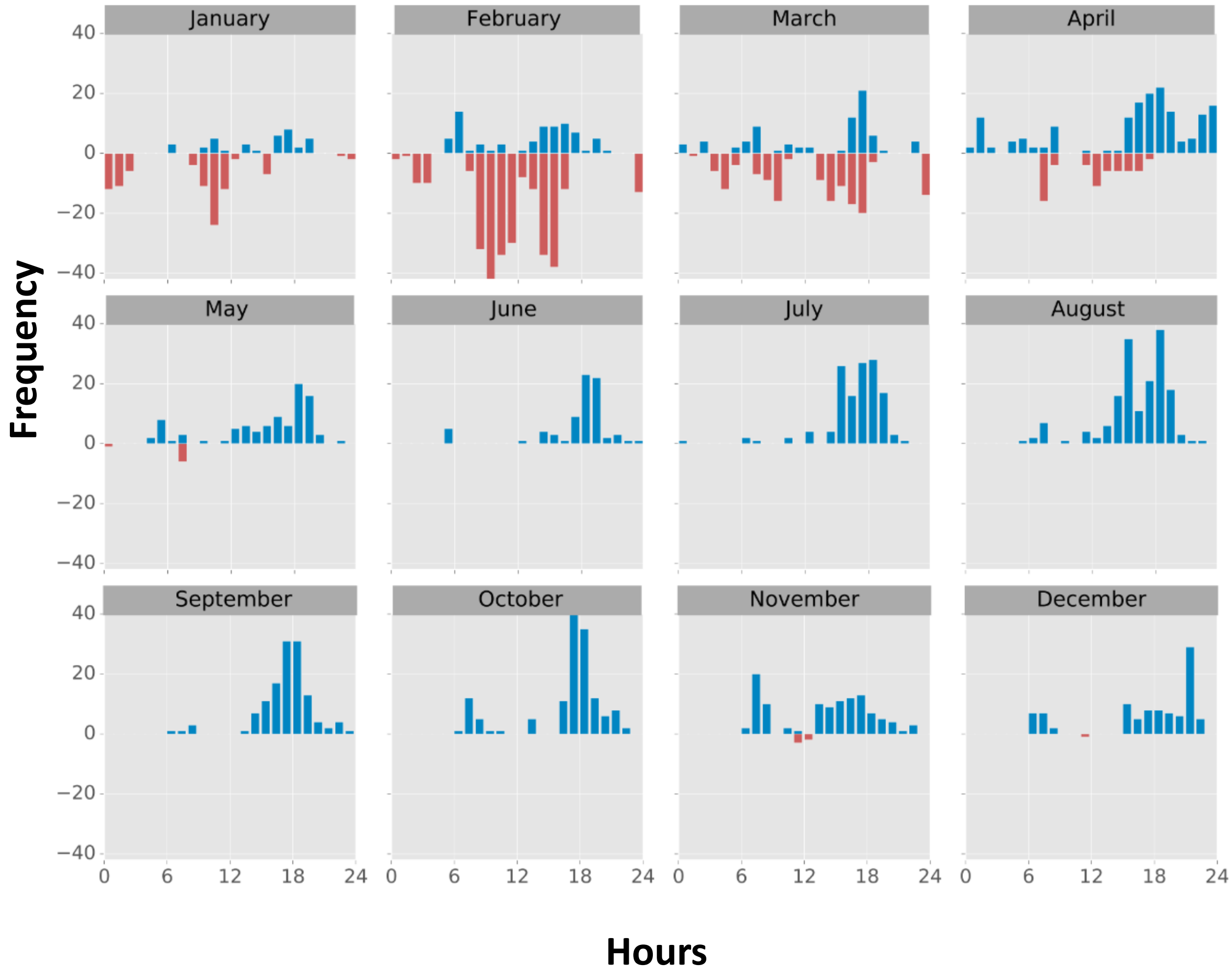
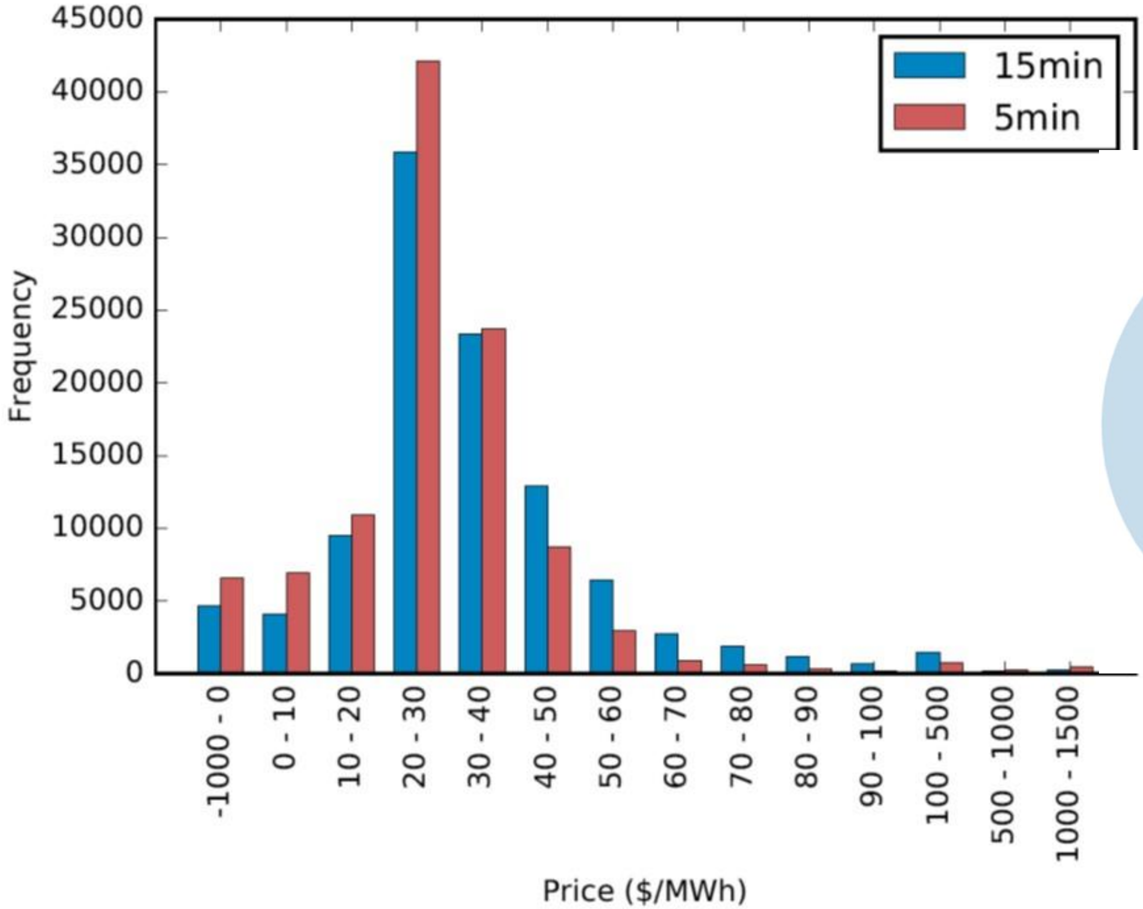
SP15 Historic Price Spikes per Month 2017



- RT Price spikes are defined as >$100 and -$20 due to tax credits
- Some negative pricing seen in January to May due to high hydro, some solar generation, and lower load
- July-September sees positive price spikes due to declining solar generation and high load in evening hours

Price Frequency Plot for 15 and 5 minute Markets

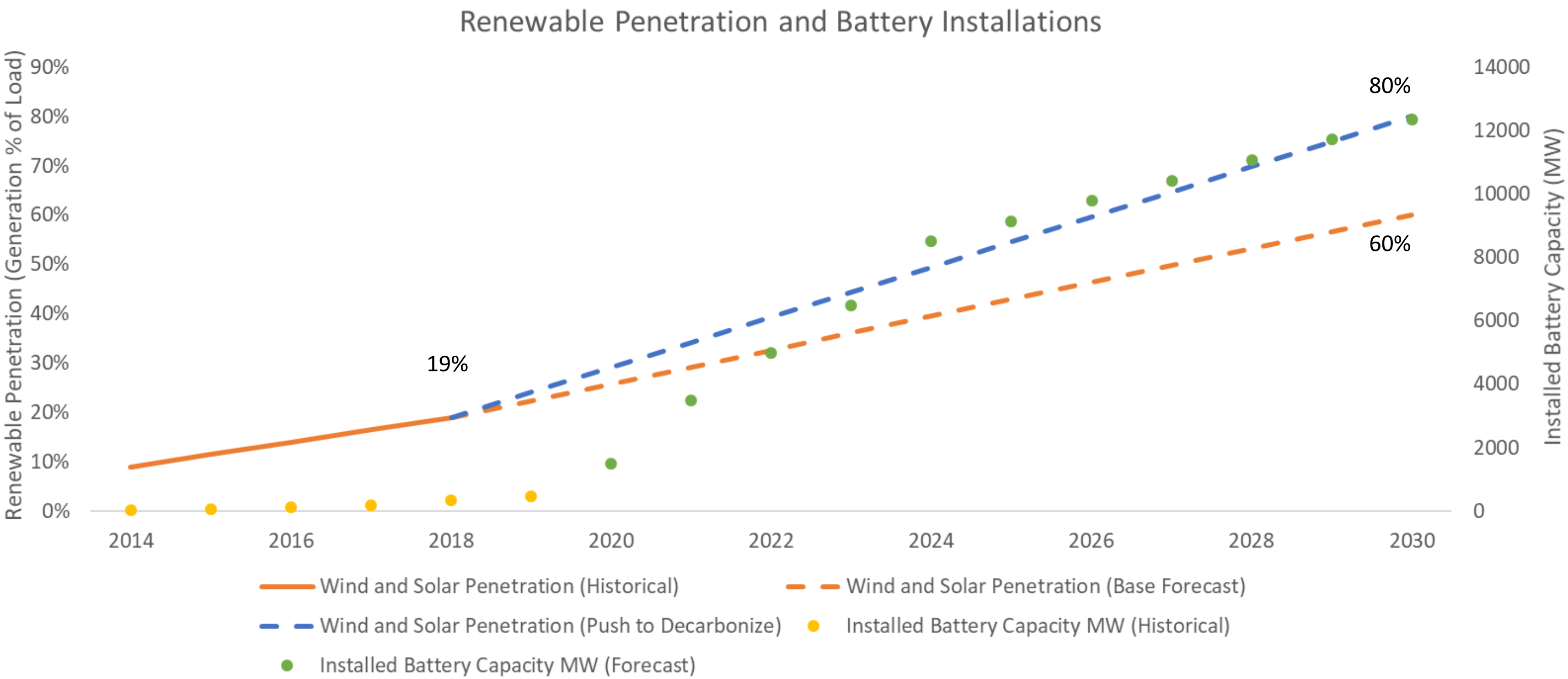
- Limited overlap creates additional profit opportunities for real-time price spikes
- ISO offer optimization can significantly improve profitability



Overlap of 15 min and 5 min prices spikes limited to 25% of time

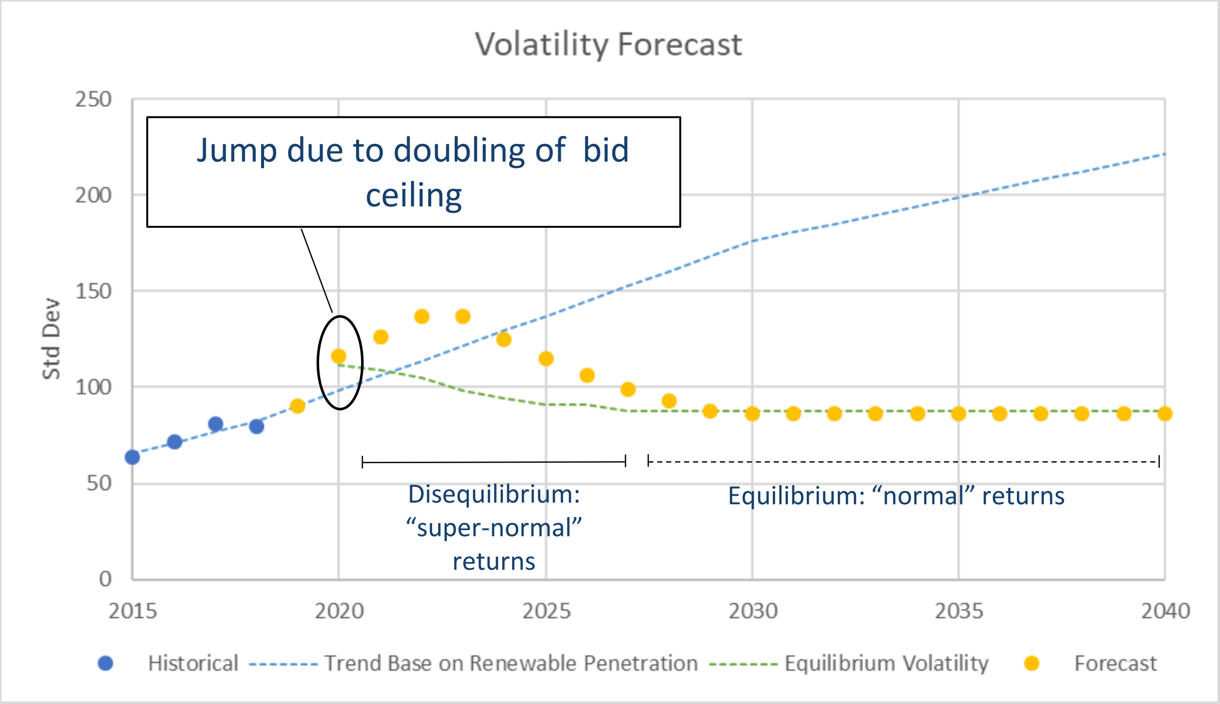
CAISO Renewable Penetration as a % of Load

Projected to Increase More Aggressively with Further Push to Decarbonize



- Renewable penetration as a % of load is increasing with greater RPS standards and renewable goals in every market
  - Growth is surpassing current goals given the greater push to decarbonize
- CA is projected to reach 60% RPS by 2030 per SB100 and 100% clean energy by 2045
- Battery growth to ~6x the mandate on IOU's alone by 2024 and then proportional to renewable installations

Projected SP15 Volatility



Forecast of volatility:

- Follows the empirical relationship between volatility and renewable penetration. Years 1-5
- Volatility growth tapers off to the long run equilibrium (8% returns) as more batteries enter the system and lower the price spikes. Years 6-10
- Additional volatility is added to the system in 2020 when the bid ceiling in CAISO doubles from $1000/MWh to $2000/MWh. Super-normal returns exist while the system is in a disequilibrium state, but eventually normal returns will prevail for new assets with lower capital costs.

Profiting from New Market Price Dynamics

Adapt to the opportunities of the market: Real-time Energy vs Ancillaries vs Physical Hedge for Renewables

Short duration storage makes economic sense today

On a merchant basis, storage as a capacity resource is challenging because of declining cost.

Increase in price ceilings will have a pronounced effect on the value of storage at Pnodes hitting ceiling.

Multi-pass Model Structure to Allow Imperfect Information & Sub-hourly Dispatch for Different Cases

- Incorporating imperfect foresight into generation dispatch captures forecast error between day-ahead unit commitment and real-time conditions

Objective: Maximize Profits

f(DA [Energy Reg-Up, Reg-Down], RT [Energy, Reg-Up, Reg-Down])

Subject to

- Battery limits
- Efficiency curves
- ISO market rules

Solver

Optimization of energy and ancillary market participation across day-ahead and real-time prices

Day-ahead

- Day-ahead dispatch and unit commitment to day-ahead prices, forecasted renewables

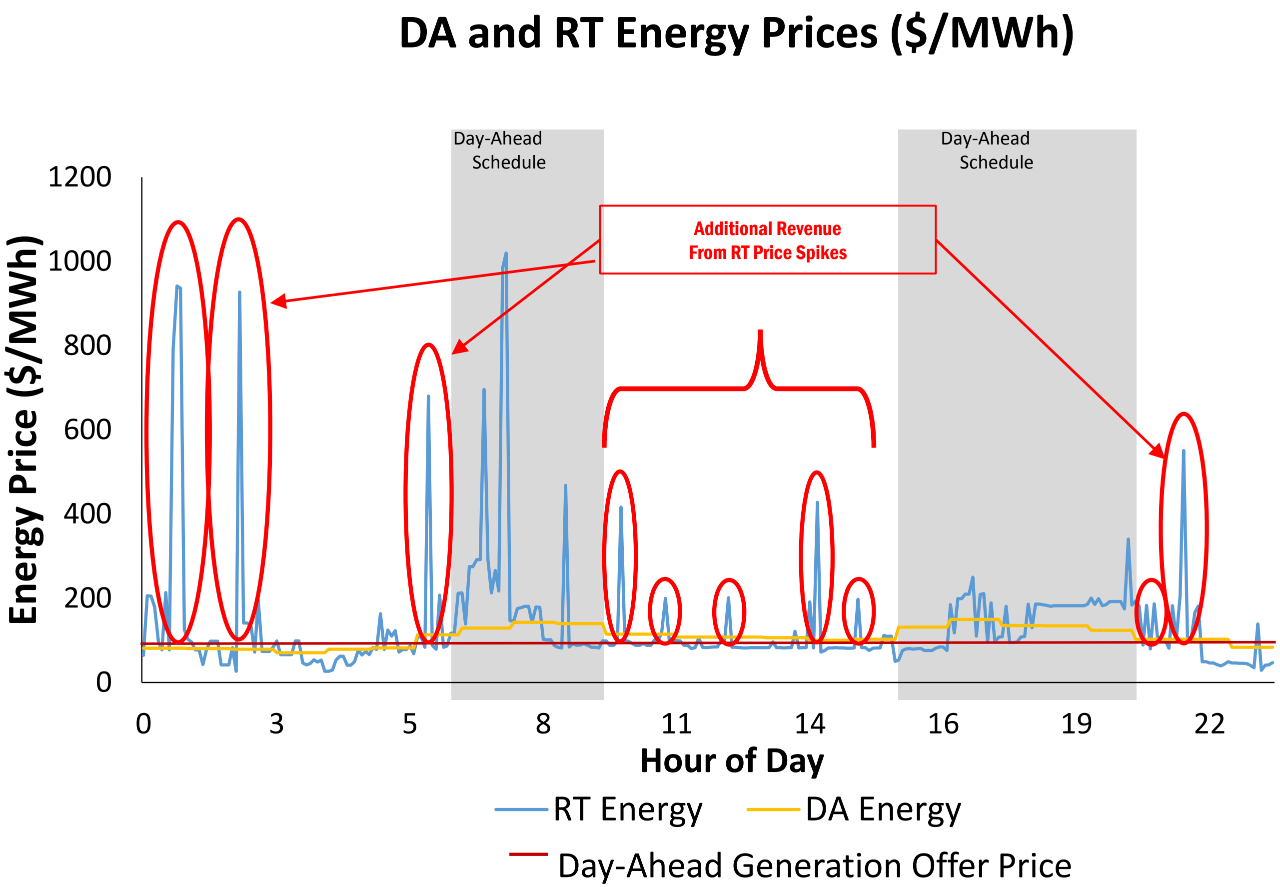
15 minute

- Dispatch to realized renewables at 15-min prices

5 minute

- Re-dispatch to EIM 5-min prices

Energy Prices: Day-Ahead (Hourly) & Real-Time (5-minute)



Importance of price spikes:

- Occur ~1.5% of time
- Represent 22% of average price and 30% of retail costs because of demand coincidence

Opportunity of chasing spikes:

- Chase price spikes
- Provide ancillaries
- Energy Prices: Day-ahead (hourly) and Real-time (5-minute)

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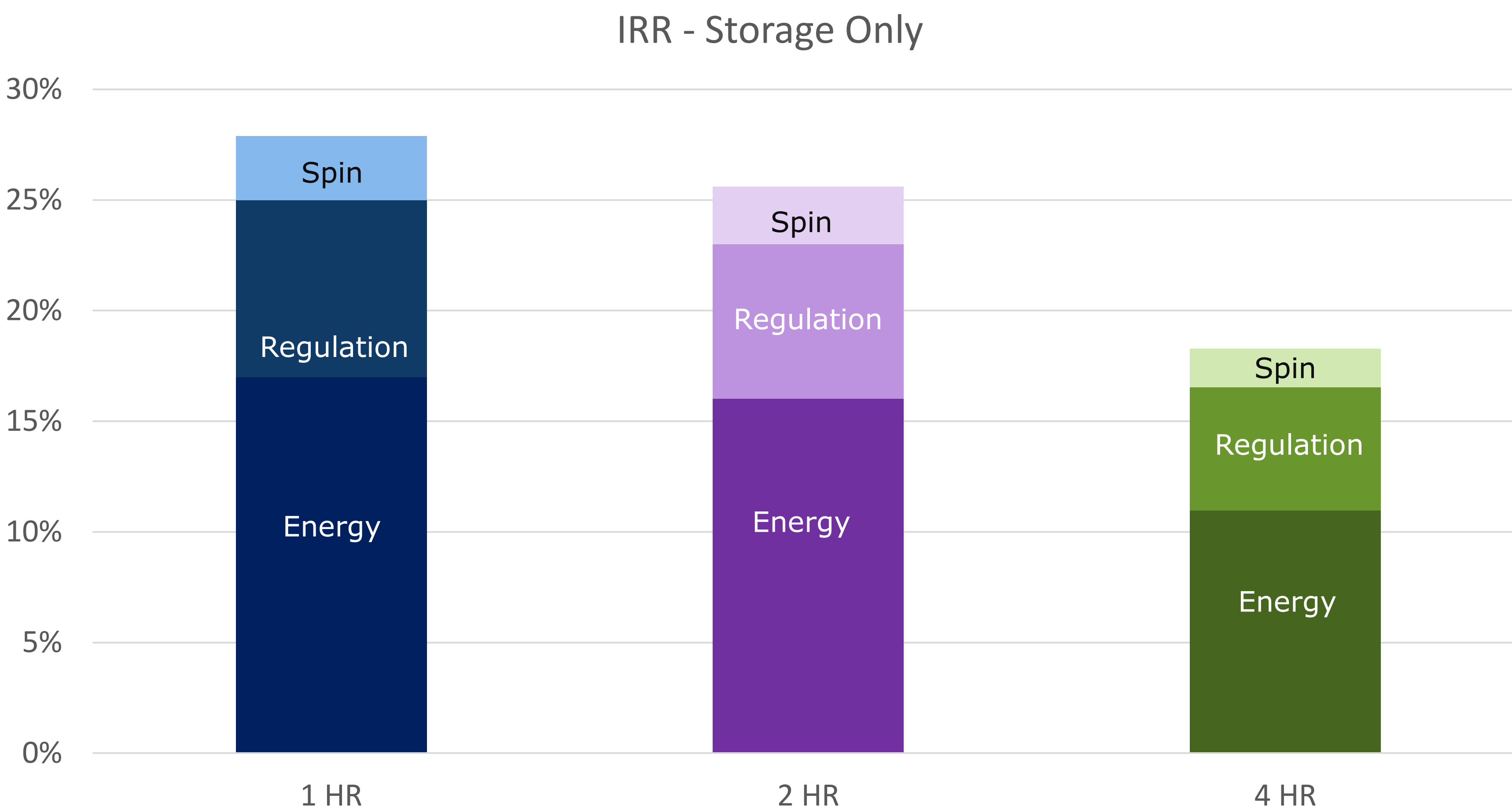
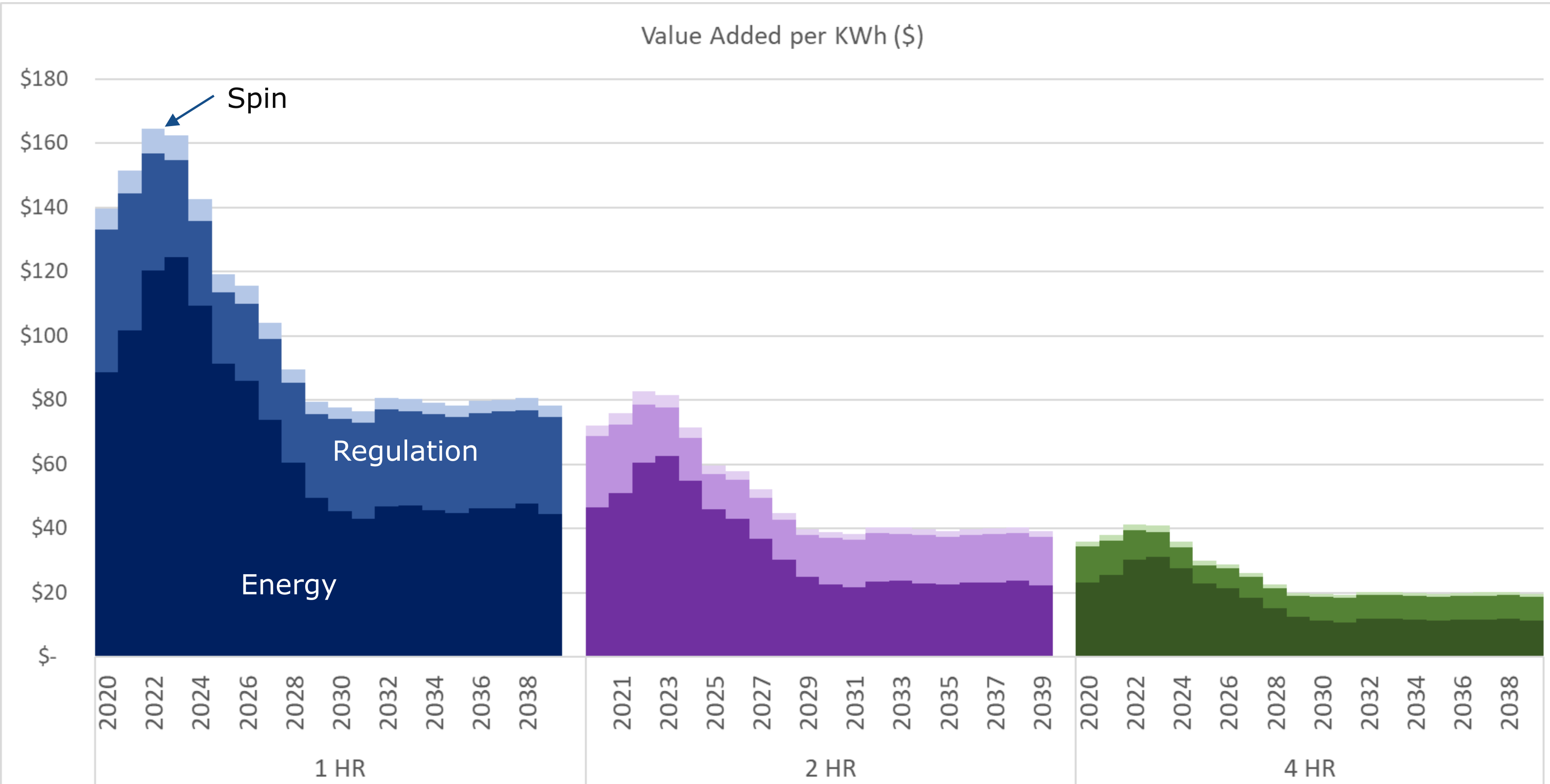
Rate of Return by Storage Duration



Higher return for shorter duration systems have more value per KWh than longer duration systems, implying chasing prices from the belly of the duck to the head of the duck is uneconomic relative to capturing real-time price volatility.

Return per KWh of Storage



Shorter duration systems have more value per KWh than longer duration systems, implying chasing prices from the belly of the duck to the head of the duck is uneconomic relative to capturing real-time price volatility.

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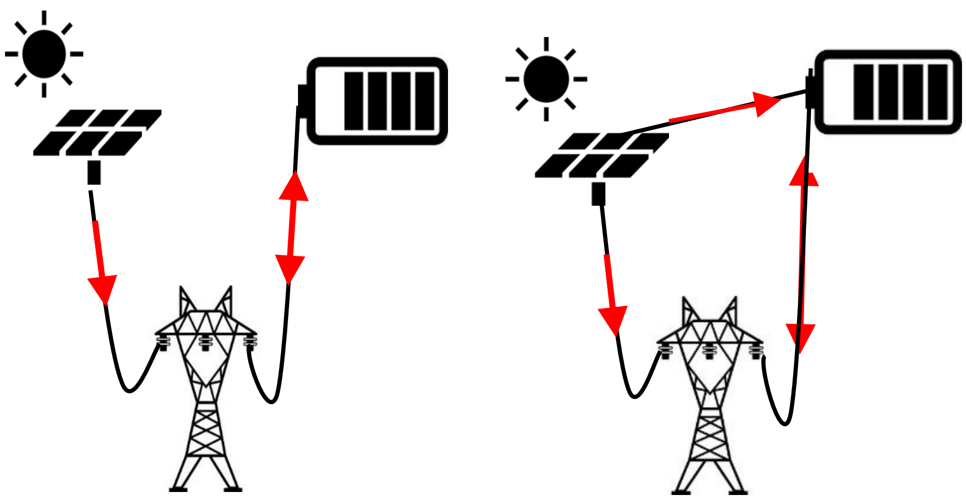
Storage Will Be Used to Shift Solar to Peak Load Hours

	HE1	HE2	HE3	HE4	HE5	HE6	HE7	HE8	HE9	HE10	HE11	HE12	HE13	HE14	HE15	HE16	HE17	HE18	HE19	HE20	HE21	HE22	HE23	HE24
Jan	-	-	-	-	-	-	-	0	24	59	74	72	68	69	72	73	62	27	3	-	-	-	-	-
Feb	-	-	-	-	-	-	-	8	44	76	84	85	81	77	74	74	69	43	11	-	-	-	-	-
Mar	-	-	-	-	-	-	0	25	69	91	97	98	98	96	94	90	82	60	21	0	-	-	-	-
Apr	-	-	-	-	-	-	10	51	87	97	99	100	100	102	103	102	100	83	39	6	-	-	-	-
May	-	-	-	-	-	0	20	61	89	99	104	105	105	104	106	106	103	92	52	12	-	-	-	-
Jun	-	-	-	-	-	0	26	71	98	106	108	109	108	107	105	100	97	86	55	16	-	-	-	-
Jul	-	-	-	-	-	0	15	50	77	88	92	93	95	96	93	89	78	62	39	11	-	-	-	-
Aug	-	-	-	-	-	-	10	46	80	95	101	99	93	90	88	85	72	47	21	4	-	-	-	-
Sep	-	-	-	-	-	-	4	35	73	91	96	95	91	89	89	87	81	54	16	0	-	-	-	-
Oct	-	-	-	-	-	-	1	29	72	89	89	88	86	84	86	84	72	35	5	-	-	-	-	-
Nov	-	-	-	-	-	-	-	13	49	73	77	75	74	75	77	76	55	17	0	-	-	-	-	-
Dec	-	-	-	-	-	-	-	3	29	61	70	67	64	65	67	68	49	15	-	-	-	-	-	-

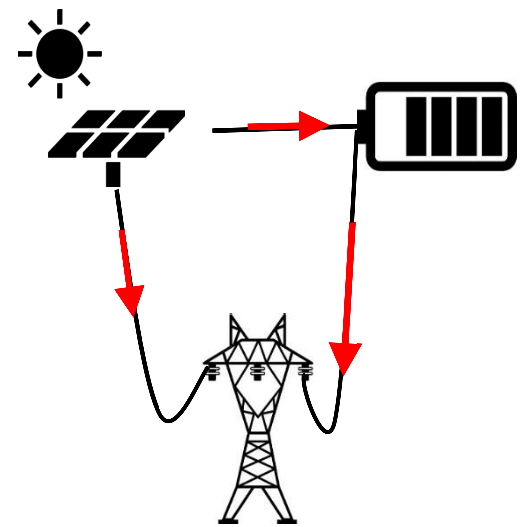
	HE1	HE2	HE3	HE4	HE5	HE6	HE7	HE8	HE9	HE10	HE11	HE12	HE13	HE14	HE15	HE16	HE17	HE18	HE19	HE20	HE21	HE22	HE23	HE24
Jan	-	-	-	-	-	-	49	0	15	31	33	27	28	32	32	41	43	26	100	100	-	-	-	-
Feb	-	-	-	-	-	-	68	8	24	38	32	36	43	49	40	43	48	38	100	98	-	-	-	-
Mar	-	-	-	-	-	-	88	26	35	49	57	56	55	55	59	58	60	57	100	100	-	-	-	-
Apr	-	-	-	-	-	-	7	27	59	70	70	71	76	68	73	78	44	31	100	99	96	19	-	-
May	-	-	-	-	-	0	11	29	60	80	78	81	87	83	86	93	26	15	100	100	100	37	-	-
Jun	-	-	-	-	-	0	4	11	39	69	77	85	91	89	19	99	98	100	100	100	93	32	-	-
Jul	-	-	-	-	-	0	6	21	40	63	76	74	80	4	4	89	79	100	100	96	62	18	-	-
Aug	-	-	-	-	-	-	5	13	40	65	78	78	83	3	2	84	72	100	100	96	45	2	-	-
Sep	-	-	-	-	-	-	2	14	26	38	64	63	66	66	6	86	80	100	100	99	40	-	-	-
Oct	-	-	-	-	-	-	0	12	26	34	45	72	76	76	71	75	3	2	100	100	78	-	-	-
Nov	-	-	-	-	-	-	-	9	29	37	39	41	43	43	53	59	2	1	100	94	66	-	-	-
Dec	-	-	-	-	-	-	34	3	11	30	34	30	29	32	30	36	37	15	100	99	-	-	-	-

Charging Constraints on the Storage

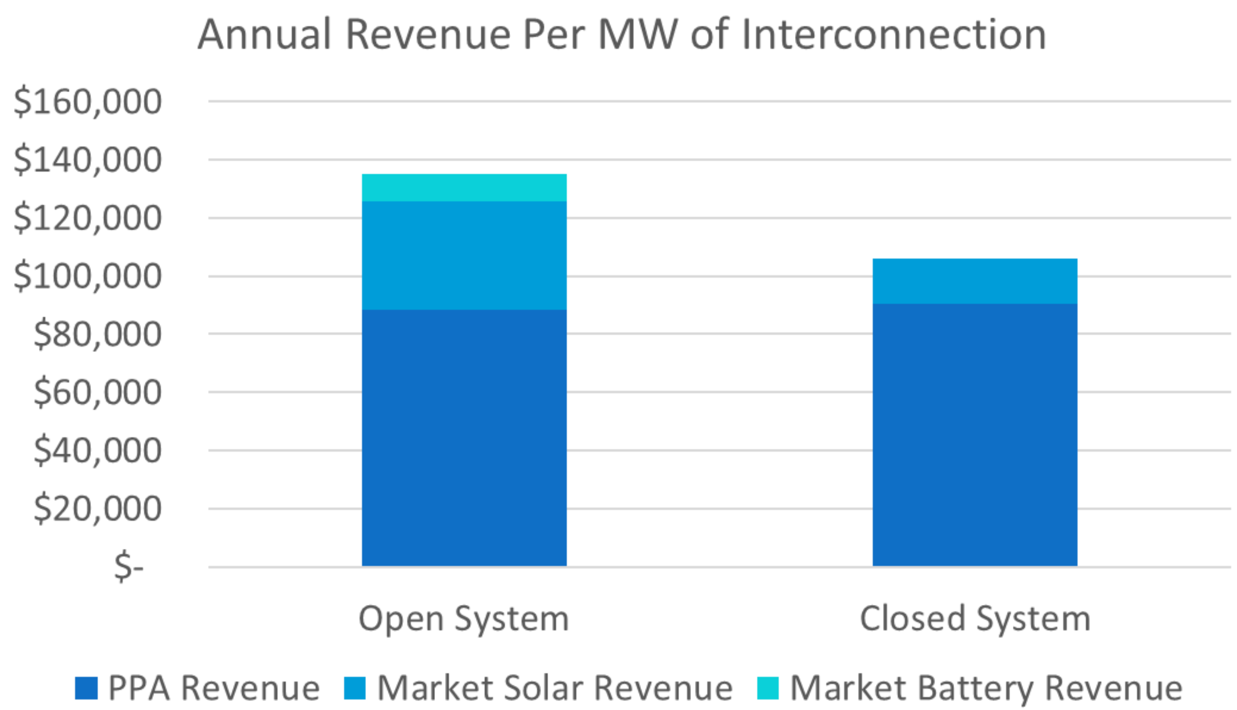
Open System:
Renewable and battery operate to direct grid deliveries for renewables + storage



Closed System:
Renewable sole power source for battery charging. Used for Investment Tax Credit (ITC of 30%)



Participating in Real-time Energy Market Furthers The Value of the Storage

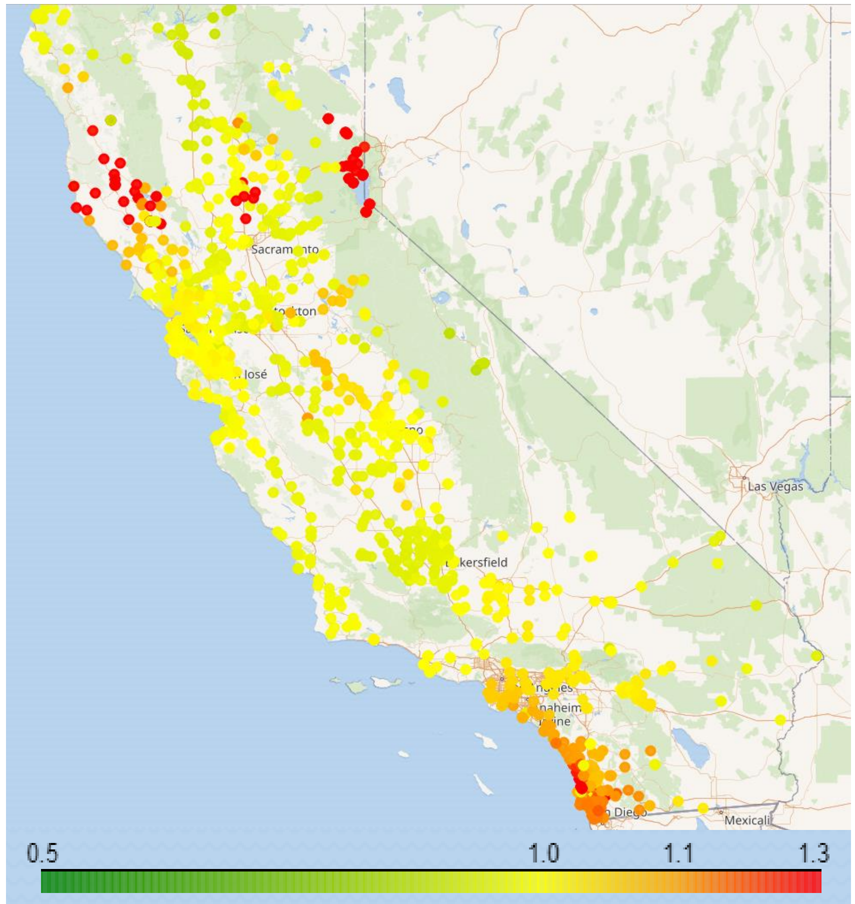


- Open systems usually earn about 5% to 30% more than closed
- In this example, open system earns 23% more than closed system annually.
- ITC impinges flexible operation and impairs system economics

Optimal Siting: Not All Sites Are Equal

Metric Design

- Measures the value of all price spikes at each node
- Differentiation between locations is driven by the persistence of large positive/negative congestion components



Units: Normalized to Median
(larger is better)

Observations

- Relative to standard deviation in prices, shifts hot spots to coast from central valley, where congestion is more difficult to mitigate
- Northern CA and the Central Valley rank better that intuition would guess
- Areas near lakes, rivers, mountains, or political borders rank higher than we would expect

Ascend Analytics

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Supplemental Materials

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NARUC Resolution on Storage Valuation

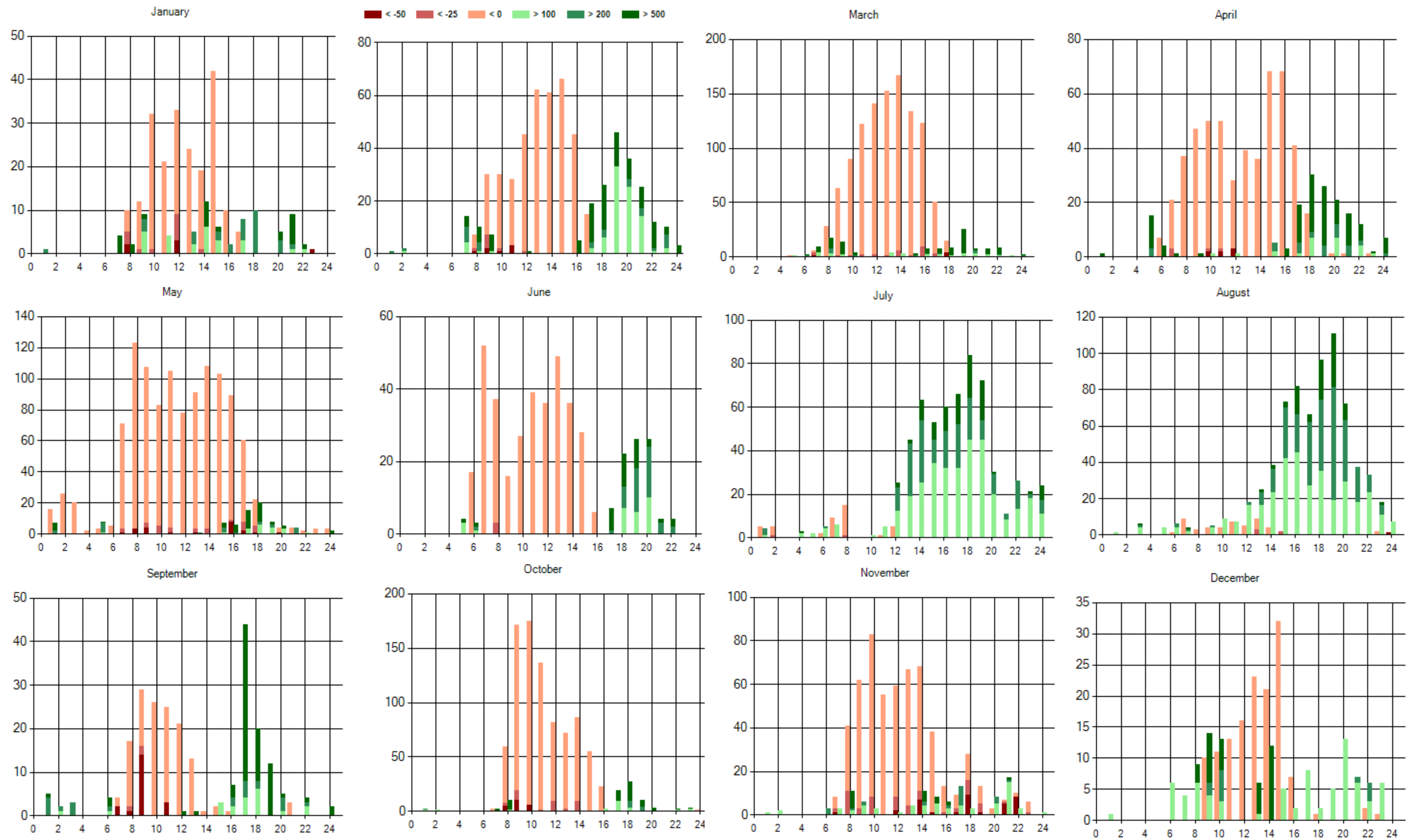
November 16, 2018 EL-4/ERE-1 Resolution on Modeling Energy Storage and Other Flexible Resources

- "Utilities should develop, if appropriate, new modelling tools and new planning frameworks that allow for a more complete evaluation of flexible resources, such as energy storage"
- "Planning frameworks and modeling tools that are publicly and commercially available should model the full spectrum of services that energy storage and flexible resources are capable of providing, including subhourly services"
- "Utilities should analyze a range of flexible resource options, such as energy storage, and current cost assumptions in their modelling, due to the diverse characteristics and resource lives of different technologies, with the goal of identifying and pursuing the most cost-effective opportunities that best meet the needs of the utilities' systems"

2018: Monthly Spike Count for SP-15

	Pos	Neg
January	101	70
February	172	320
March	122	887
April	91	529
May	76	854
June	74	309
July	729	20
August	741	3
September	108	20
October	50	718
November	158	98
December	173	170
Count	2,595	3,998
Count > 1000	176	
Std Dev	79	

Spike Count: 2018



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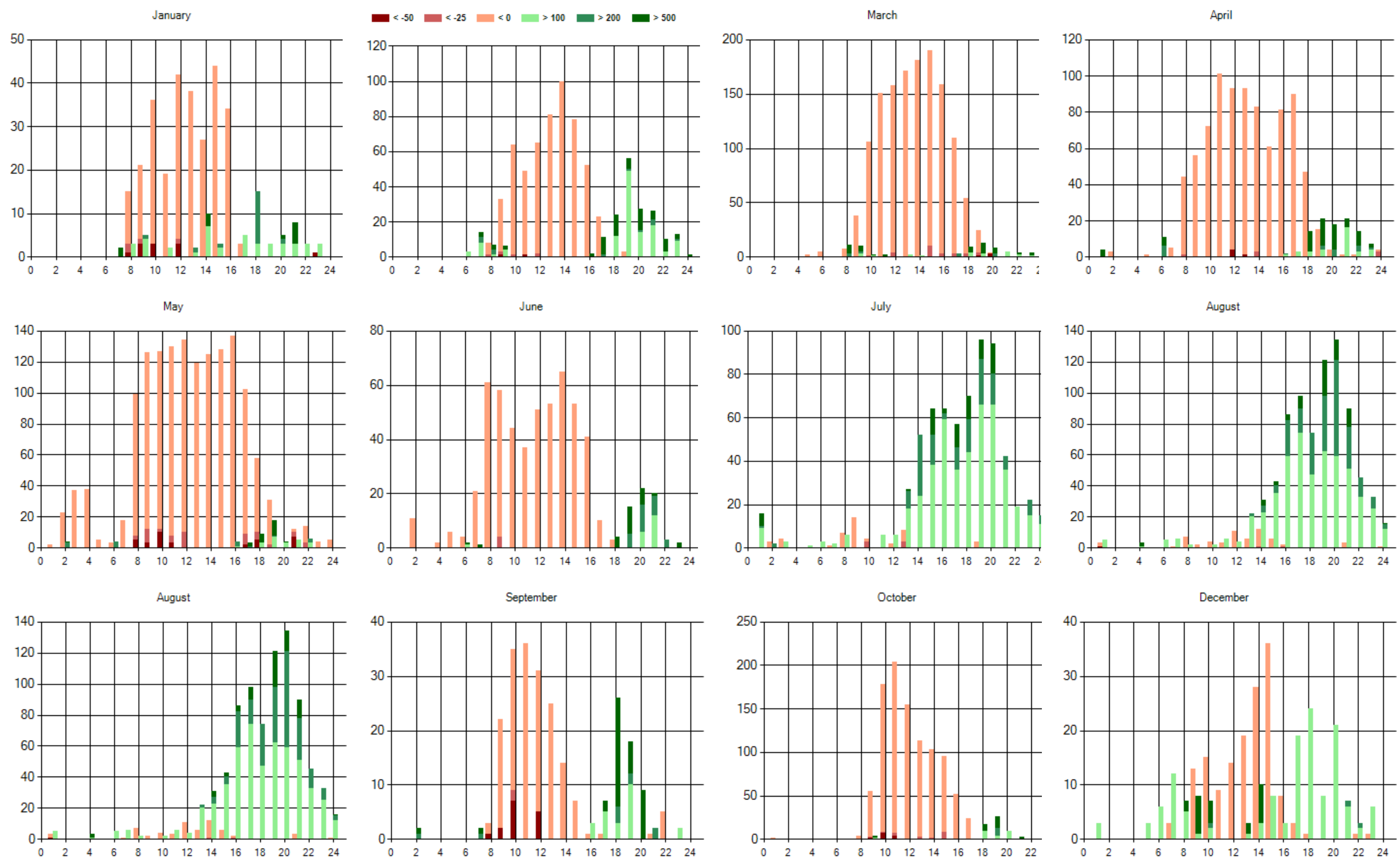
Spike Count: 2030



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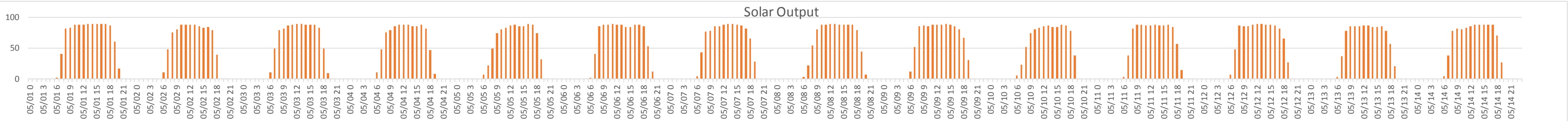
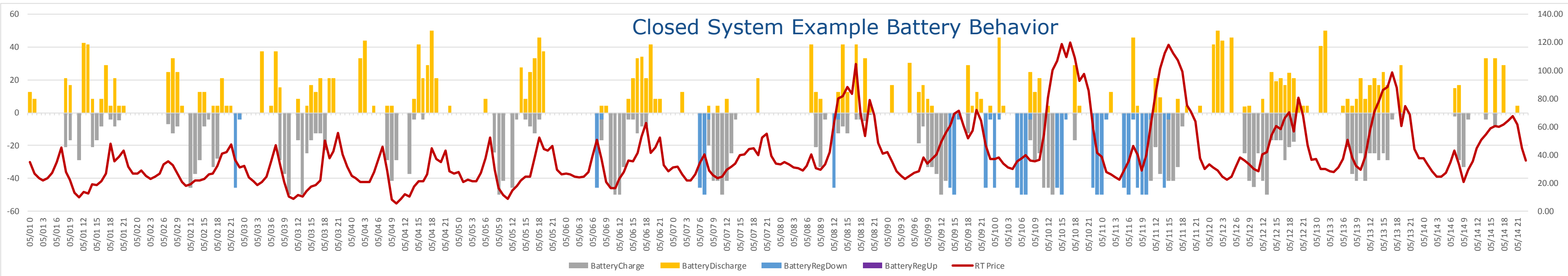
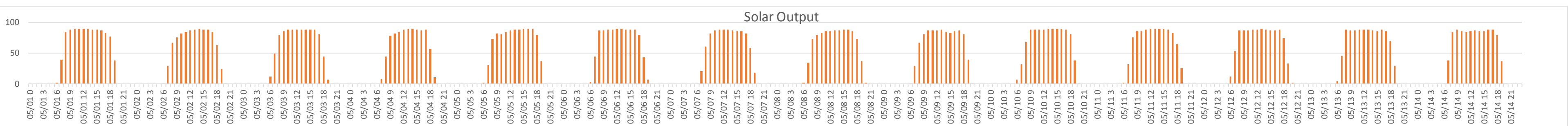
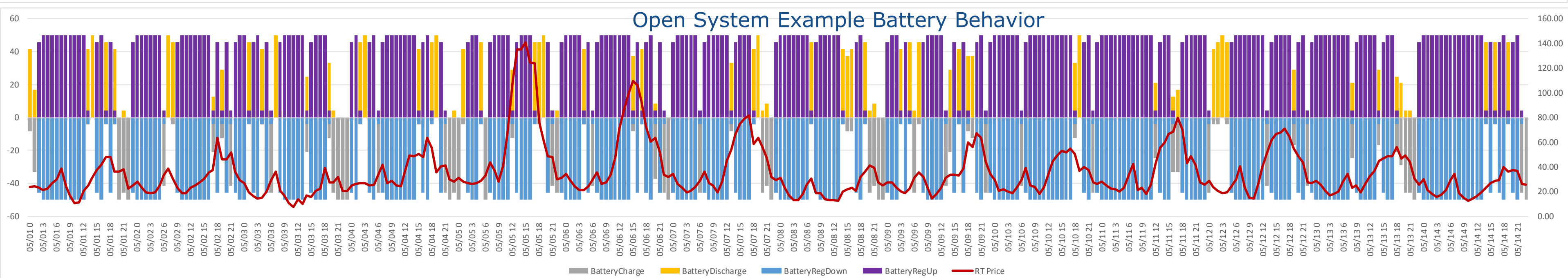
Illustrative Hourly Generation Comparisons









Ancillary Prices

Historic

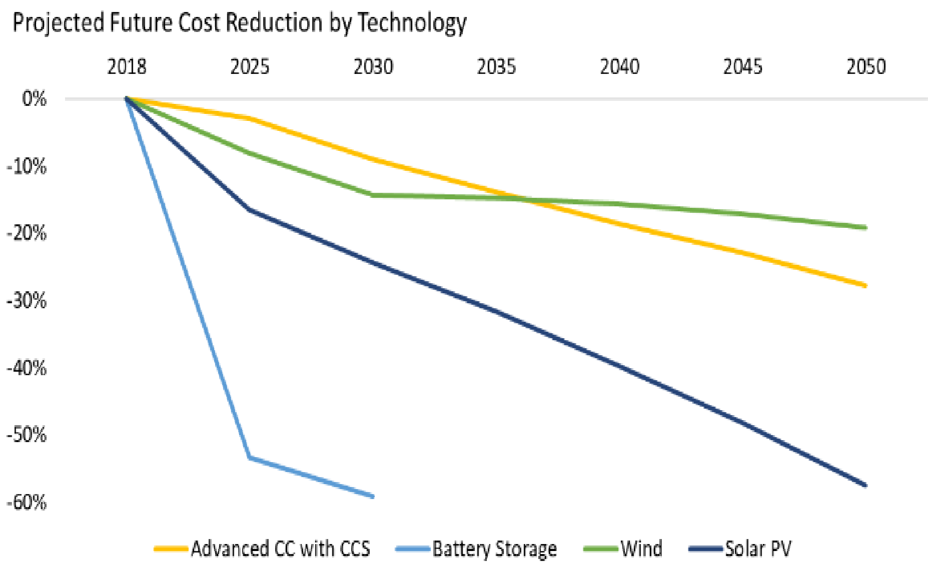
Forecast

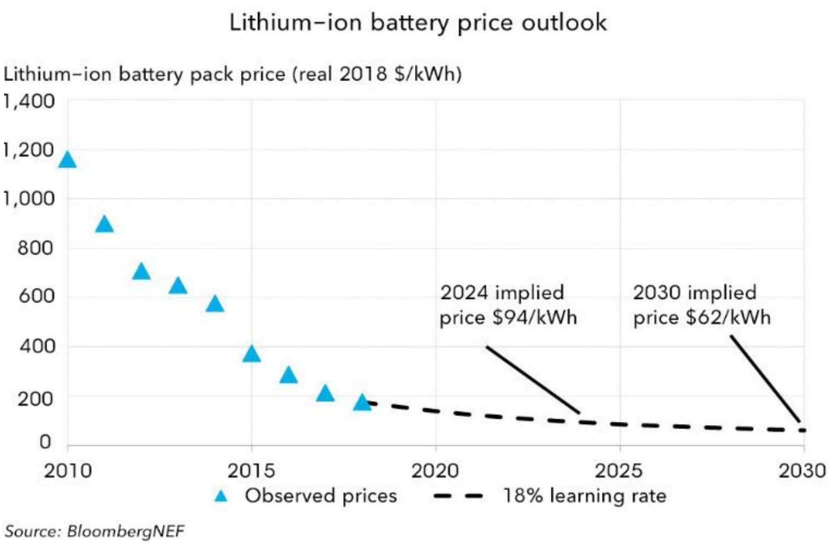
Year	Spin	Reg Up	Reg Down
2016	$4.38	$8.20	$6.90
2017	$7.67	$9.92	$5.52
2018	$6.76	$10.89	$10.33
2019	$6.37	$10.26	$9.74
2020	$5.97	$9.62	$9.12
2021	$5.55	$8.95	$8.49
2022	$5.12	$8.25	$7.83
2023	$4.67	$7.53	$7.14
2024	$4.20	$6.76	$6.42
2025	$4.04	$6.51	$6.17
2026	$3.88	$6.25	$5.93
2027	$3.71	$5.98	$5.67
2028	$3.54	$5.71	$5.41
2029	$3.37	$5.43	$5.15
2030	$3.19	$5.14	$4.88

Ancillary Service prices fall as batteries saturate the market.

Declining Costs for Storage

- Declining costs for storage makes investment "risky"?





- **Future technology costs taken from the NREL Annual Technology Baseline: https://atb.nrel.gov/electricity/data.html**
- **Li-Ion batter prices from Bloomberg New Energy Finance: https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/**