Realistic modeling of sub-hourly flexibility and energy storage in resource planning

ESIG 2023 Fall Technical Workshop

October 25, 2023

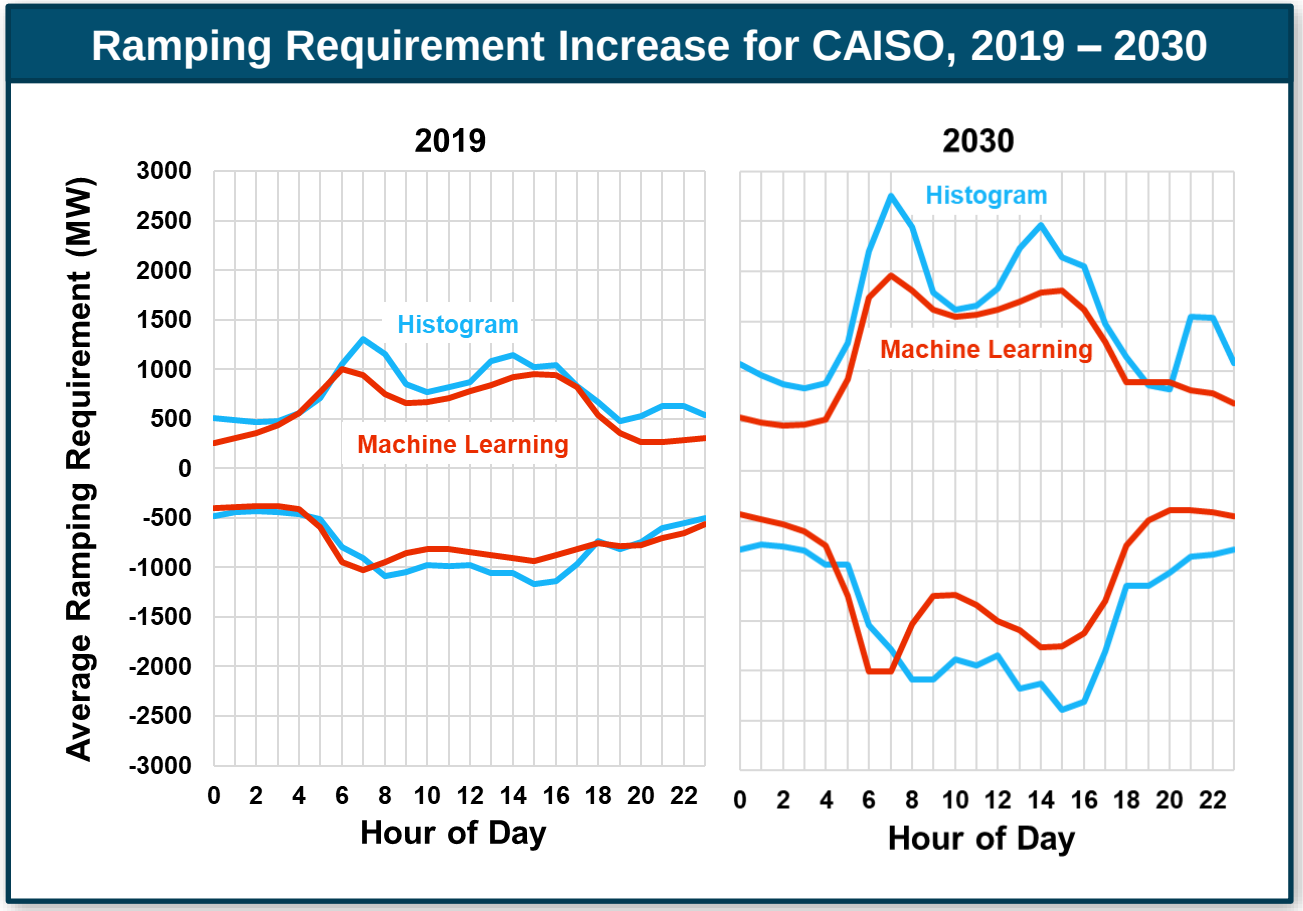
La Jolla, California

Energy+Environmental Economics

Arne Olson, Senior Partner

Need for grid services will grow with higher penetrations of wind and solar generation

- Grid operators have always balanced variability and uncertainty in demand and supply using ancillary services
- The need for grid services will grow as wind and solar increase due to increased variability and forecast errors
- The need for grid services will also become more dynamic as grid conditions change with the weather

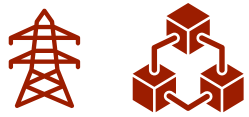


Source: E3, Predicting Reserve Needs Using Machine Learning, project partially funded with grant from ARPA-E

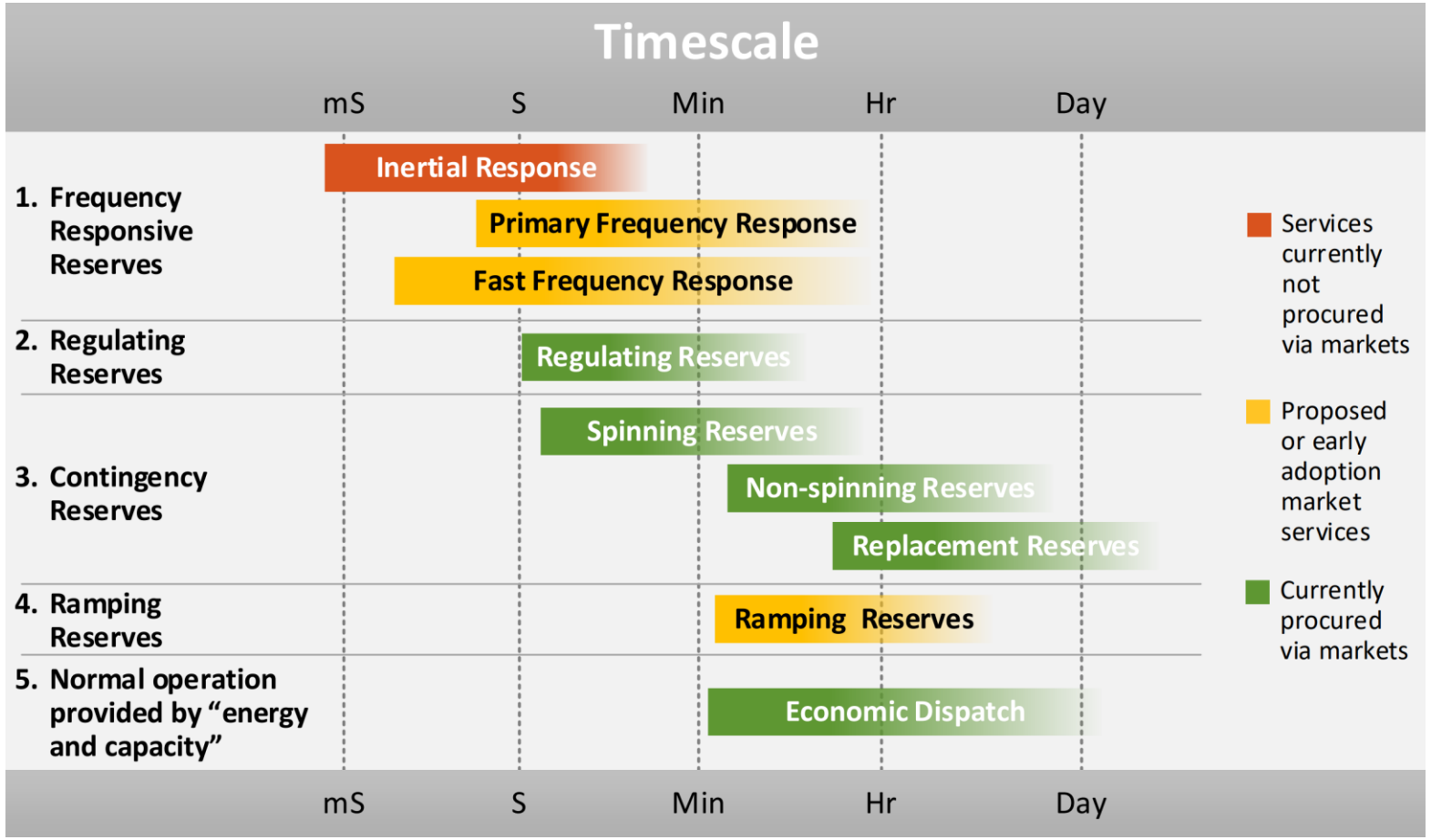
Operational Flexibility Drivers

Lower operational flexibility
(Operator has less control)

Higher operational flexibility
(Operator has more control)

Inflexible load		Flexible Load
Non-dispatchable solar and wind		Dispatchable / curtailable solar and wind
Inflexible thermal: high Pmin, slow ramp rate, must-run, etc.		Flexible thermal: quick start, quick ramping
Run-of-river/inflexible hydro		Dispatchable Hydro
Small system, fewer ties, or big ties relative to load		Larger system, more ties
Behind-the-meter storage operated to minimize customer bills		Storage operated to maximize system benefit

Reserve types and timescales



All reserves are held in one timeframe to prepare for another timeframe

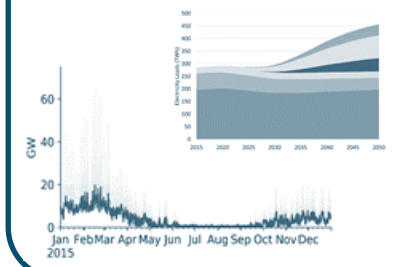
Reserves are used or released when needed during grid operations

https://www.nrel.gov/docs/fy19osti/72578.pdf

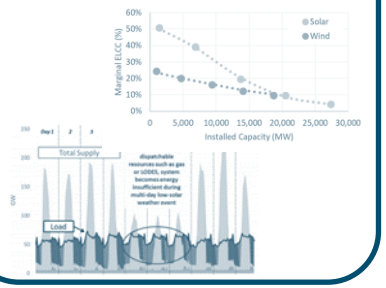
Portfolio planning framework

Inputs: resource and fuel costs, policy goals, resource potential, etc.

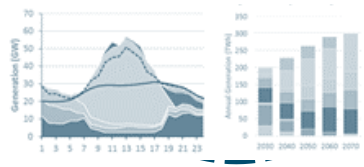
Modeling Input Development



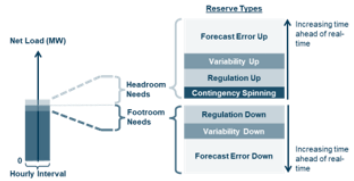
Reliability Assessment (Loss of Load Model)



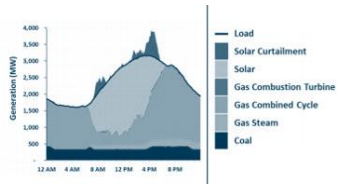
Portfolio Optimization (PLEXOS LT)



Reserve requirements (RESERVE)



Operability analysis (PLEXOS ST)

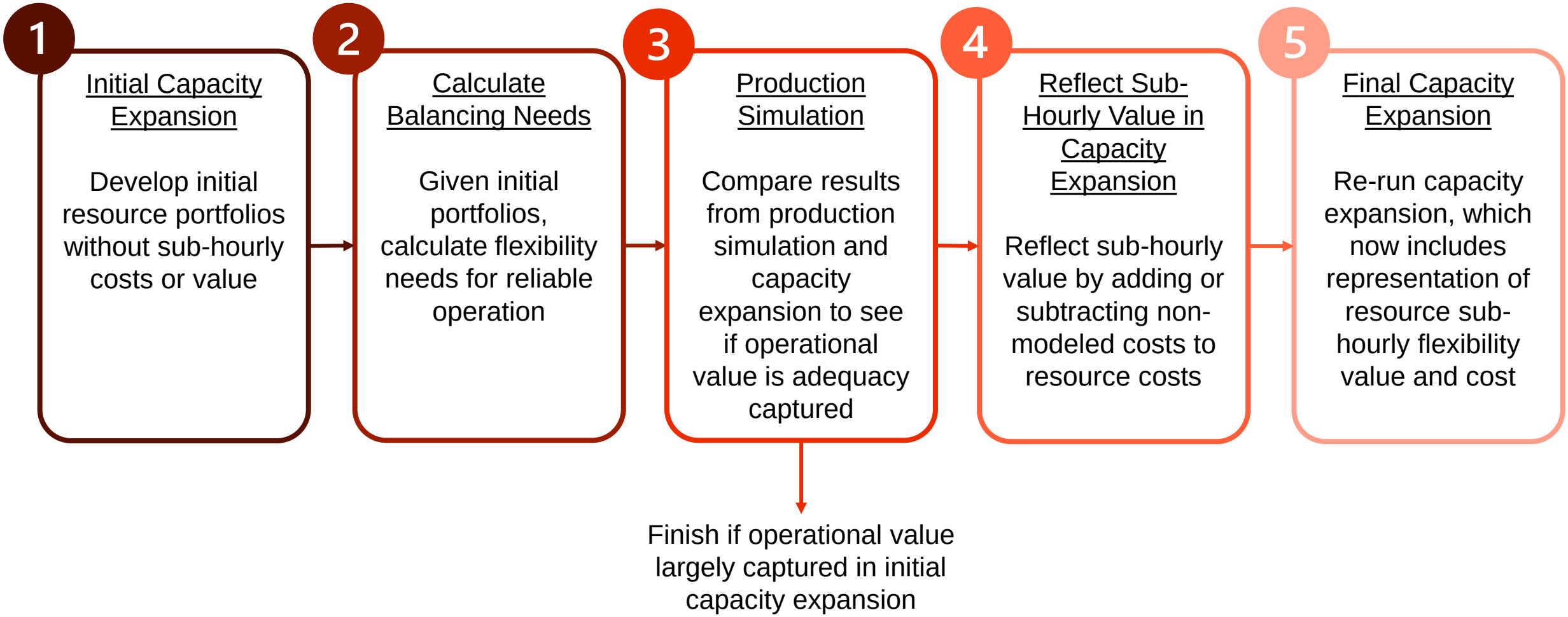


Additional Related Studies:

- Avoided Costs
- DER optimization
- Distribution needs for EV adoption
- Bulk Transmission needs
- Resilience to large disruptions

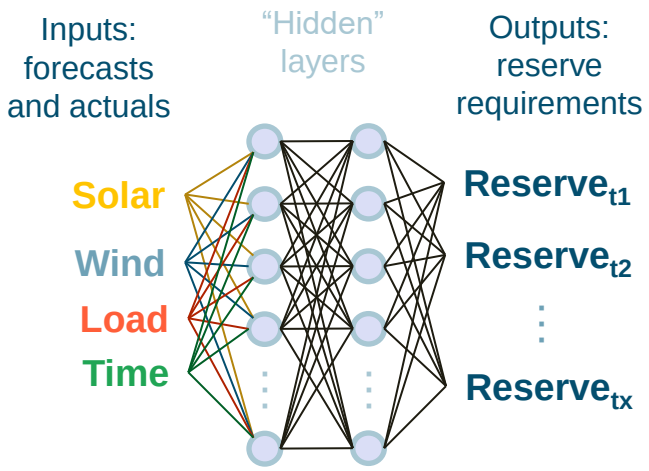
Final recommendations, builds, costs, emissions

Workflow for valuing operational flexibility in planning

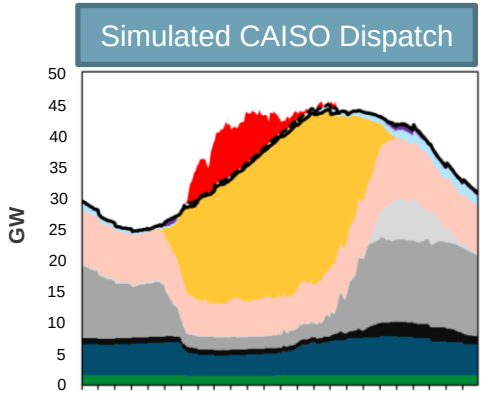


E3's RESERVE tool uses machine learning for dynamic operating reserve calculation

Machine learning generates reserve needs using artificial neural network



PLEXOS production simulation of CAISO system validates operability



PLEXOS SIMULATION SOFTWARE

Summary and CAISO Comparison

- Compare machine learning reserves to CAISO current practice
- Estimate cost, GHG and curtailment savings

+ **E3 Team:** Adrian Au + Charles Gulian + Saamrat Kasina + Jimmy Nelson + Patrick O'Neill + Arne Olson + John Stevens + Yuchi Sun + Vignesh Venugopal + Mengyao Yuan

+ ARPA-E PERFORM program provided grant funding

arpa·e U.S. DEPARTMENT OF ENERGY

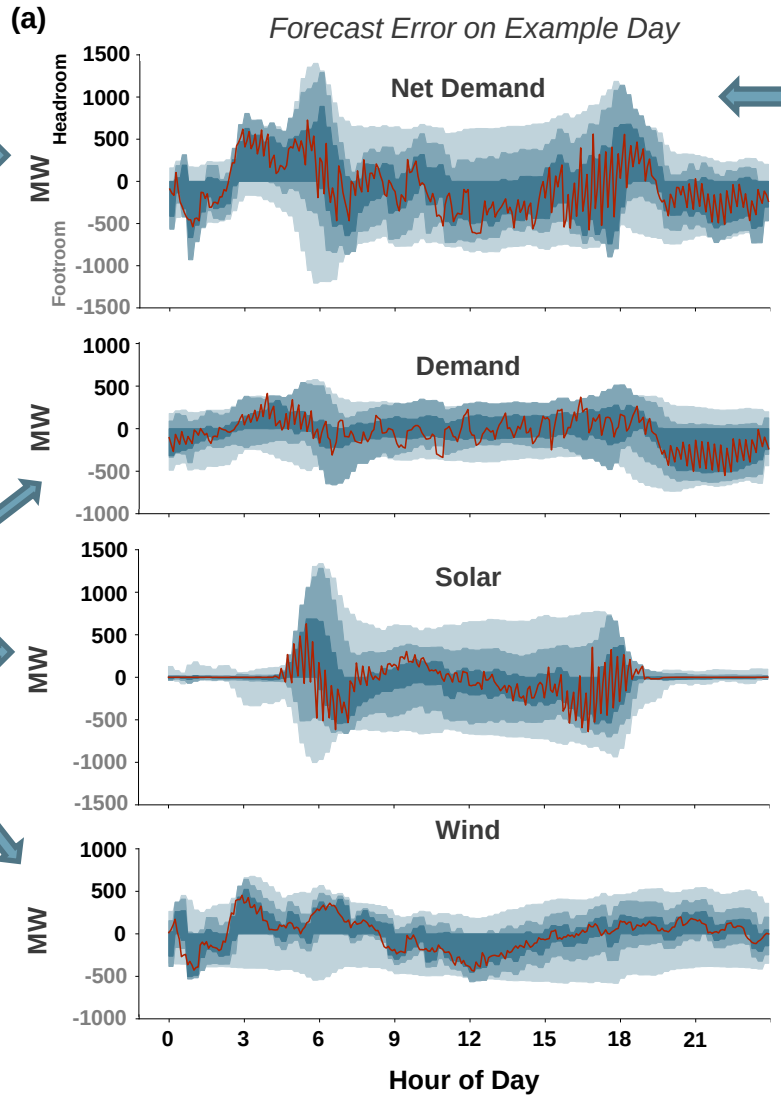
+ CAISO was our industry partner

California ISO

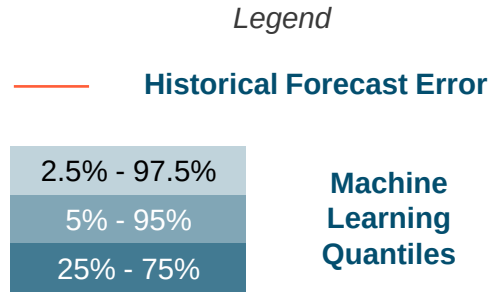
Probabilistic uncertainty from machine learning reserves

Net load forecast error…

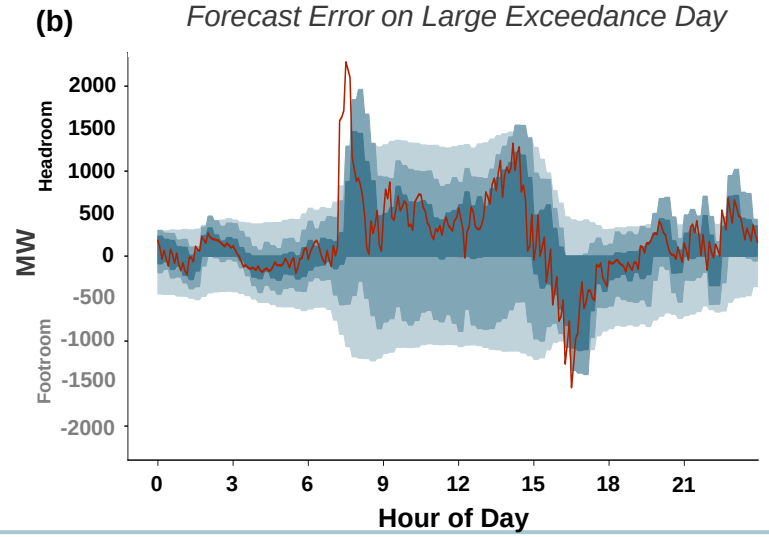
is assembled from the individual constituent components



Dynamic based on grid conditions…

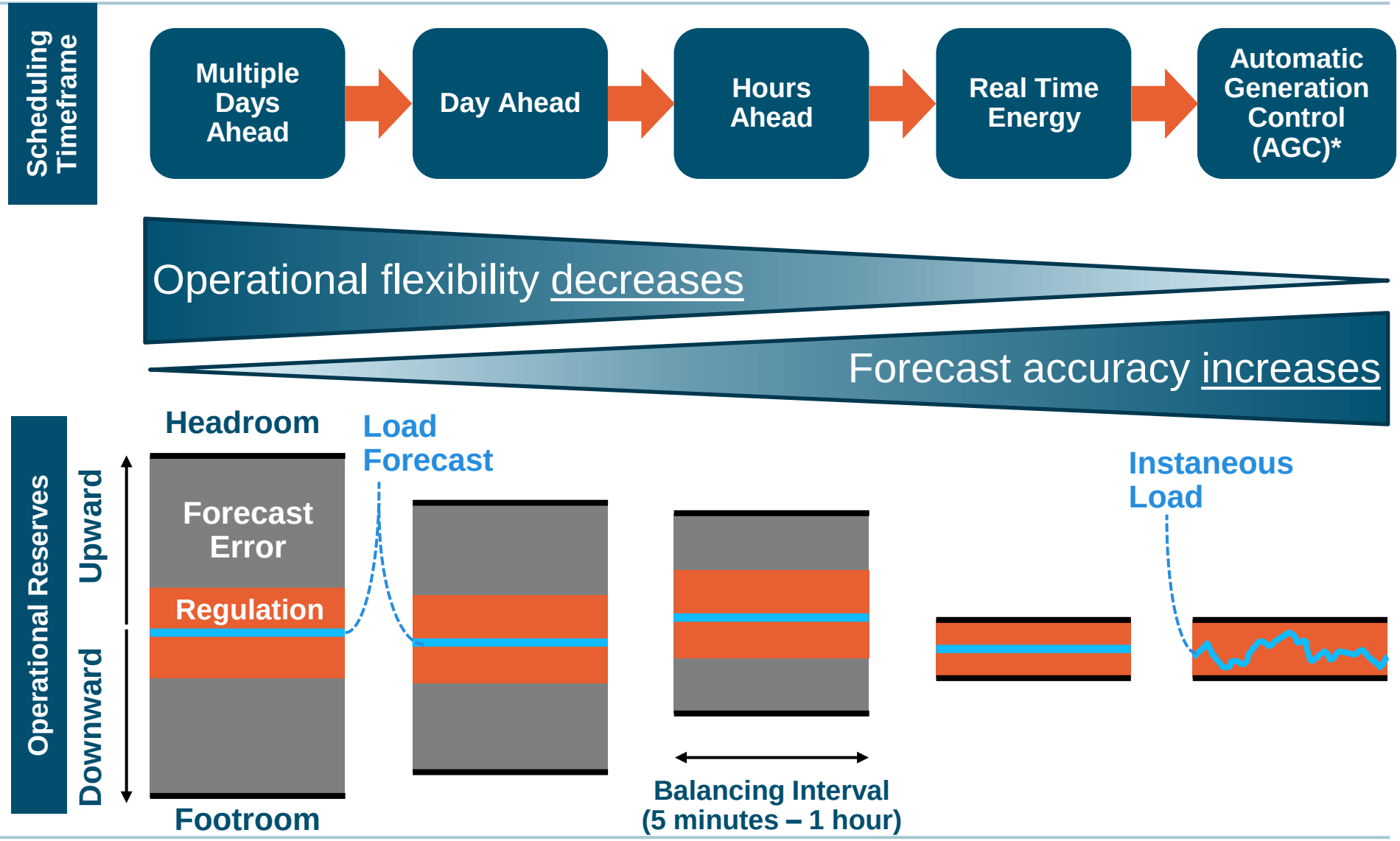


More dynamic when grid conditions are more dynamic…



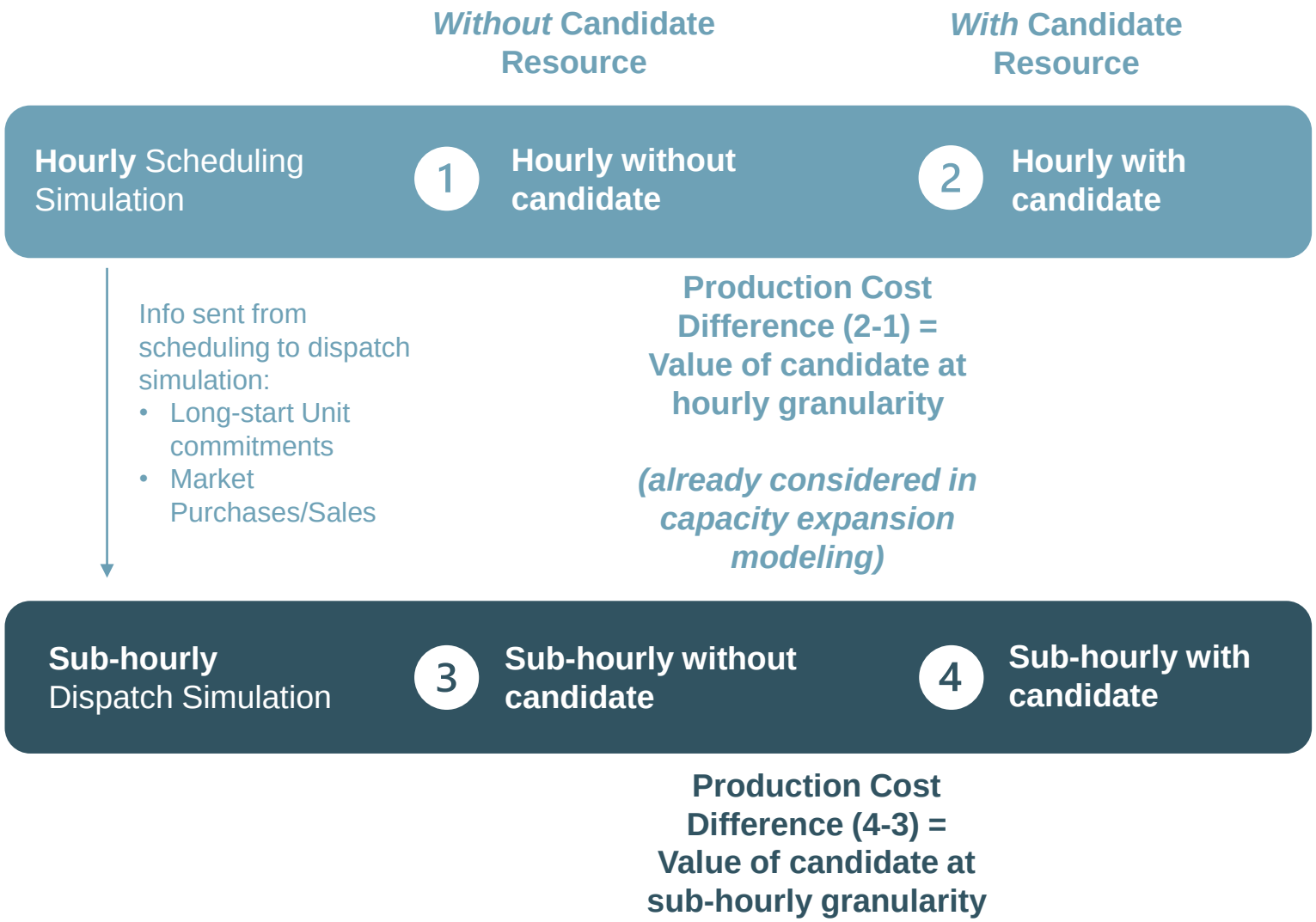
Multi-stage production simulation captures sub-hourly operational flexibility needs and benefits

PLEXOS production simulation model mimics scheduling and dispatch decisions that system operators make on many timeframes



* AGC typically not simulated

Isolating sub-hourly operational flexibility value to supplement capacity expansion modeling



Sub-hourly benefit =
Value of candidate at sub-hourly granularity
- Value of candidate at hourly granularity
= (4-3) – (2-1)

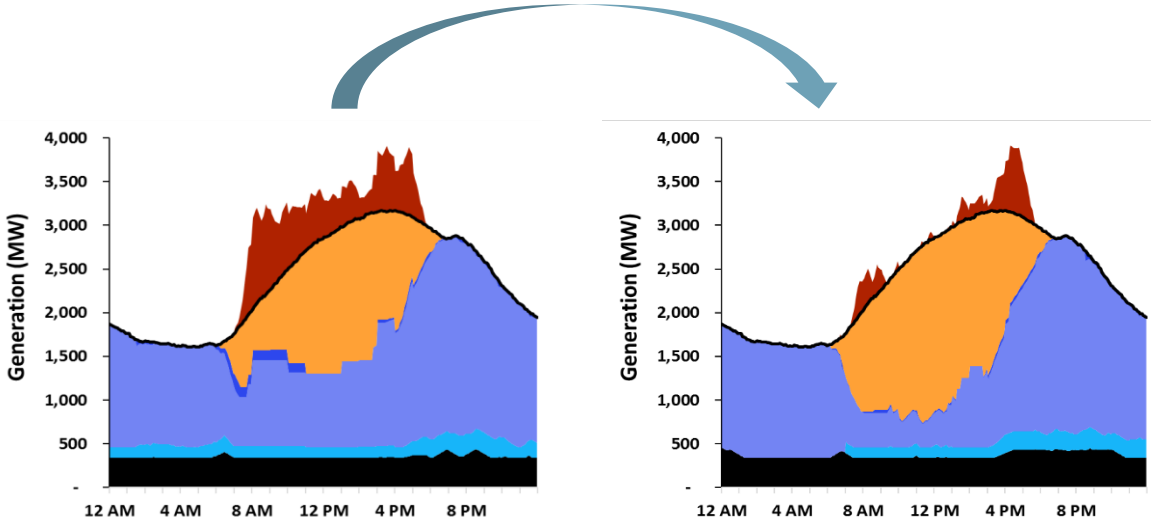
Repeat for multiple candidate resources

Add as cost or benefit in capacity expansion

Case study: explore tradeoffs in thermal cycling vs. renewable curtailment

- Lowering output from thermal units during heavy solar production hours can decrease solar curtailment and thereby make solar more economical
- BUT cycling thermal units can increase wear and tear
- Also, turning plants off can decrease the flexibility of the system to respond to higher net loads
- Production simulation can explore the tradeoff between increased thermal cycling and renewable curtailment, while simultaneously exploring the reliability of different operational strategies

Lower thermal generation enables higher uptake of solar



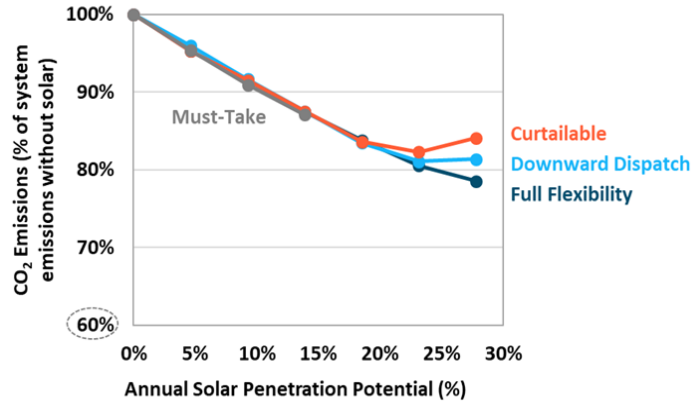
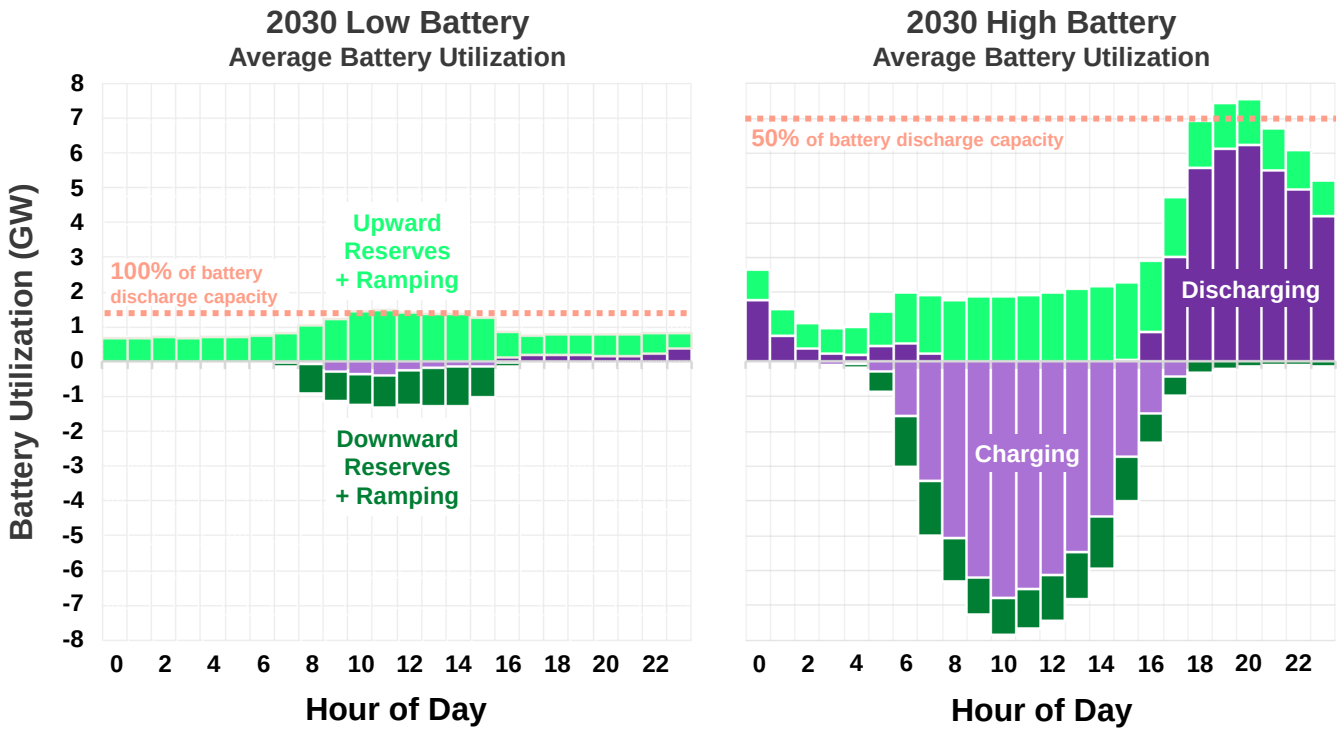


Figure: https://www.ethree.com/wp-content/uploads/2018/10/Investigating-the-Economic-Value-of-Flexible-Solar-Power-Plant-Operation.pdf

Case study: value of batteries

- **Production cost modeling can identify the most economic way to operate batteries**
  - Timing of batteries providing energy arbitrage, regulation, spinning reserve, flexible ramping
- **Can inform how to manage battery state of charge in operations**
- **Can quantify battery cycling**
  - Helps to understand the impact of battery contract terms about number of cycles allowed

Optimal use of batteries evolves as more storage is added to the system



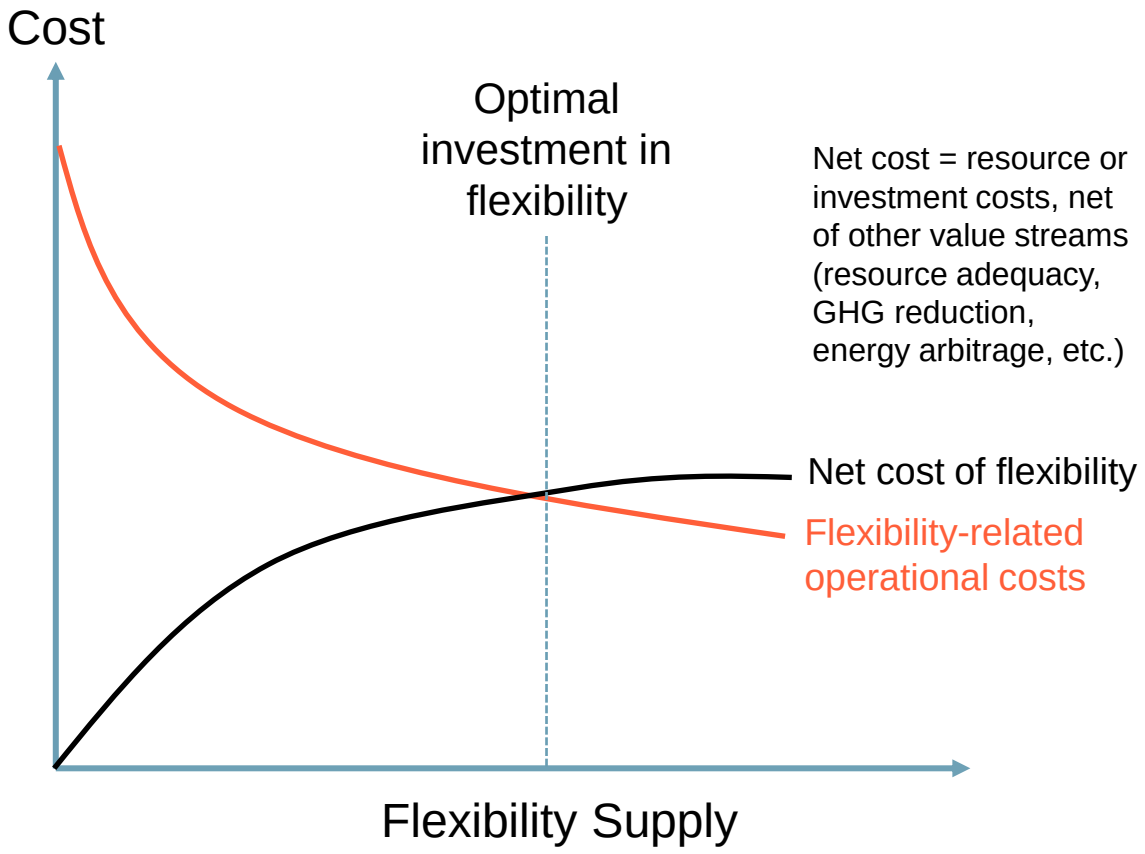
Sun, Yuchi, et al. "Machine learning derived dynamic operating reserve requirements in high-renewable power systems." Journal of Renewable and Sustainable Energy 14.3 (2022): 036303.

Capacity expansion modeling includes options to increase flexibility, for a cost

Planning models include options to increase flexibility… at a cost

- Increase load flexibility
- Make solar or wind curtailable
- Build, retire or retrofit thermal plants to improve flexibility
- Improve hydro flexibility
- Add battery storage capacity
- Build or upgrade ties to other systems

***Theoretical* Flexibility cost curve:**
Dependent on system conditions and the resource portfolio



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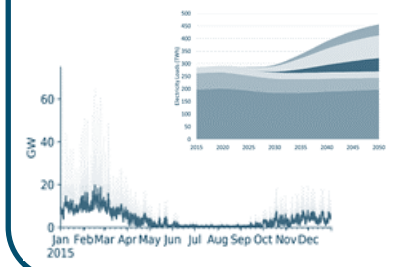

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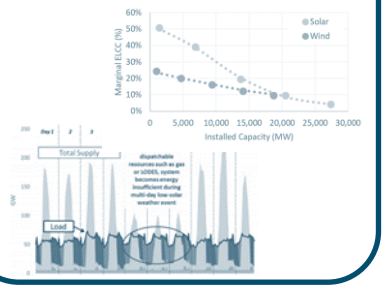

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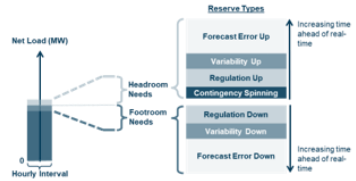

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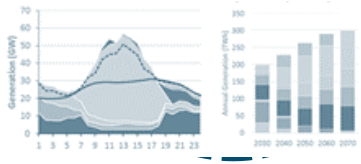

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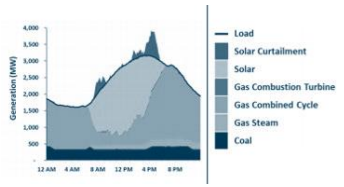

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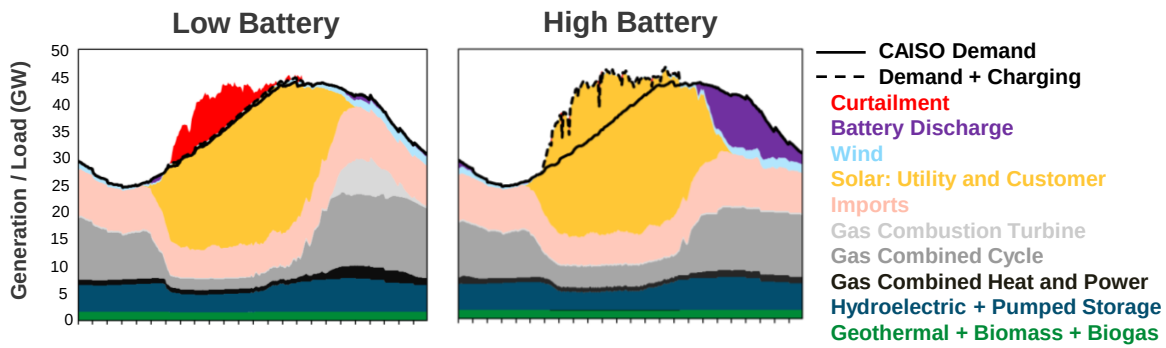
Higher battery penetration adds flexibility and reduces reserve prices

2030 Example Summer Day

Generation

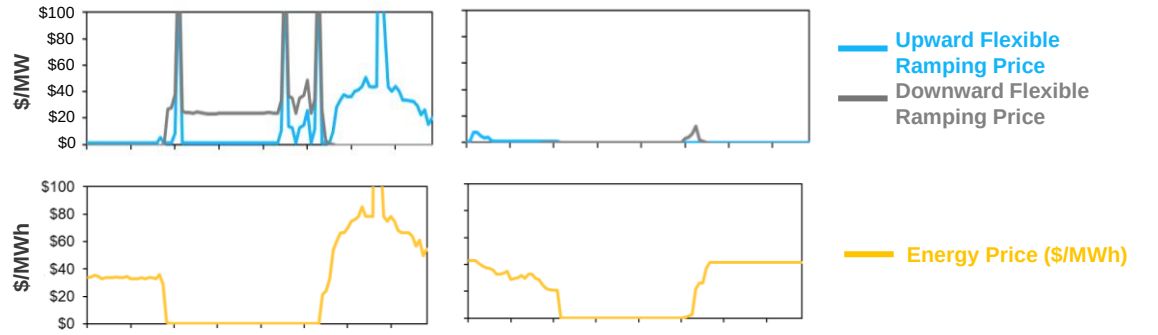
With few batteries, curtailment is abundant



More batteries use solar that would have been curtailed to reduce peaker dispatch

Reserve and Energy Prices

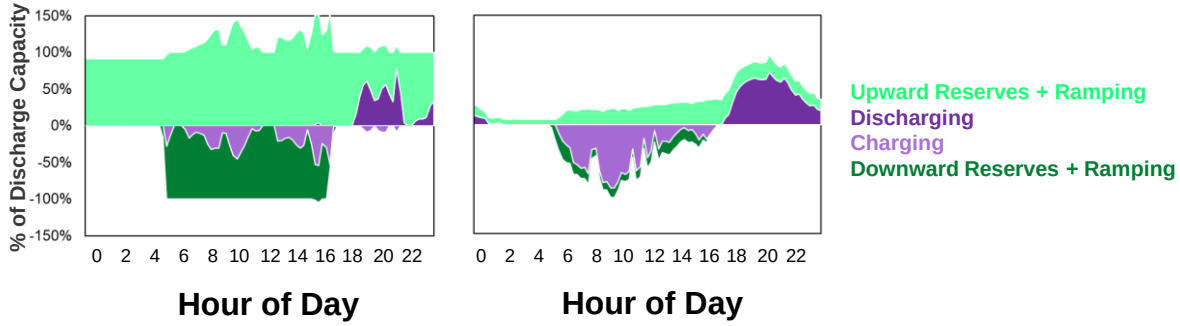
While system flexibility is low, reserve prices stay high



With more batteries, flat energy prices in the day and night give the batteries enough flexibility to provide reserves at low or zero cost

Battery Operations

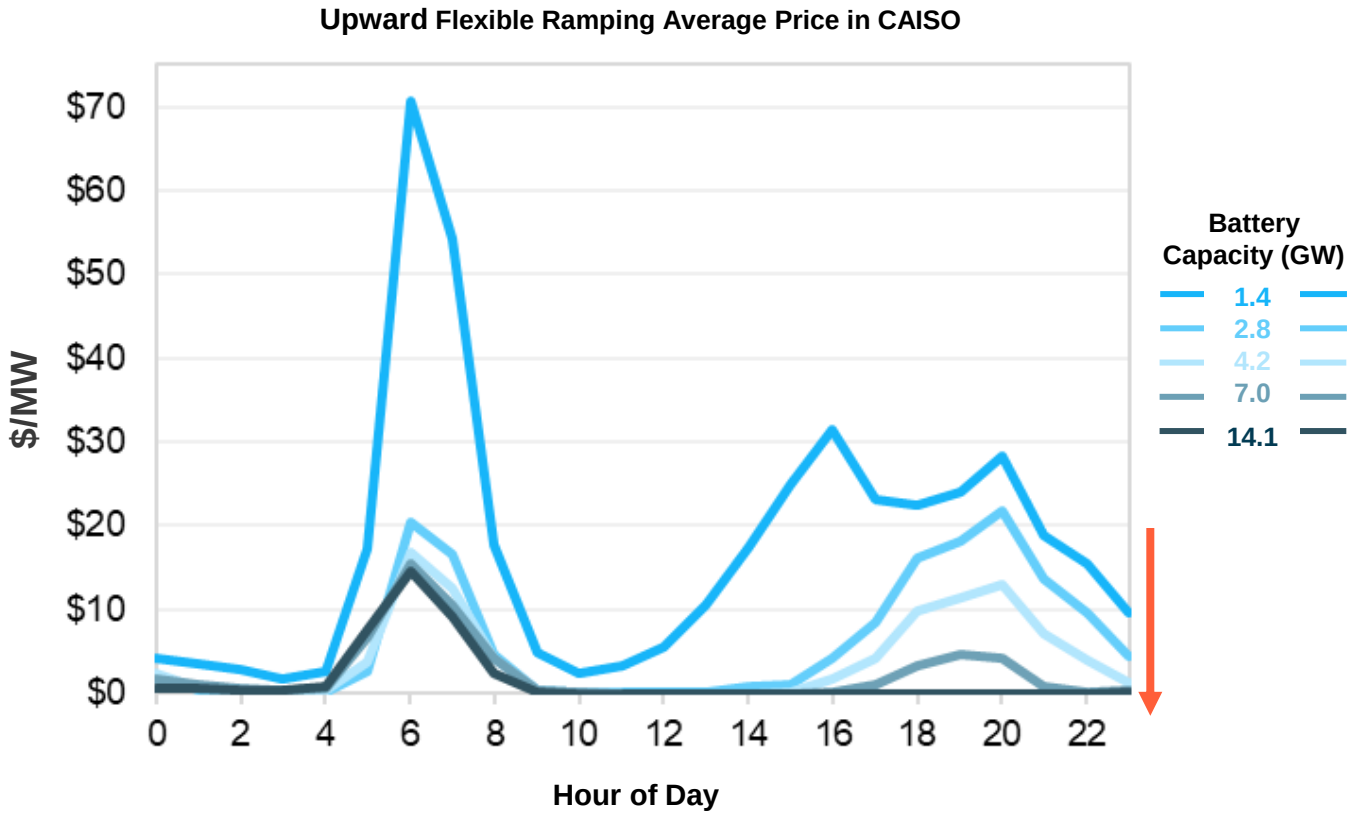
With few batteries, batteries focus on providing reserves



With more batteries, they can provide most of the reserves and also perform energy arbitrage

Sun, Yuchi, et al. "Machine learning derived dynamic operating reserve requirements in high-renewable power systems." Journal of Renewable and Sustainable Energy 14.3 (2022). Available at: https://www.osti.gov/servlets/purl/1872755

Higher battery penetration adds flexibility and reduces reserve prices



- Increasing flexibility from batteries leads to decreasing reserve prices
- In California, this grid flexibility is "free" because batteries are "paid for" through the resource adequacy need

2.5% of peak load

25% of peak load

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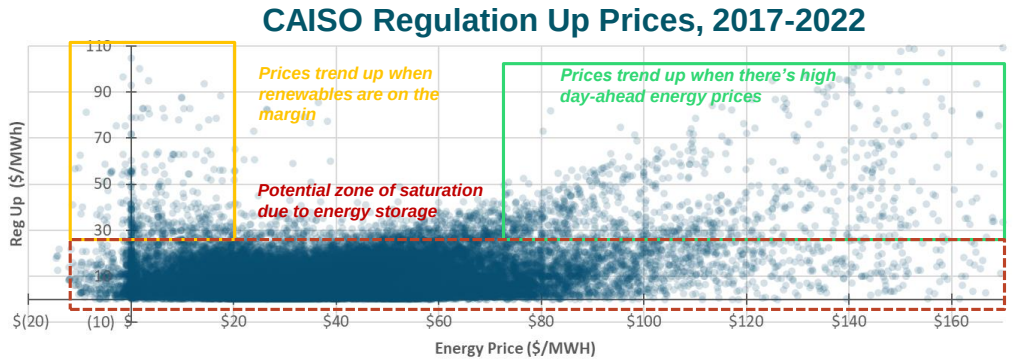
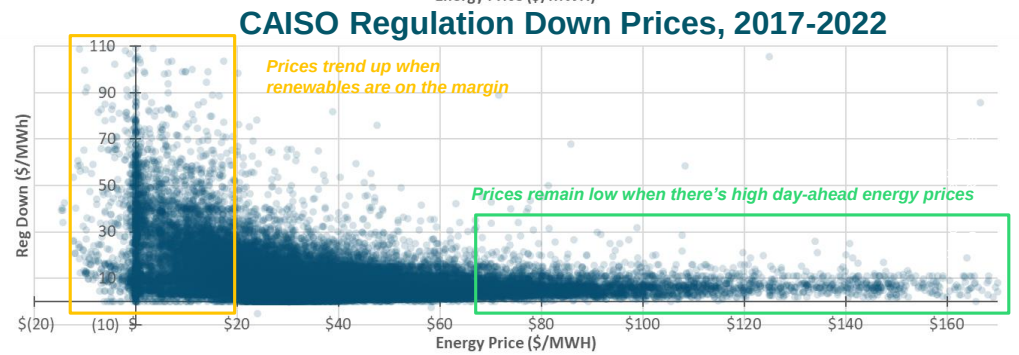
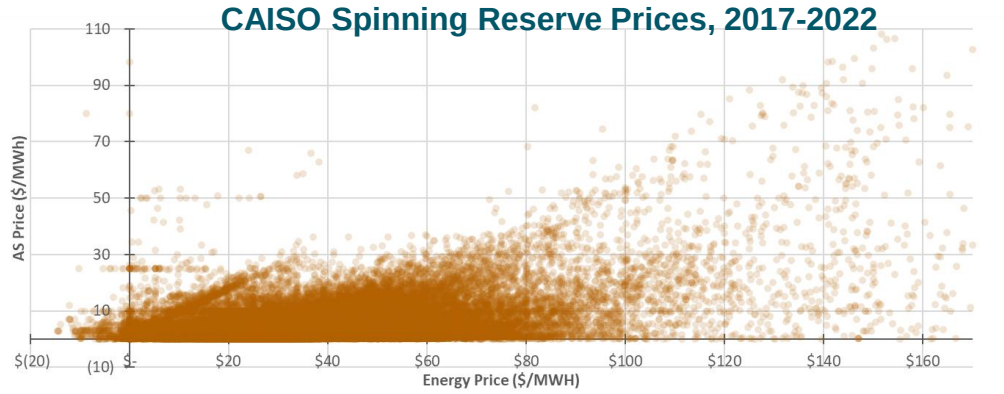
For organized markets, operational studies are replaced by ancillary service price forecasts

- Organized markets provide the grid services needed for operations, at a price
- Utilities in organized markets need to be concerned not with operations of their own system, but rather the price of grid services from the market
- Grid service prices will change as the resource mix changes

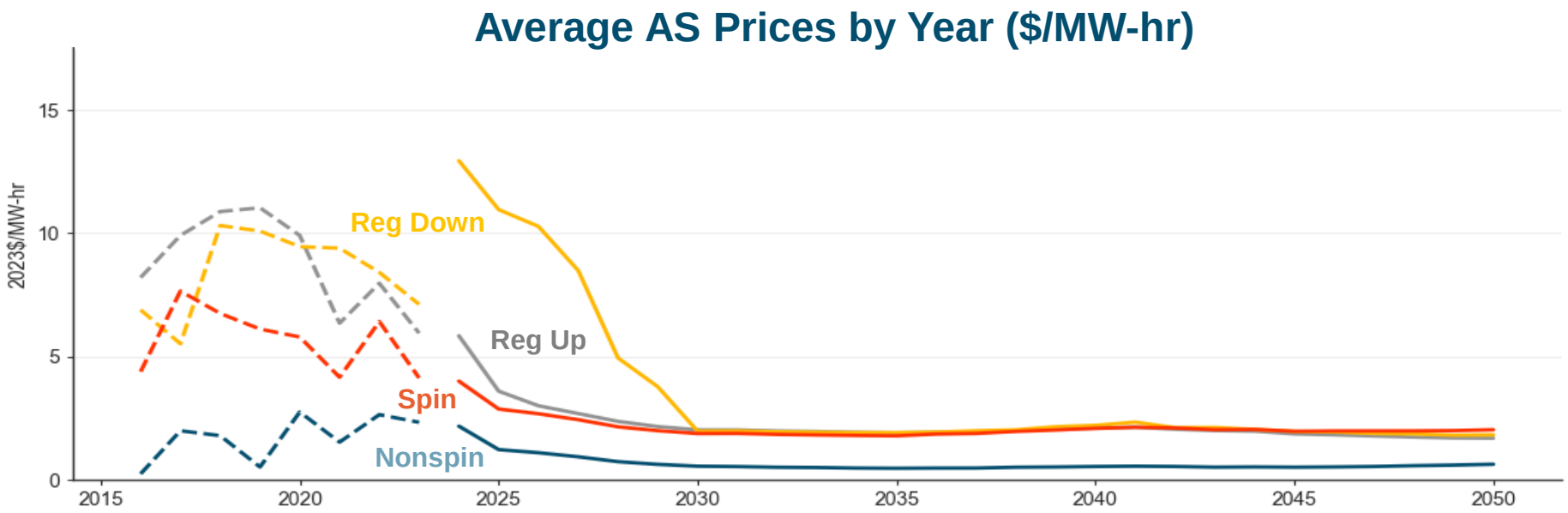






Ancillary service markets are small and prices are dynamic with changes to the resource mix

- Storage participation has already reduced average AS prices in the CAISO market today
- Frequency of low ancillary service prices rapidly increases between 2023-2025 as storage further saturates the market
- Reg down saturates more slowly as seen in current market trends



Thank you!

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