Market-integrated optimization of Wind-Battery-Hydrogen hybrids for peaking capacity via storage

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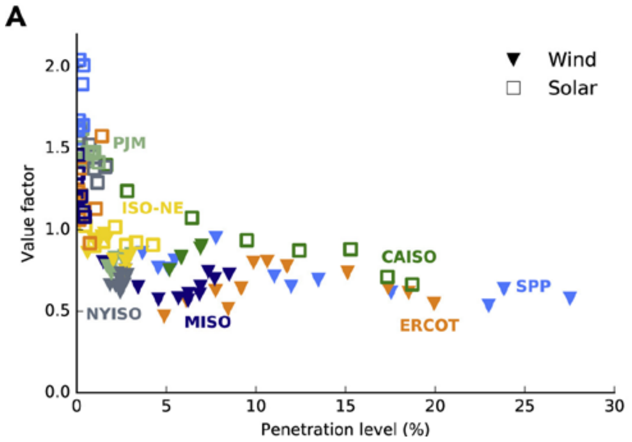
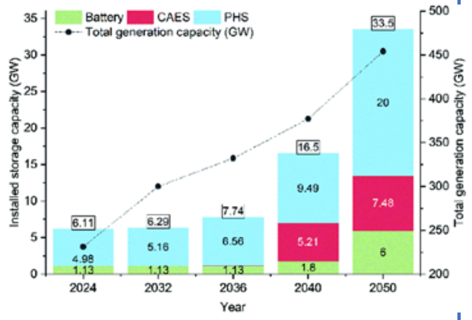
INFORMS 2022

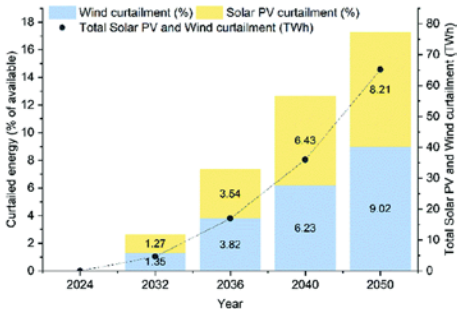
Decarbonization and challenge of increasing renewables

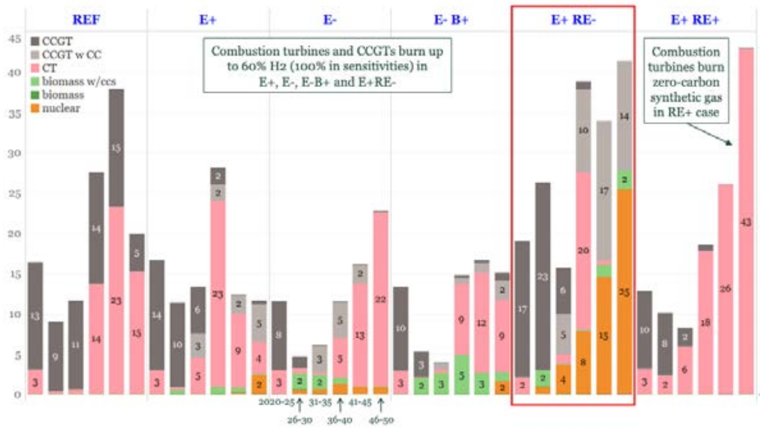


- Increasing curtailment
- Lowered prices
- Variability

- Storage reshapes daily and seasonal fluctuations







- Electrification
- Clean fuels
- Clean chemicals

Now

Decarbonizing Electricity and other Sectors

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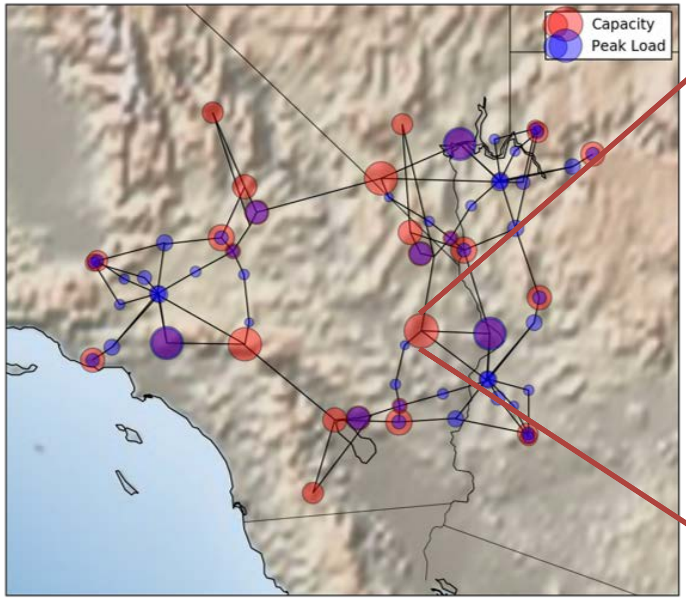
Figures. Left: D. Millstein, et al. Solar and wind grid system value in the United States: The effect of transmission congestion, generation profiles, and curtailment. Joule. 2021.
Center: O.J. Guerra, et al. The value of seasonal energy storage technologies for the integration of wind and solar power. Joule 2020.
Right: E. Larson, et al. Net-Zero America: Potential Pathways, Infrastructure, and Impacts. 2021

Dynamic and flexible operation is part of IES design



RTS-GMLC. Not intended to represent existing infrastructure.

Integrated Energy System (IES)

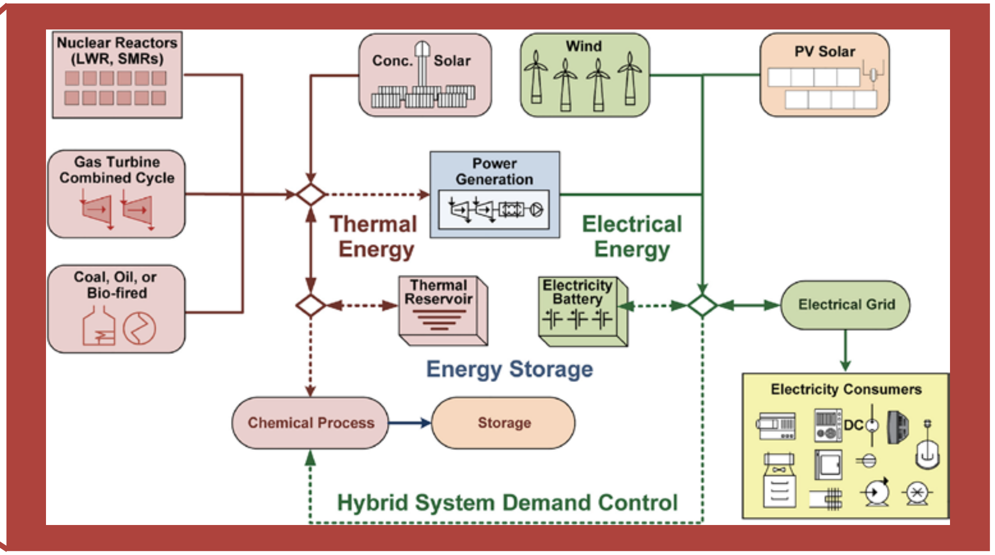


Figure: Arent, Bragg-Sitton, Miller, Tarka, Engel-Cox, Boardman, Balash, Ruth, Cox, and Garfield. (2020). *Joule*.

Multiple outputs and markets:

- Electricity energy
- Ancillary services
- Chemicals
- Heating
- Cooling

IESs provide **greater operational flexibility** by optimally coordinating material flows and energy conversions

Dispatched to have **any type of profile and bidding strategy** for a focus on services to markets

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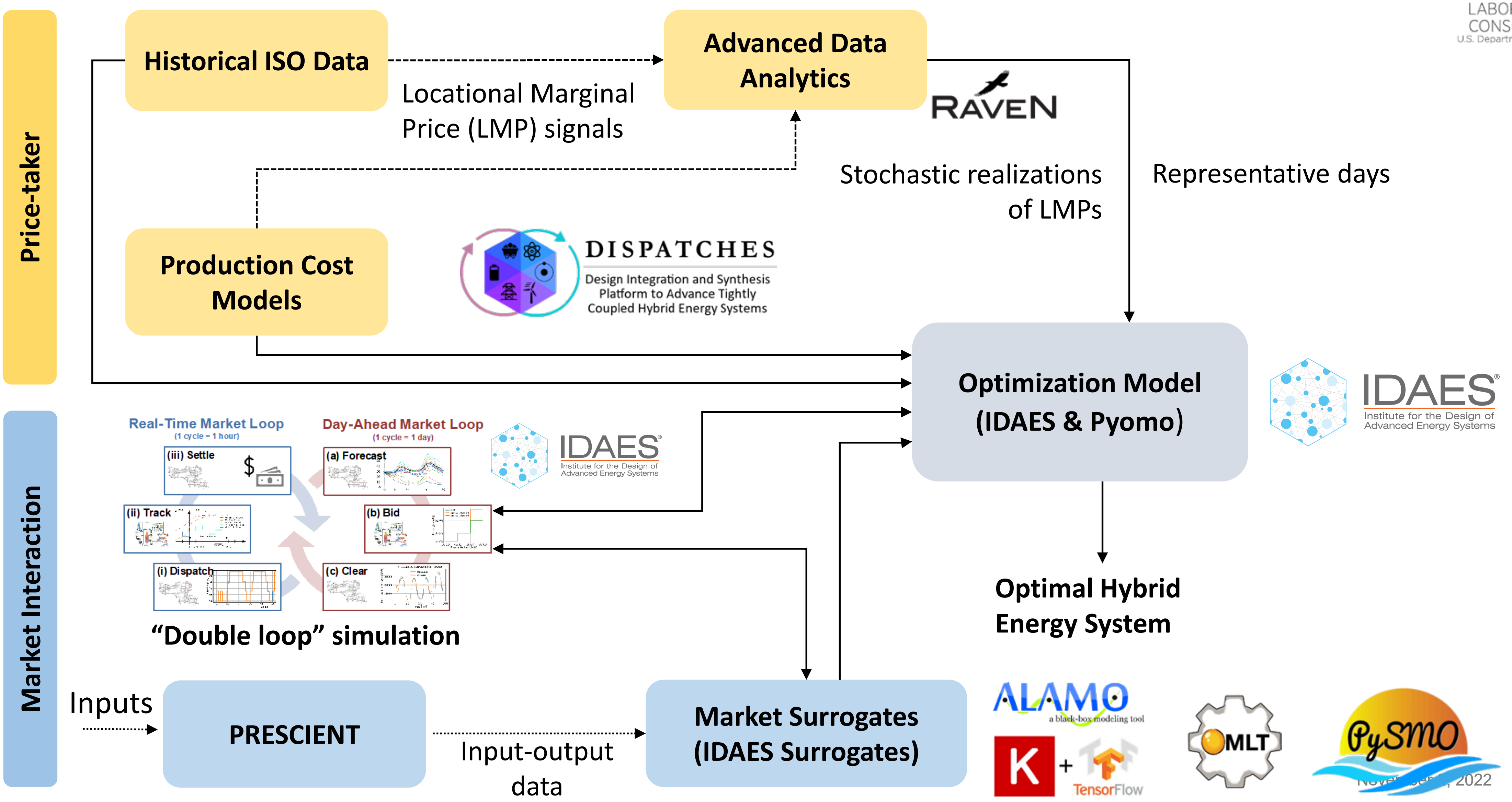
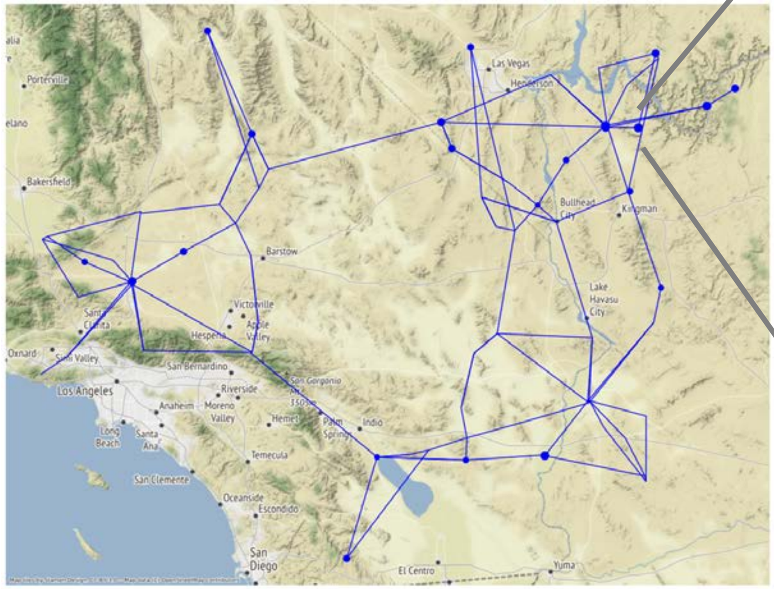
Challenge of operating the IES in an electricity market



How to design a Wind + Battery + Hydrogen plant?

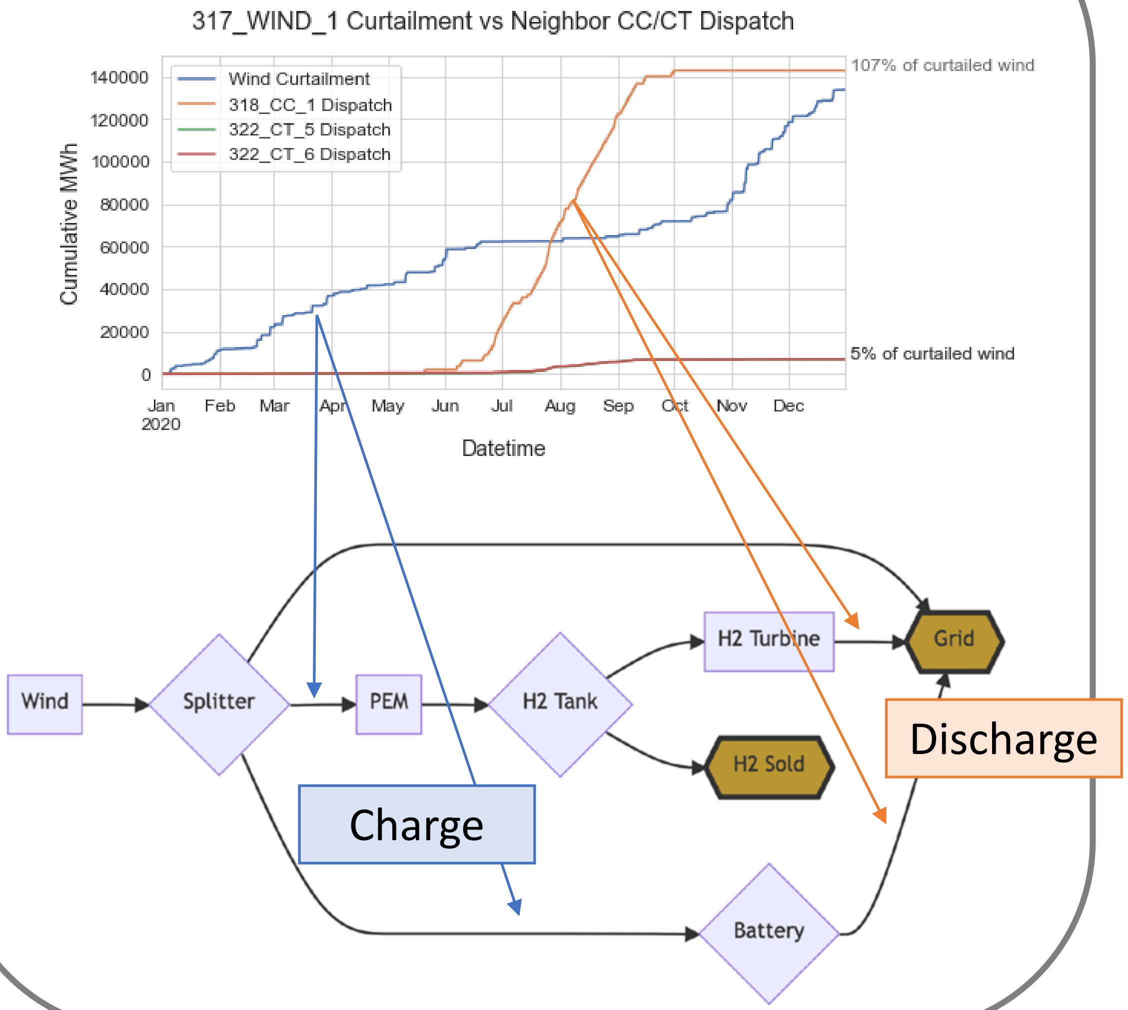
Cross-Correlations of Wind Outputs on RTS-GMLC

Wind Output RT vs **LMPs**
Wind Curtailed vs *LMPs*
Natural Gas Output RT vs *LMPs*



"RTS-GMLC: Reliability Test System - Grid Modernization Lab Consortium", 2019

Wind Plant and Neighbor NG Plants



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IDAES
Institute for the Design of Advanced Energy Systems

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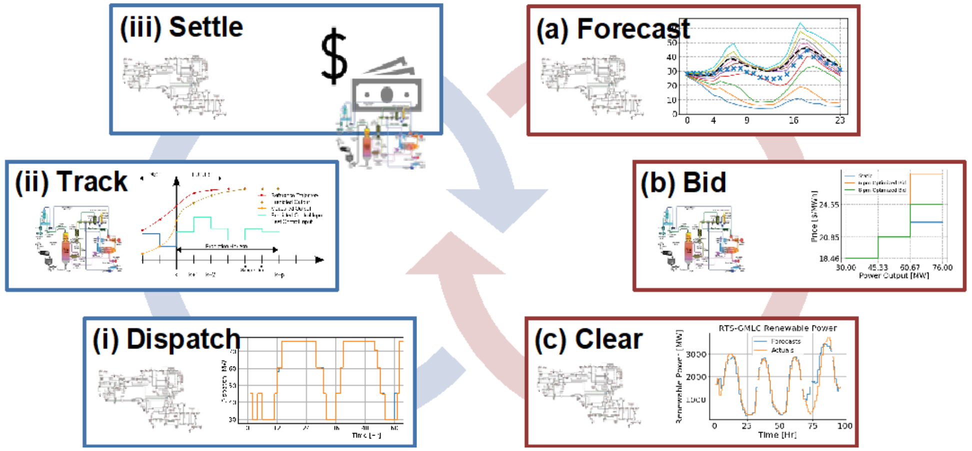
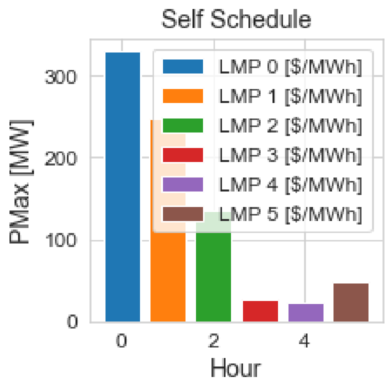
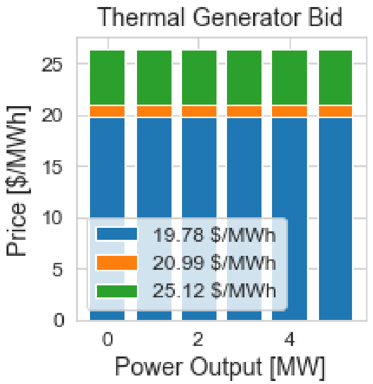
How does the IES communicate with the market?

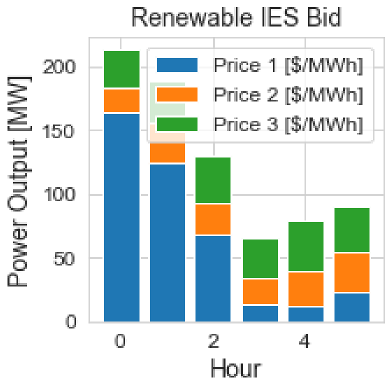




Submit price-taker optimized power outputs?



Block load bids like thermal generators?



Time-varying bid to account for variable and stored capacity?

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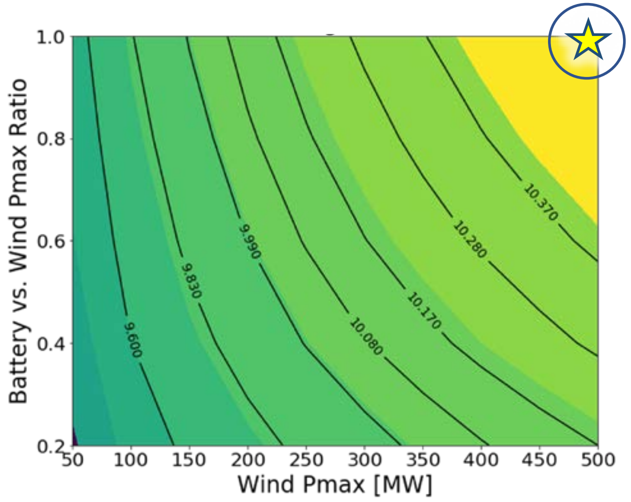
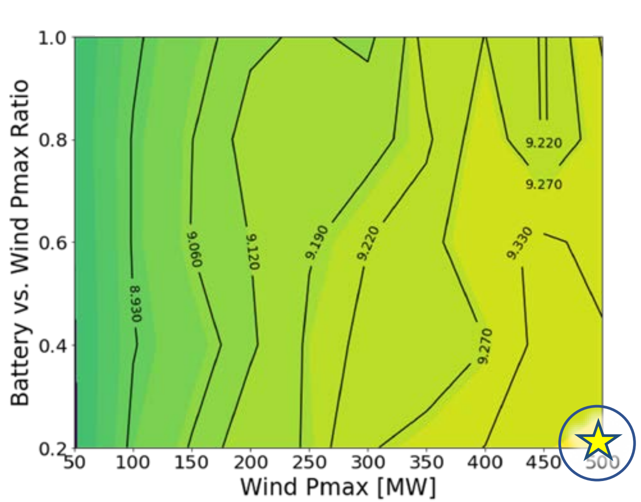
Price-taker misses market depth and storage utilization

Log NPVs of
Price-taker w/ Full-year Horizon



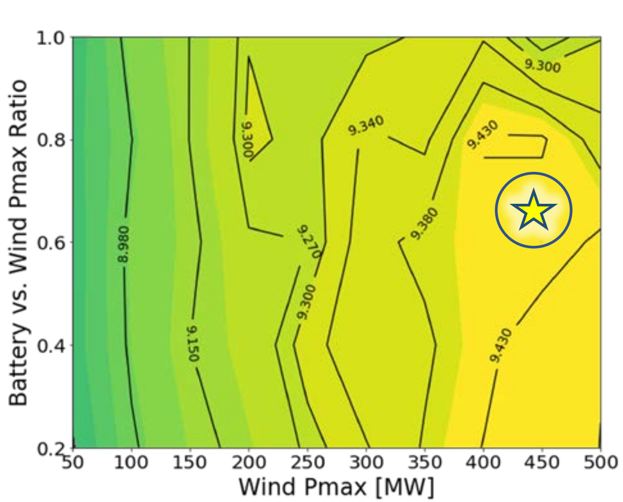
- NPV increases without bound with Wind and Battery size
- Optimal design is largest possible

Log NPVs of
Market loop w/ Self-schedule



- Bidding the price-taker dispatch leads to no battery value
- Optimal design is no battery at all

Log NPVs of
Market loop w/ Optimized Bid



- Bid varies with wind resource and is stochastically optimized w/ LMPs
- Optimal design has moderate battery size

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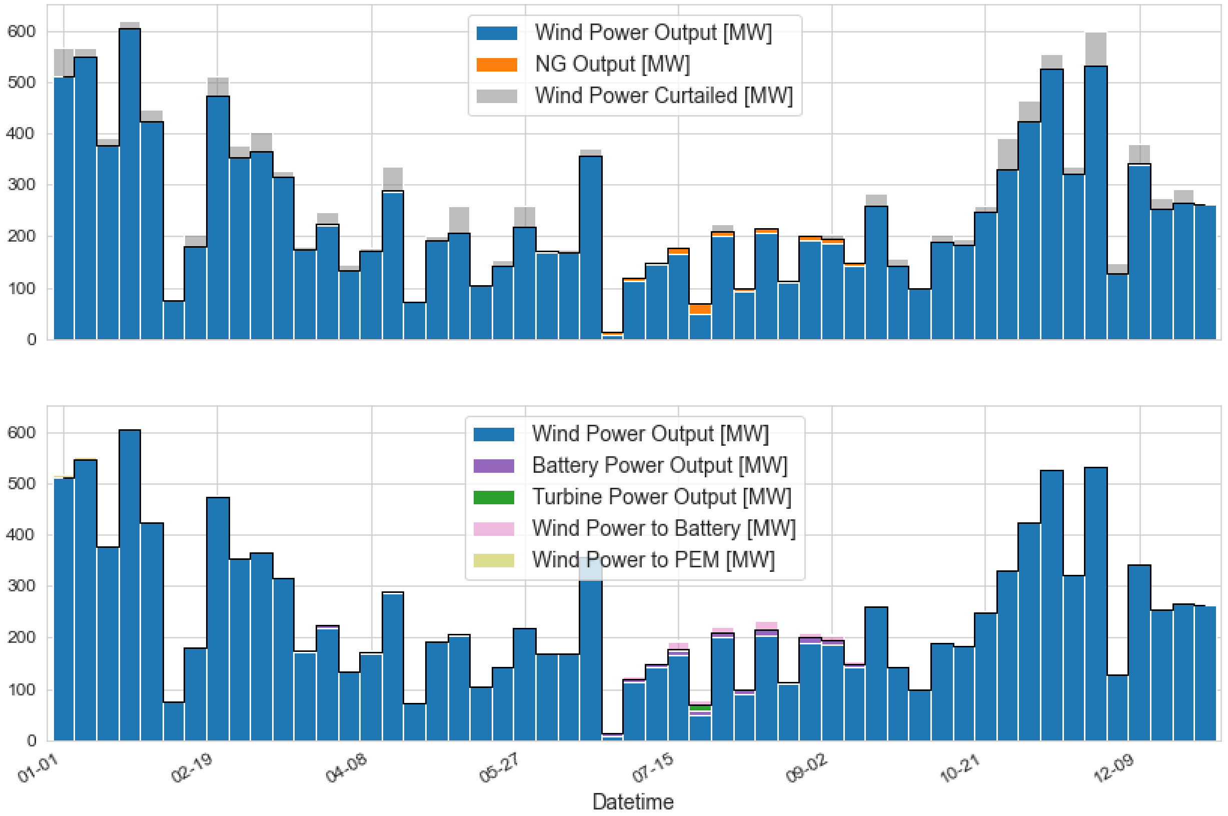
IES bids as the sum of a pair of wind and NG plants

Wind + Battery + Hydrogen Turbine Retrofit Designed to Follow Existing Load at Lowest NPV

Existing Wind and NG generator

IES with w/ Retrofit Turbine to burn Hydrogen



- A wind plant and natural gas plant pair is selected
- Example shows very low-capacity factor peaker

- Curtailment is reduced but not eliminated
- NG output replaced by combination of battery and turbine output

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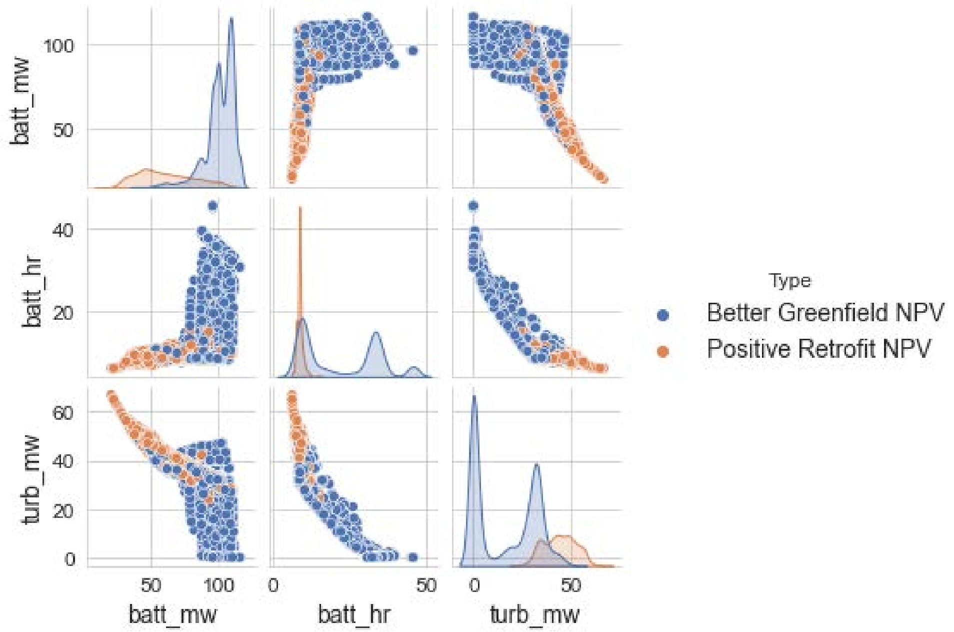
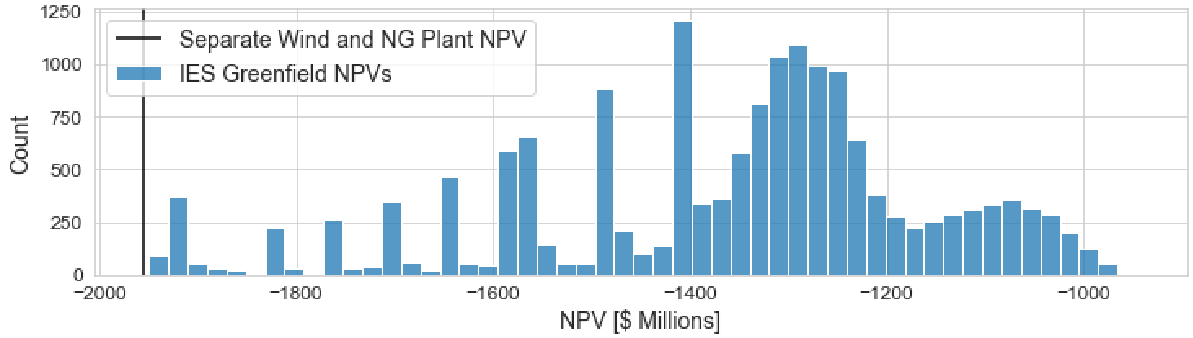
Parametric design results with varying cost inputs

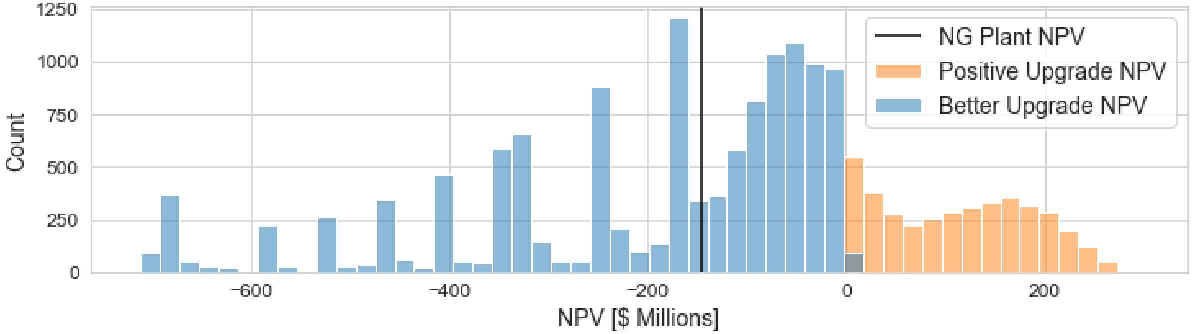
Distribution of Battery and Turbine Sizes



Wind + Battery + Hydrogen IES can have a better Greenfield NPV



And a Positive Retrofit NPV



Most impactful inputs:

1. Battery energy capital cost
2. Battery power capital cost
3. Turbine conversion rate

Least impactful inputs:

1. Turb capital cost
2. Tank capital cost
3. PEM capital cost

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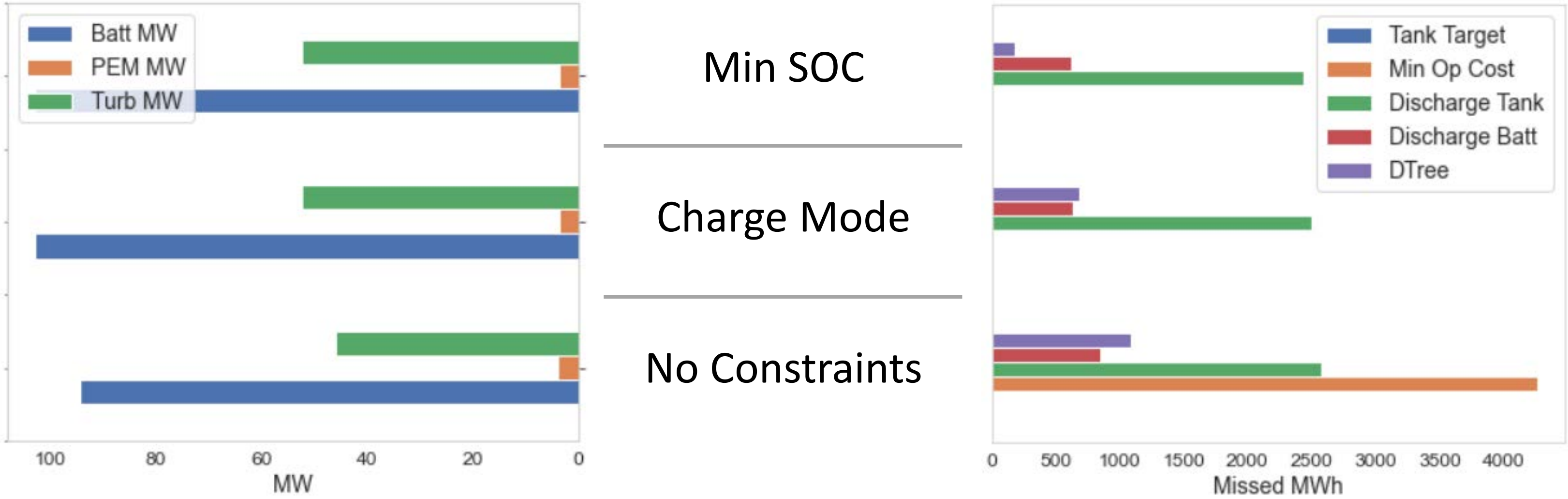
IES achieves yearly dispatch with day-timescale operation

Adding constraints of a 24-hr operation strategy into the design
<u>increases the battery sizes and turbine size</u>

Sizes by Operationally-Constrained Design

Missed Load by Operating Strategy per Design



No operating constraints results in missed dispatch for all strategies except Tank Target

Min SOC equivalent to 1 hr of storage allows daily operation to meet desired full year load

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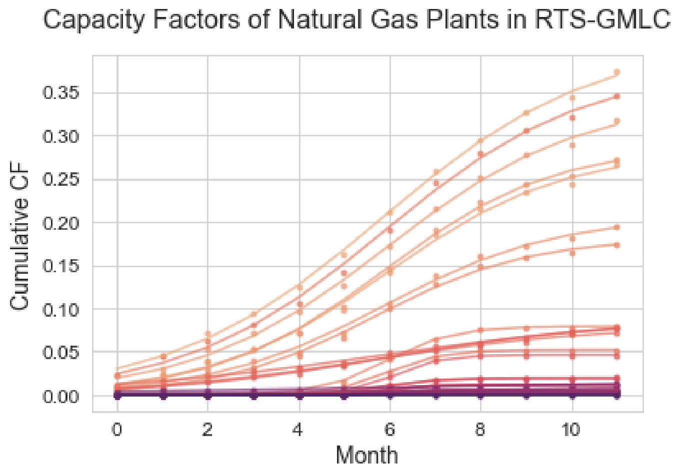
Market surrogates co-optimizes load, bid and design

Dispatch surrogate

- Model the battery and hydrogen turbine output after the output of NG plants
- Cumulative Capacity Factor varies by Bid Price and Plant Capacity

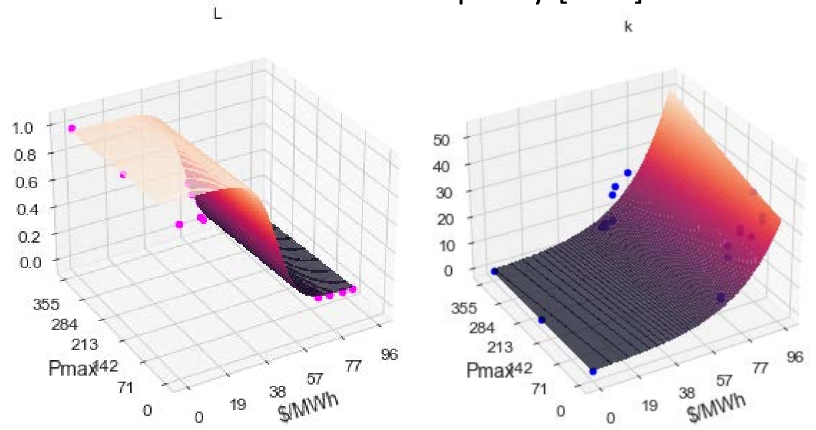
Revenue surrogate

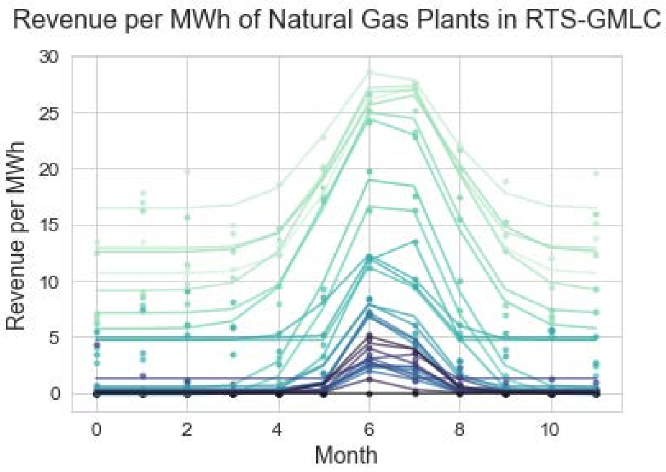
- Revenue per MWh of peaking capacity also varies by Bid Price and Plant Capacity



Lighter colors show plants with lower bid prices

Curve parameters are functions of Bid Price [$/MWh] and Plant Capacity [MW]





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Thank you!

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