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Modeling storage technologies in Capacity Expansion Models

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- RPM Overview
- Motivation for better storage modeling
- Storage Methodology
- Results

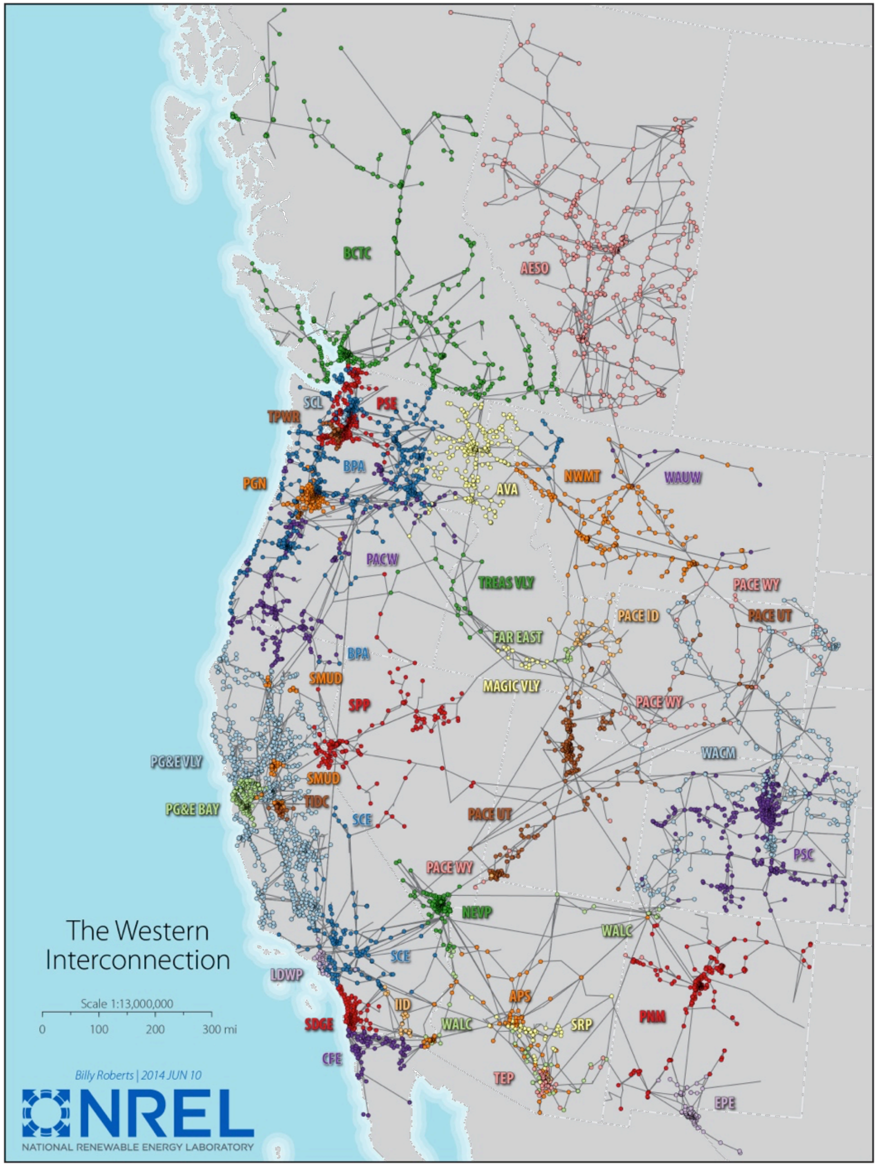
RPM Overview

Resource Planning Model (RPM)

- Capacity expansion model that simulates least-cost investments in and operation of a generation and transmission system

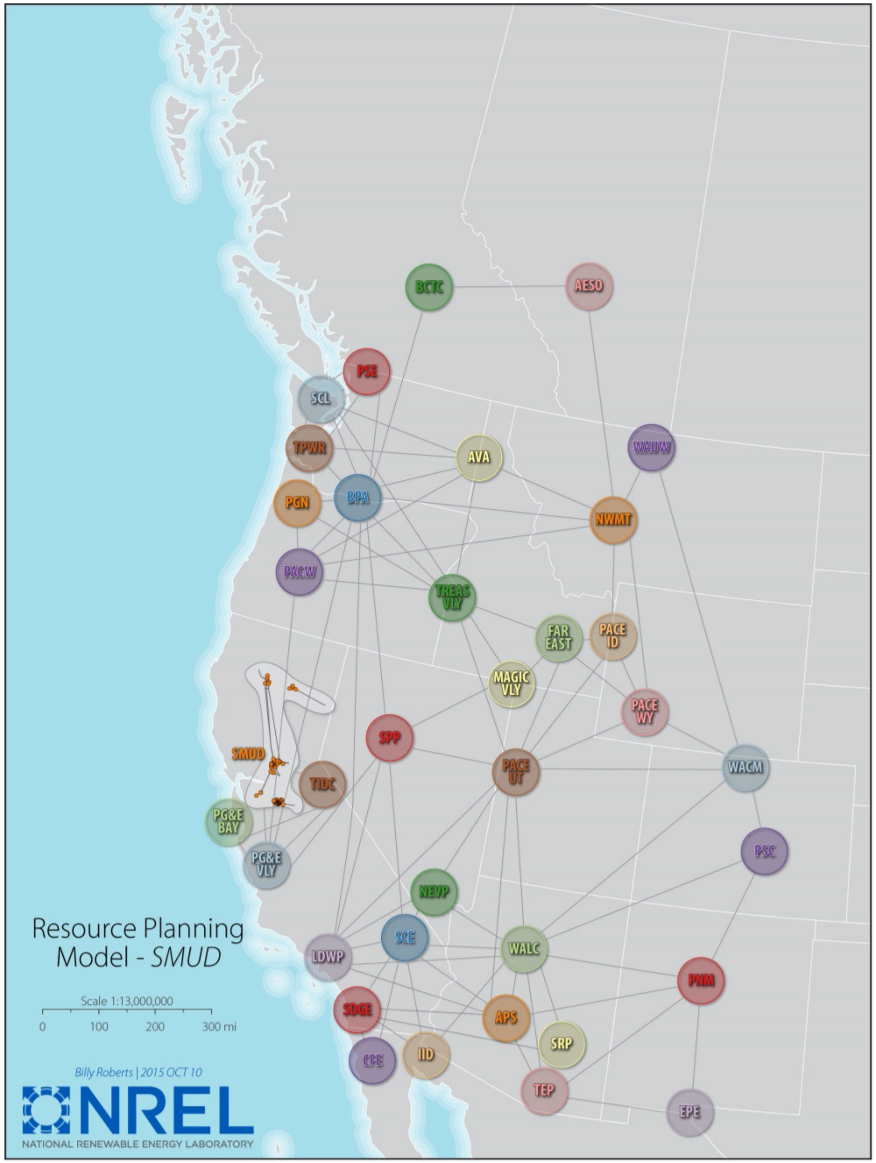
- Specialized for analysis of a *regional* electric system over a utility planning horizon (10-20 years)
  - Includes hourly chronological dispatch
  - High spatial resolution of existing and new resources
  - Real-world transmission system

Database: Complete Western Interconnection data for all major generation units and transmission lines



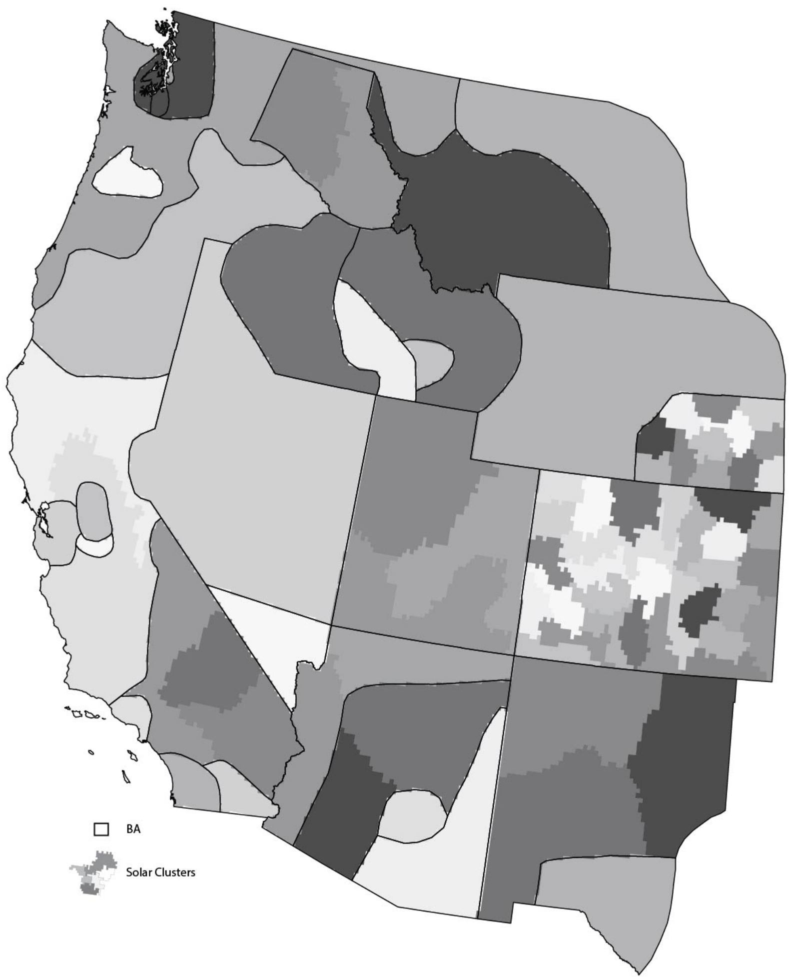
Technology	Units	Capacity in 2010 (GW)
Coal	143	39
Gas-CC	208	60
Nuclear	8	10
Gas-CT	434	20
Other Gas	184	23
Biomass	62	2
Geothermal	57	3
Hydropower	641	70
Pumped Hydro	15	4
PV	5	< 1
CSP	10	< 1
Wind	144	12
Total	**1,911**	**243**
20,086 Transmission Lines		

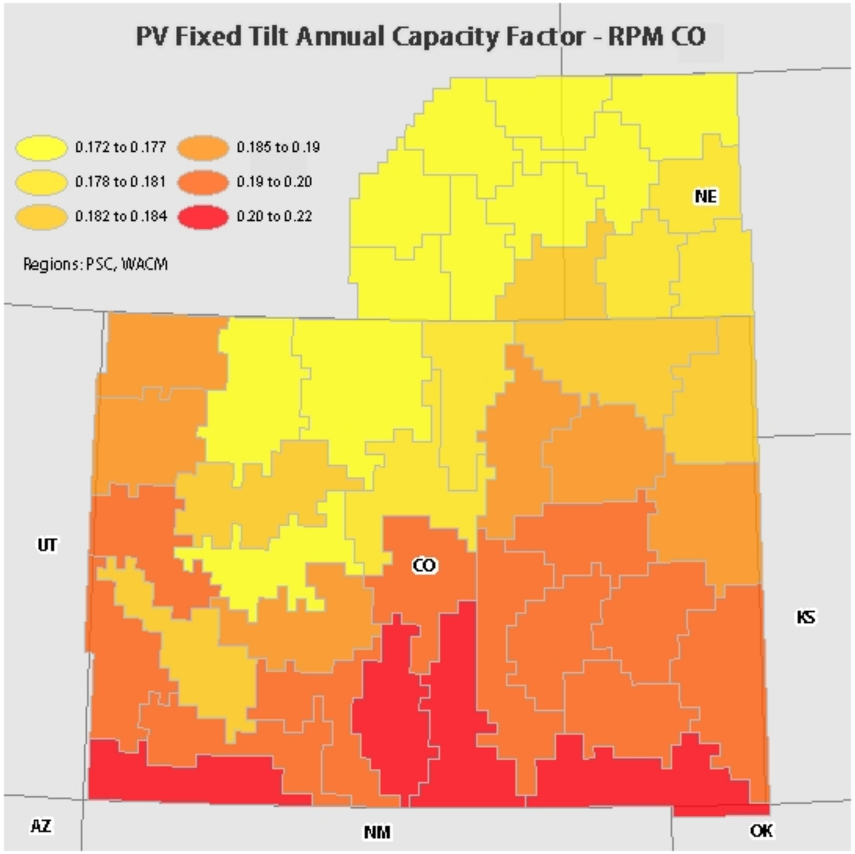
Flexible data platform allows development of region-specific models



- Aggregated transmission and generation outside of focus-region
- Maintains spatial resolution of focus region
- Full transmission model and individual units within focus region
- Represent hurdle-rates between regions
- Temporally consistent with production cost model

Highly detailed renewable resource data is aggregated for high definition in the focus-region



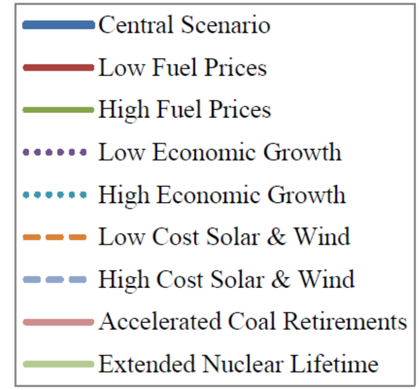


Solar Resource Regions

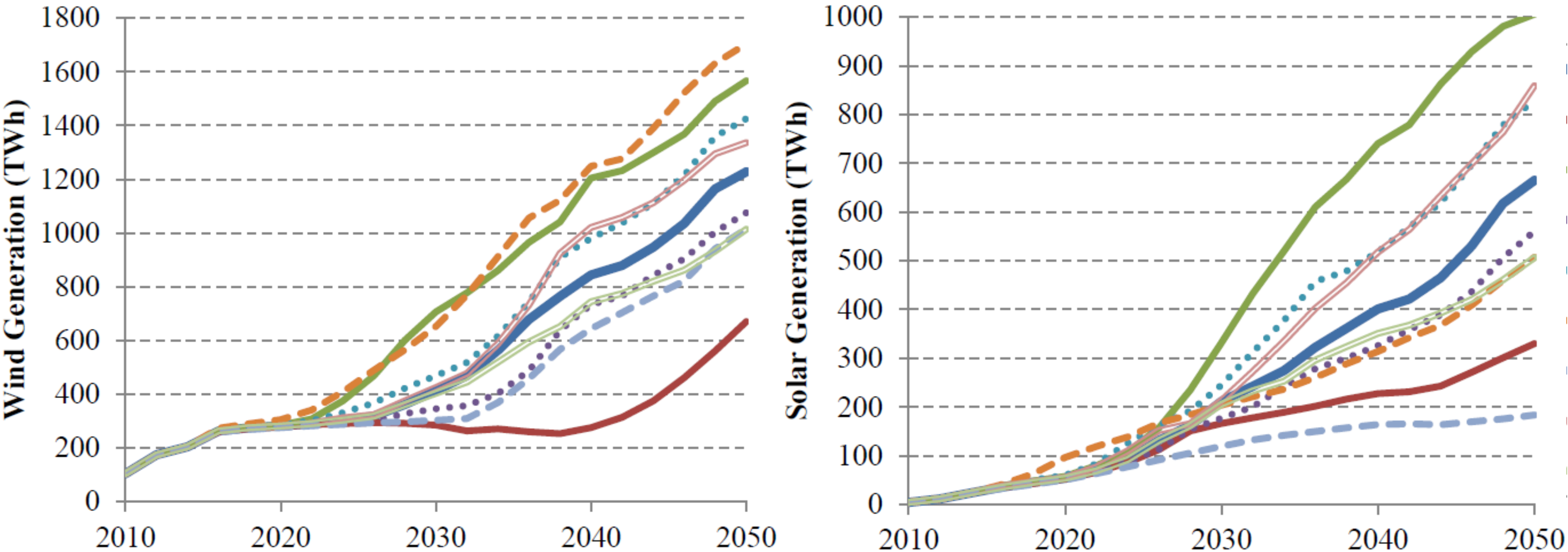
Motivation for better storage modeling

Renewable deployment expected based on policy and economics

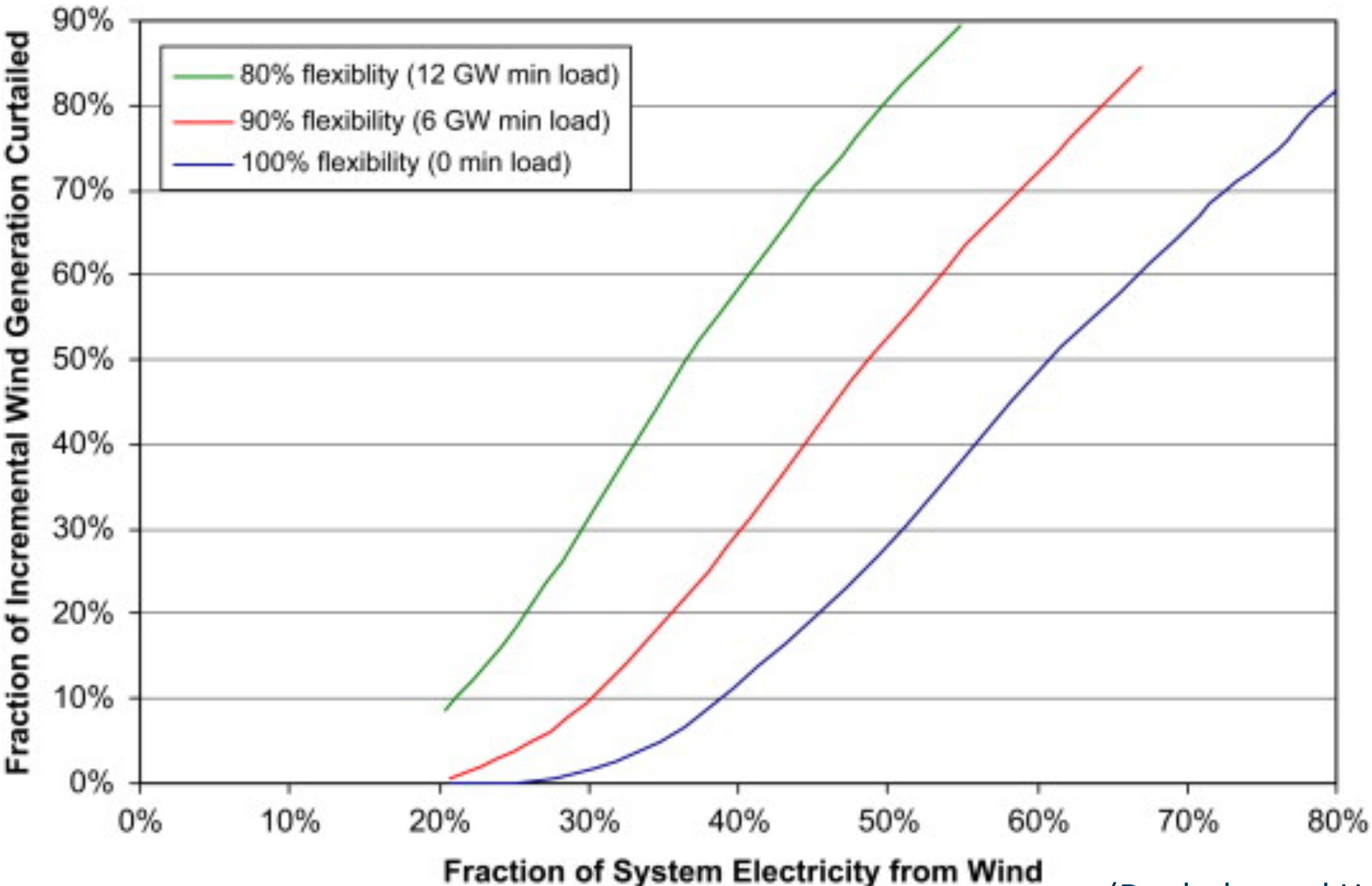
- State Renewable Portfolio Standards (RPS)
- California AB32
- EPA Clean Power Plan (CPP)



Results from ReEDS 2015 Standard Scenarios (Sullivan et al. 2015)



Increased system flexibility is known to support RE grid integration



(Denholm and Hand 2011)

Challenges for Capacity Expansion Modeling

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- Operational issues. With a given portfolio of assets including variable generation (VG),
  - **Is dispatch feasible?**
  - **Are there enough operating reserves?**

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  - **Flexible**, but **energy-constrained** resources: capacity value, use for energy and operating reserves, ability to reduce curtailment

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- Operational issues. With a given portfolio of assets including variable generation (VG),
  - **Is dispatch feasible?**
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- Resource valuation issues
  - **Flexible**, but **energy-constrained** resources: capacity value, use for energy and operating reserves, ability to reduce curtailment
- Associated computational limitations
  - Optimization formulation geared toward annual investment decisions
  - Necessitates **reduced geospatial and temporal resolution**

Methodology

Approach

0. RPM was initially designed with high renewable futures and flexibility in mind
   - Chronological, hourly dispatch
   - Operating reserves based on VG penetration
   - Unit commitment and ramping constraints
   - Unit-level detail and transmission in focus region
   - Dynamic capacity value calculations

Approach

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   - Chronological, hourly dispatch
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- RPM can capture many of the key valuations for flexibility.
- However computational limitations prevent adequate coverage over time (e.g., hourly is not possible).
- We use time-series and load duration curve techniques outside of the optimization to better capture flexibility during "tail" events.

Approach

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   - Parameterize impacts of VG and flexible technologies on capacity value and curtailment.

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1. "Yoga for capacity expansion models" – capture flexibility needs and provision in models with limited temporal resolution and coverage
   - Hourly time series and load duration curve methods, similar to NREL REFlex model.
   - Parameterize impacts of VG and flexible technologies on capacity value and curtailment.
   - Similar, but less-detailed methods being used in global Integrated Assessment Models

Approach

2. Add flexible technology investments
   - Storage with maximum and minimum energy constraints
   - Capture appropriate value streams, some of which require 8760 calculations (e.g. capacity value, curtailment reduction)
   - Current and future cost estimates vary significantly and are uncertain. Thus we include a range of possible costs to determine tipping points for measurable deployment.

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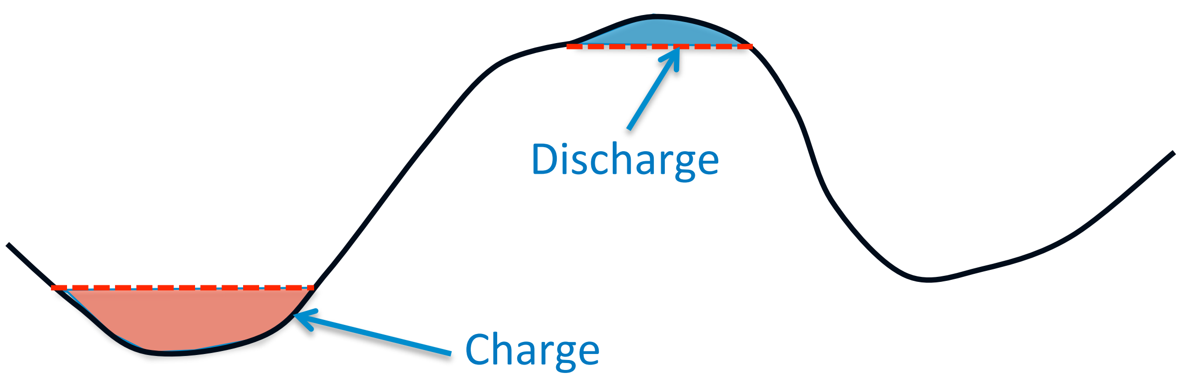
- Assume grid operators will utilize storage efficiently, particularly during peak periods
- Create a heuristic dispatch to maximize capacity value and minimize curtailment, which is used to create a modified ‘storage load curve’



Yoga: Capacity Value

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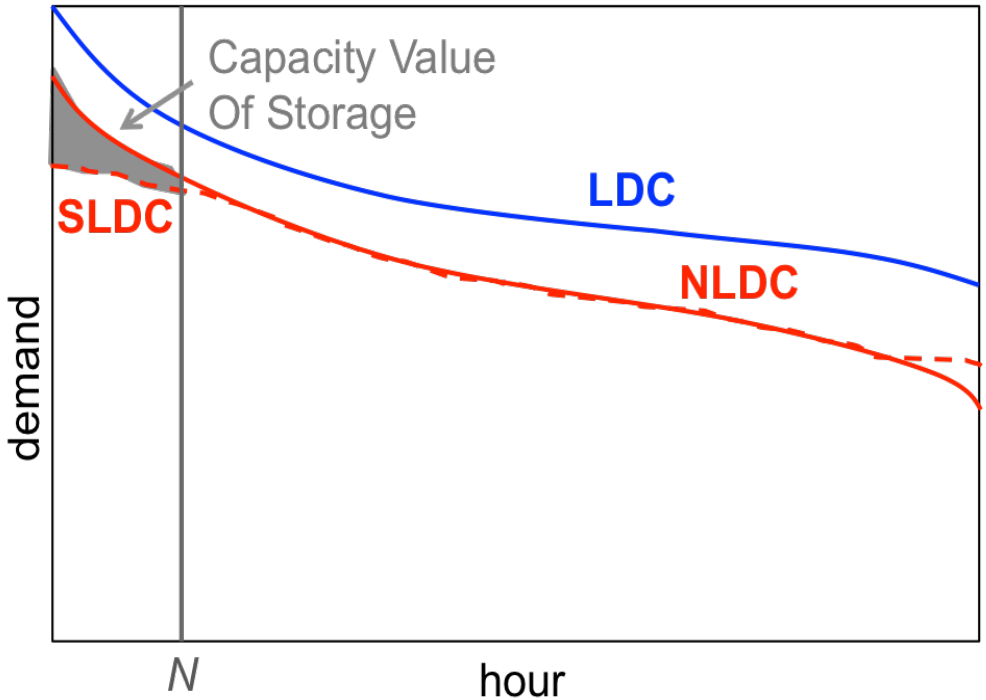
Yoga: Capacity Value

- Capture shift in net peak load based on top 100 hours
- Values geospatial and technology diversity
- At the NERC level and by storage technology:
  - capacity value of existing storage = <NLDC – SLDC>$_{\text{top 100}}$ / existing capacity
  - marginal capacity value of new storage = <SLDC(δ)>$_{\text{top 100}}$ / δ



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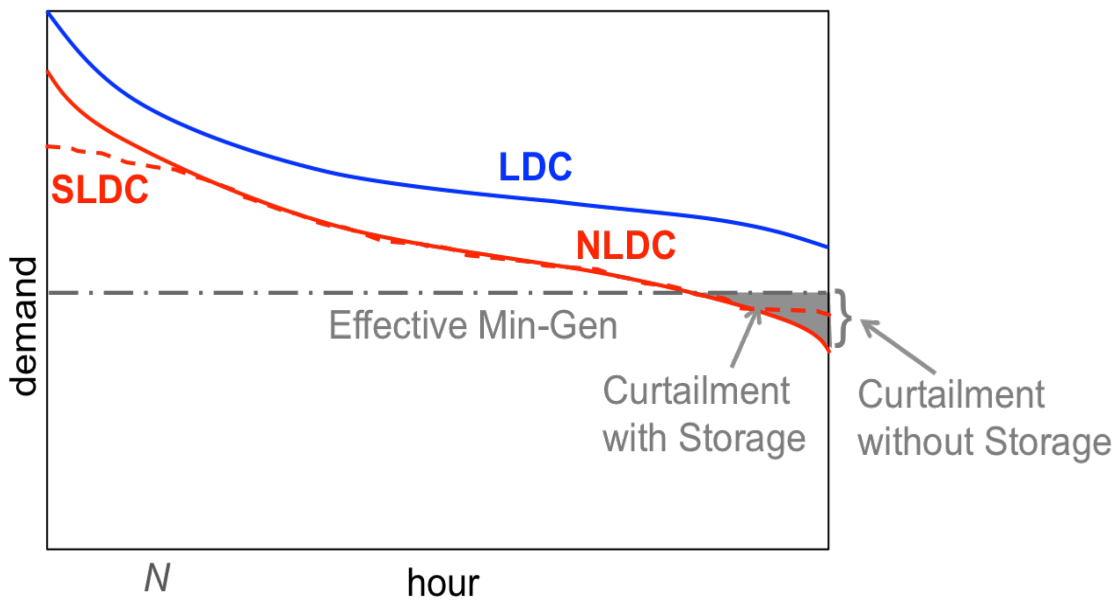
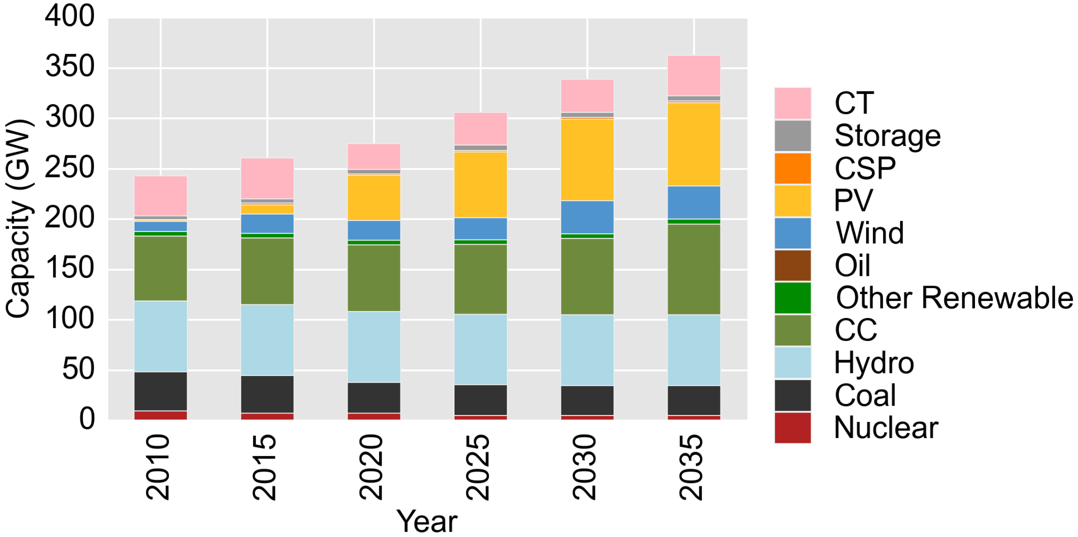


Scenarios

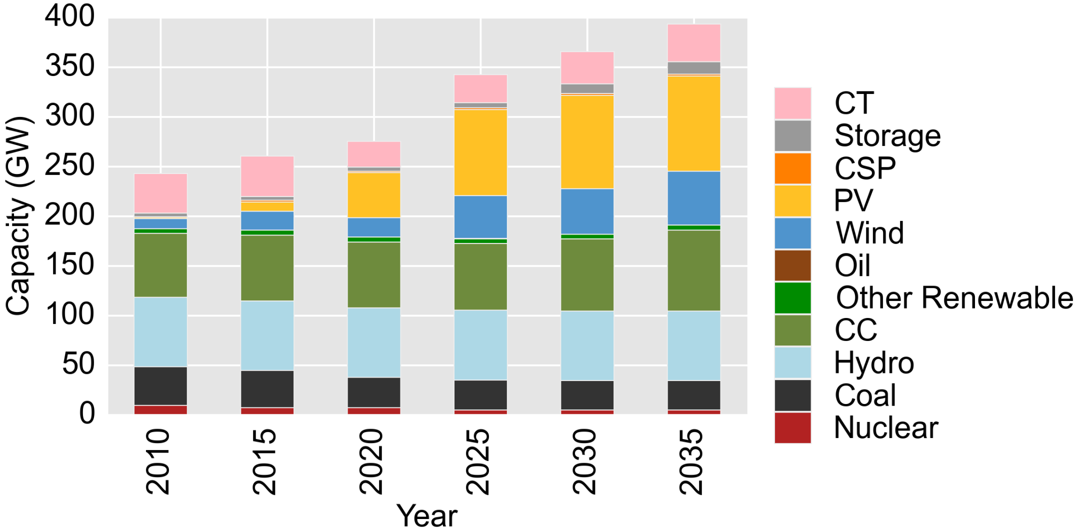
Capacity Expansion for Baseline Scenarios

Base



- Existing policies
- Mid-line PV and wind costs
- Mid Storage costs
- AEO Reference Natural Gas prices
- No Carbon price

High Renewable



- Existing policies
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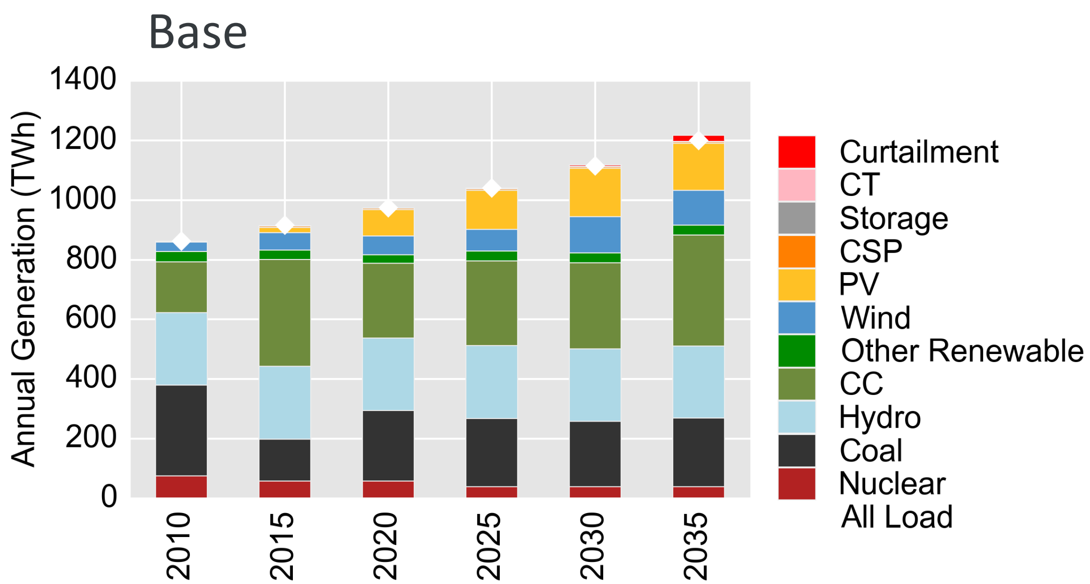
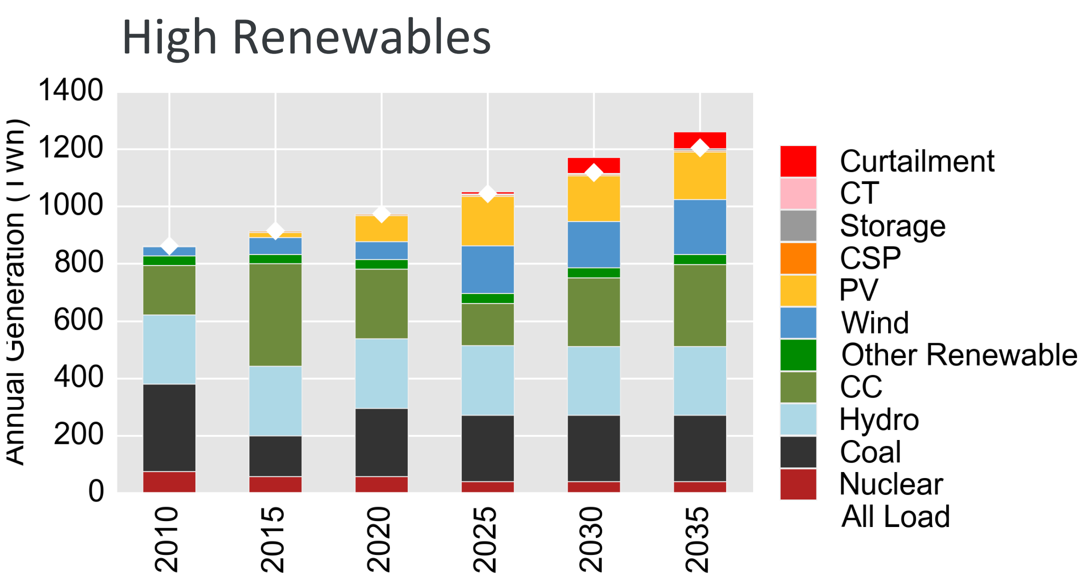
- AEO High Natural Gas prices
- Median Carbon price

Annual Generation for Baseline Scenarios

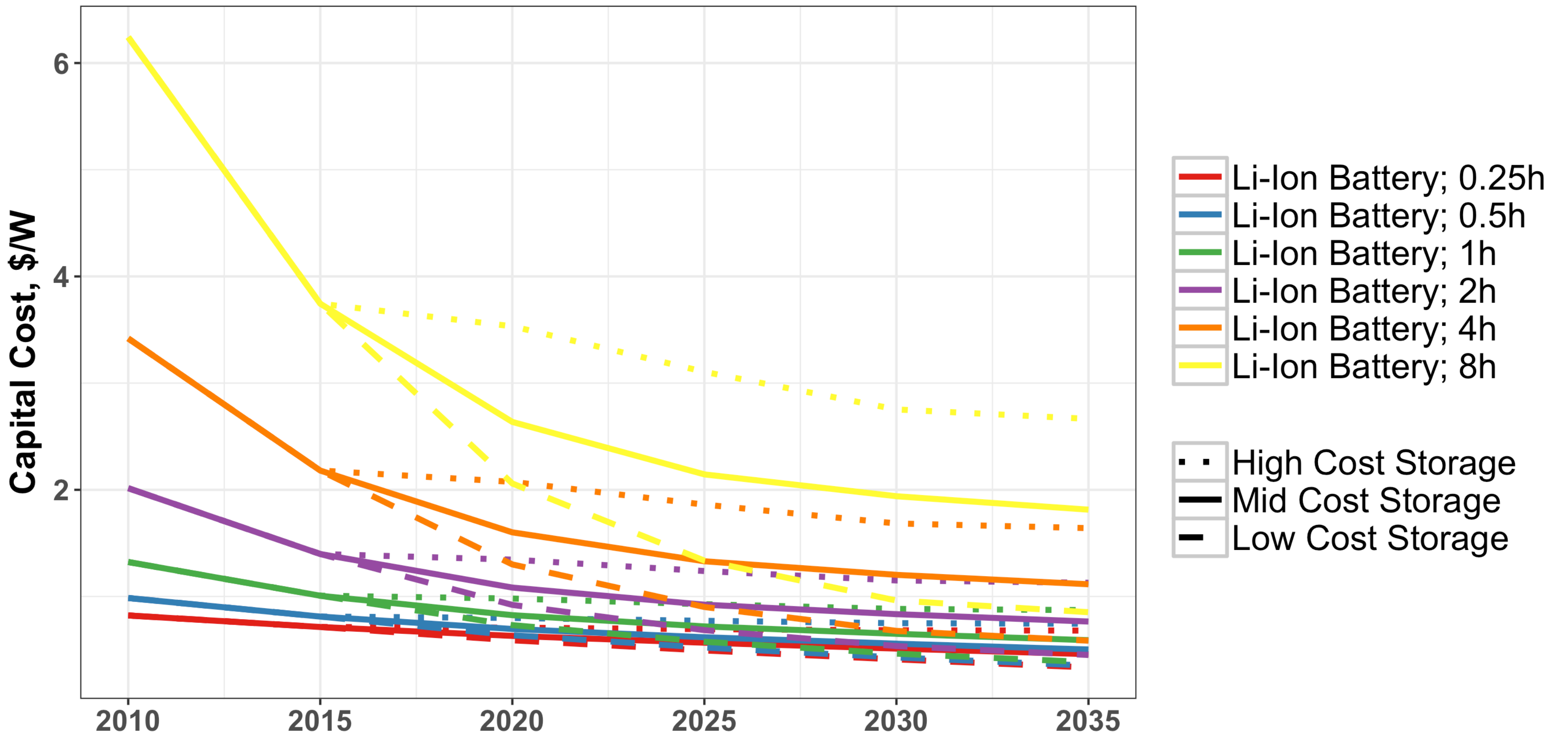


- Solar growth starts in 2020
- Mild wind growth
- Significant curtailment doesn't start until 2035
- Increase in gas CC generation in 2035



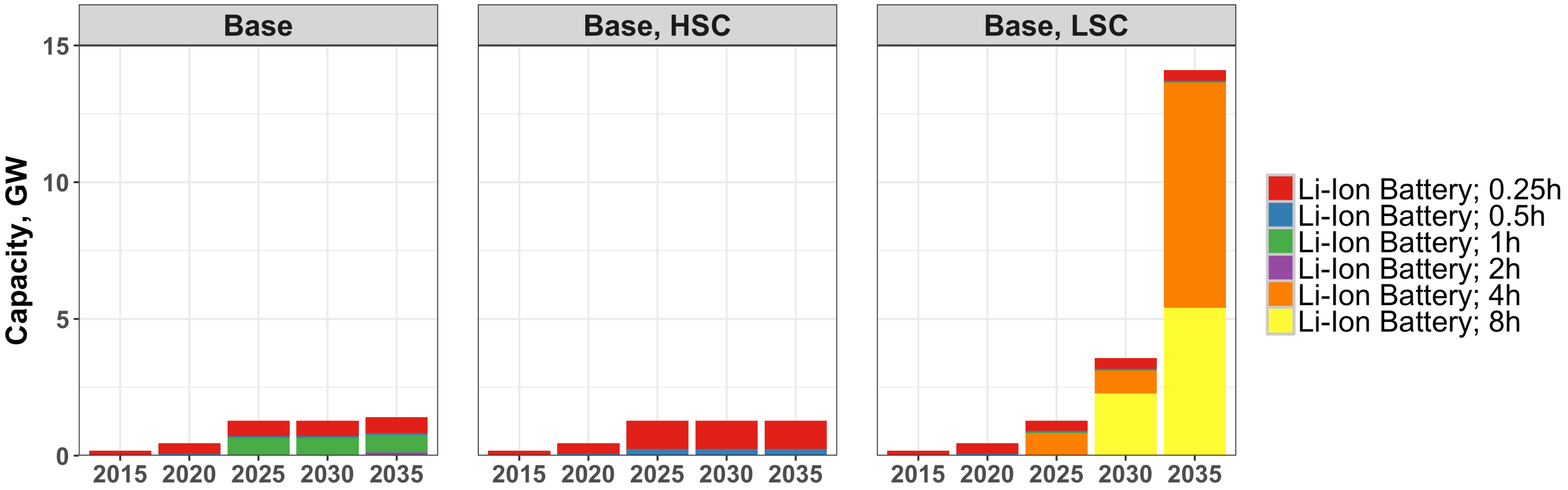
- Solar growth starts in 2020
- Significant wind generation in 2025
- Significant curtailment starts in 2030

Storage cost trajectories

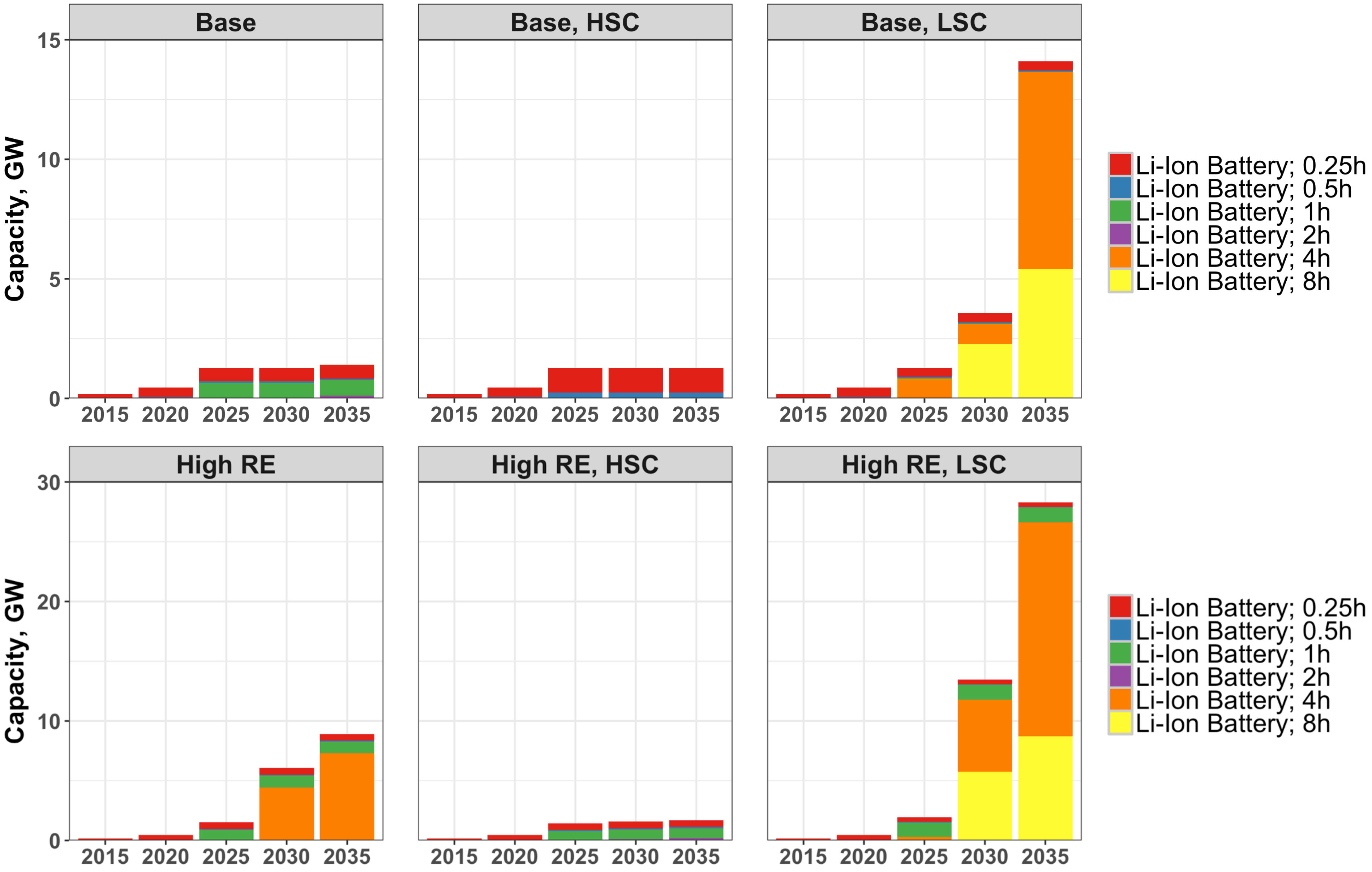


Trajectories from Cole et. al. for several storage capacities

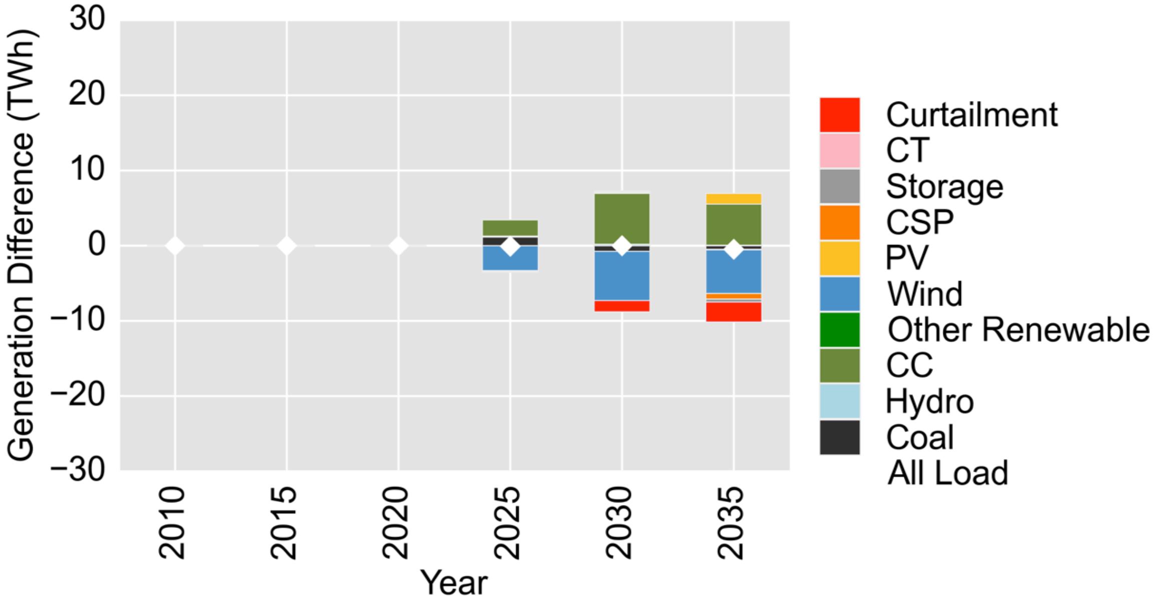
Storage capacity built by RPM



Storage capacity built by RPM



Storage Cost Impacts on Annual Generation, Base



High Storage Costs

- Reduction of wind and increase of gas CC
- Reduction of curtailment largely from lower renewable dispatch

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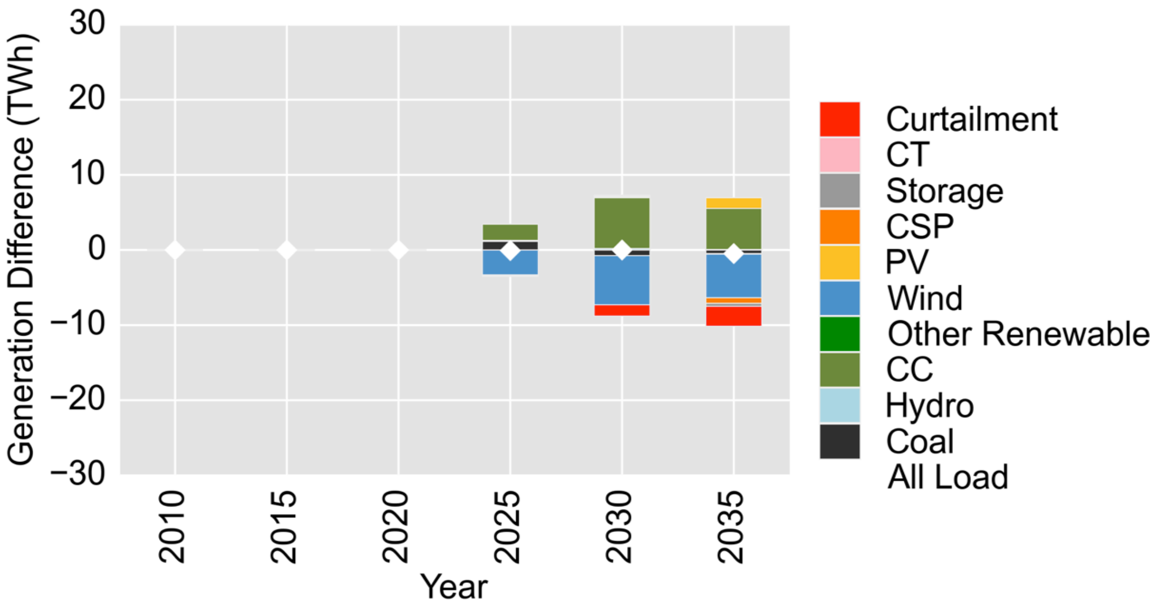

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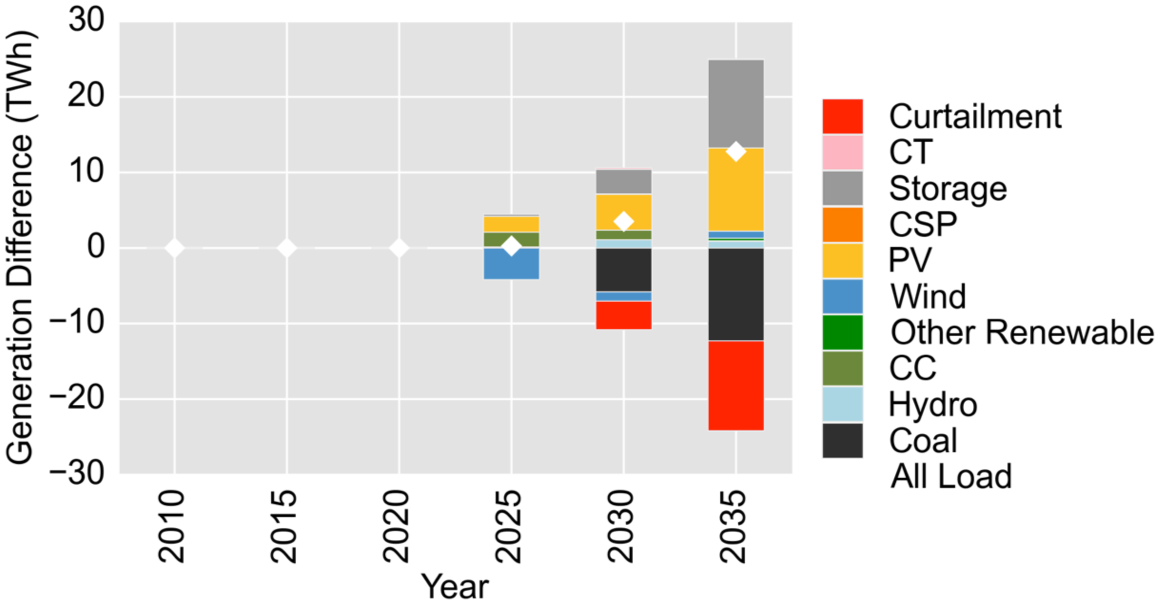
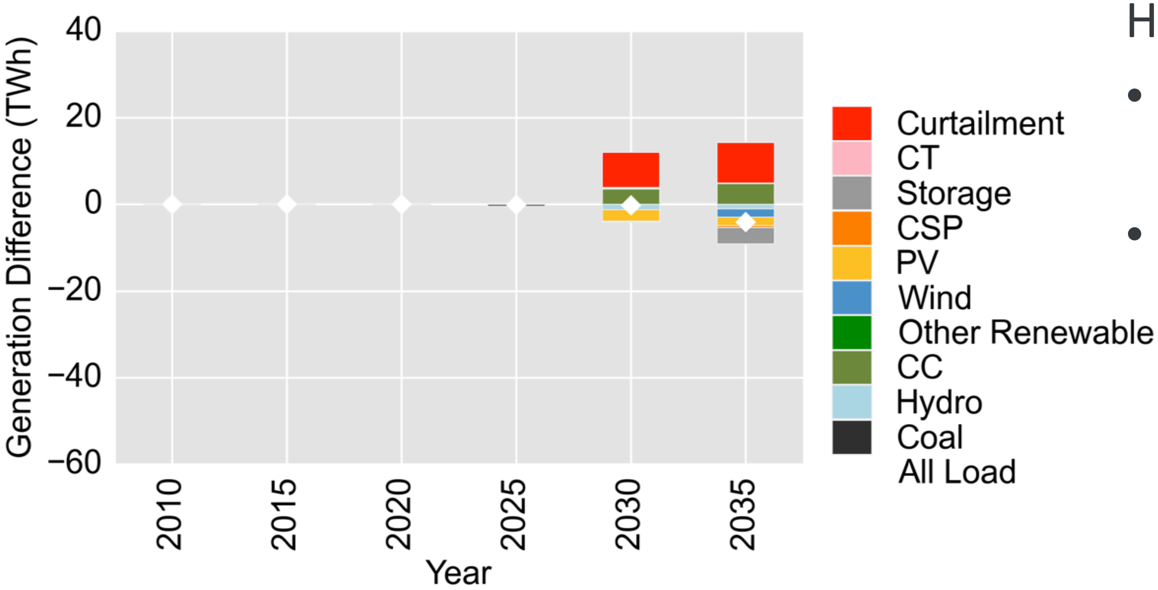


Low Storage Costs

- Large increase solar and storage generation
- Reduction in solar curtailment and coal generation

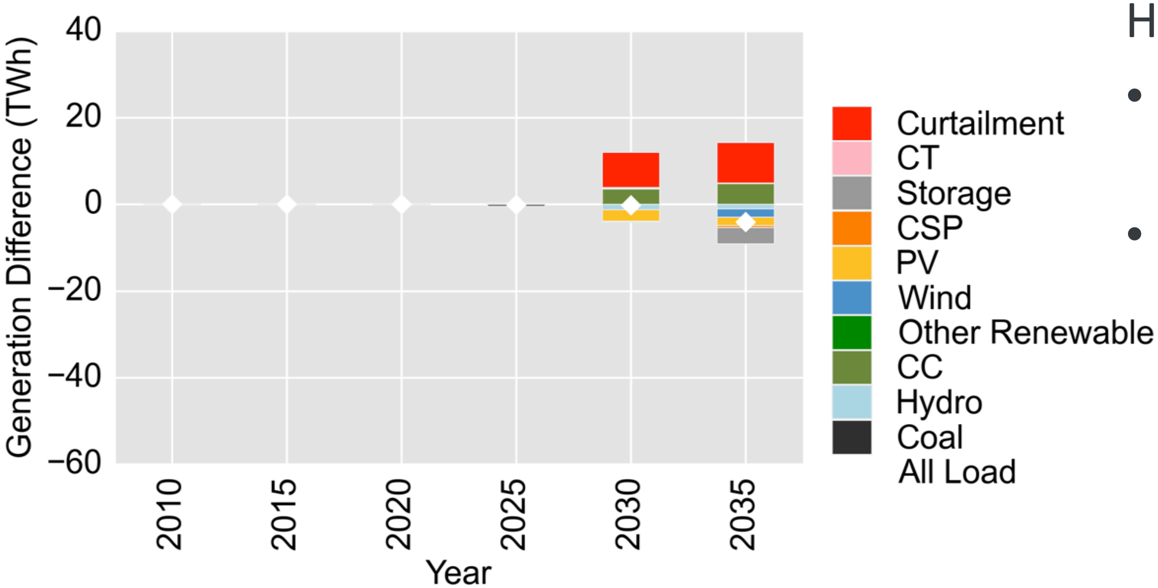
Storage Cost Impacts on Annual Generation, High RE



High Storage Costs

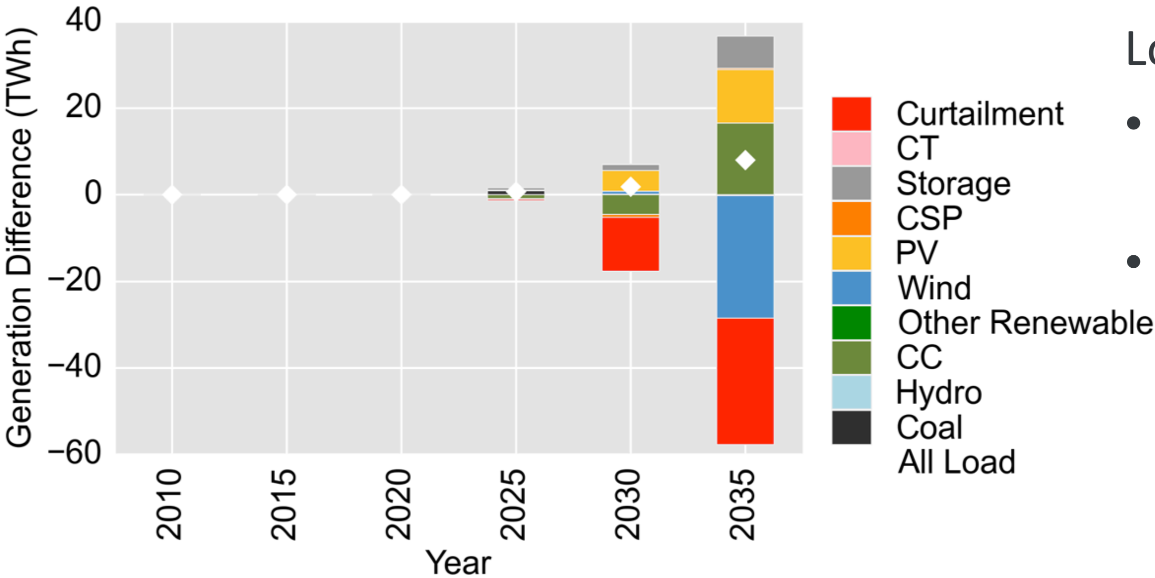
- Increase in curtailment and gas generation
- Reduction in solar and storage generation

Storage Cost Impacts on Annual Generation, High RE



High Storage Costs

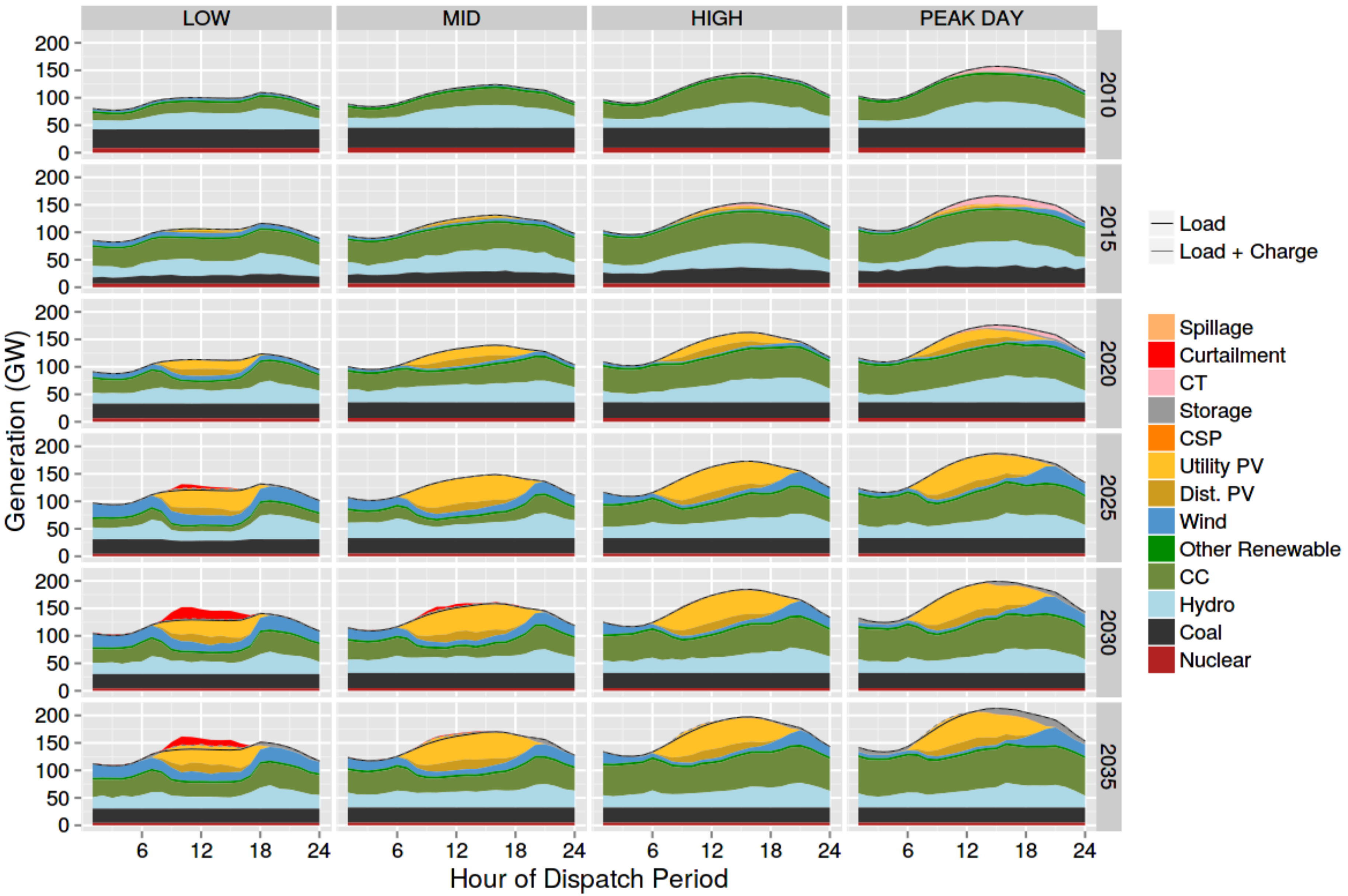
- Increase in curtailment and gas generation
- Reduction in solar and storage generation



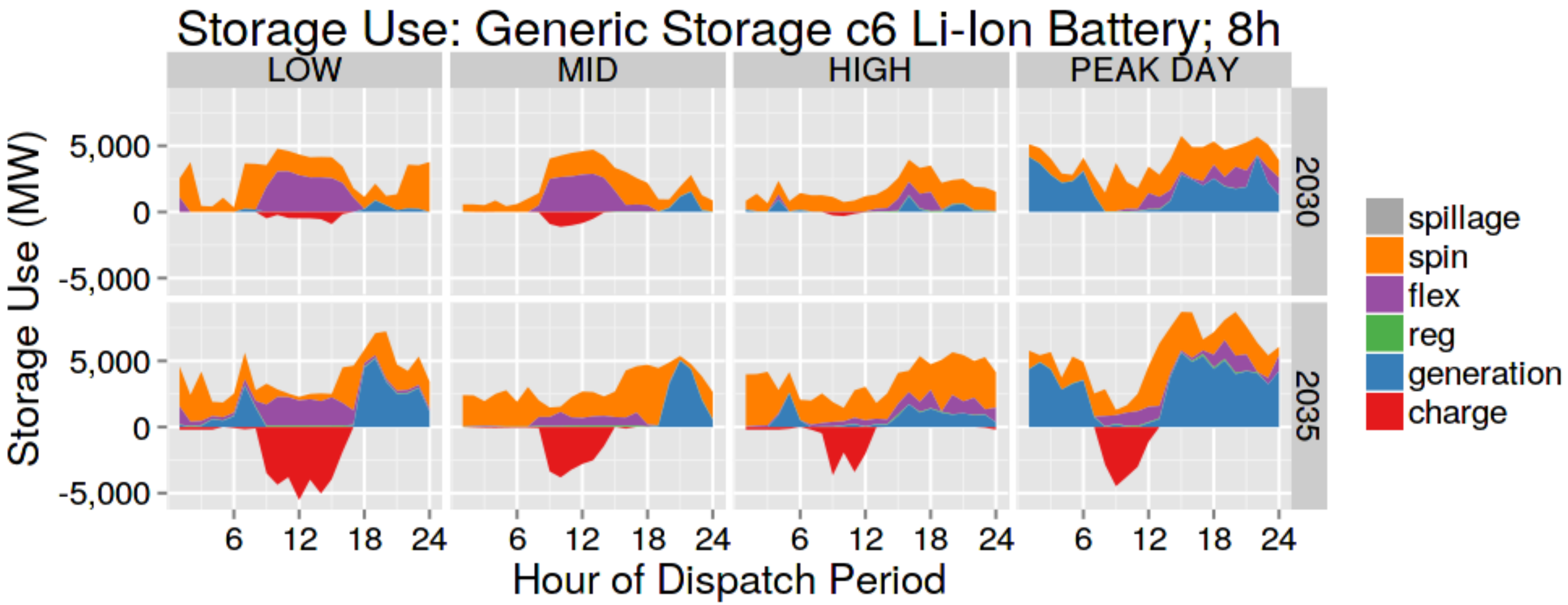
Low Storage Costs

- Increase in solar, storage and gas generation
- Decrease in curtailment, and wind generation from reduced installations

Dispatch, High RE, low storage costs

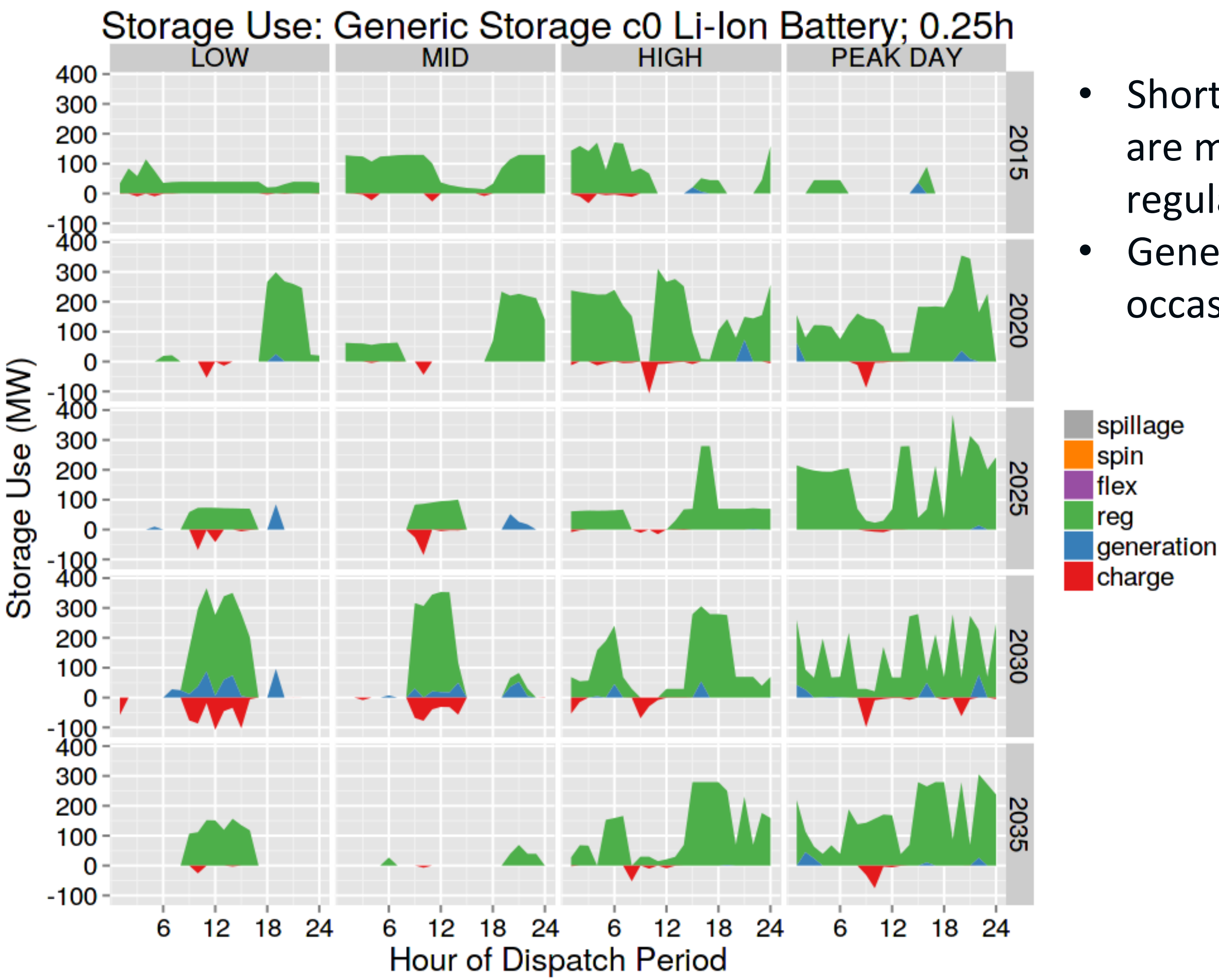


Storage Operation, long-duration



- Charging largely occurs during high solar hours
- Dispatch largely occurs during afternoon peak
- Long-duration storage provides spinning and regulation reserves

Storage Operation, short-duration

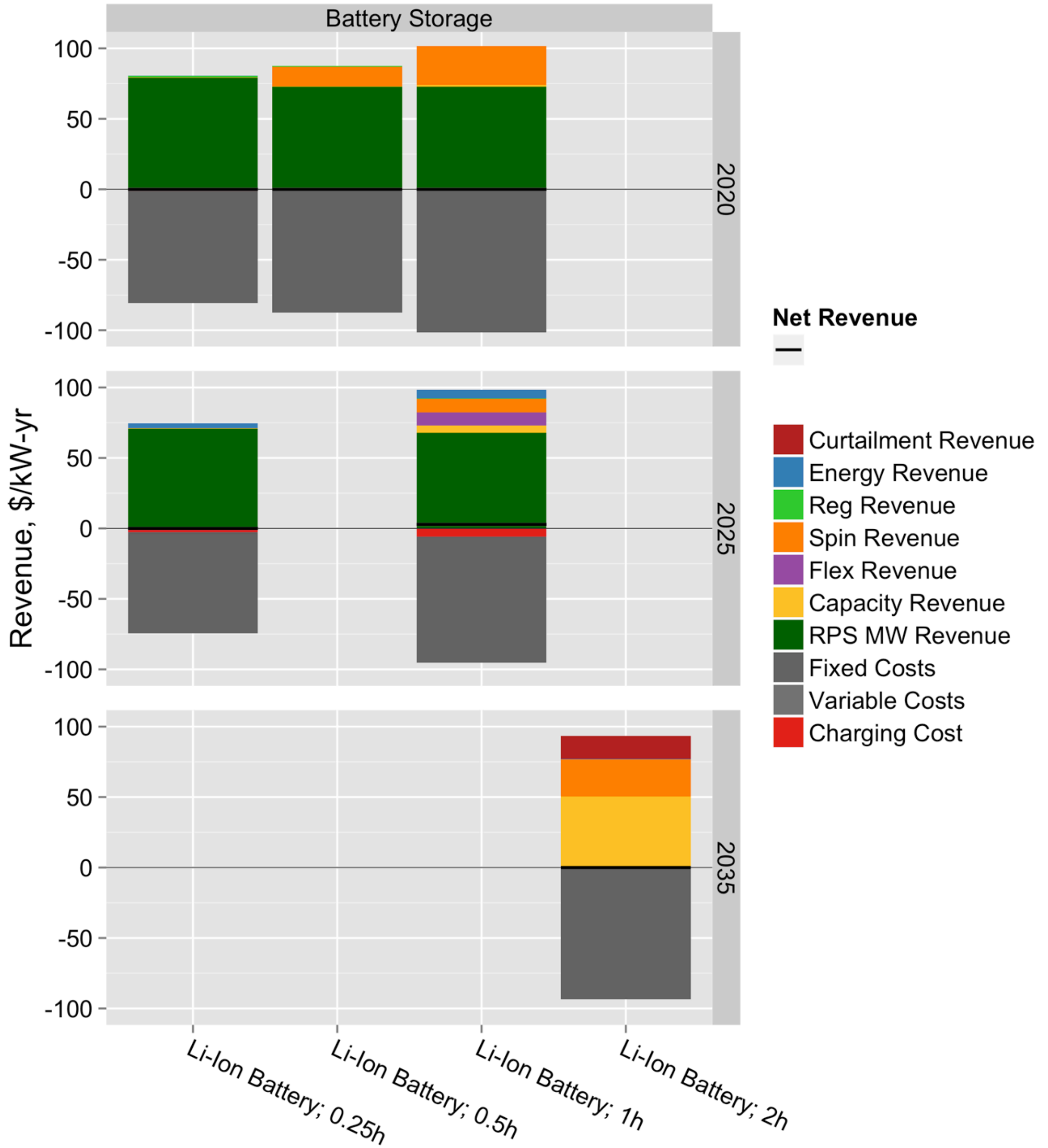


- Short-term batteries are mostly used for regulation reserves
- Generation provided occasionally

Value of Storage, Base, mid storage costs

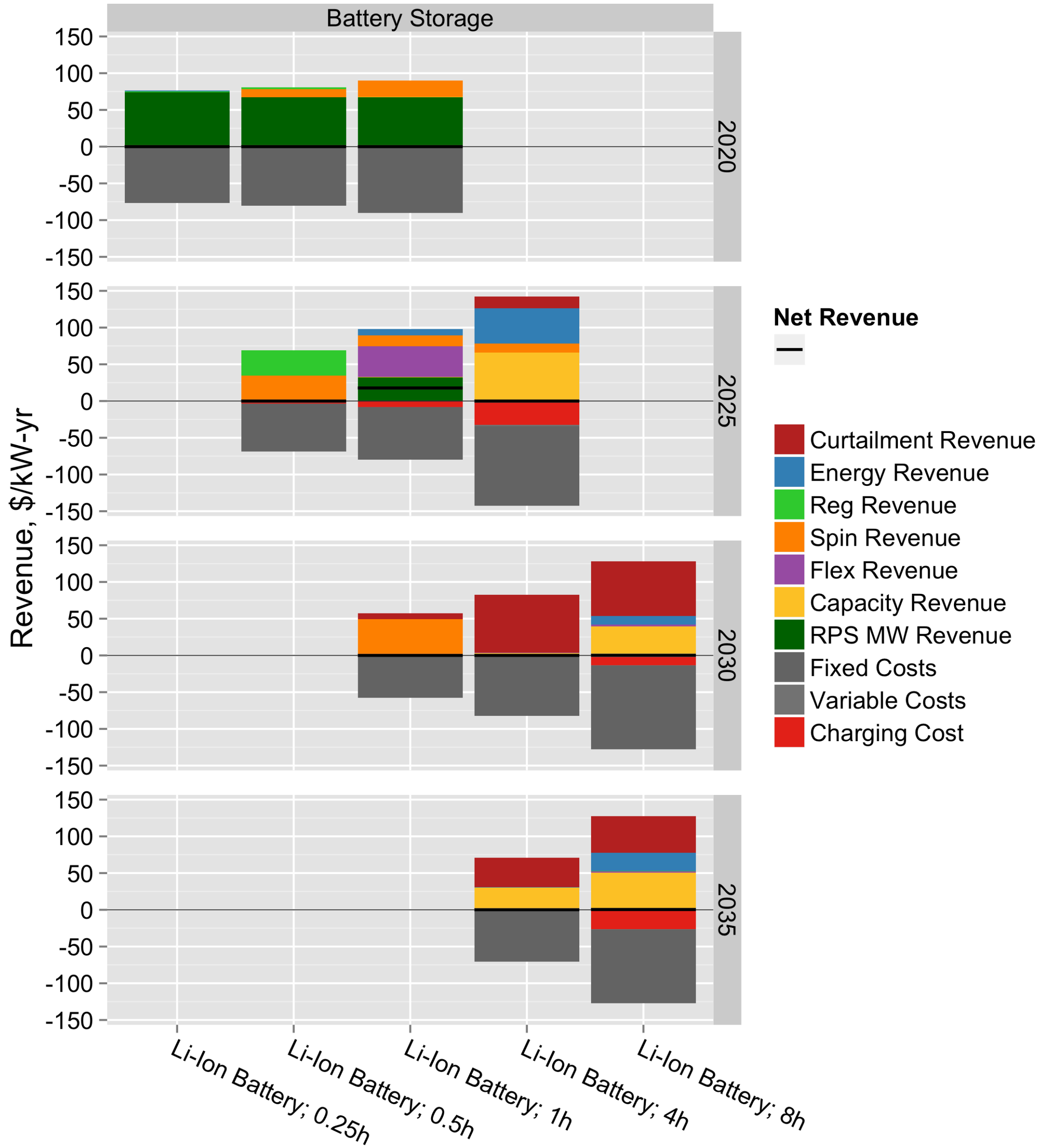
Value of Storage, Base, mid storage costs

- Storage is only installed in 2020 and 2025 to meet AB32
- Reserves provision enables higher energy capacities in these years
- No economic storage installed until 2035
- 2-hour storage installed for capacity, curtailment reduction, and reserves



Value of Storage, High RE, low storage costs

- Storage is only installed in 2020 to meet AB32, with reserves provision enabling higher energy capacities
- 30-min to 1-hour storage are installed largely for reserves provision
- By 2030, 4 and 8 hour storage are installed for capacity, curtailment reduction, and energy shifting



Conclusions

- RPM represents renewables and flexible technology with high resolution in resource availability and dispersion
- Use methodology designed to fully capture the tails of operation to ensure we capture the full value flexible technologies provide
- RPM represents multiple value streams available to storage technologies in planning and operations of an electric grid

Questions?

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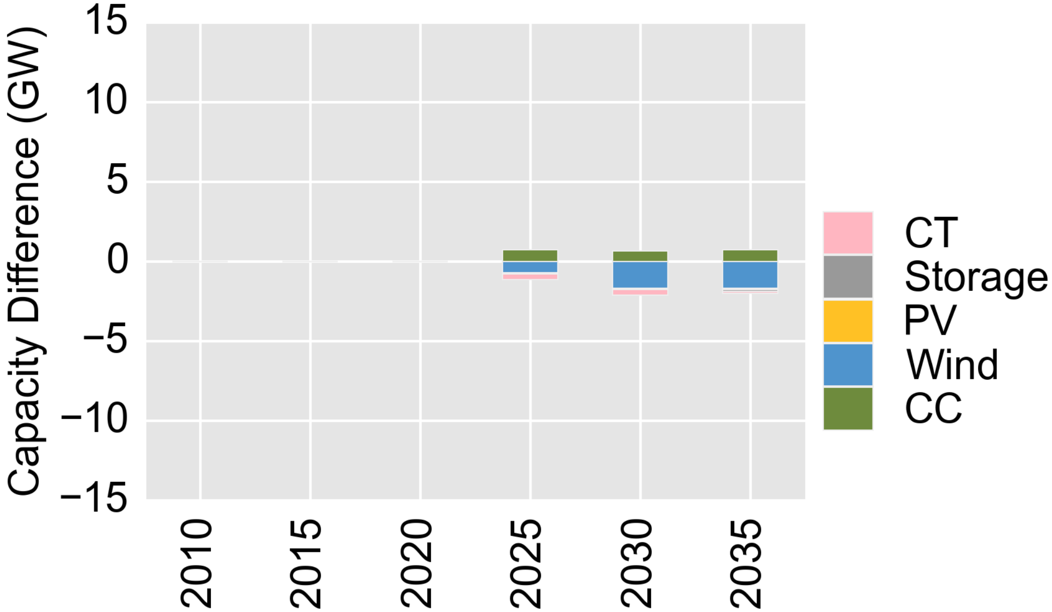
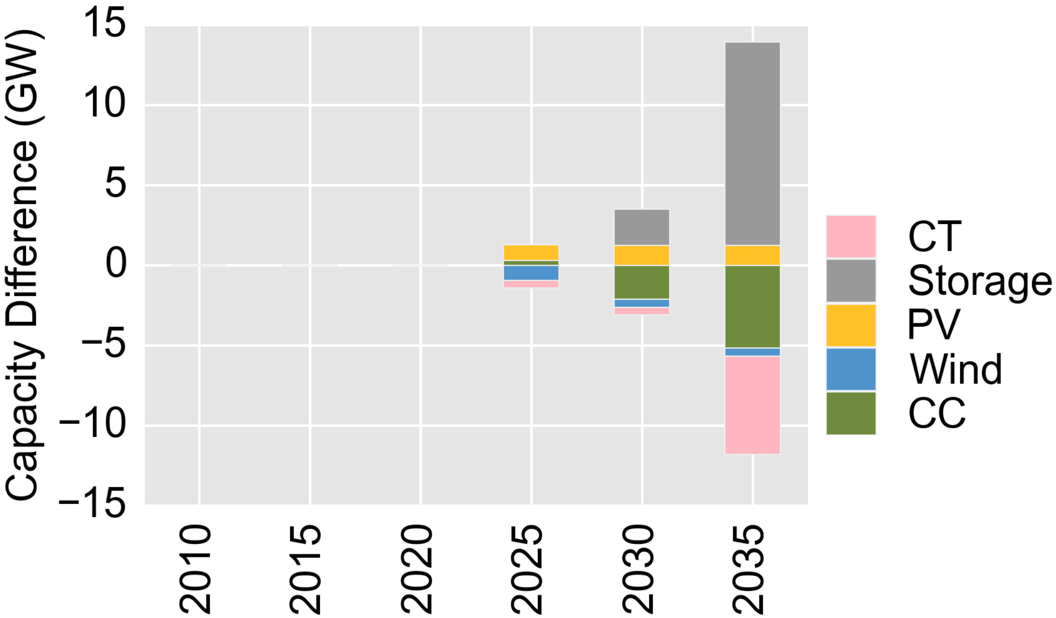
Storage Cost Impacts on Capacity, Base



High Storage Costs

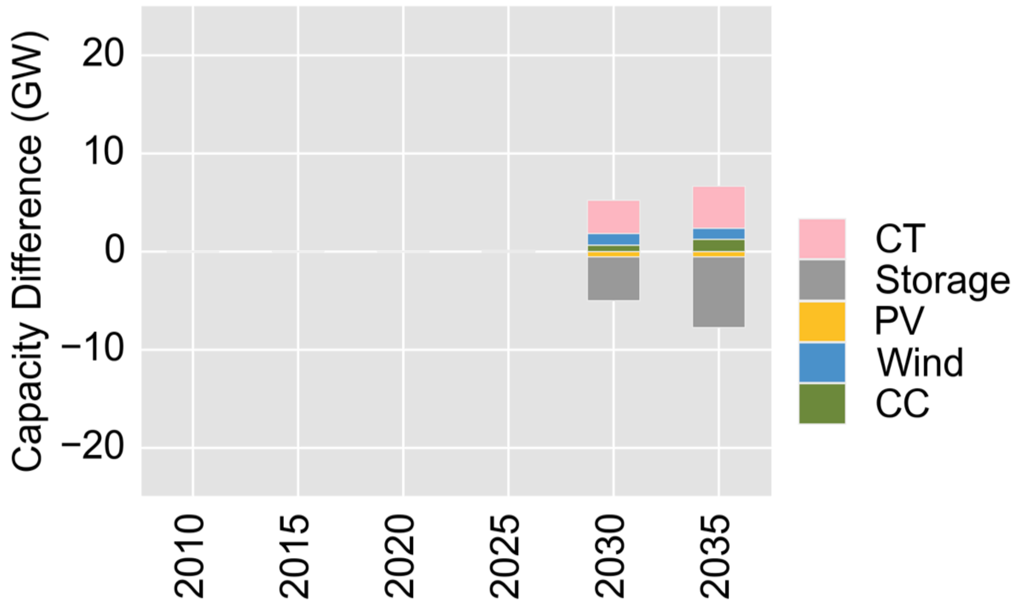
- Approximately the same total storage capacity, but smaller energy capacities
- Reduction of wind capacity gets built, with increase in gas CC units



Low Storage Costs

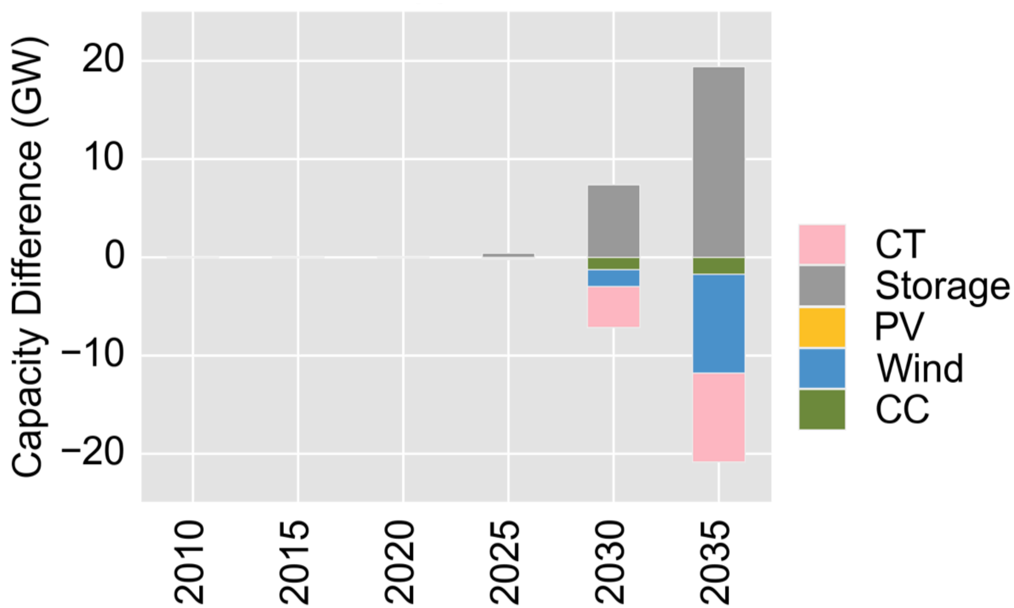
- Large increase in total storage capacity built, with larger energy capacities built starting in 2025
- Increase in solar capacity, reduction of wind and both gas technologies

Storage Cost Impacts on Capacity, High RE



High Storage Costs

- Reduction in storage capacity starting in 2030
- Increase in wind and gas technologies and decrease in solar PV



Low Storage Costs

- Large increase in total storage capacity built, with larger energy capacities built starting in 2030
- Decrease in wind and gas technologies

Resource Planning Model (RPM)

For each model year (2010, 2015, …, 2030)…

min (capital and fixed costs for new generators) +
(capital and fixed costs for new transmission) +
(variable, fuel, start-up, and carbon costs) +
(transmission hurdle rates)

s.t. allowed locations and sizes of new assets
wind and solar resource availability
load balancing (hourly chronological, 4 dispatch periods)
transmission constraints
capacity, reserve, and energy constraints
policy constraints (RPS and CPP)
unit commitment (optional)
minimum plant size (optional)