System Perspectives on Long Duration Storage

ARPA-E

EVOLVED ENERGY RESEARCH

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Outline

- Long-term context for long duration storage
- Example from NY
  - Roles for storage and the durations needed for each
- Final thoughts and observations

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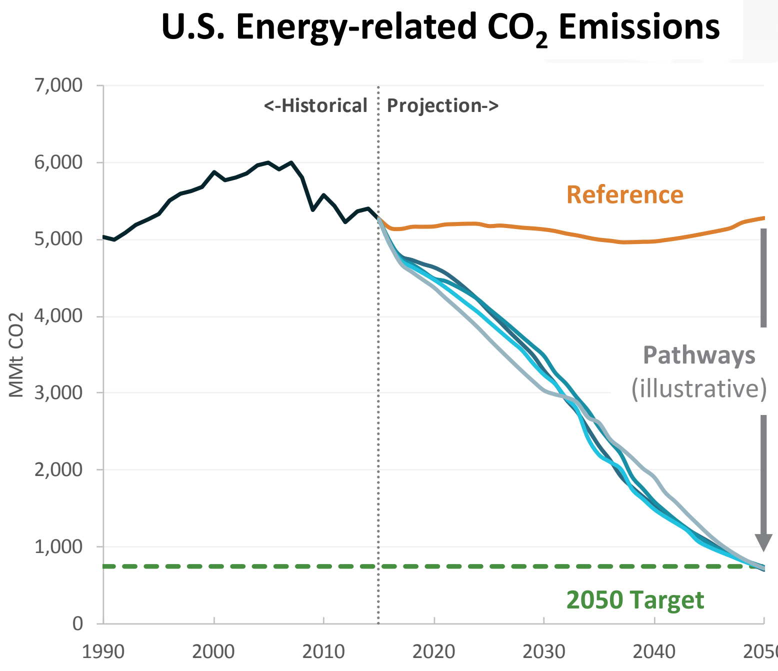
About Evolved Energy Research

- Energy consulting firm focused on addressing key energy sector challenges posed by climate change
- Lead developers of EnergyPATHWAYS, a bottom-up energy system model used to explore the near-term implications of long-term deep decarbonization
- We advise clients on issues of policy implementation and target-setting, R&D strategy, technology competitiveness and impact investing

What are pathways?

- Plausible future energy infrastructures which deeply reduce energy-related CO_2 emissions
- Provides a plan or blueprint to achieve the deep decarbonization of the energy system



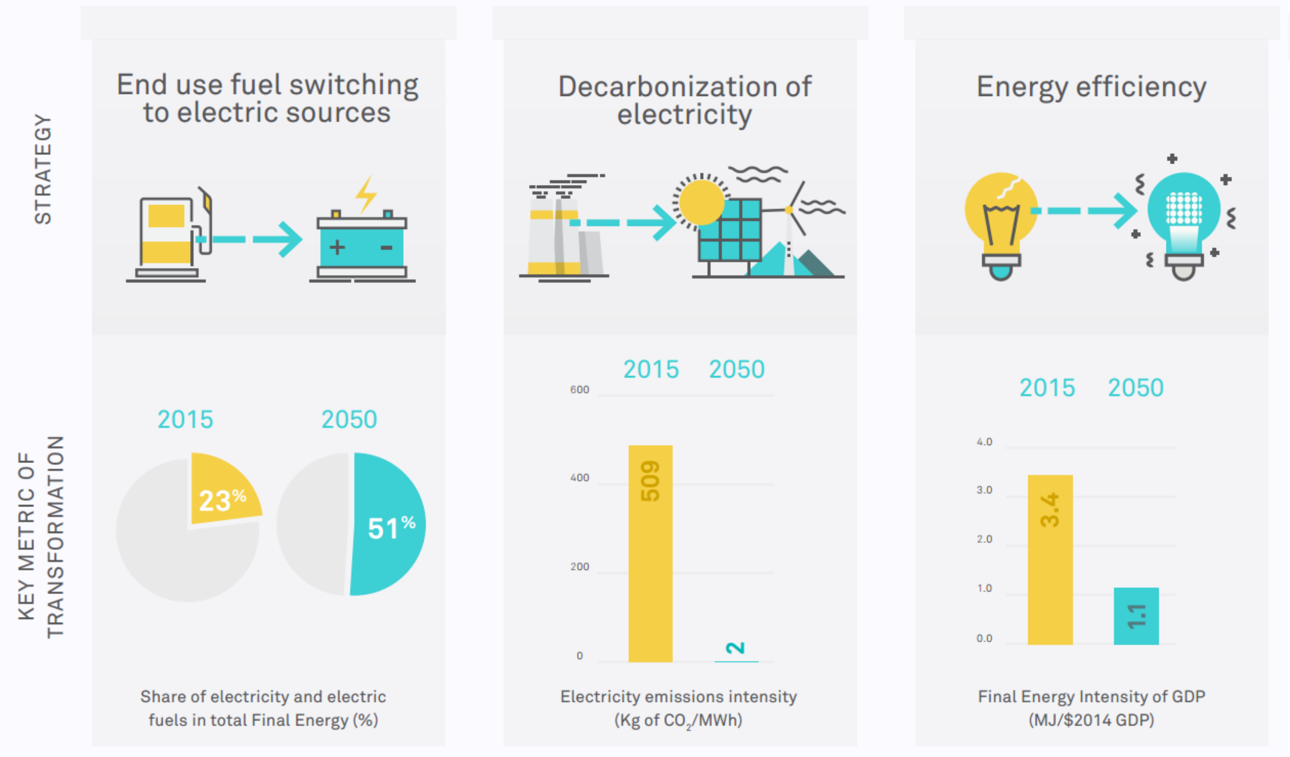
Source: historical emissions data from EIA Monthly Energy Review.

Three pillars of deep decarbonization

United States

2050 U.S. Benchmarks

- 2x increase in the share of energy from electricity or electrically derived fuels
- ~99% decrease in the emissions intensity of electricity generation
- 3x drop in energy use per unit GDP



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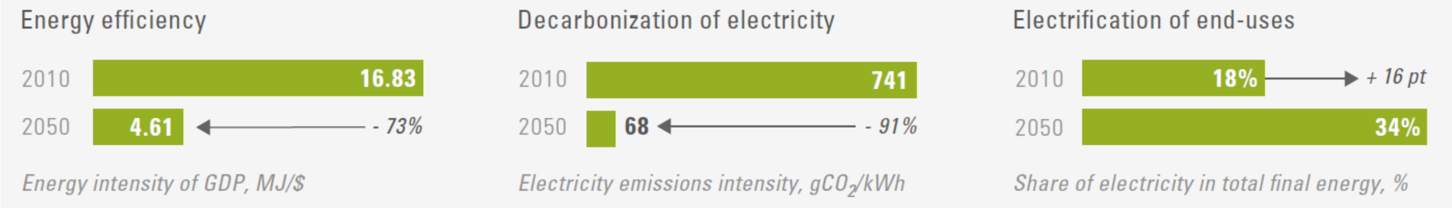
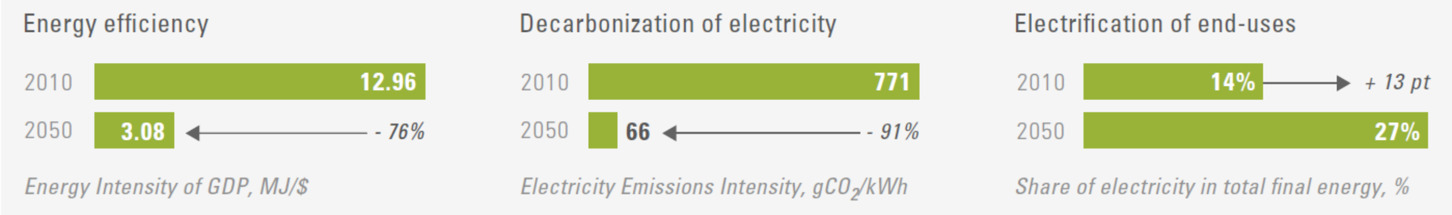
Three pillars cont.

China, India and United Kingdom

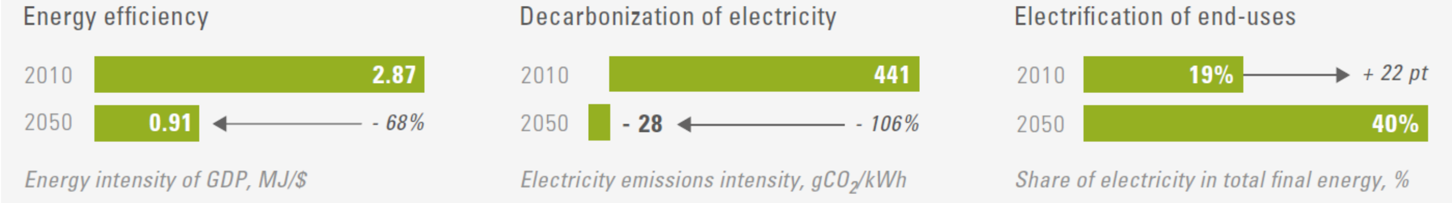
China



India



UK

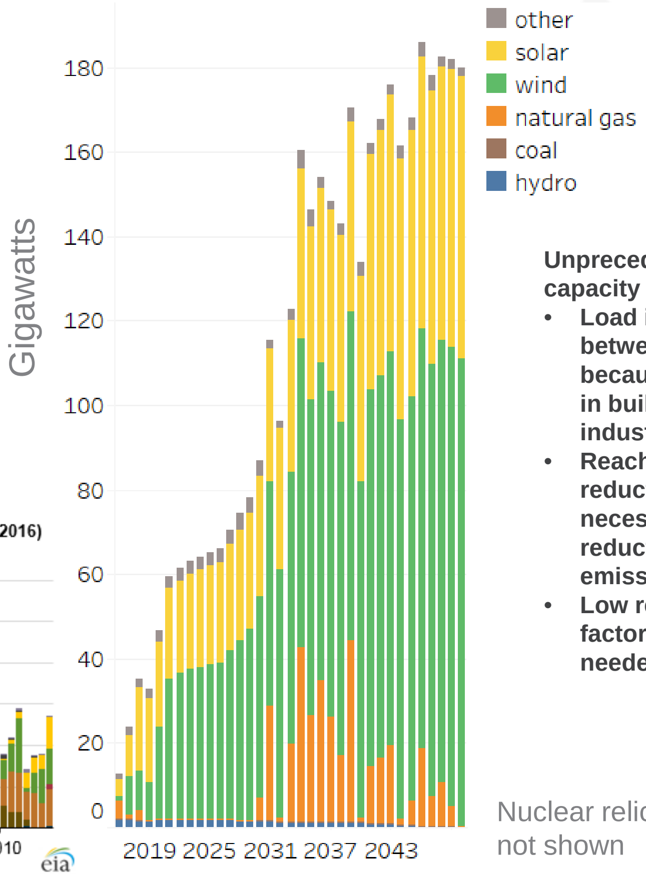


Source: figures from Deep Decarbonization Pathways Project country reports (2015)

Rapid growth of renewables

At the end of 2017 renewables are the cheapest source of new energy for most of the world—this is a fundamental shift

High Renewables DDPP Scenario new capacity by year

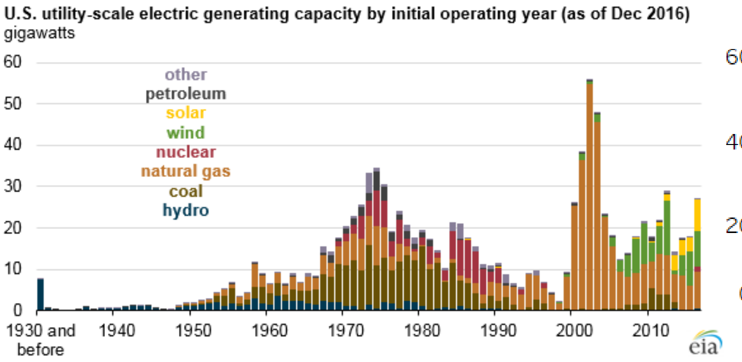


Unprecedented growth in capacity due to:

- **Load is nearly doubling between 2015 & 2050 because of electrification in buildings, transport, & industry**
- **Reaching 80% carbon reductions by 2050 necessitate a 50x reduction in electricity emissions intensity**
- **Low renewable capacity factors (3-4x capacity is needed per unit energy)**

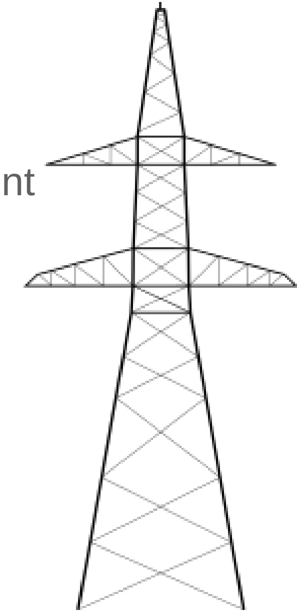
Nuclear relicensing not shown

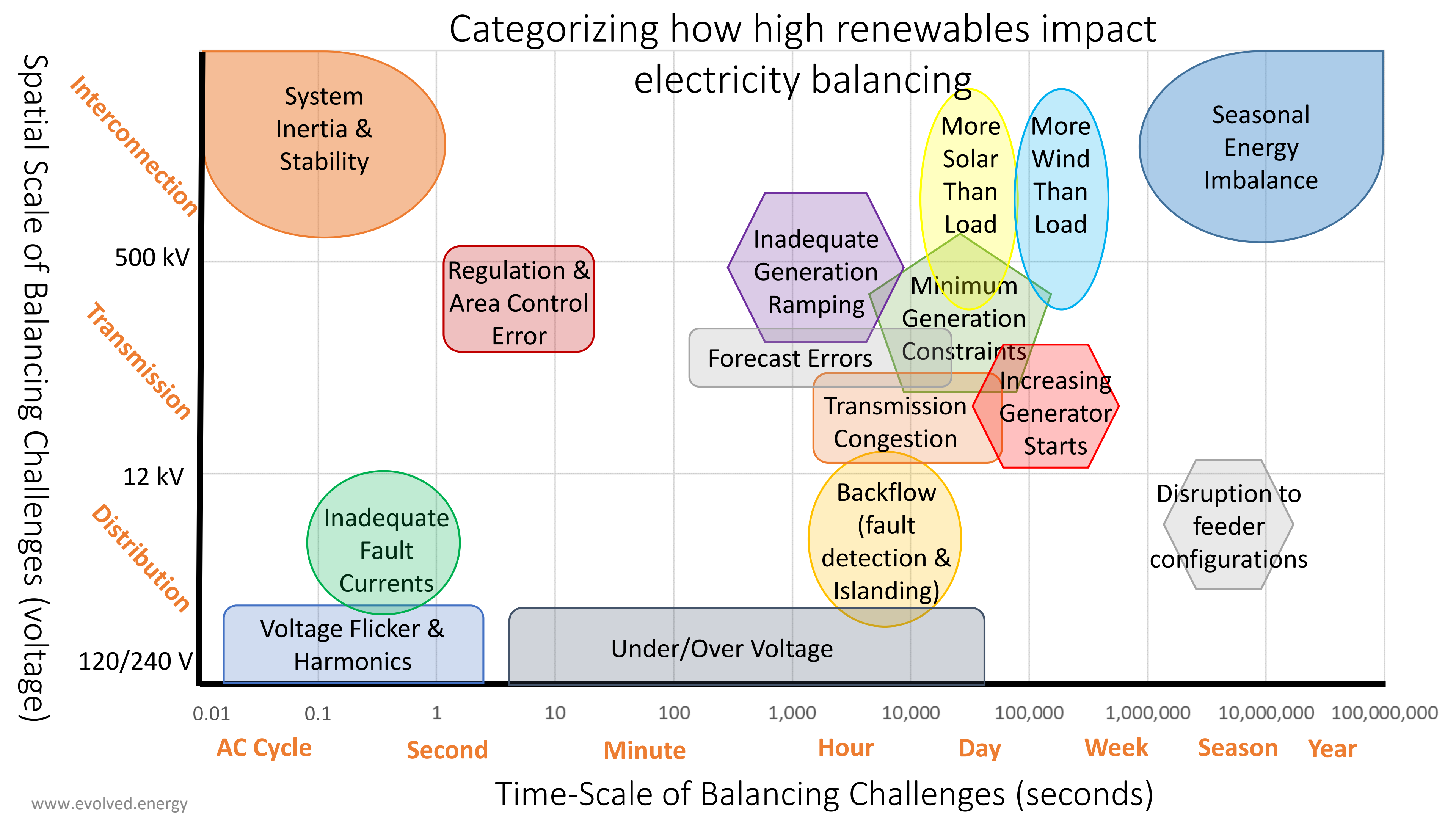
Historical Build (EIA)



How do renewables present unique challenges for balancing?

- Renewables have certain characteristics that make them difficult to manage in the context of today's electricity system
  - **Variability** – output is not controllable and can change rapidly
  - **Uncertainty** – future output can be difficult to predict
  - **New locations** – deployment in locations not anticipated when the grid was built
  - **Inverters vs. synchronous motors** – technical character of inverters are different





Categorizing how high renewables impact electricity balancing
Spatial Scale of Balancing Challenges (voltage)
Interconnection
Transmission
Distribution
500 kV
12 kV
120/240 V
System Inertia & Stability
Regulation & Area Control Error
Inadequate Generation Ramping
More Solar Than Load
More Wind Than Load
Seasonal Energy Imbalance
Minimum Generation Constraints
Forecast Errors
Transmission Congestion
Increasing Generator Starts
Backflow (fault detection & Islanding)
Disruption to feeder configurations
Inadequate Fault Currents
Voltage Flicker & Harmonics
Under/Over Voltage
0.01
0.1
1
10
100
1,000
10,000
100,000
1,000,000
10,000,000
100,000,000
AC Cycle
Second
Minute
Hour
Day
Week
Season
Year
Time-Scale of Balancing Challenges (seconds)
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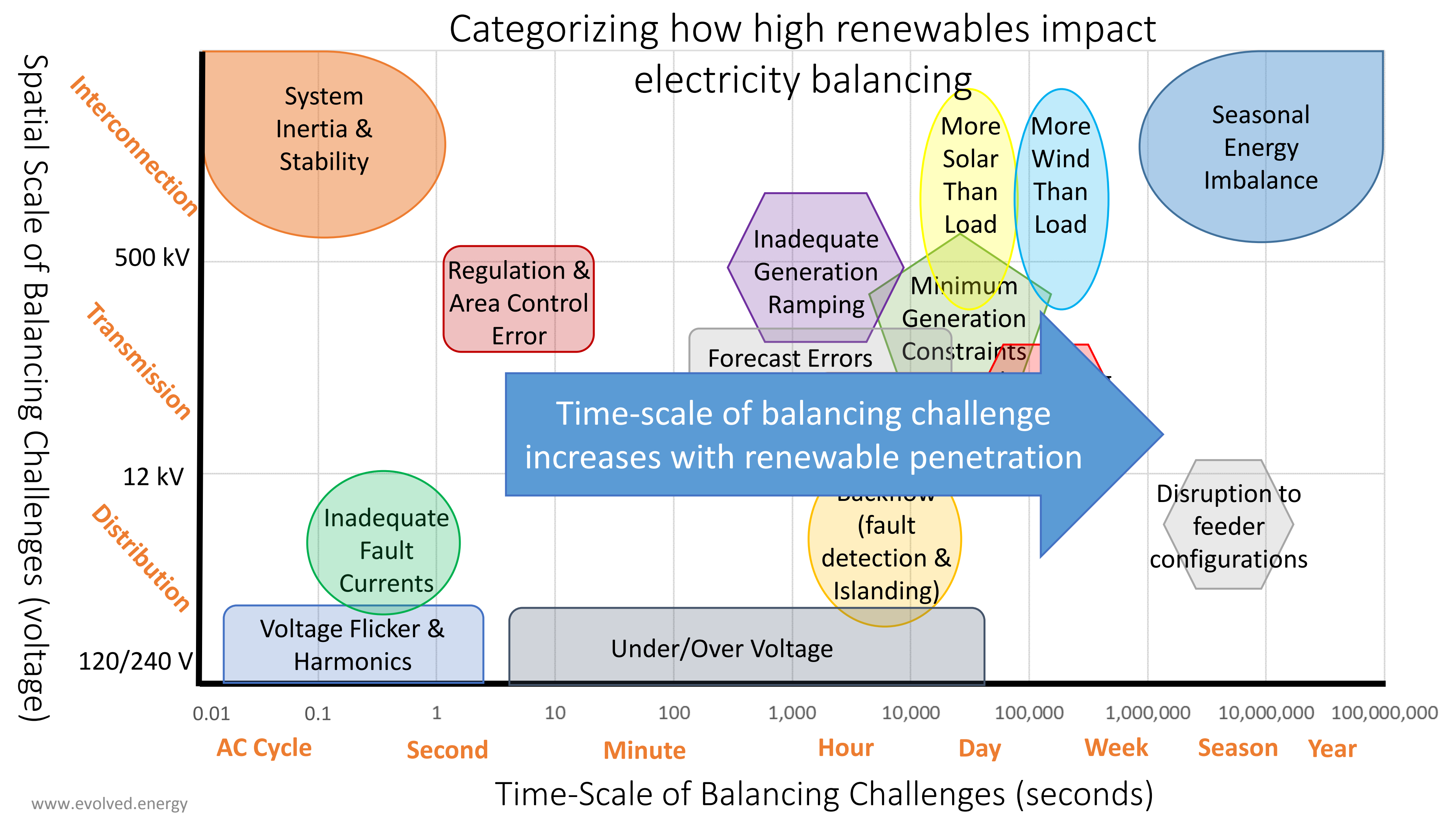
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Time-scale of balancing challenge increases with renewable penetration
(fault detection & Islanding)
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Voltage Flicker & Harmonics
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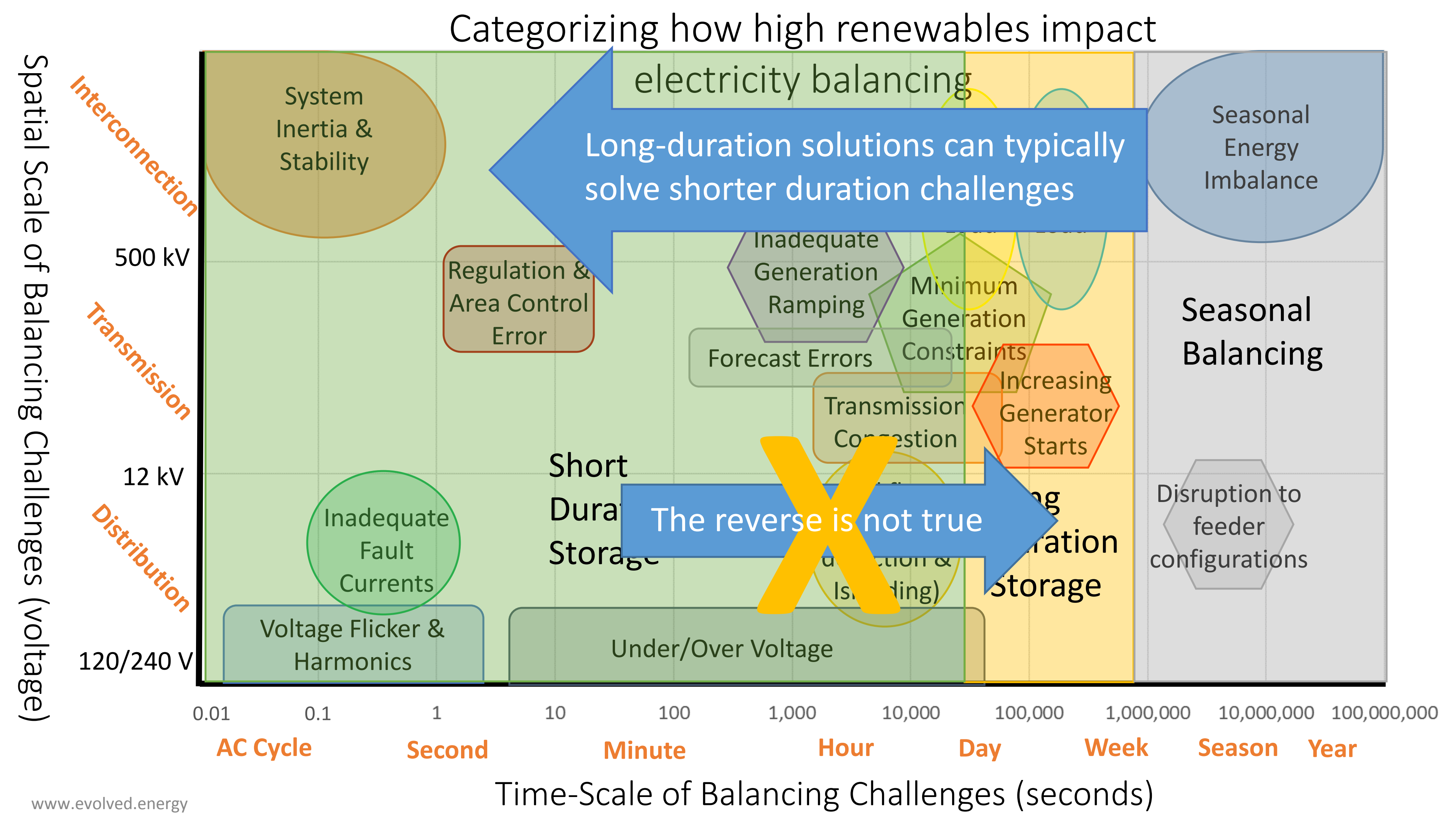
Categorizing how high renewables impact
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Long-duration solutions can typically solve shorter duration challenges
The reverse is not true
System Inertia & Stability
Regulation & Area Control Error
Inadequate Generation Ramping
Minimum Generation Constraints
Forecast Errors
Transmission Congestion
Increasing Generator Starts
Seasonal Energy Imbalance
Seasonal Balancing
Disruption to feeder configurations
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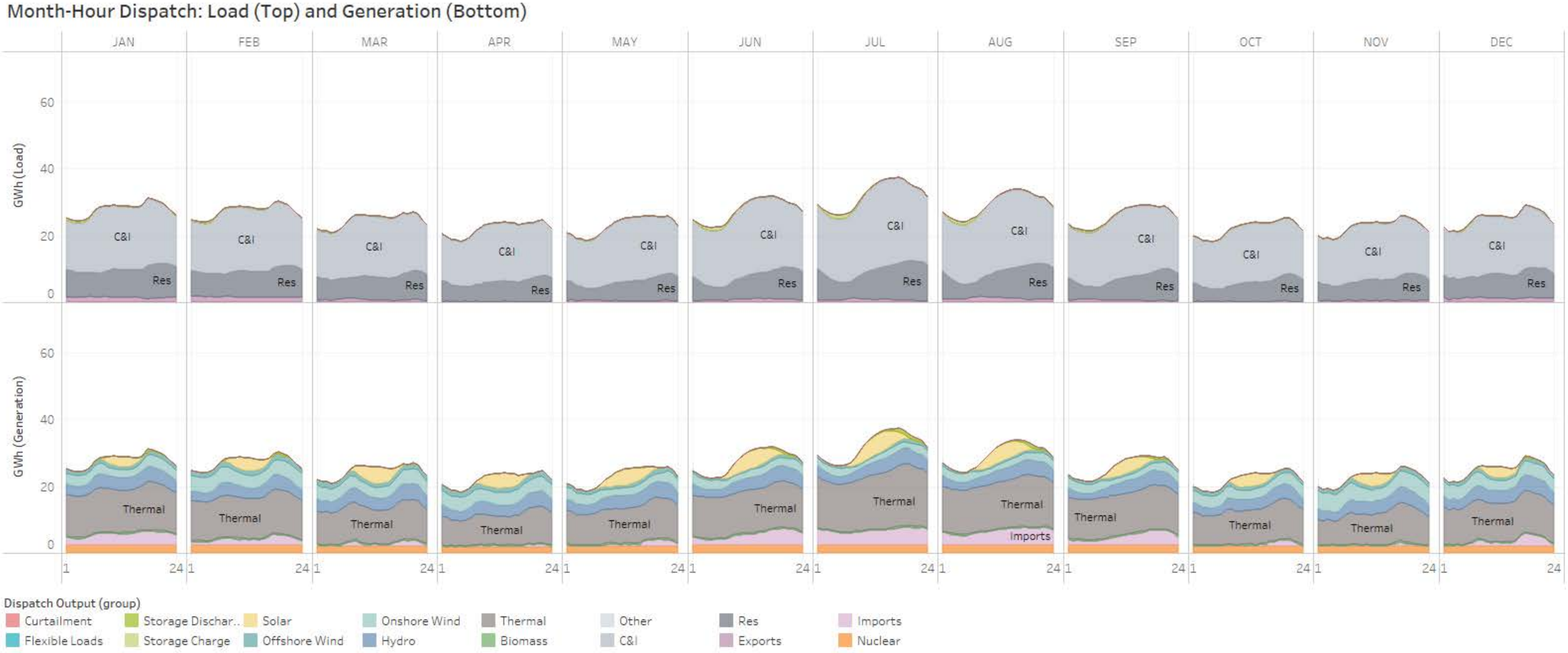
Long Duration Storage Example in NY State

New York: Annual Energy Outlook Reference Scenario

Month-Hour Generation and Load, 2050



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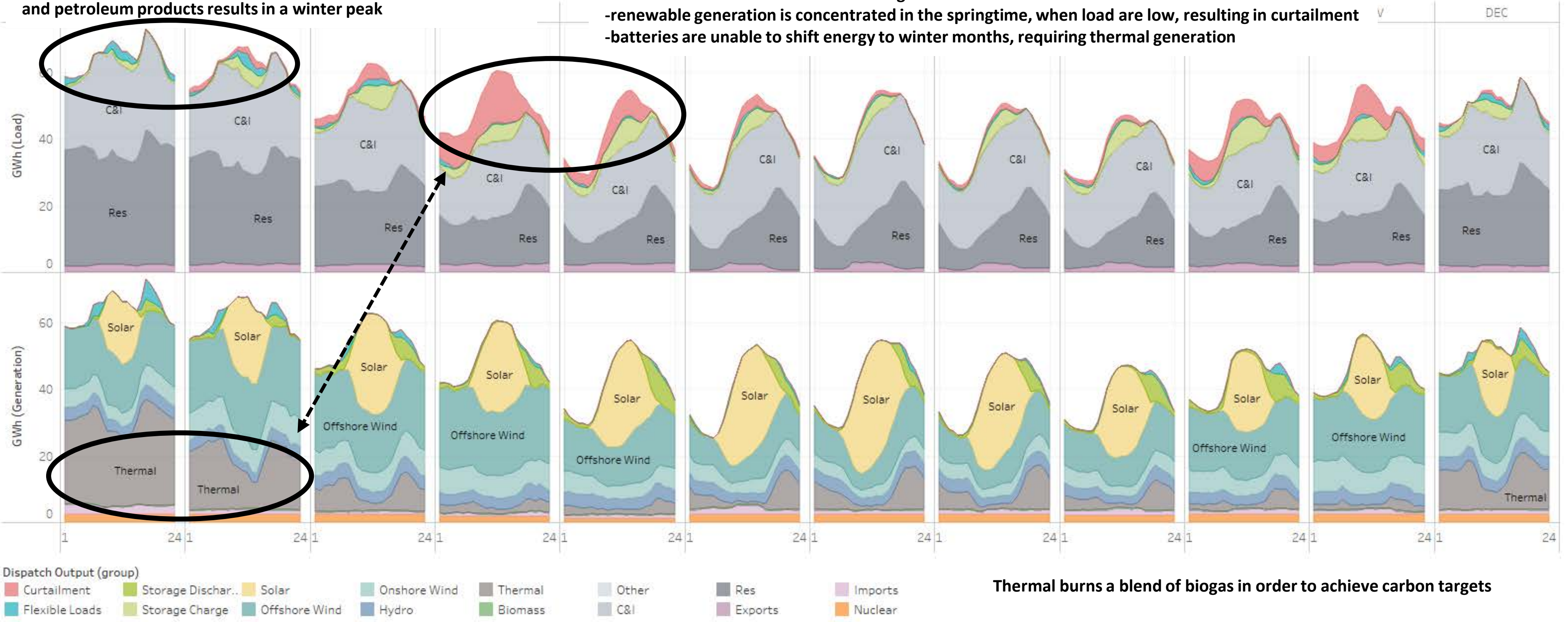
New York: Deep Decarbonization Pathway – high renewables

Month-Hour Generation and Load, 2050

Electrification of space heating currently provided by natural gas and petroleum products results in a winter peak

Seasonal imbalance between load and generation occurs:
-renewable generation is concentrated in the springtime, when load are low, resulting in curtailment
-batteries are unable to shift energy to winter months, requiring thermal generation



Thermal burns a blend of biogas in order to achieve carbon targets

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LDS function 1: deliver renewable generation to load at high penetrations

New York State example: 2011 weather with in-state renewables & high electrification

- After 30% renewables (in this NY example), curtailment increase rapidly
- At a 50% RPS and equal amounts of wind and solar, marginal curtailment of solar is 56% and wind 21%

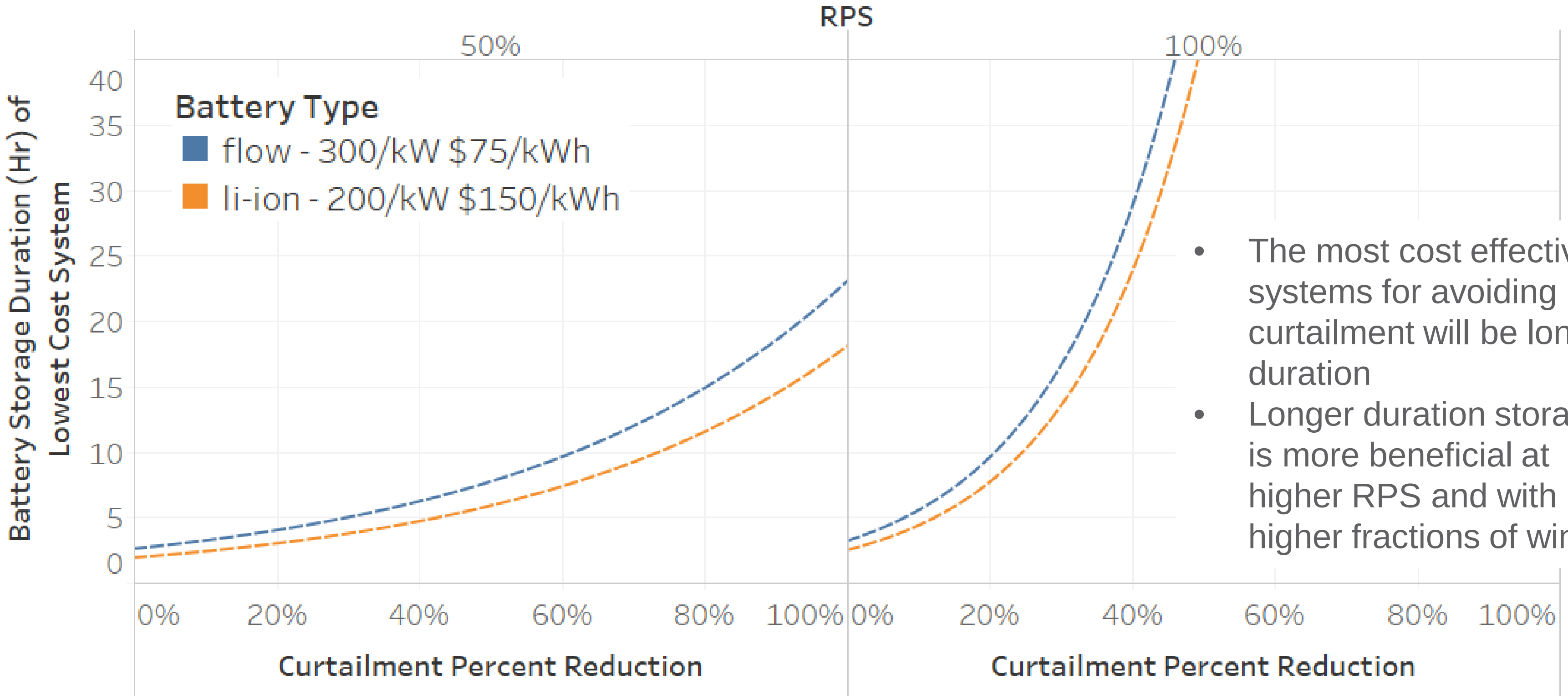
Percent of Renewables Curtailed Without Storage or Flexible Load

	RPS (%)											
	130%	49%	45%	44%	45%	45%	47%	49%	53%	58%	64%	70%
	120%	46%	42%	41%	41%	42%	44%	46%	50%	55%	62%	68%
	110%	43%	39%	37%	37%	38%	40%	43%	47%	53%	59%	65%
	100%	39%	35%	32%	32%	33%	36%	39%	44%	50%	56%	62%
	90%	35%	30%	27%	27%	28%	31%	35%	40%	46%	52%	59%
	80%	30%	26%	22%	21%	23%	26%	31%	36%	42%	48%	55%
	70%	24%	20%	17%	16%	17%	21%	25%	31%	37%	43%	50%
	60%	18%	14%	11%	10%	11%	15%	19%	25%	31%	37%	43%
2030 Policy Target →	50%	11%	9%	7%	6%	6%	9%	13%	18%	23%	29%	35%
	40%	6%	4%	3%	2%	2%	3%	6%	10%	15%	20%	25%
	30%	2%	1%	1%	0%	0%	1%	1%	3%	5%	9%	13%
	20%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	2%
	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Solar Fraction		0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Wind Fraction		100%	90%	80%	70%	60%	50%	40%	30%	20%	10%	0%

Renewable delivery respects a must run requirement of nukes, co-gen, and hydro (16% by energy)

What duration storage is needed to avoid curtailment?

New York State: 2011 weather with in-state renewables & high electrification 70% wind, 30% solar



- The most cost effective systems for avoiding curtailment will be long duration
- Longer duration storage is more beneficial at higher RPS and with higher fractions of wind

LDS function 2: provide capacity to avoid capital investment (T, D & G)

New York State example: 2011 weather with in-state renewables & high electrification

- In a highly electrified, winter peaking system, in-state renewables provide little native capacity value for the NY system – very large residual capacity needs exist.

Percent System Peak Reduction From Renewables

RPS (%)											
130%	15%	24%	23%	22%	21%	20%	18%	17%	16%	14%	11%
120%	15%	23%	22%	21%	20%	19%	18%	17%	15%	14%	11%
110%	14%	23%	22%	21%	20%	19%	18%	16%	15%	14%	11%
100%	14%	22%	21%	20%	19%	18%	17%	16%	15%	14%	11%
90%	13%	21%	20%	19%	19%	18%	17%	16%	15%	14%	11%
80%	12%	20%	20%	19%	18%	17%	16%	15%	14%	14%	11%
70%	12%	19%	19%	18%	17%	17%	16%	15%	14%	13%	11%
60%	11%	19%	18%	17%	17%	16%	15%	15%	14%	13%	11%
2030 Policy Target → 50%	11%	18%	17%	17%	16%	15%	15%	14%	14%	13%	11%
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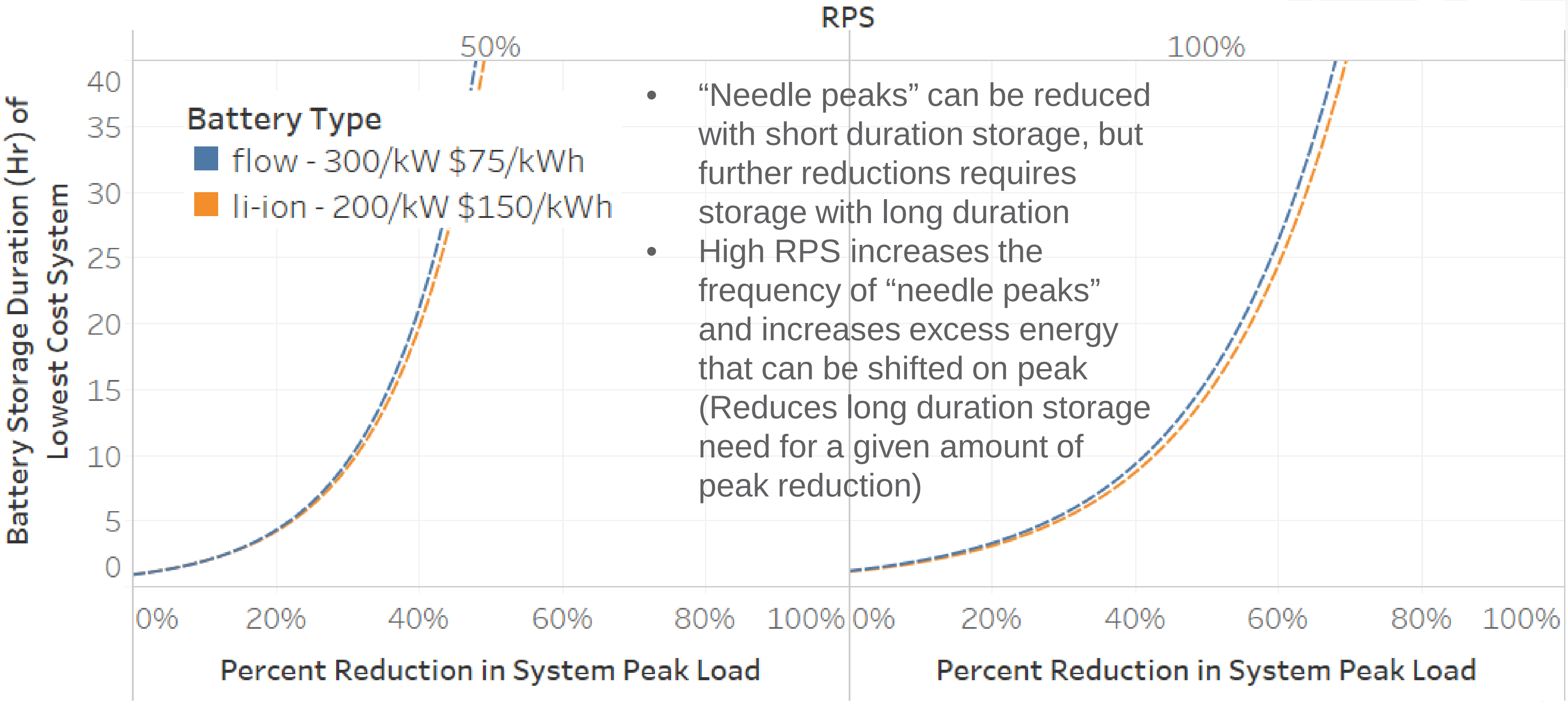
30%	9%	15%	15%	15%	15%	14%	14%	14%	13%	13%	11%
20%	6%	10%	14%	14%	14%	14%	14%	13%	13%	13%	11%
10%	3%	5%	7%	9%	12%	13%	13%	13%	13%	12%	11%
0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Solar Fraction	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Wind Fraction	100%	90%	80%	70%	60%	50%	40%	30%	20%	10%	0%

Renewable delivery respects a must run requirement of nukes, co-gen, and hydro (16% by energy)

What duration storage is needed to reduce system peak?

New York State: 2011 weather with in-state renewables & high electrification 70% wind, 30% solar



- “Needle peaks” can be reduced with short duration storage, but further reductions requires storage with long duration
- High RPS increases the frequency of “needle peaks” and increases excess energy that can be shifted on peak (Reduces long duration storage need for a given amount of peak reduction)

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Final thoughts and observations

- Fundamentally, storage resources should be located at the geographic scale where the issues occur
  - “Firming” renewable generation on site has no inherent value – wires provide essential diversity services for loads and generation at no cost. Could be a near-term bridge due to market rules.
- Long-duration balancing solutions can solve short duration challenges but not vice versa
  - It is therefore beneficial to keep the long-term perspective in mind when focused on R&D and system planning
- Bulk system load/gen imbalance is only part of the picture, as storage opportunities increase with transmission constraints
  - Wires are cheaper, but they are often difficult or impossible to build

THANK YOU

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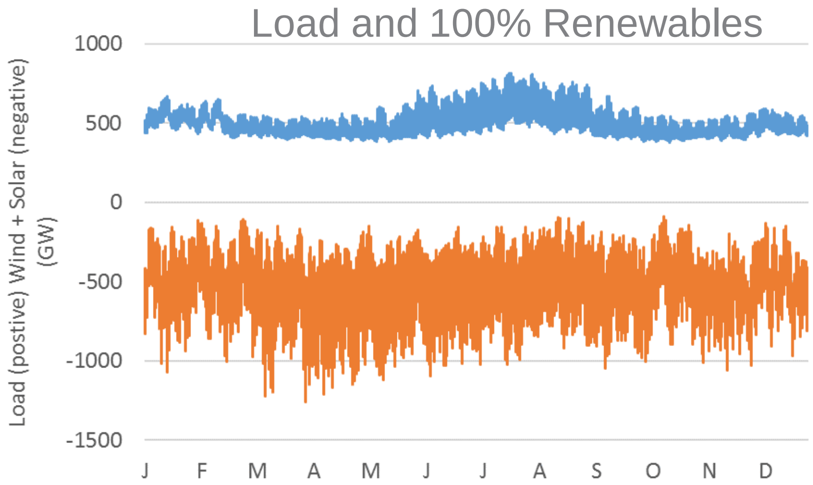
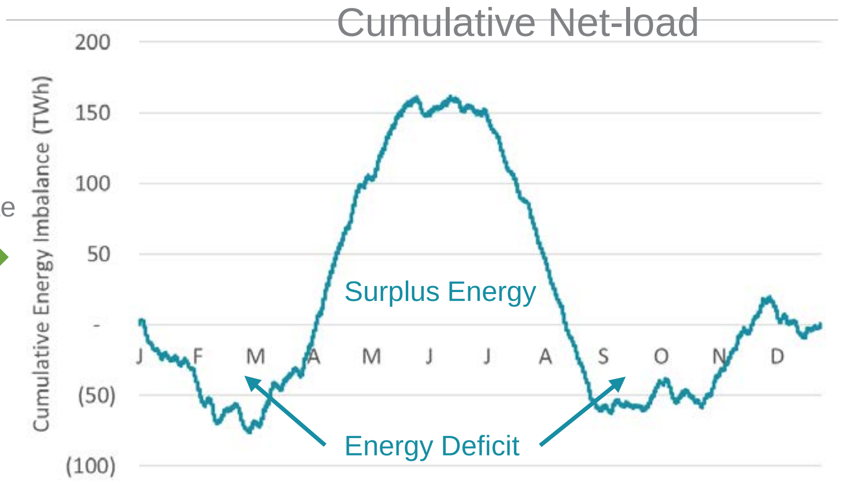
Seasonal energy imbalance

- Increasing the penetration of wind & solar beyond ~75% in temperate climates results in seasonal energy imbalances that become the dominate challenge for achieving deep decarbonization in electricity



Cumulate



U.S. Eastern Interconnect 2015 Load with simulated 40% Solar & 60% Onshore Wind by Energy

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