NYISO Grid in Transition Study

DETAILED ASSUMPTIONS AND MODELING DESCRIPTION

PRESENTED TO

NYISO ICAP/MIWG/PRLWG STAKEHOLDERS

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THE Brattle GROUP

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Agenda

- Introduction
- Regulations, Policies, and Market Design Assumptions
- Supply Assumptions
- Demand Assumptions
- Transmission Assumptions
- Modeling Approaches

Project purpose and scope

NYISO has retained Brattle to develop **simulations of NYISO markets through 2040** to inform the **Grid in Transition effort.**

- New York has established aggressive clean energy and decarbonization mandates, codified in the **Climate Leadership and Community Protection Act** (CLCPA).
- NYISO's **Grid in Transition** effort seeks to understand the reliability and market implications of the State's plans to transition to clean energy sources.
- NYISO has retained Brattle to **simulate NYISO market operations and investment through 2040** to inform NYISO staff and stakeholders on market evolution.

Study design makes several simplifying assumptions, such as:

- Zonal, "pipe and bubble" transmission topology
- Stylized representation of generators
  - Aggregated generators by zones and types
  - Economic additions and retirements in continuous increments, not "lumpy"
- Implementing current market rules and policies.

Project key questions to address

- How many and what types of **renewable resources and storage** will be needed to achieve the CLCPA standards?
- What types of **flexible resources and storage** will be needed to match variable renewable output and load?
- What is the future of **current New York generation** (e.g., nuclear and gas)?
- How might **electrification** affect market operations and investments?
- What is the role of a flexible and market-engaged **demand side**?

Purpose of this presentation

This presentation is a continuation of the March 6 MIWG Presentation and describes the key assumptions and modeling decisions to be used in the Grid in Transition Study

- Modeling the New York power system through 2040 requires **informed assumptions** regarding regulations, market design, supply, demand, and transmission
- This presentation outlines the **initial assumptions** Brattle has developed in conjunction with NYISO
- The presentation also outlines initial proposals for key modeling decisions, including:
  - How to select and weigh **representative days**
  - How to determine the **UCAP value of wind, solar, and storage** at high deployment levels
  - How to model new supply technologies such as **flexible load** and **renewable natural gas**

We are requesting stakeholder feedback on these assumptions and modeling decisions

GridSIM model framework

Inputs

Supply

Existing resources
Fuel prices
Investment/fixed costs
Variable costs

Demand

Representative day hourly demand
Capacity needs

Transmission

Zonal limits
Intertie limits

Regulations, Policies, Market Design

Capacity market
Carbon pricing
Procurement mandates

GridSIM Optimization Engine

Objective Function

Minimize NPV of Investment & Operational Costs

Constraints

- Market Design and Co-Optimized Operations
  - *Capacity*
  - *Energy*
  - *Ancillary Services*
- Regulatory & Policy Constraints
- Resource Operational Constraints
- Transmission Constraints

Outputs

Annual Investments and Retirements

Hourly Operations

System and Customer Costs

Supplier Revenues

Emissions and Clean Energy Additions

Market Prices

Regulations, Policies, and Market Design Assumptions

Modeled clean energy policies

Description of Key Policies

CLCPA	• **Renewable generation:** 70% of NY annual electricity supplied from renewables (solar, wind, hydro) by 2030 • **100% zero emissions** by 2040 • **Solar:** 6,000 MW distributed solar by 2025 • **Offshore wind:** 9,000 MW by 2035 • **Storage:** 3,000 MW by 2030 • **Economy-wide emissions:** 85% reduction by 2050 and 40% reduction by 2030 from 1990 levels
RGGI	• Northeast regional cap-and-trade program • Avg. 2019 price: $5.4/ton; expected to reach $12.6 by 2030
ZEC Program	• Zero emission credit payments to New York nuclear plants • Program expires March 2029
DEC NO_X rule	• DEC rule to reduce NO_X emissions from peakers • Peakers built pre-1986 will most likely retire instead of retrofit to meet emissions requirements (this assumption may be refined based on Generators' compliance plans)

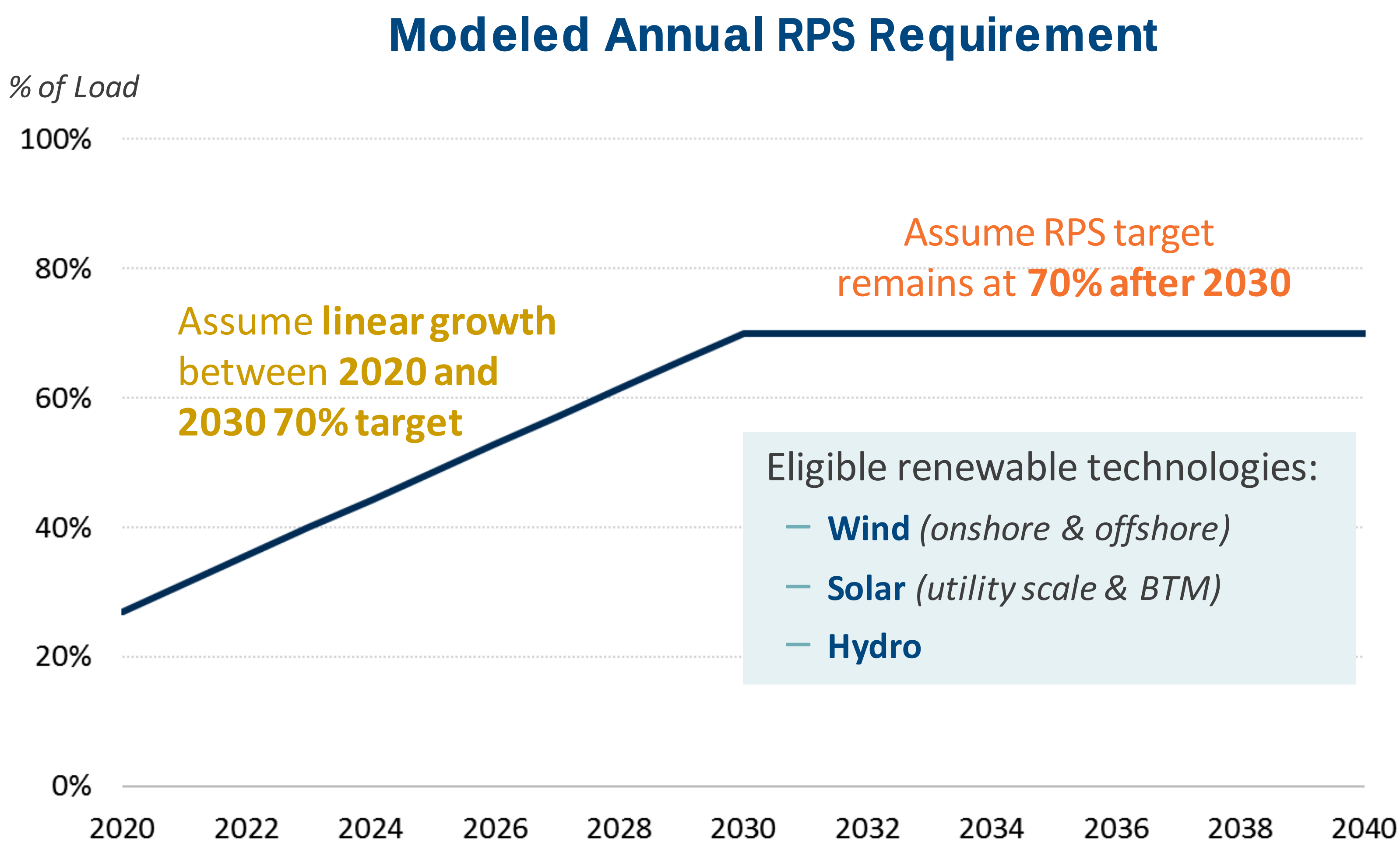
Policy Timeline

- **2009** — **RGGI:** First control period
- **2016** — **ZEC:** Program in effect
- **2025** — **Solar:** 6,000 MW mandate; **NO_X Rule:** In full effect
- **2029** — **ZEC:** Program expires
- **2030** — **CLCPA:** 70% renewable electricity; **Storage:** 3,000 MW mandate
- **2035** — **OSW:** 9,000 MW mandate
- **2040** — **CLCPA:** 100% zero emissions electricity
- **2050** — **CLCPA:** 85% NY economy-wide decarbonization

Sources and Notes:

RGGI Auction Allowance Price and Volumes Results
New York Public Service Commission Order Adopting a Clean Energy Standard. August 1, 2016
New York DEC Adopted Subpart 227-3
New York Senate Bill S6599

70% Renewable Portfolio Standard



Sources and Notes:
New York Senate Bill S6599

Regulations, Policies, and Market Design Assumptions

100% zero emissions mandate

Eligible "zero emissions" generation technologies

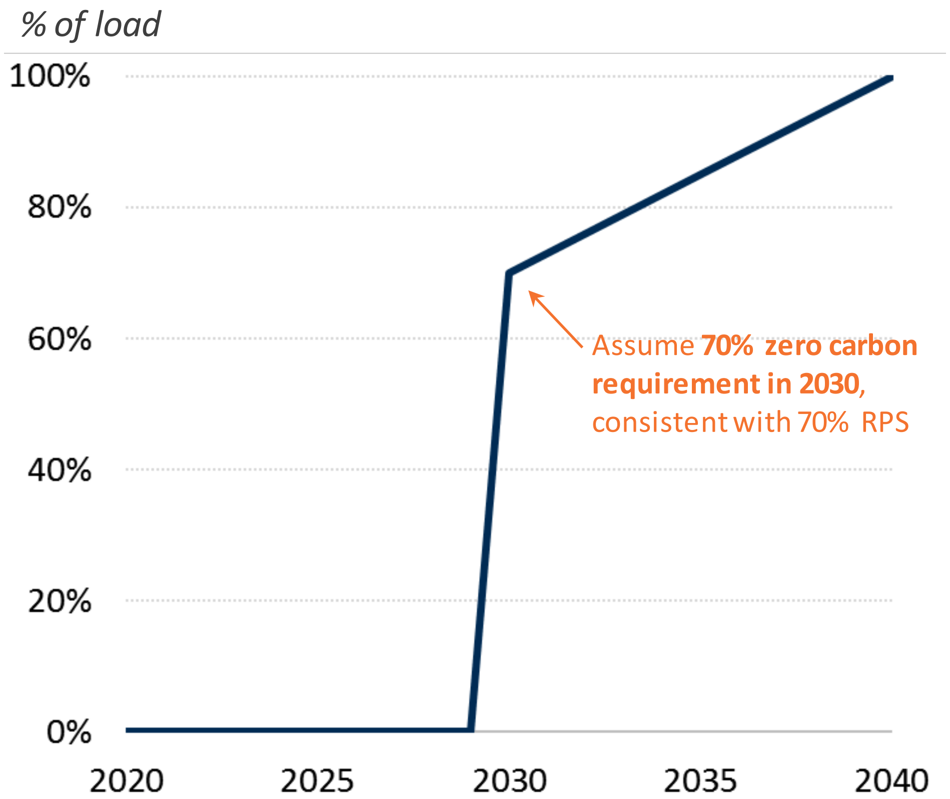
- **Renewables**
- **Nuclear**
- **Renewable natural gas**

Interpretation of mandate: Net annual carbon emissions must equal zero

- Allows some emissions from NY generators or imports
- But all emissions must be offset ton-for-ton by exports that reduce emissions in neighboring systems

Assume **intermediate** carbon reduction targets in 2030-40, although not specified in the CLCPA

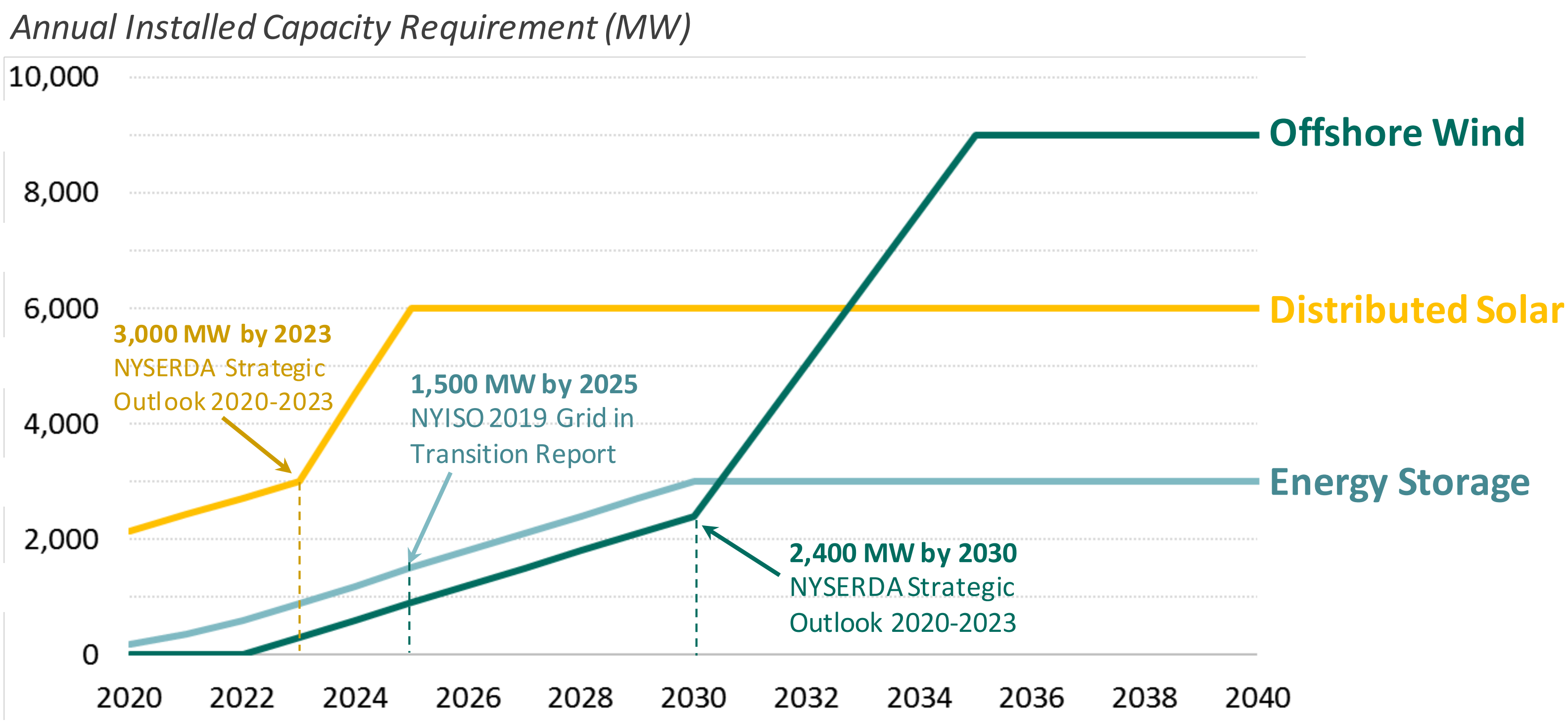
Modeled Annual Zero Emissions Requirement



Sources and Notes:
New York Senate Bill S6599

Technology-specific mandates

We model the **technology-specific mandates of the CLCPA**, with **intermediate targets** from multiple sources (more may be economically built to satisfy other constraints).

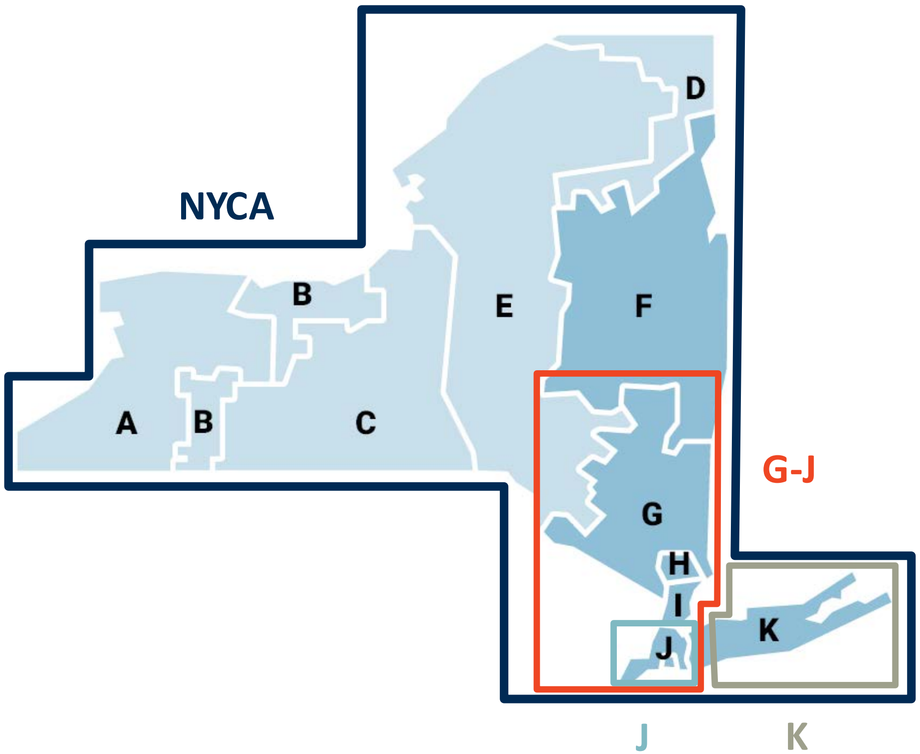


Sources and Notes:

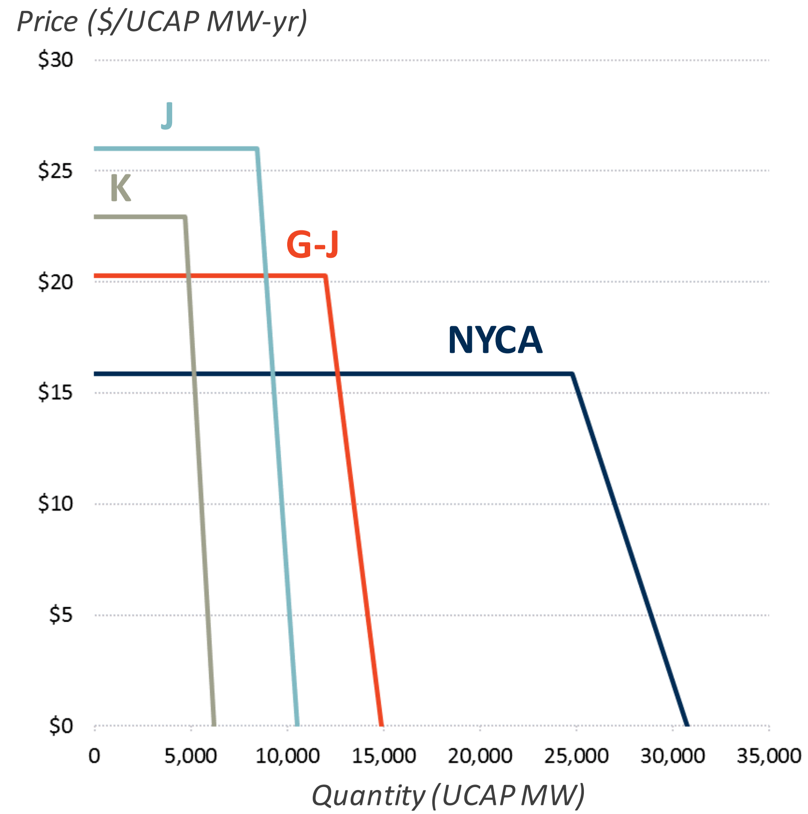
New York Senate Bill S6599
Reliability and Market Considerations for a Grid in Transition. NYISO. May 2019
Toward a Clean Energy Future: A Strategic Outlook 2020-2023. NYSERDA.

ICAP market

ICAP market modeled consistent with current design, including **nested capacity zones**, **sloped demand curves**, and **summer/winter clearing**.



2020 Summer Capacity Demand Curves

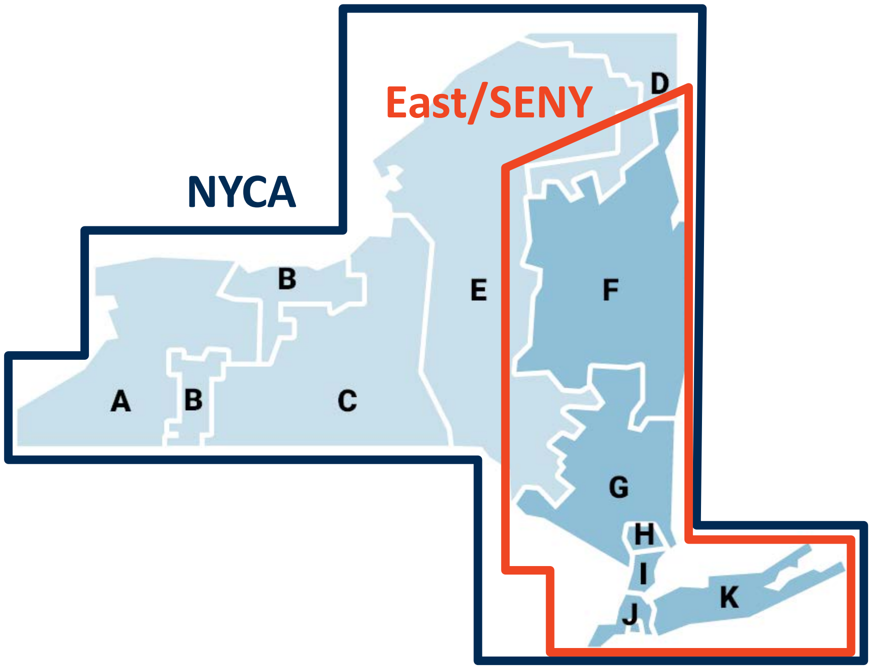


Sources and Notes:
NYISO ICAP/UCAP Translation of the Demand Curve – Summer 2018 Capability Period
NYISO ICAP/UCAP Translation of the Demand Curve – Winter 2018-2019 Capability Period
Demand curve represents modeled 2020 demand curve, derived from 2018 demand curve parameters and adjusted to reflect 2020 demand and resource costs

Ancillary service requirement

- We model **3 A/S products: 10-min reserves, 30-min reserves, regulation**
- We specify separate **system-wide** and **Downstate (EAST/SENY) requirements**
- **Quantities and shortage pricing** consistent with NYISO guidance

Simplified Reserve Zones



Model Reserve Assumptions

	NYCA		EAST/SENY (G-K)	
Product	Quantity (MW)	Shortage Price ($/MWh)	Quantity (MW)	Shortage Price ($/MWh)
10-Minute Reserves	1,310	$750	1,200	$775
30-Minute Reserves	1,310	$750	100	$500
Regulation	225	$775	N/A	N/A

Sources and Notes:
30 minute reserve requirement reflects incremental requirement from 10 minute reserves. Reserve requirements derived from below sources and discussions with NYISO:
NYISO Locational Reserve Requirements
Establishing Zone J Operating Reserves. NYISO. January 2019.

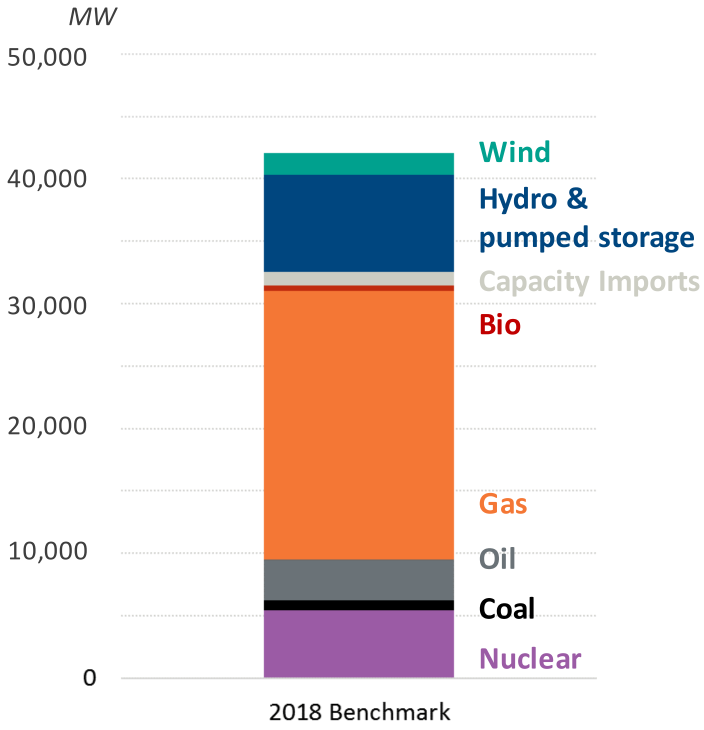
Supply Assumptions

Existing supply resources

We model all **existing generators in New York**, consistent with the **2019 Gold Book** and other sources of data.

- 2019 Gold Book primary source of generator data
- Most generators aggregated by zone and type (e.g., gas CC & CT, nuclear, OSW)
- Subset of generators modeled independently due to unique characteristics
- Generator characteristics (e.g., heat rate, VOM) developed w/ NYISO input

2018 Installed Capacity

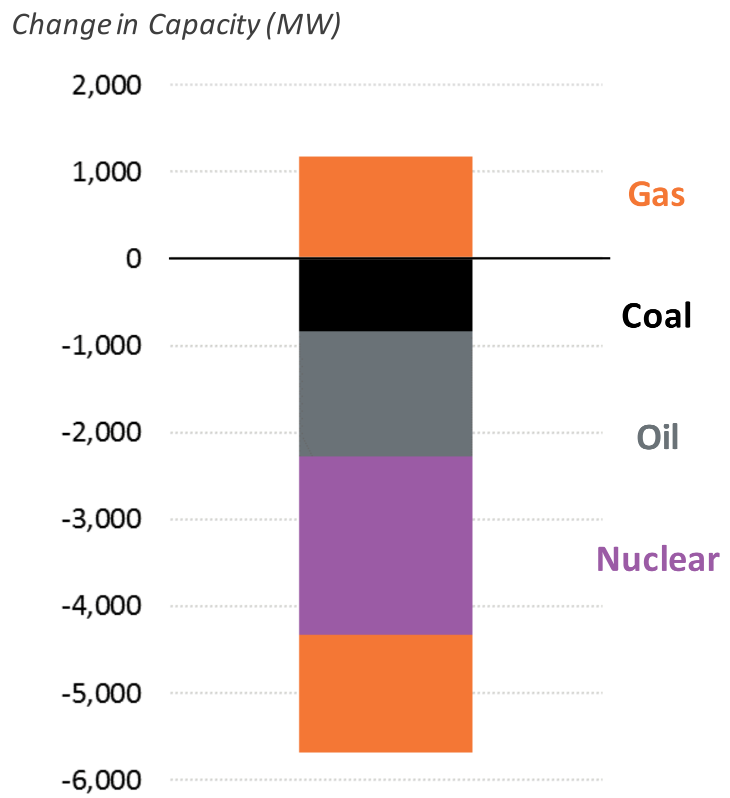


Supply Assumptions
Planned builds and retirements

We model all planned additions and retirements of generators including:

- Downstate peaker (**gas CT** and **oil/kerosene**) NOx rule retirements (2025):
  - Downstate peakers built before 1986 retire
  - All frame units built after 1986 retire
  - Aero-derivative units built after 1986 may choose to economically retrofit
  - These assumptions may be refined based on Generators' compliance plans
- Indian Point **nuclear** retirement (2020-21)
- Remaining **coal** retirements (2020)
- Planned **gas** build is Cricket Valley (2020)

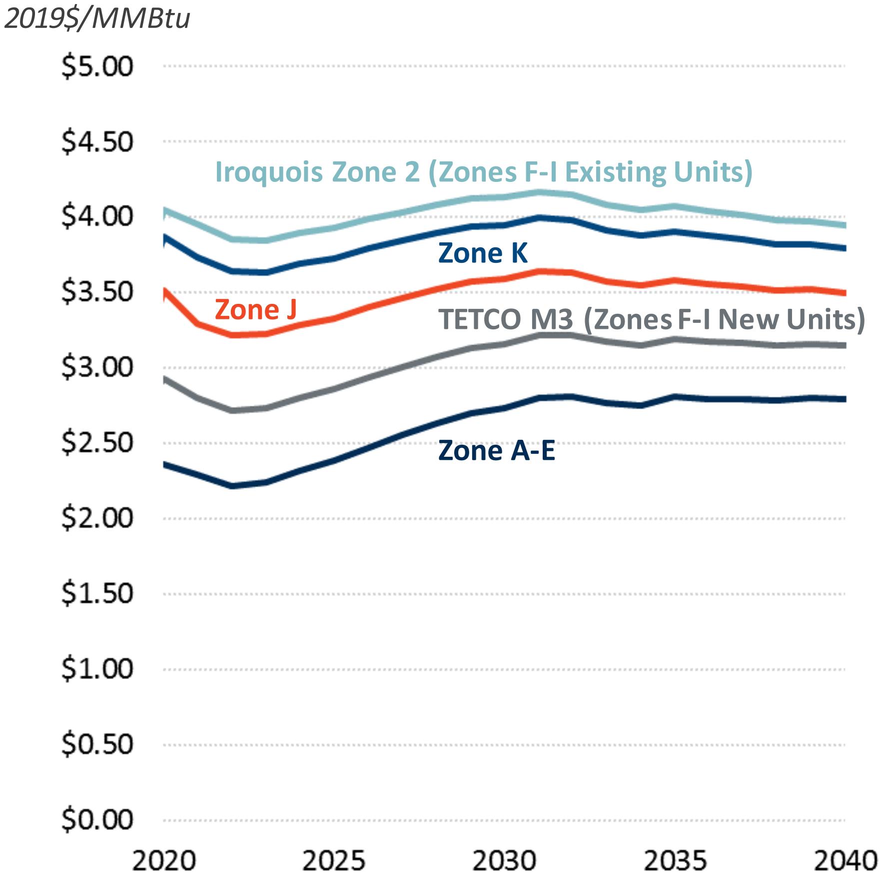
Cumulative Planned Capacity Changes 2020-2030



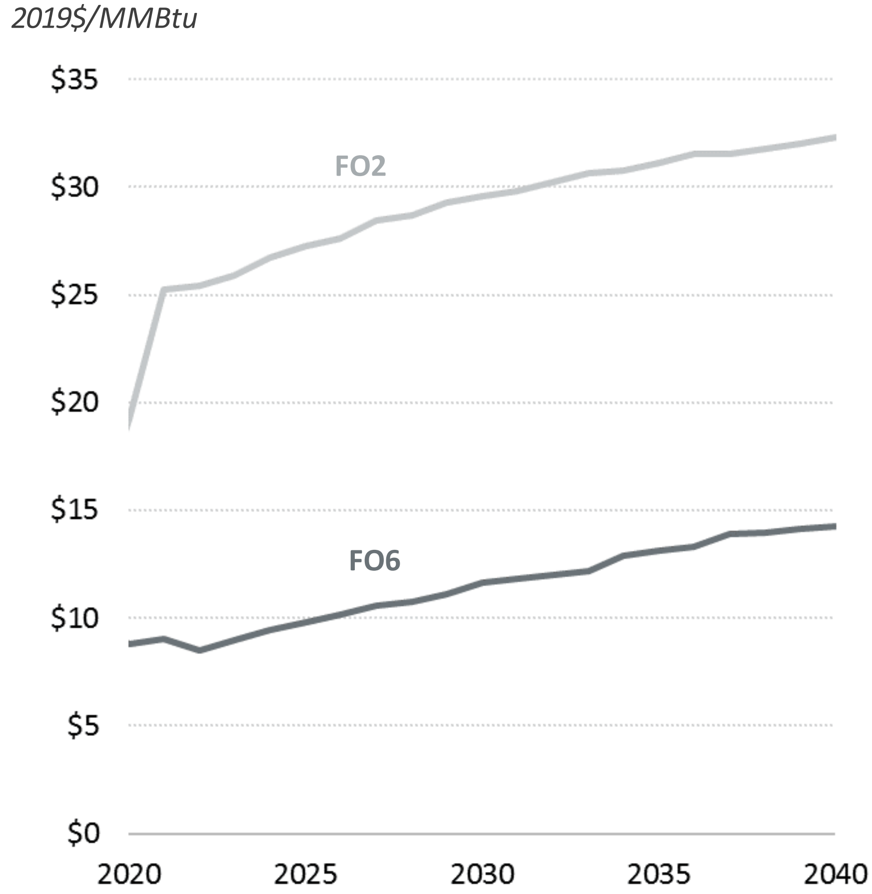
Sources and Notes:
ABB Velocity Suite. NOx retirement assumptions derived from NYDEC NOx Revised Regulatory Impact Statement Summary and conversations with NYISO
NYISO Grid in Transition Report. 2019

Fuel price assumptions

Gas Price Forecasts



Oil Price Forecasts



Sources and Notes:

Gas price forecast based on blend of NYMEX futures and EIA growth rates

Oil prices based on 2019 NYMEX futures; taken from ABB Velocity Suite

Supply Assumptions
New resources

Supply Resource	Description
Gas-fired generators	• **Combined cycles** (CCs) and **simple-cycle combustion turbines** (CTs) • Can burn natural gas or more expensive, zero emissions renewable natural gas
Storage	• Model **battery storage** with two-hour and four-hour durations • **Long-duration storage** (e.g., flow batteries or thermal) may be considered in a 1-off "representative week" sensitivity • **Seasonal storage** (e.g., via HQ) not considered, other than via RNG
Small modular nuclear	• Model as producing zero emissions (but not renewable) energy
Load flexibility	• Model **controllable EV charging** and **HVAC loads** • Amount of participation assumed (not endogenously determined) • Modeling flexibility over 24-hour period. 1-off "representative week" sensitivity may test if value increases over a longer horizon
Renewable natural gas (RNG)	• Assume supply from interstate pipelines at a price of \$20-\$30/MMBtu • Model potential in-state RNG production from excess renewable energy

New generators and storage

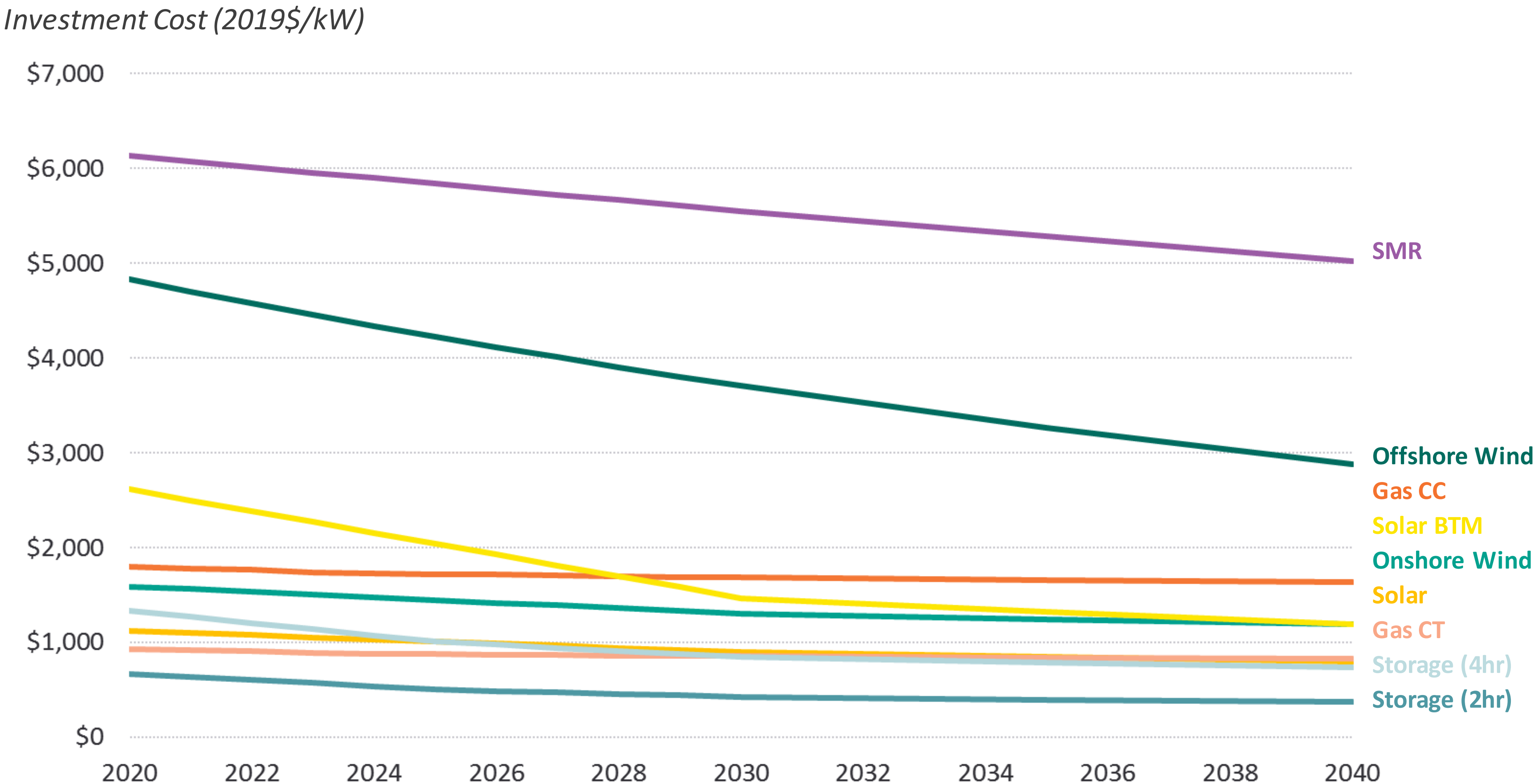
- **Natural gas generators** can be fueled with zero carbon renewable natural gas
- **Offshore wind** connected to either zone J or K
- **Utility-scale PV and onshore wind** cannot be built in zones J or K
- Sources of installed cost:
  - *Natural gas*: 2019 costs from DCR, cost decline rate from 2019 NREL ATB
  - *Wind, solar, storage*: 2019 costs and cost decline rate from 2019 NREL ATB
  - *Small Modular Nuclear*: 2019 costs from EIA
- Downstate costs higher, per EIA and DCR
- Detailed assumptions in appendix (technical parameters, variable and fixed costs)

	2019 Upstate installed cost *$/kW*	Annual cost decline rate (real) *2020 – 2040*
Natural Gas		
Combined cycle	$1,800	-1%
Combustion turbine	$900	-1%
Battery Storage		
2 hour duration	$700	-4%
4 hour duration	$1,400	-4%
Solar PV		
Utility scale	$1,100	-2%
Behind the meter	$2,700	-5%
Wind		
Offshore	$4,500	-3%
Onshore	$1,700	-2%
Small Modular Nuclear	$6,200	-1%

Sources and Notes:
Includes interconnection and network upgrade costs. NREL 2019 ATB, NYISO DCR Model 2019-2020
EIA Capital Cost and Performance Characteristic Estimates for Utility Scale Electric Power Generating Technologies, 2020

Supply Assumptions

New generators and storage costs over time



Sources and Notes:

NREL 2019 ATB

NYISO DCR Model 2019-2020

EIA Capital Cost and Performance Characteristic Estimates for Utility Scale Electric Power Generating Technologies, 2020

Costs do not include network upgrades or interconnection costs, with the exception of offshore wind

Demand Assumptions

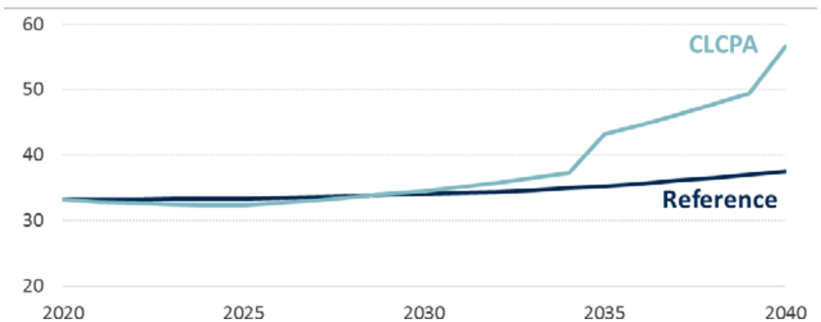
Load forecasts

We will model two load growth cases, per Climate Change Phase I study.

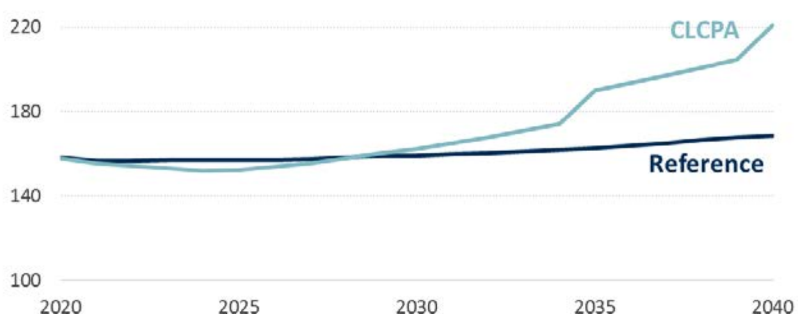
- **Reference Case:** Gold Book assumptions plus 0.7 °F warming per decade
- **CLCPA Case:** Aggressive electrification and energy efficiency

Gross Load Forecast

Annual Peak (GW)



Annual Energy (TWh)



Components of 2040 Gross Load

Annual Energy (TWh)

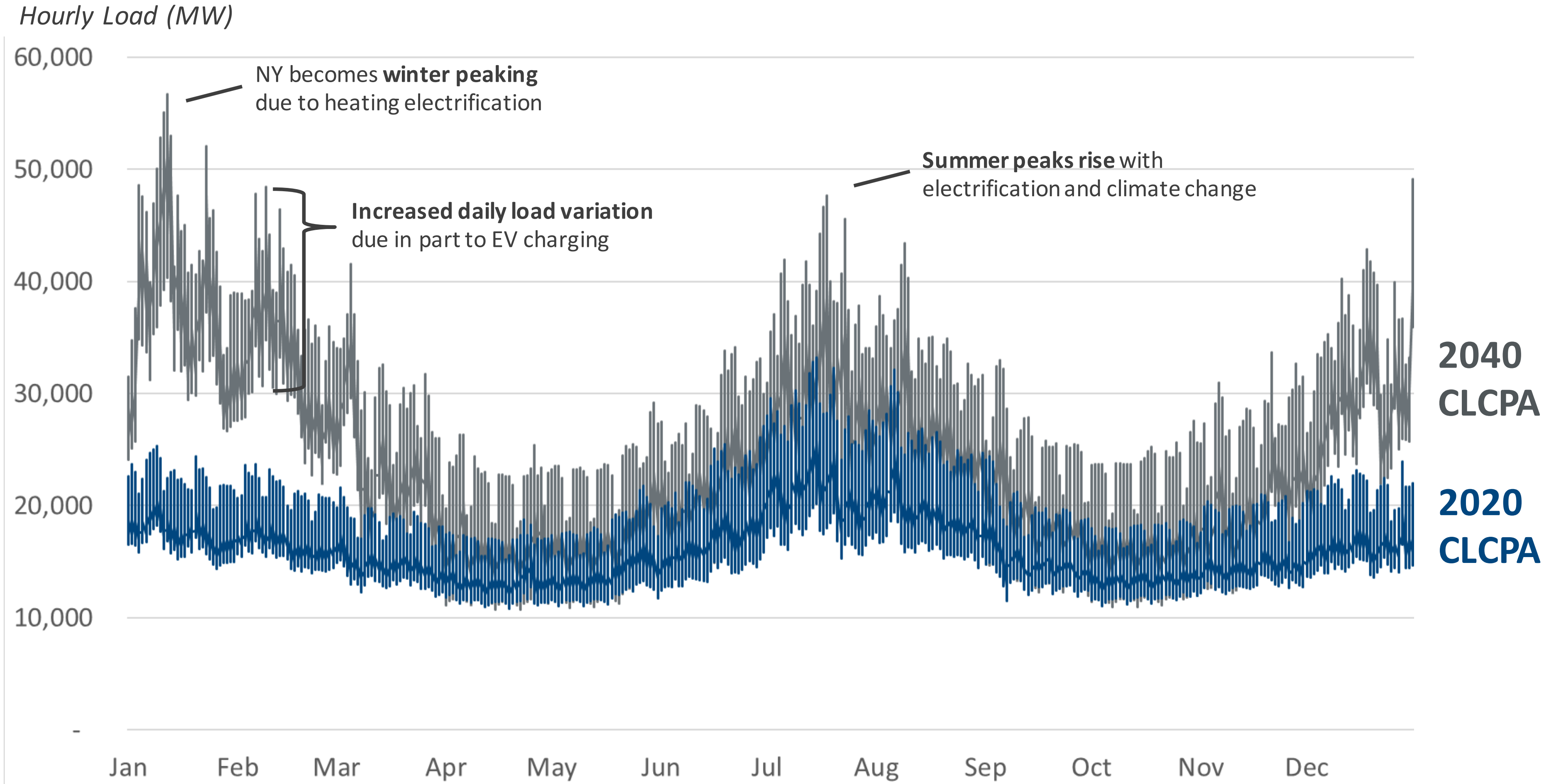
	Reference Case	CLCPA Case
Base load *(excluding energy efficiency)*	156	175
EV adoption	13	16
Additional electrification	--	76
Energy efficiency	--	-46
Total 2040 gross load	169	221

Sources and Notes:

Load forecasts from Climate Change and Resilience Study - Phase I, ICAP WG December 17, 2019.
Gross load forecasts exclude BTM solar generation.

Load shapes

Electrification and climate change are forecast to affect load shapes.

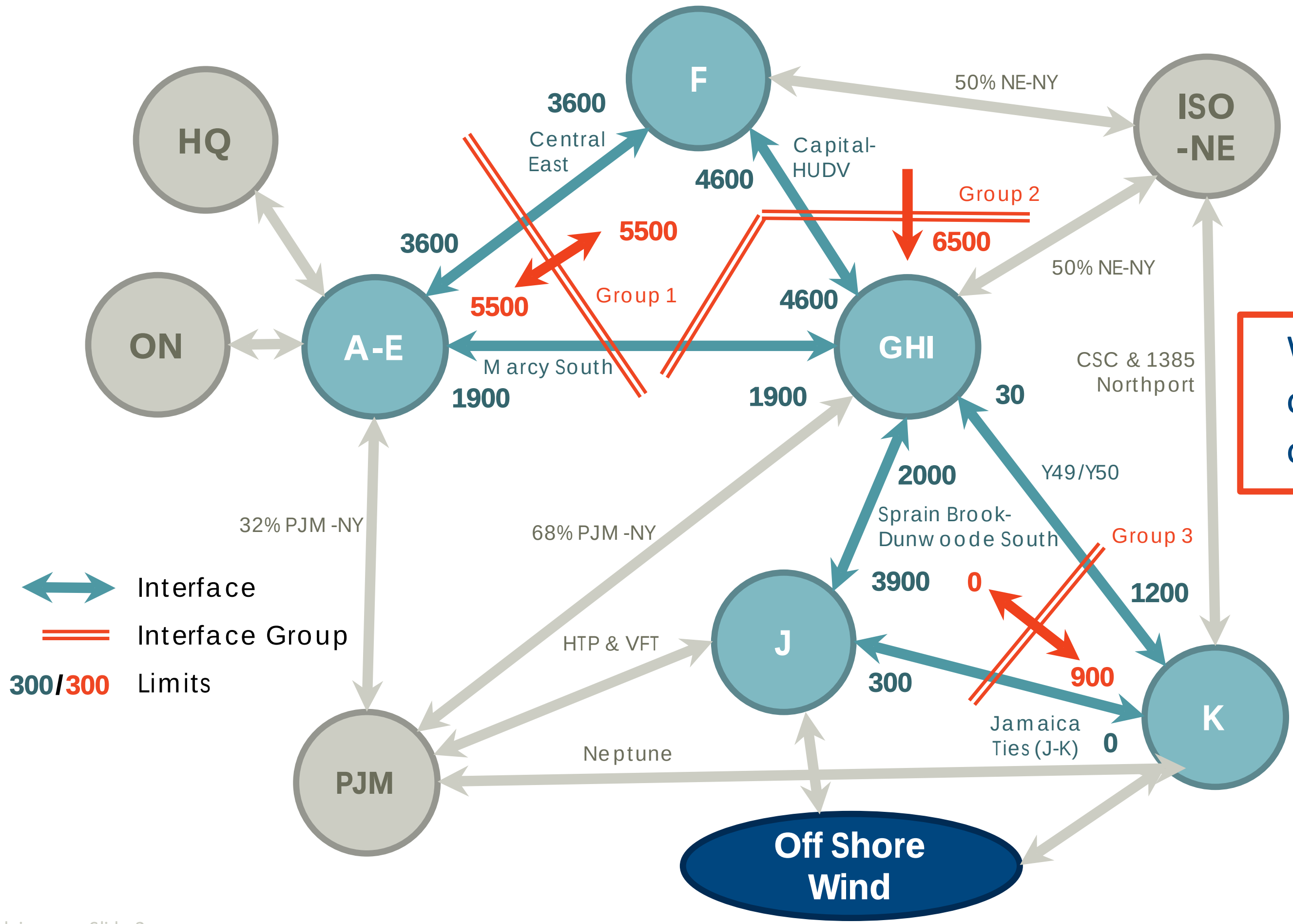


Sources and Notes:
Load forecasts from Climate Change and Resilience Study - Phase I, ICAP WG December 17, 2019.

Transmission Assumptions

Transmission topology

In conjunction with NYISO, **Brattle developed a 5-zone "pipe-and-bubble" representation of the New York grid**.



We are considering a one-off sensitivity on benefits of increased transmission.

See Disclaimer on Slide 2

Imports and exports

We model New York interties consistent with historical flows, but reflect some ability of neighboring systems to help balance NY renewable generation.

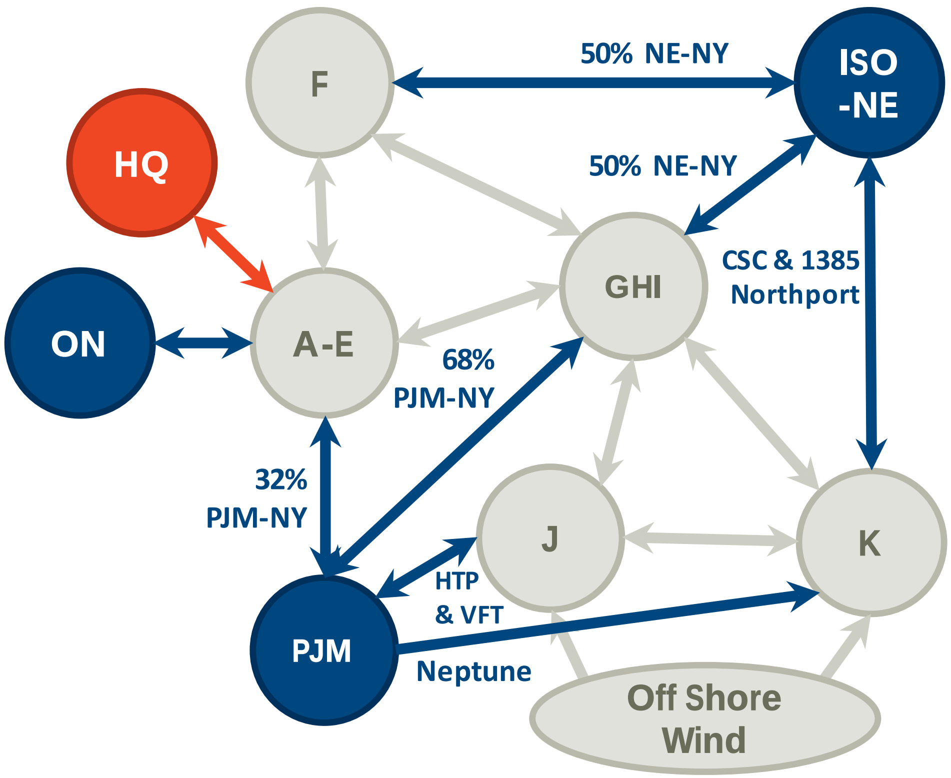
Hydro Quebec modeled as flexible

- Reflects HQ's hydro storage potential
- In all hours, allow flows up to line limit (1500 MW import, 1000 MW export)

Others modeled as less flexible

- Reflects similar balancing challenges in neighboring systems
- Lock **hourly exports** at 2018 levels
- **Hourly imports** allowed to flex between zero and 2018 levels (e.g. model can reduce imports if uneconomic)

Treatment of New York Interties



Modeling Approaches

Selection of representative days for 2022

We select and weight representative days for each year to reflect NYISO's forecasted hourly net demand. Here we show 2022 as an example.

Identify 10 days to represent a year's variety of conditions

- 10 stand-alone days can effectively represent a full year if selected and weighted carefully
- We validate the representative days by comparing the resulting net load duration curve to that of the 8760-hours forecast
- Modeling stand-alone days increases computational efficiency and flexibility
- Sequential days may be considered in a sensitivity analysis

Selection process

- Days selected based on **net load** to ensure extreme conditions are captured (e.g., high load and low renewable generation)
- Pre-select summer peak, winter peak, and minimum load days
- Remaining days selected and weighted with a **k-means clustering algorithm**, which clusters similar days together and selects best representative

Representative Days in 2022

CLCPA Load Forecast

	Day	Weight	
5 Extreme Days	Jul 20	1	Summer peak days
	Jul 8	10	
	Jan 13	1	Winter peak days
	Feb 10	10	
	Apr 24	1	Minimum load day
5 General Days	Jul 28	39	
	Mar 3	78	
	Oct 1	51	
	Oct 13	90	
	Dec 21	84	

Representative days across years

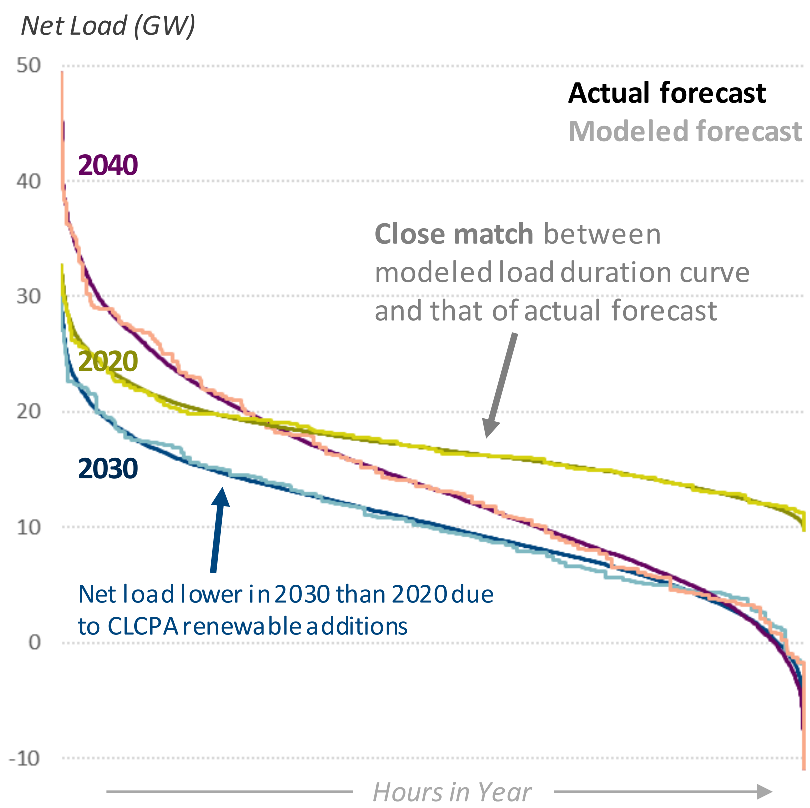
Each year, we select and weight new representative days to capture evolving net load shapes.

Net load shapes evolve from 2020 to 2040 with electrification and renewables growth

- Electrification assumptions from NYISO load forecasts
- Renewable growth forecast with preliminary GridSIM runs

This approach enables close representation of net load in all years

Net load duration curves
2020, 2030, 2040



Modeling the declining capacity value of wind, solar, and storage

We have developed an approach to approximate the **marginal UCAP value** of wind, solar, and storage as more are deployed.

High-level approach

1. For the technology in question, vary the amount installed, holding all else equal
2. Assess the capacity value of the last MW added (see next slide)
3. Quantify relationship between penetration and marginal capacity value
4. This relationship is an **input** into GridSIM

This **simplified approach** does not replace a full probabilistic effective load carrying capability (ELCC) study and may overstate capacity value

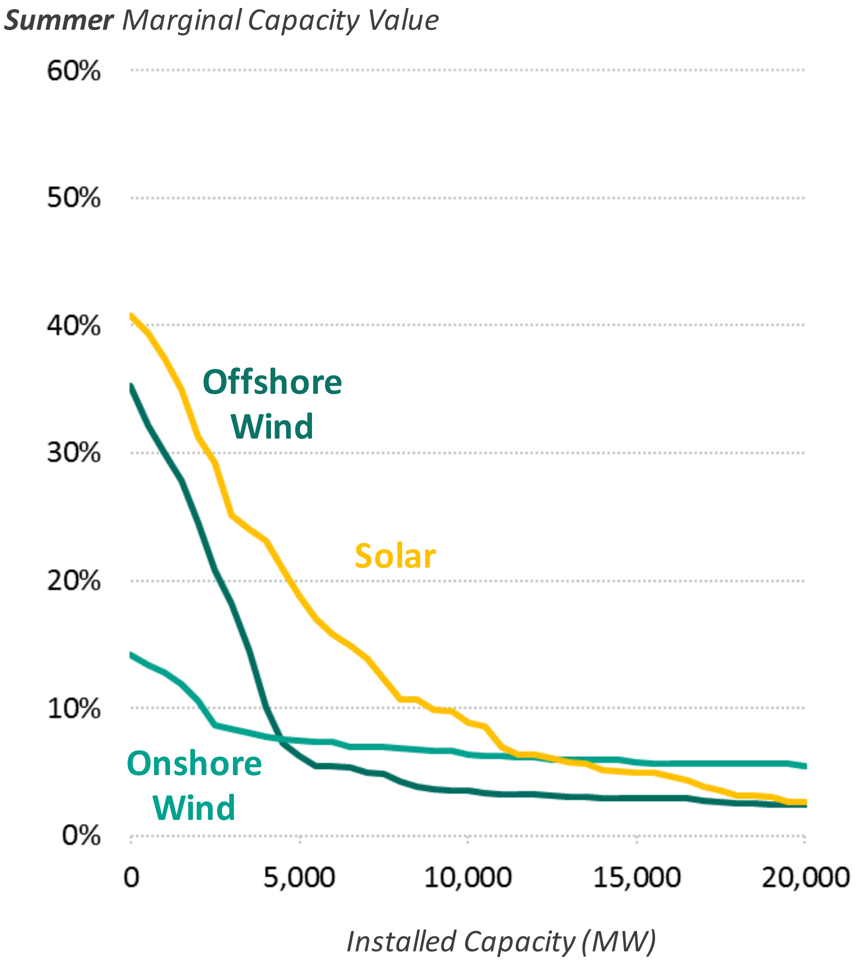
- Does not account for **variability in conditions across many years**, like GE MARS
- Does not account for impacts of **internal transmission constraints**

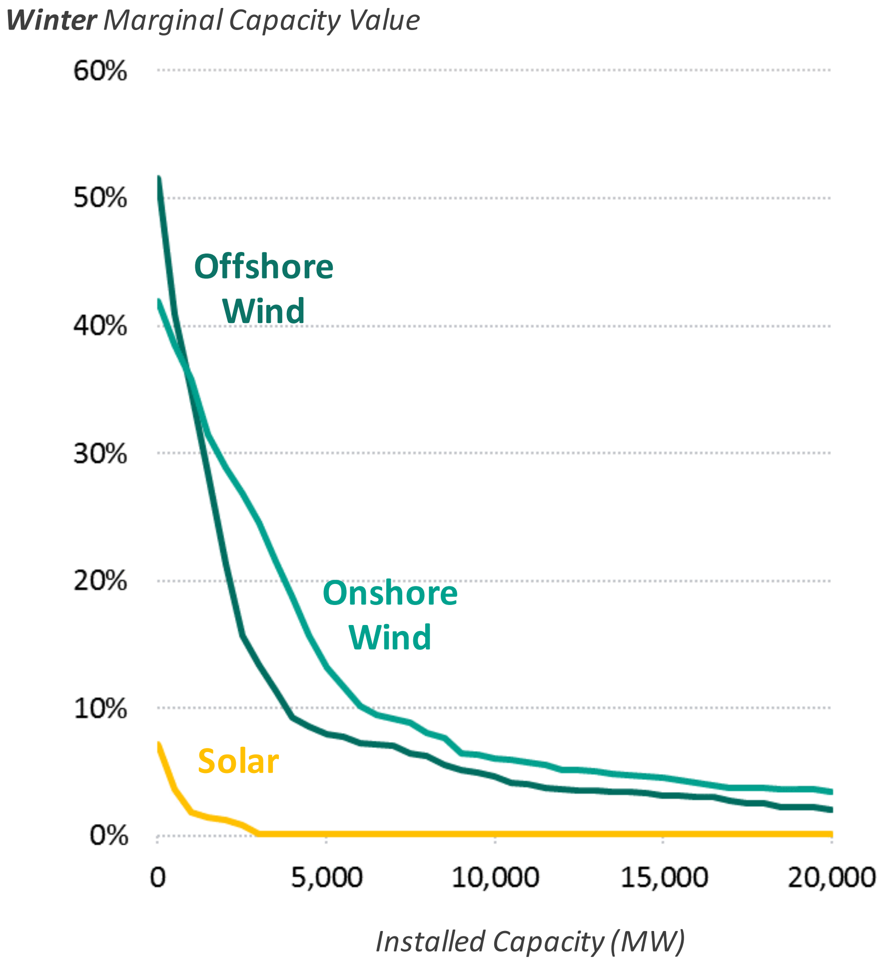
Modeling the declining capacity value of wind, solar, and storage

Supply Resource	Concept	Methodology
Wind and Solar Resources	Generation of new wind and solar additions is correlated with previously deployed resources. New resources therefore provide less marginal capacity value than previously added resources.	1. Across 8760 hours, identify 20-100 top NYCA net load hours 2. Calculate wind UCAP value as avg. output in those hours 3. Repeatedly change the MW of wind installed, holding all else equal 4. Each time, find top 100 net load hours and the avg. output 5. Repeat process for offshore wind and solar; for each one, hold other variable technologies at likely 2030 levels
Storage Resources	Energy storage can change the "shape" of peak net load periods, flattening and elongating peak periods. As more storage is deployed, longer discharge durations are therefore required to provide the same capacity value.	1. Across 8760 hours, analyze MW of storage required to reduce NYCA net peak load by 1 MW 2. Calculate UCAP value as 1 MW peak reduction / MW storage required 3. Increase amount of storage assumed, holding all else equal. Simulate effect of increased storage on net peak load 4. Repeat steps 1 – 3 across many storage deployment levels 5. Repeat process for storage of different durations

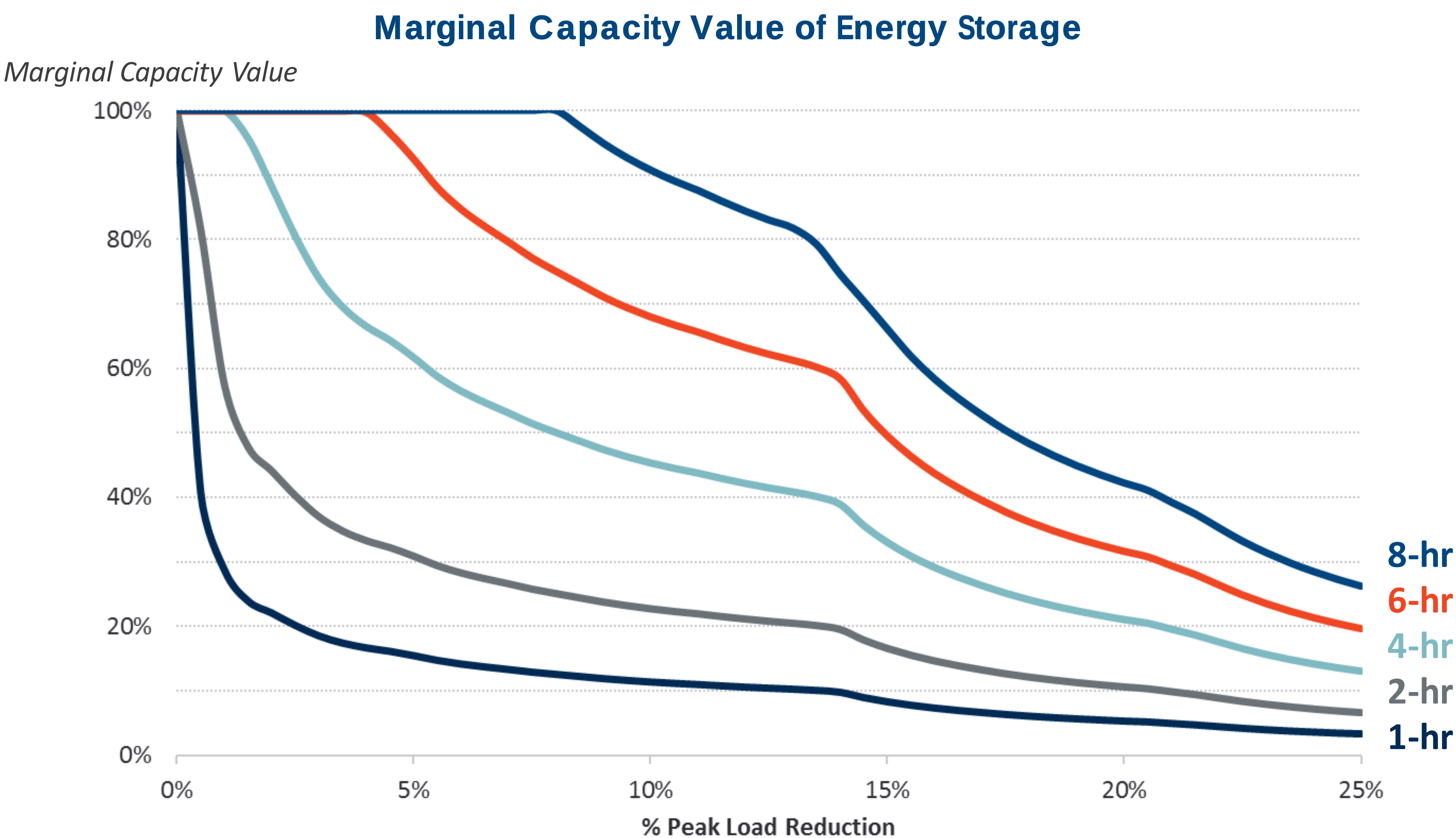
Capacity value of wind and solar

Marginal Capacity Value of Solar and Wind





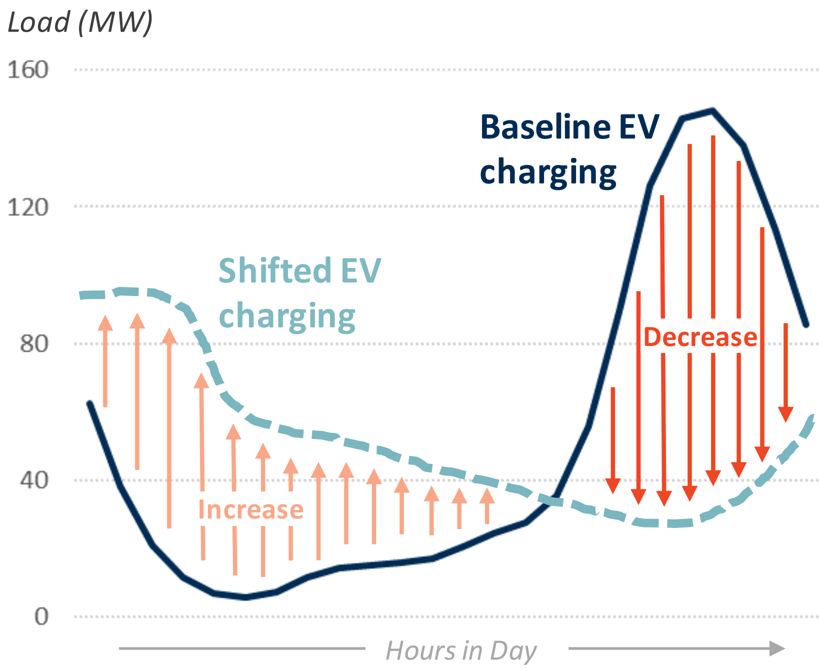
Capacity value of storage



Modeling flexible load

- Flexible loads can adjust their consumption in response to **market prices**
- We model a subset of **electric vehicles** and **HVAC systems** as flexible
- Treatment of flexible loads in GridSIM
  - In any hour, loads can flex their consumption (increase or decrease) from a baseline level
  - Flexibility varies by technology, hour, and season
  - Total flex is net-zero on a daily basis
  - Unlike battery storage, no efficiency losses
- We will make assumptions regarding:
  - Fraction of EV and HVAC load that is flexible
  - Degree of flexibility in any given hour
  - Reservation price (e.g. expected profits) required for a load to flex its consumption
- We will not capture load shifting across days, except possibly as one-off sensitivity

Example of Electric Vehicle Flexibility



Renewable natural gas (RNG)

We consider RNG as a potential future **zero emissions** technology.

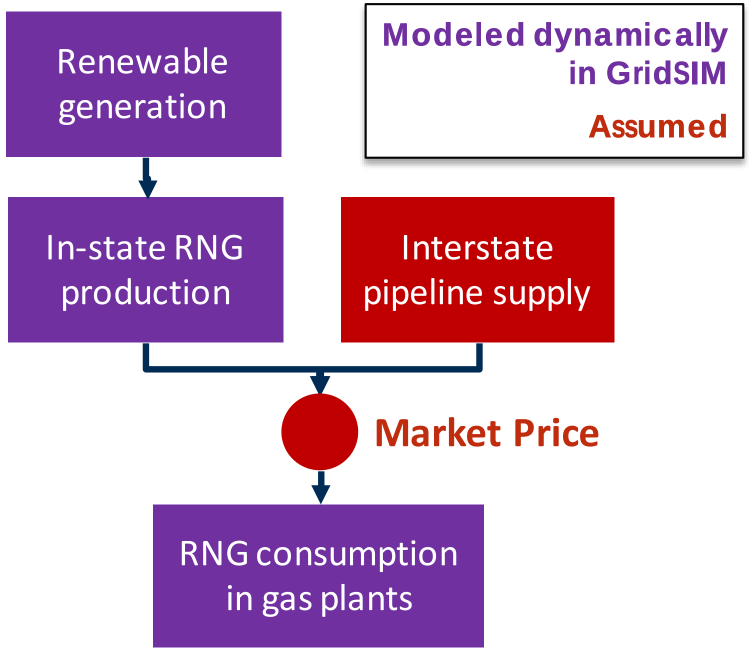
- In this context, RNG refers to gas created via electrolysis + methanation
  - Can also refer to methane from agriculture or landfills
- Producing RNG is a multi-step process
  - **Electrolysis** utilizes grid electricity (likely curtailed renewables) to create hydrogen
  - **Direct air capture** uses electricity and heat to capture CO_2 from ambient air
  - **Methanation** combines hydrogen and air-captured CO_2 to create methane, or RNG
- Burning RNG emits no net carbon emissions
  - Ignoring any release of methane in production and transport, which we will assume can be controlled to be small
- Increasingly viewed as an important part of future zero-carbon system

Modeling RNG in GridSIM

We dynamically model RNG supply, production, and consumption.

- Assume RNG **supply** is available via the interstate gas pipeline system
- Assume some RNG **produced** in-state by using renewable generation that would otherwise be curtailed
- Assume all gas-fired plants can **consume** either RNG or natural gas. As carbon constraints tighten, plants become willing to burn RNG
- Assume an RNG **market price** (~$20 - $30/MMBtu), informed by the costs of production and with a buy/sell price spread to account for transmission and pipeline charges
- Will test sensitivities since significant uncertainty about production cost of RNG

Treatment of RNG in GridSIM



Stakeholder Input

We are requesting stakeholder feedback on these assumptions and modeling decisions

We would also like to hear stakeholder interests in the different sensitivities, including those discussed today:

- 1-off "representative week" sensitivity
  - Would capture **Long-duration storage** (e.g. flow batteries or thermal)
  - Would test if value of load flexibility increases over a longer time frame (may capture load shifting over multiple days)
- One-off sensitivity on benefits of increased transmission

What other sensitivities should we consider?

Appendix

Detailed generator assumptions

Type	New/Existing	EFORd (%)	Heat Rate (MMBTU/MWh)	Minimum Generation Level (% of ICAP)	Startup Cost $/MW-start	Variable O&M ($/MWh)	Fixed O&M ($/kW-year)
Biogen	Existing	5%	9.7 - 10.8	31%	$21	$3.00	$111 - $149
Gas CC	Existing	6%	6.8 - 7.6	47%	$11 - $18	$1.81	$40 - $76
Gas CT	Existing	6%	10.6 - 16.2	15%	$1 - $2	$5.60	$21 - $51
Gas ST	Existing	6%	10.3 - 10.7	31%	$24 - $41	$8.50	$66 - $140
Nuclear	Existing	15%	10.6 - 10.9	100%	$0	$2.41	$0
Oil CT	Existing	17%	14.3 - 14.3	15%	$12	$5.60	$33 - $52
Oil ST	Existing	17%	10.6 - 10.6	31%	$90	$8.50	$66
Pumped Storage	Existing	4%	0	0%	$0	$9.00	$32
Solar	Existing	0%	0	0%	$0	$0.00	$17
Solar - BTM	Existing	0%	0	0%	$0	$0.00	$21 - $44
Storage	Existing	0%	0	0%	$0	$5.00	$23
Wind - Offshore	Existing	0%	0	0%	$0	$0.00	$0
Wind - Onshore	Existing	0%	0	0%	$0	$0.00	$43 - $52
Hydro	Existing	0%	0	0%	$0	$0.00	$30 - $37
Gas CC	New	6%	6.8	47%	$11 - $18	$1.81	$194 - $367
Gas CT	New	6%	10.3	40%	$1 - $2	$0.76	$104 - $180
Solar	New	0%	0	0%	$0	$0.00	$129 - $143
Solar - BTM	New	0%	0	0%	$0	$0.00	$77 - $321
Storage	New	0%	0	0%	$0	$5.00	$125 - $326
Wind - Offshore	New	0%	0	0%	$0	$0.00	$630
Wind - Onshore	New	0%	0	0%	$0	$0.00	$207

Sources and Notes:

NYISO Grid in Transition Report 2019
NREL 2019 ATB
NREL Power Plant Cycling Costs
Variable O&M Costs for storage and pumped storage resources reflect efficiency losses

Gas hub assumptions

We map generators to a blend of hubs, with input from NYISO.

Zone	Existing/New	Fuel Blend					
		Dominion South	Iroquois Waddington	Dawn	Iroquois Zone 2	TETCO-M3	Transco Zone 6
Zone A-E	Existing	70%	20%	10%	0%	0%	0%
Zone F	Existing	0%	0%	0%	100%	0%	0%
Zone GHI	Existing	0%	0%	0%	100%	0%	0%
Zone J	Existing	0%	0%	0%	0%	5%	95%
Zone K	Existing	0%	0%	0%	65%	0%	35%
Zone A-E	New	70%	20%	10%	0%	0%	0%
Zone F	New	0%	0%	0%	0%	100%	0%
Zone GHI	New	0%	0%	0%	0%	100%	0%
Zone J	New	0%	0%	0%	0%	5%	95%
Zone K	New	0%	0%	0%	65%	0%	35%

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