New York's Evolution to a Zero Emission Power System

MODELING OPERATIONS AND INVESTMENT THROUGH 2040 INCLUDING ALTERNATIVE SCENARIOS

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JUNE 22, 2020

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Note: Updated on 6/22 from initial posting with adjustments to slides 40, 49 – 52, and 55. Minor adjustments made to appendix text and formatting.

Study purpose and scope

NYISO retained Brattle to simulate the resources that can meet state policy objectives and energy needs through 2040, in order to inform separate inquiries into reliability and market design issues.

This study focuses on the following questions about resource mix:

- How many and what types of **renewable resources and storage** will be needed to achieve New York's decarbonization mandates?
- 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**?

Contents of this presentation

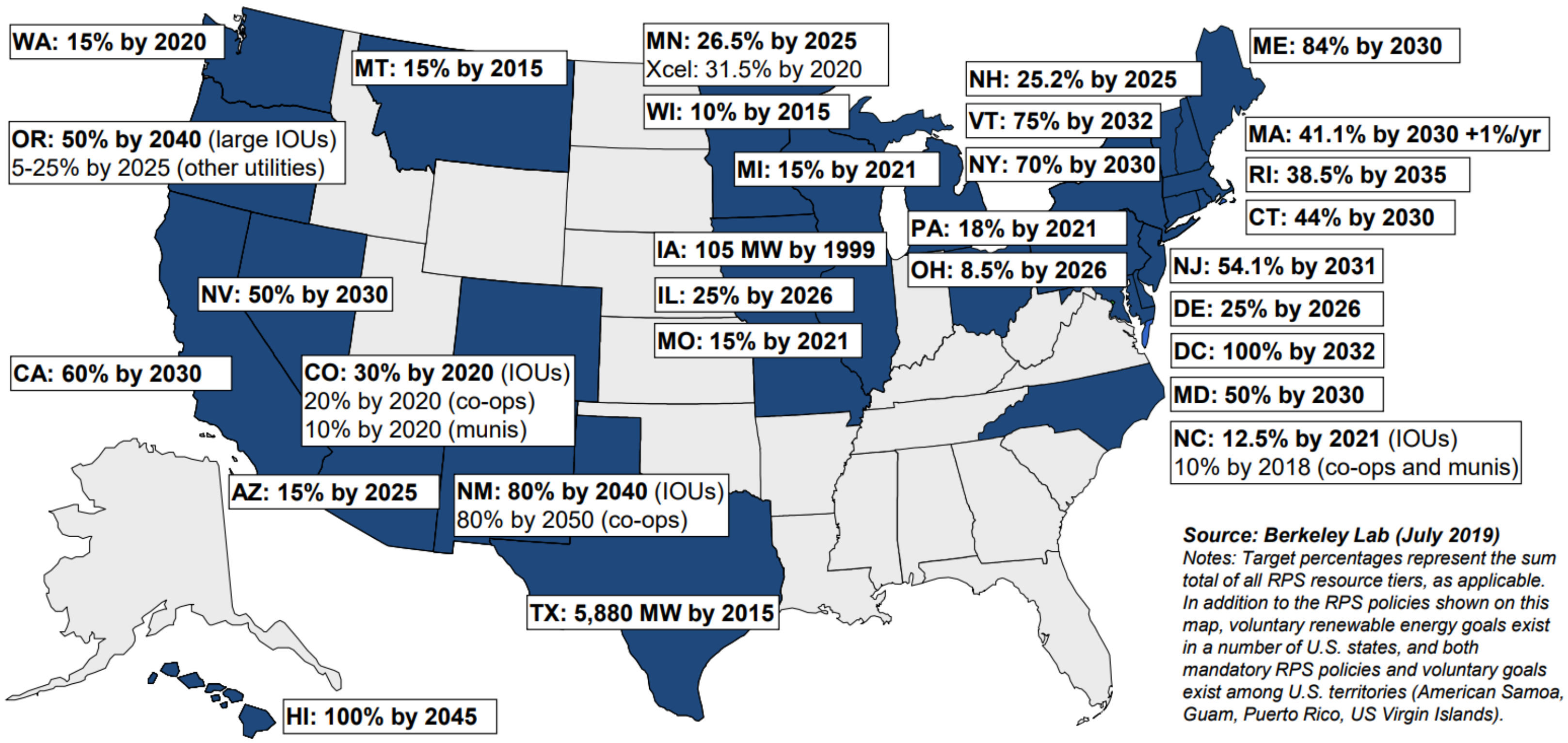
The Policy Context

DECARBONIZING THE ELECTRIC SYSTEM AND BROADER ECONOMY

Decarbonization policies around the United States

- As of early May 2020, 16 states/territories have adopted 100% clean/renewable energy system mandates or targets.
- This raises important questions about how a fully (rather than partially) decarbonized energy system and market might work.
- New York is the first entire RTO market moving to 100% clean.

Renewable & Clean Energy Standards



Source: Berkeley Lab (July 2019)
Notes: Target percentages represent the sum total of all RPS resource tiers, as applicable. In addition to the RPS policies shown on this map, voluntary renewable energy goals exist in a number of U.S. states, and both mandatory RPS policies and voluntary goals exist among U.S. territories (American Samoa, Guam, Puerto Rico, US Virgin Islands).

Source: Galen Barbose, "U.S. Renewables Portfolio Standards 2019 Annual Status Update," Lawrence Berkeley National Lab, July 2019. rps.lbl.gov

THE POLICY CONTEXT

New York's clean energy policies

Description of Key Policies

Climate Leadership and Community Protection Act (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
Zero-Emissions Credit (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

Policy Timeline

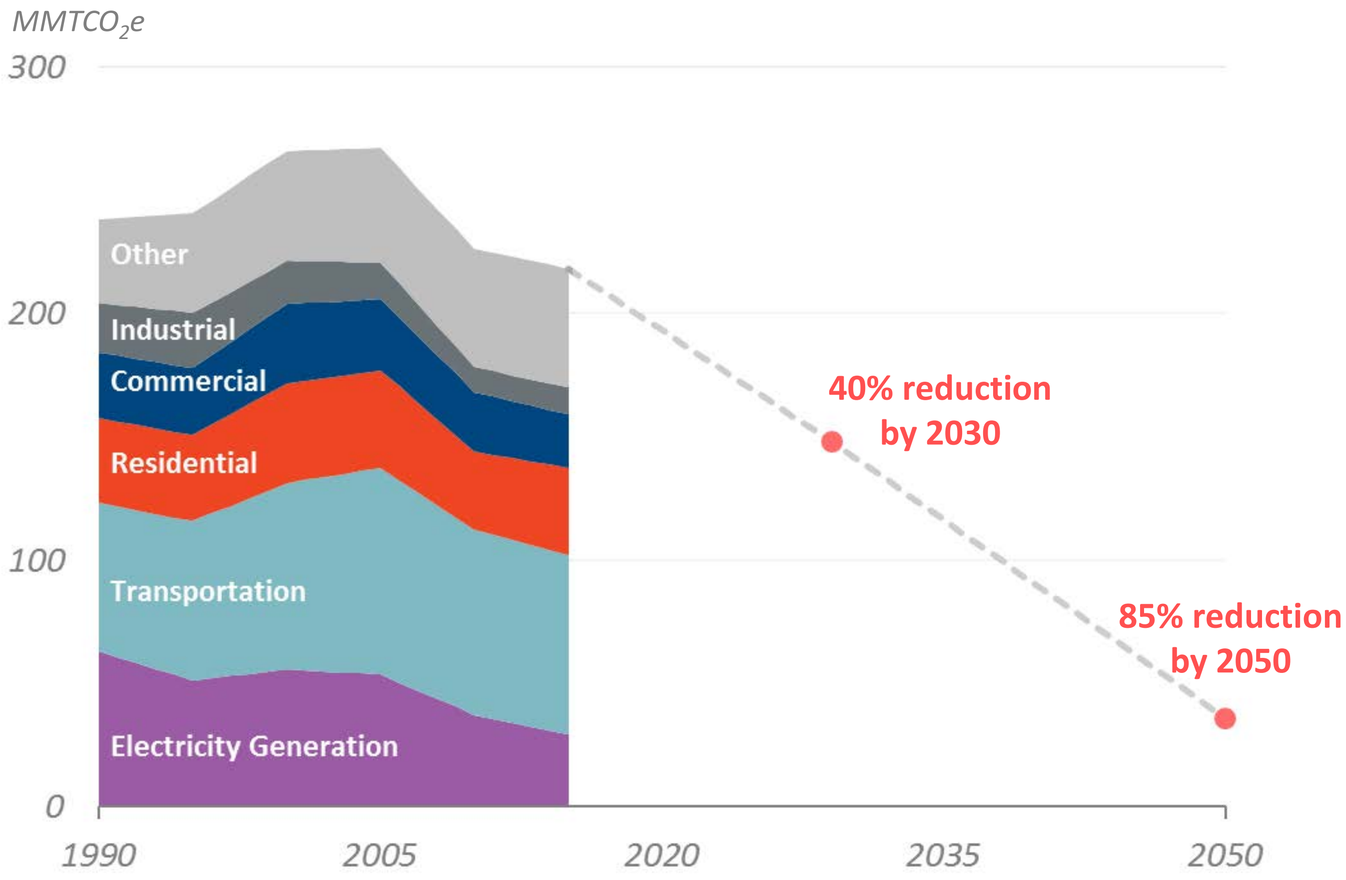
- **2009** — **RGGI:** First control period
- **2016** — **ZEC:** Program in effect
- **2025** — **Solar:** 6,000 MW mandate; **NO_X Rule:** In full effect
- **2029** — **ZEC:** Program expires
- **2030** — **CLCPA:** 70% renewable electricity; **Storage:** 3,000 MW mandate
- **2035** — **OSW:** 9,000 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

New York's economy-wide decarbonization trajectory

- Electricity generation is already a relatively minor source of GHG emissions in New York, representing less than 16% of total emissions.
- Reaching 2030 and 2050 economy-wide decarbonization goals likely implies significant electrification of buildings and transport.
- NYISO's "high electrification" case (the basis of this study) reflects an electrifying economy.

New York Historical GHG Emissions and Goals



Sources and Notes: New York State Energy Research and Development Authority (2018). New York State Greenhouse Gas Inventory: 1990–2015. Analysis by Brattle. MMtCO2e is million metric tons of carbon dioxide equivalent. Mandates relative to 1990.

Key Issues in Decarbonizing Systems

MEETING DEMAND IN LOW WIND AND SOLAR PERIODS

Planning for a zero-emission system

New wind and solar provide clean but intermittent power

Load grows with economy-wide electrification

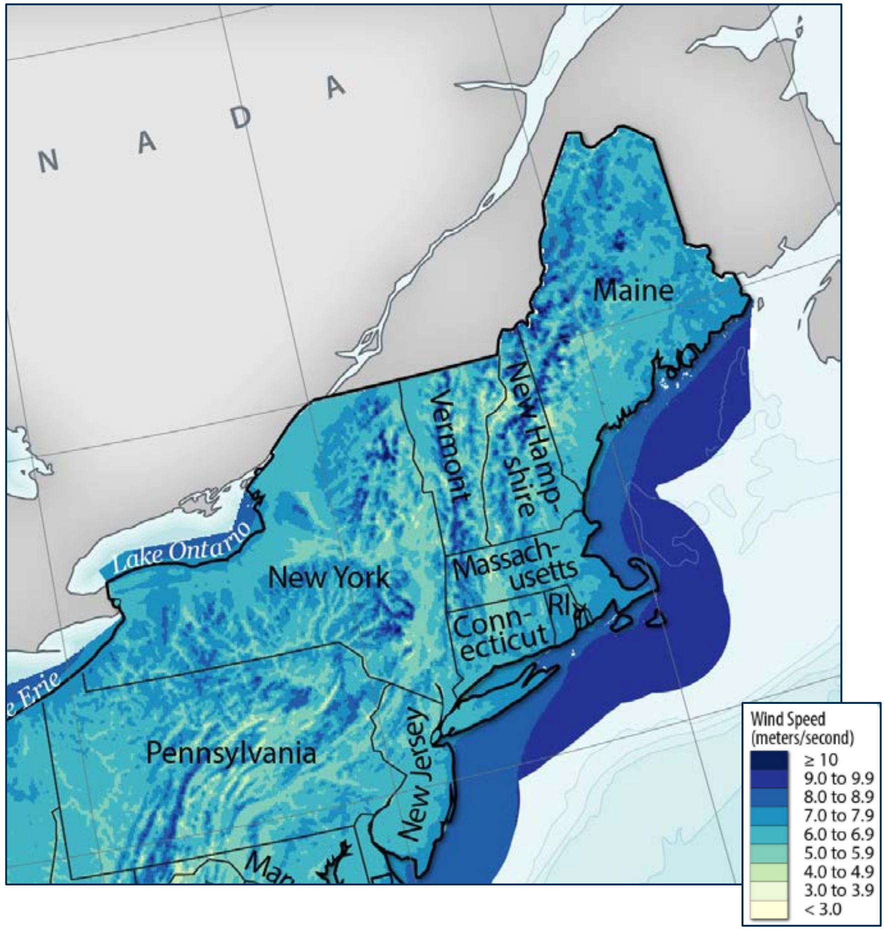
Challenge: Meeting demand when wind and solar are low, hour-to-hour and seasonally

Note: predictable and unpredictable changes in net load may also create ramping challenges requiring flexibility, but this is not addressed in this study.

Region will increasingly rely on wind and solar, whose output is intermittent

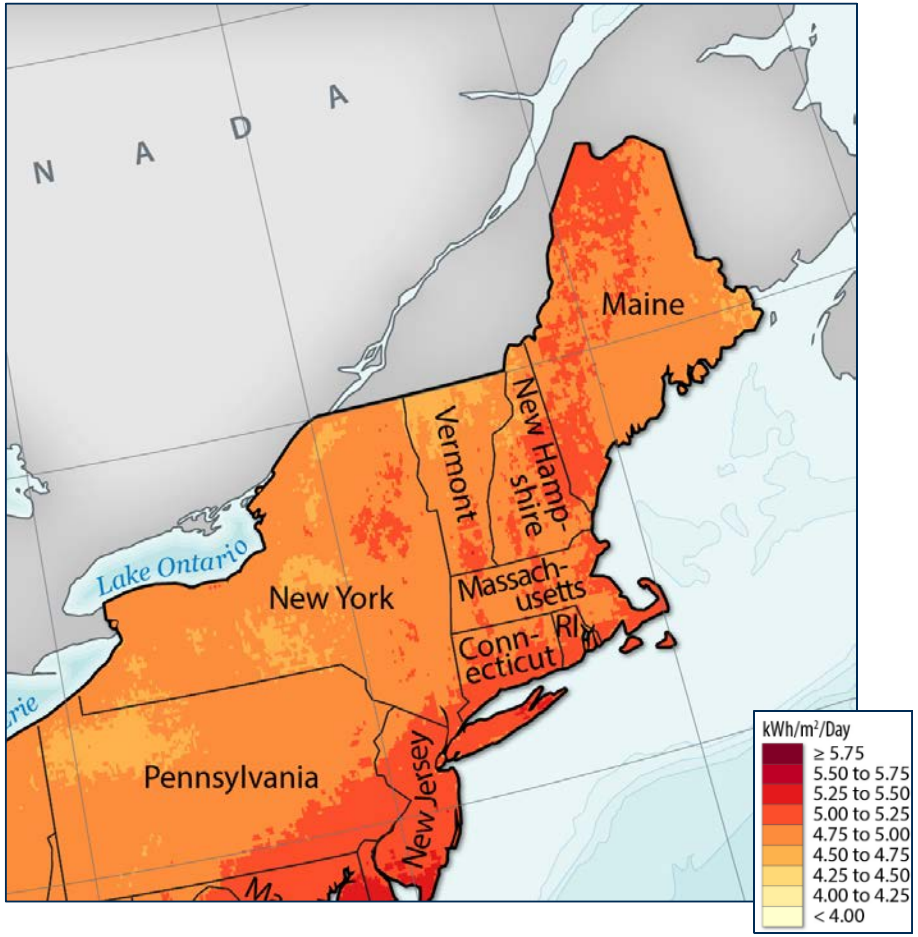
Wind Resources

Average Annual Wind Speed 100 Meters Above Surface Level



Solar Resources

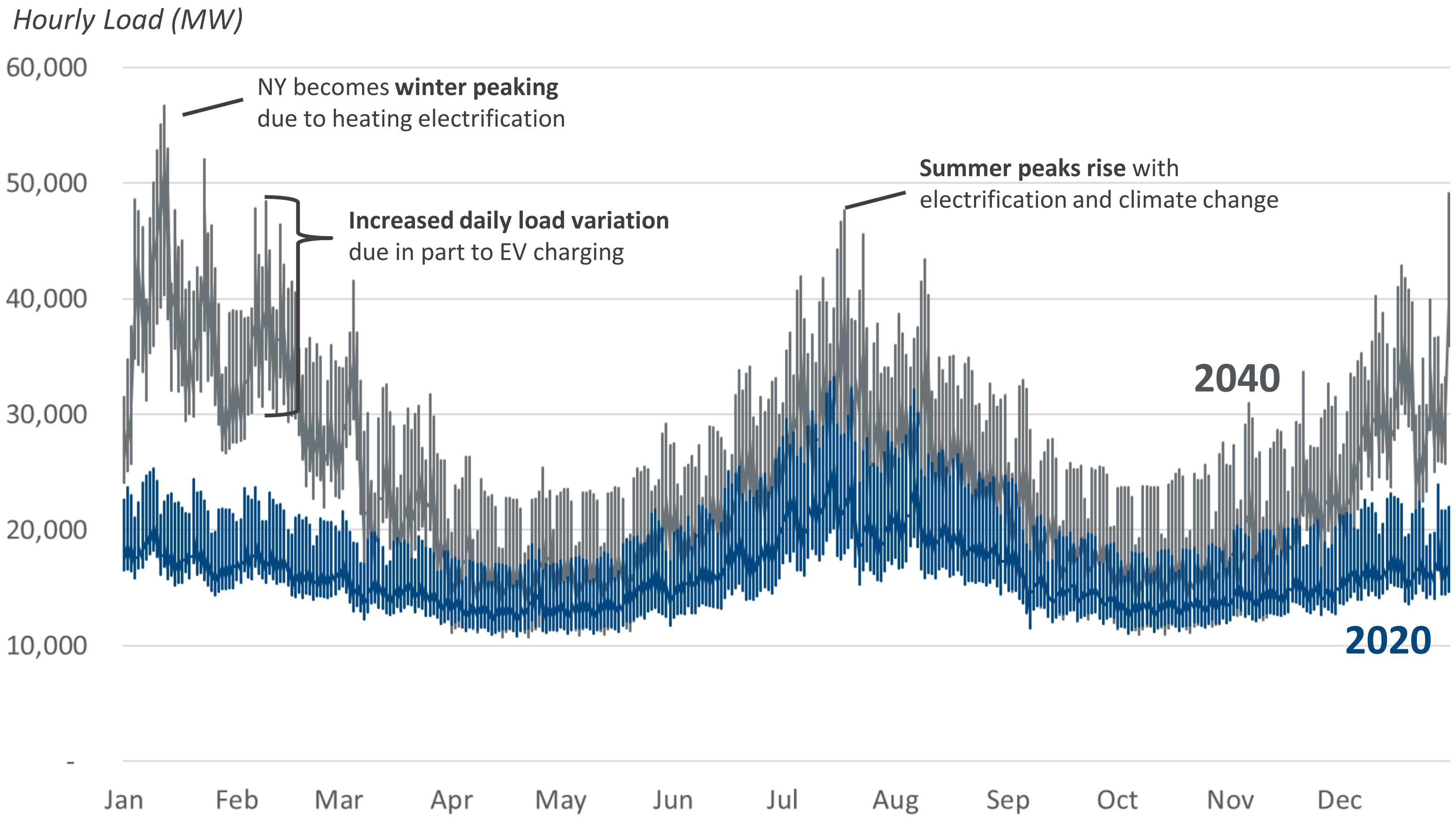
Global Horizontal Solar Irradiance in April



Sources and Notes: National Renewable Energy Laboratory. Wind map, Solar map

Loads will grow with economy-wide electrification

- Electrification and climate change will alter long-standing NY load patterns
  - Loads will rise in all periods
  - Shift to winter peaking
  - Load will become more variable hour-to-hour
- The basis of this study is NYISO's high electrification load forecast
- Results also provided for reference case with less electrification



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

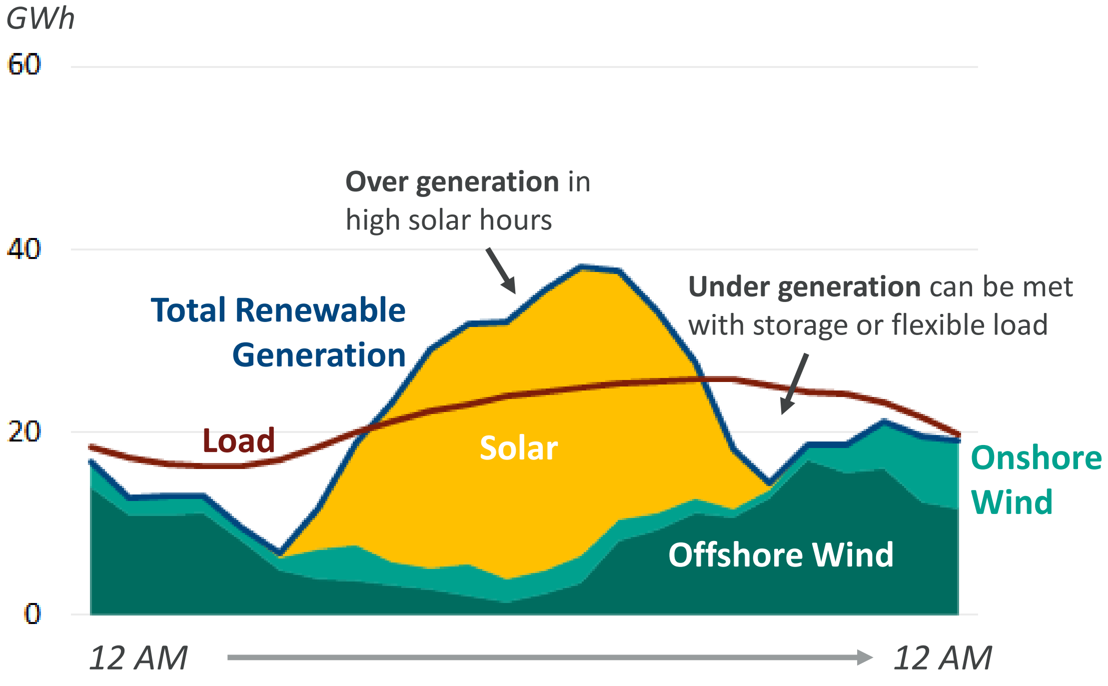
Flexibility needed to always balance supply and demand when wind and solar are low

- Today, gas-fired generators, dispatchable hydro and pumped hydro storage are a key source of flexibility. Gas-fired generators can be used less in the future due to carbon mandates.
- A clean future system will include large amounts of wind and solar generation, whose output is primarily driven by weather, thus reducing the amount of flexibility provided by generation.
- The future system will require <u>more</u> flexibility across all timescales (hourly, multi-day, seasonal) to balance intermittent renewables and more volatile load.
- Short-duration storage, such as batteries, can help provide balancing across hourly and daily timescales.
- Flexible loads, such as controllable electric vehicles and HVAC, can provide limited balancing in the hourly timeframe.
- New technologies will be needed to provide seasonal storage or zero-emission, dispatchable supply.

Paradigm Shift: Transition from controlling generation to adjusting load and using storage to shift excess renewables to match supply and demand.

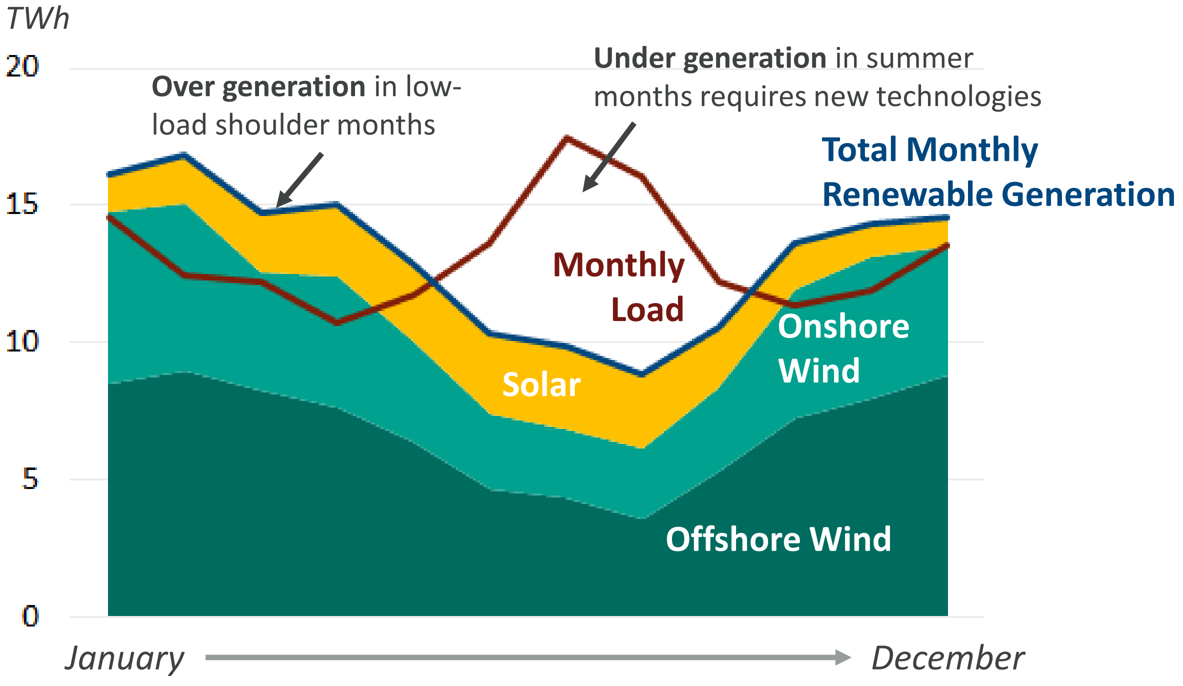
The balancing challenge is across multiple timescales

Hourly Balancing Challenge



Batteries and load flexibility can provide short-term balancing.

Seasonal Balancing Challenge



Seasonal balancing is the more difficult challenge, requiring <u>new technologies</u> such as seasonal storage or zero-emission dispatchable generation.

Sources and Notes: Illustrative examples. Load data is from NYISO's 2020 "High Electrification" CLCPA Load Case forecast. Generation capacities in both examples set such that total renewable generation over the period matches load. Left: Forecast for 8/19/2020; capacity of 63 GW assumed of each renewable type. Right: Capacity of 22 GW assumed for each type.

The role of new technologies to provide flexibility and resource adequacy

- **Several new technologies** are under development that could potentially be considered under zero-emission requirement, including:
  - Hydrogen
  - Renewable natural gas (RNG)
  - Flow batteries
  - Gravity storage
  - Carbon capture and sequestration
  - New nuclear technologies
- **The costs and capabilities of these technologies are uncertain**. We modeled RNG as a proxy for potential future zero-emission technology to illustrate the potential role of these technologies. RNG is utilized as a proxy due to availability of various cost estimates for such technology.
  - RNG used as fuel in existing and new gas-fired plants during peak periods
  - RNG produced in NY from electrolyzer and methanation plants using clean electricity in low cost periods
  - Additional RNG can be purchased from interstate pipeline system
- We did not model carbon capture and sequestration or new nuclear.
- RNG cost assumptions drawn from multiple sources, but given the degree of uncertainty in technology costs we recommend further scenario analysis to develop more robust understanding of role of long-duration storage.

Analytical Approach

MODELING THE GRID'S EVOLUTION WITH GRIDSIM

High-level approach

Brattle has used the **GridSIM model** to simulate investment and operations through 2040, consistent with assumptions developed in conjunction with NYISO staff and stakeholders.

1.	**Construct Scenarios**	Develop model inputs and vet assumptions with stakeholders. Previously discussed at March 30 ICAP working group.
2.	**Base Case GridSIM Modeling**	Use GridSIM to identify cost-effective investment path through 2040
3.	**Alternative Cases**	Simulate operations and investments under different future scenarios.

Study makes several **simplifying assumptions:**

- Climate Change CLCPA "High Electrification" load forecast
- 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"
- Current market rules and policies
- Model 30 representative days each year (10 summer, 10 winter, 10 spring/fall)

GridSIM: Brattle's next-gen capacity expansion model

Features

- Designed to simulate **highly-decarbonized systems**
- Detailed representation of **NY power system** and **NYISO markets**
- **Co-optimized** modeling of energy, ancillary, and capacity markets
- Chronological commitment and dispatch to robustly model **storage**
- Modeling of emerging technologies such as **renewable natural gas**

Example Insights

- How to balance a **100% carbon-free** grid?
- How are **nuclear** revenues affected by 70% renewable energy?
- How does the cost of **offshore wind** affect the future resource mix?

gridSIM

GridSIM model framework

INPUTS

Supply
- Existing resources
- Fuel prices
- Investment/fixed costs
- Variable costs

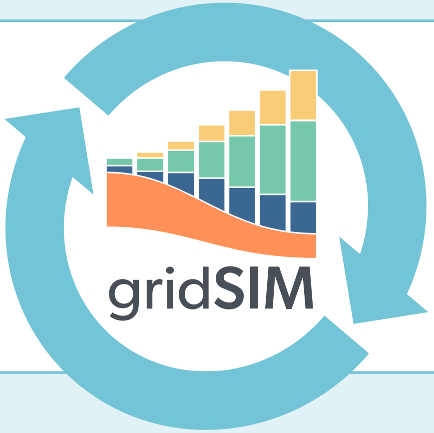
Demand
- Representative day hourly demand
- Capacity needs

Transmission
- Zonal limits
- Intertie limits

Regulations, Policies, Market Design
- Capacity market
- Carbon pricing
- State energy policies and 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

Supplier Revenues

Emissions and Clean Energy Additions

Insights into the Future New York Fleet

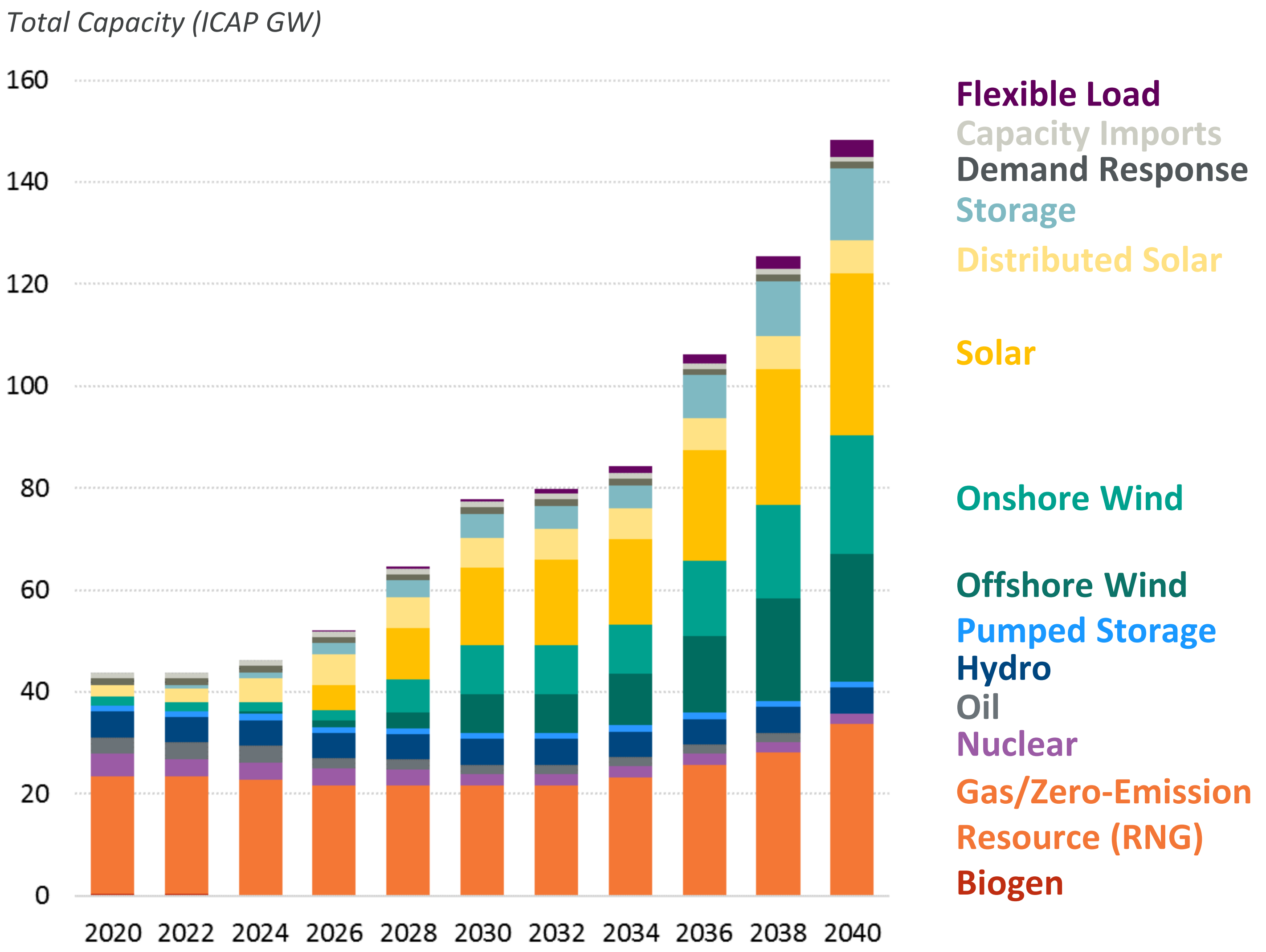
EVOLUTION OF THE GRID THROUGH 2040

The value of modeling the grid's evolution

The value in studying the future grid is to provide illustrative outcomes of how the grid may evolve in order to understand future attributes of the power system.

Ultimately, this exercise will inform key issues including NYISO's market design enhancements and reliability analyses.

The evolution of New York's generation fleet



Resources that **grow** in capacity

- **Renewables** to meet zero-emissions mandate
- **Storage and flexible load** for short-term balancing
- **Dispatchable zero-emission resources:** gas-fired generators switch to zero-carbon fuel (RNG) in 2040, for long-term balancing

Resources that **maintain** their capacity

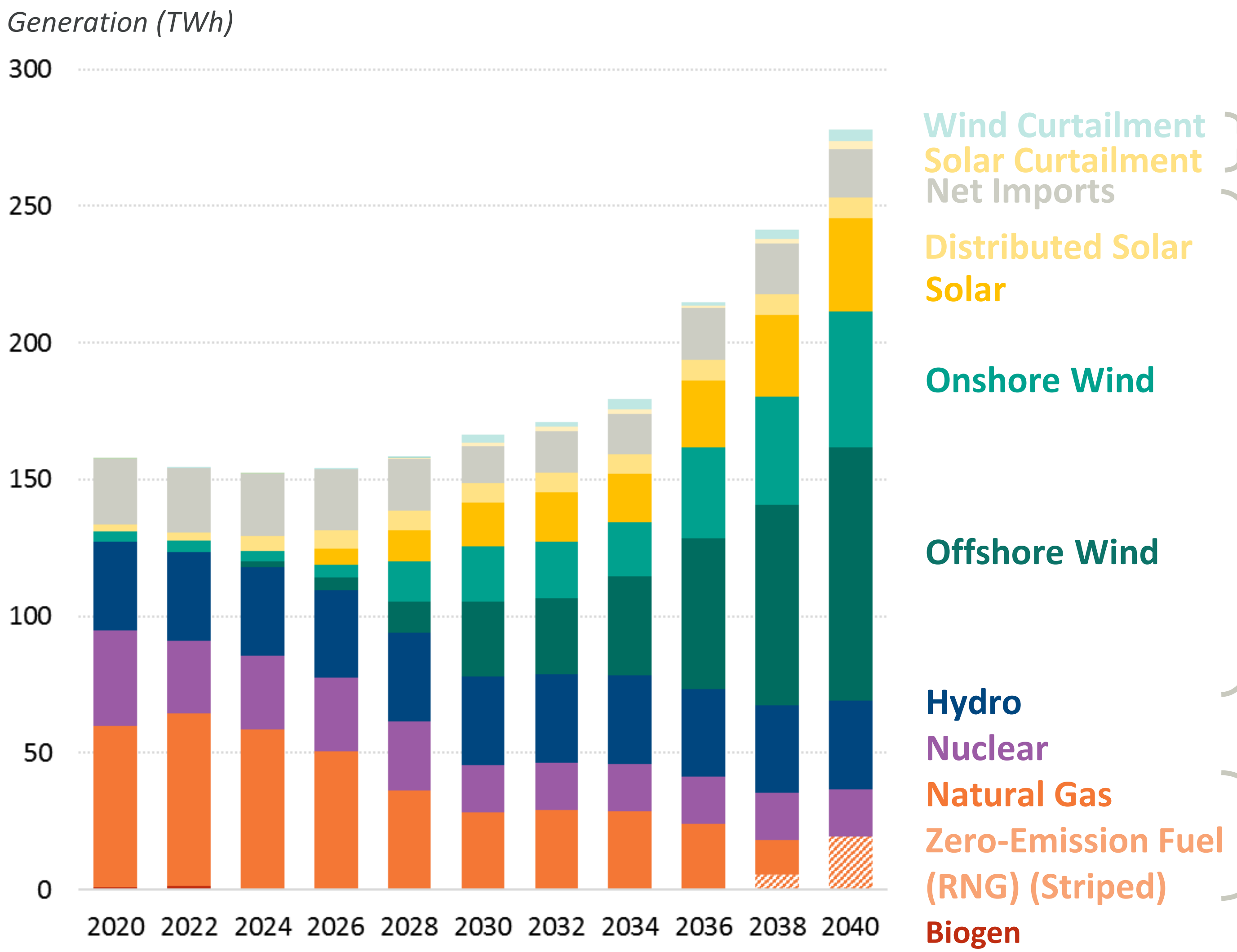
- **Pumped storage** for short-term balancing
- **Hydro** continues to provide clean power

Resources that **shrink** in capacity

- Portion of **nuclear fleet** retires by 2030 due to high refurbishment costs
- **Oil-fired generation** fully retires by 2040

See Slide 2 Disclaimer

The transition to zero emissions generation



Minimal curtailments due to short- and long-term balancing (including RNG production)

Wind and solar become primary source of energy

Gas-fired generation falls, eventually switches to zero-emission fuel sources (RNG)

See Slide 2 Disclaimer

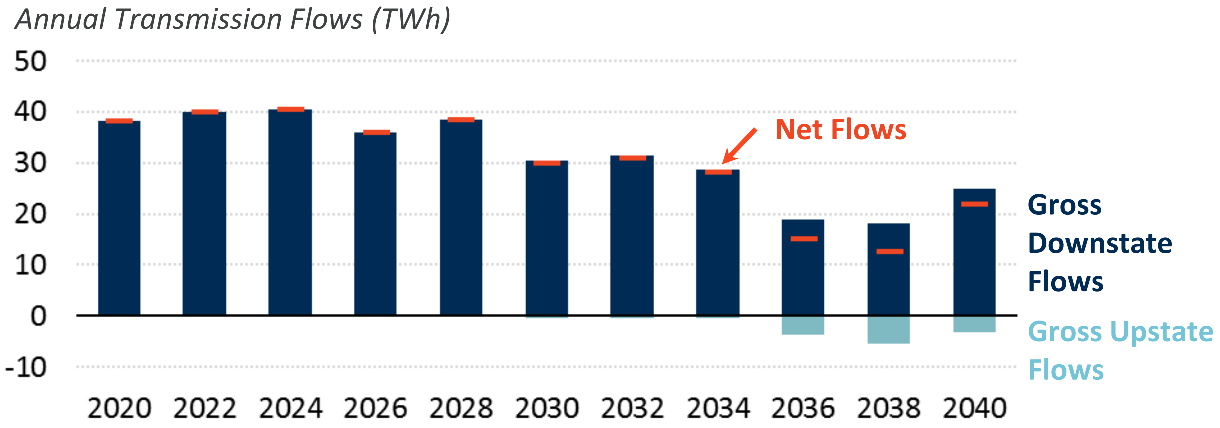
Transmission flows reflect an evolving fleet

Today, transmission flows are primarily southbound, transferring power from Upstate zones to Downstate zones.

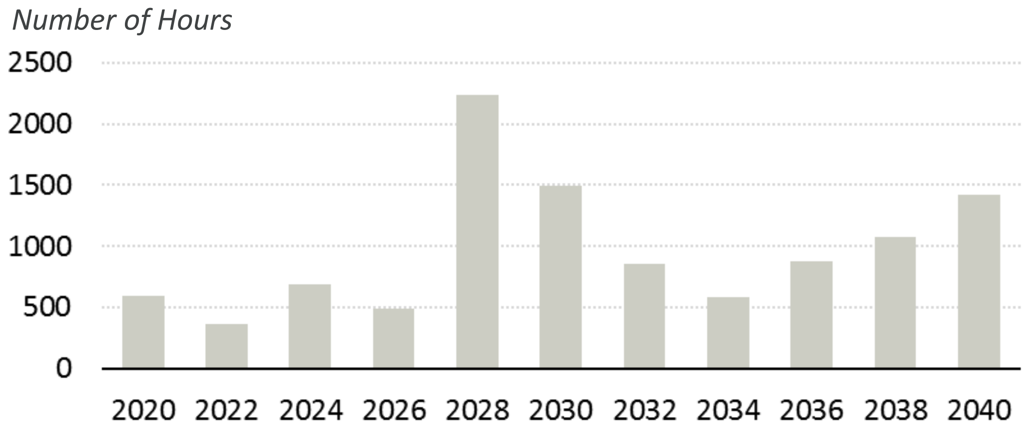
In the future, flow patterns become more variable, with flows occasionally reversing direction.

The frequency of constrained hours southbound generally increases.

Gross Annual Upstate/Downstate Flows



Number of Hours with Constrained Downstate Flows



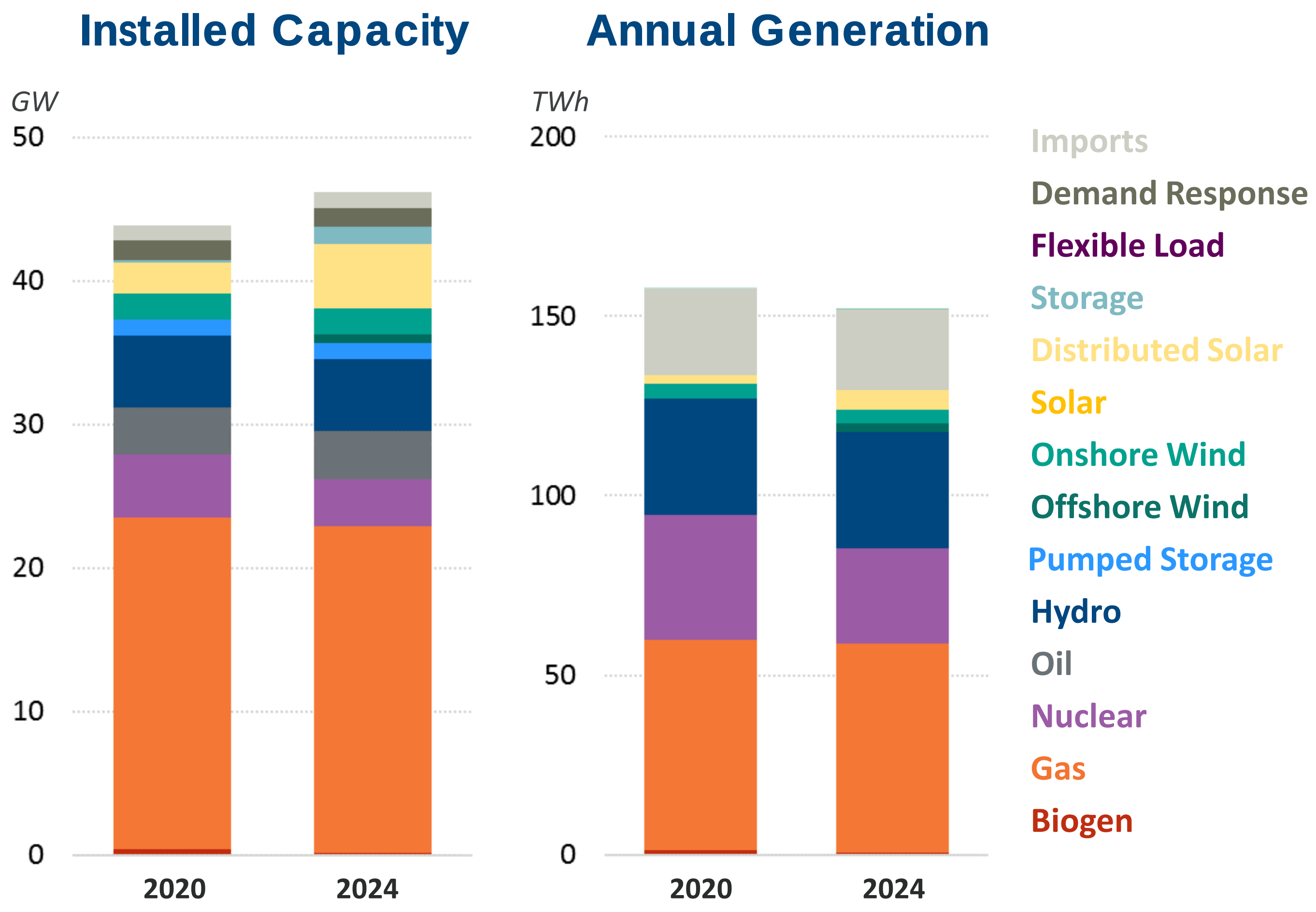
Notes: Measured as total flows between A-E and neighboring zones (GHI and F)

Stages of Decarbonization

FLEET COMPOSITION AND OPERATIONS IN 2024, 2030, AND 2040

Near term (2024): Supply mix and operations similar to today

Resource mix



- **Nuclear** capacity and generation falls due to Indian Point retirement
- **Distributed solar** capacity doubles from today's levels due to procurement mandate
- **Energy storage** deployments grow with procurement mandates
- Small amount (<1 GW) of **offshore wind** comes online
- **Gas and hydro** capacities and operations similar to today

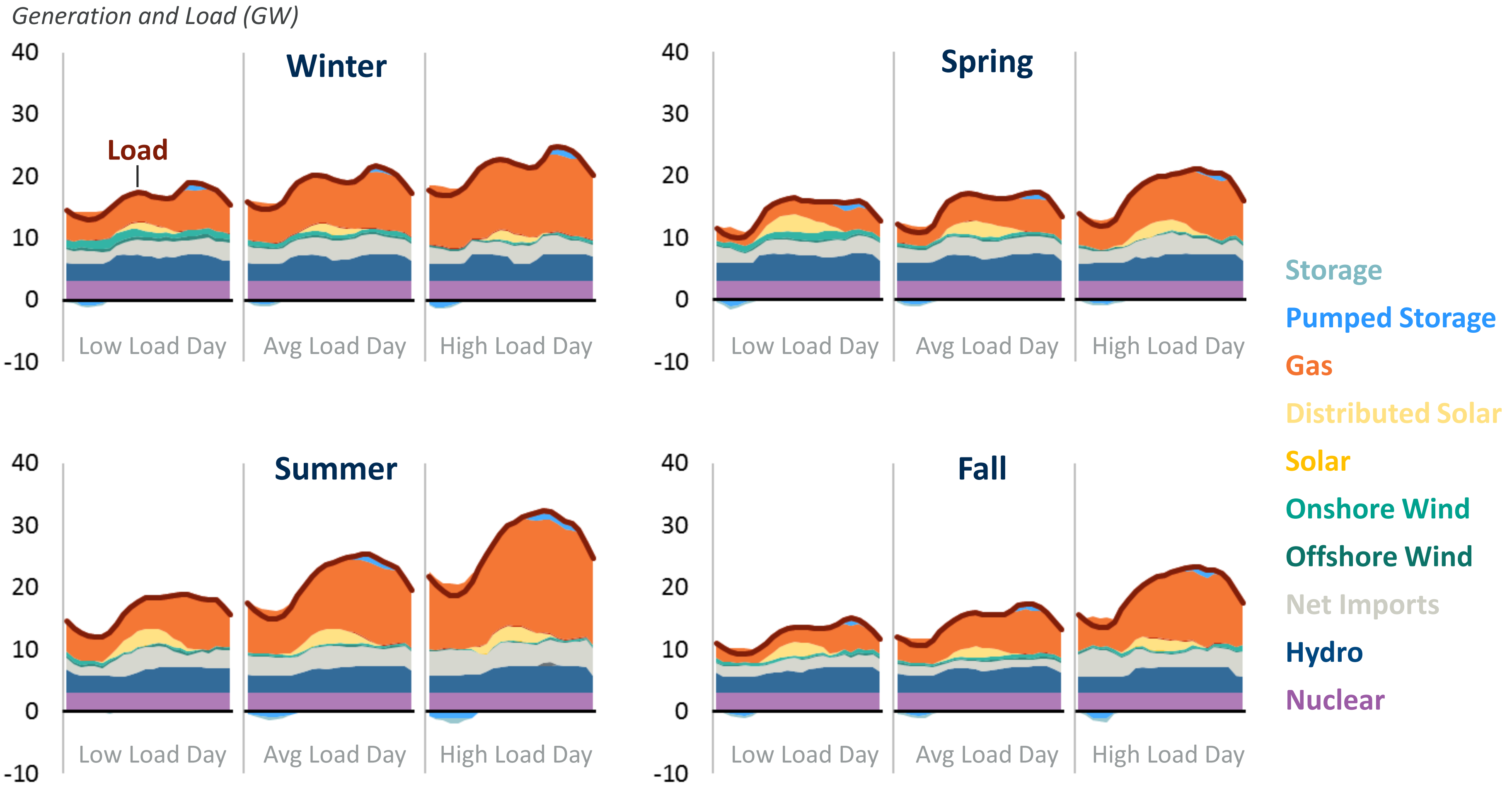
See Slide 2 Disclaimer

Near term (2024): Supply mix and operations similar to today

Seasonal supply and demand patterns

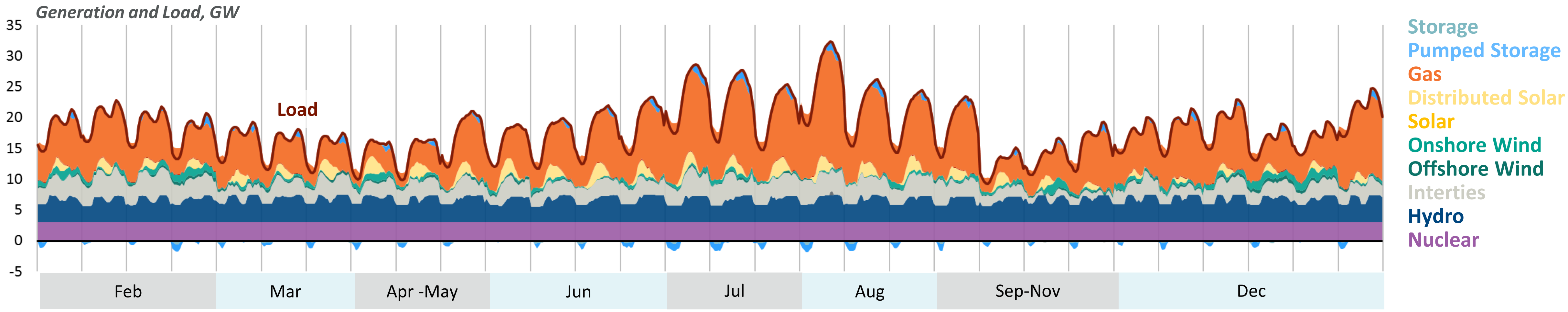
- Demand
  - System remains summer peaking
- Generation
  - Natural gas is the marginal resource for nearly all hours
  - Minimal renewable generation and balancing challenges

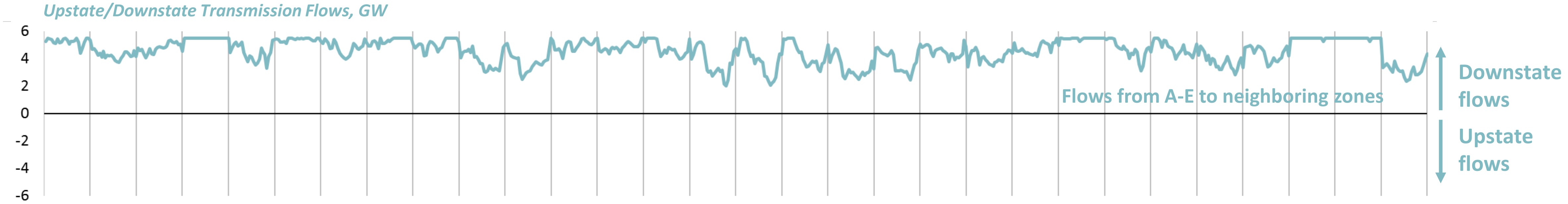
Hourly Operations, by Season



Near term (2024): Supply mix and operations similar to today

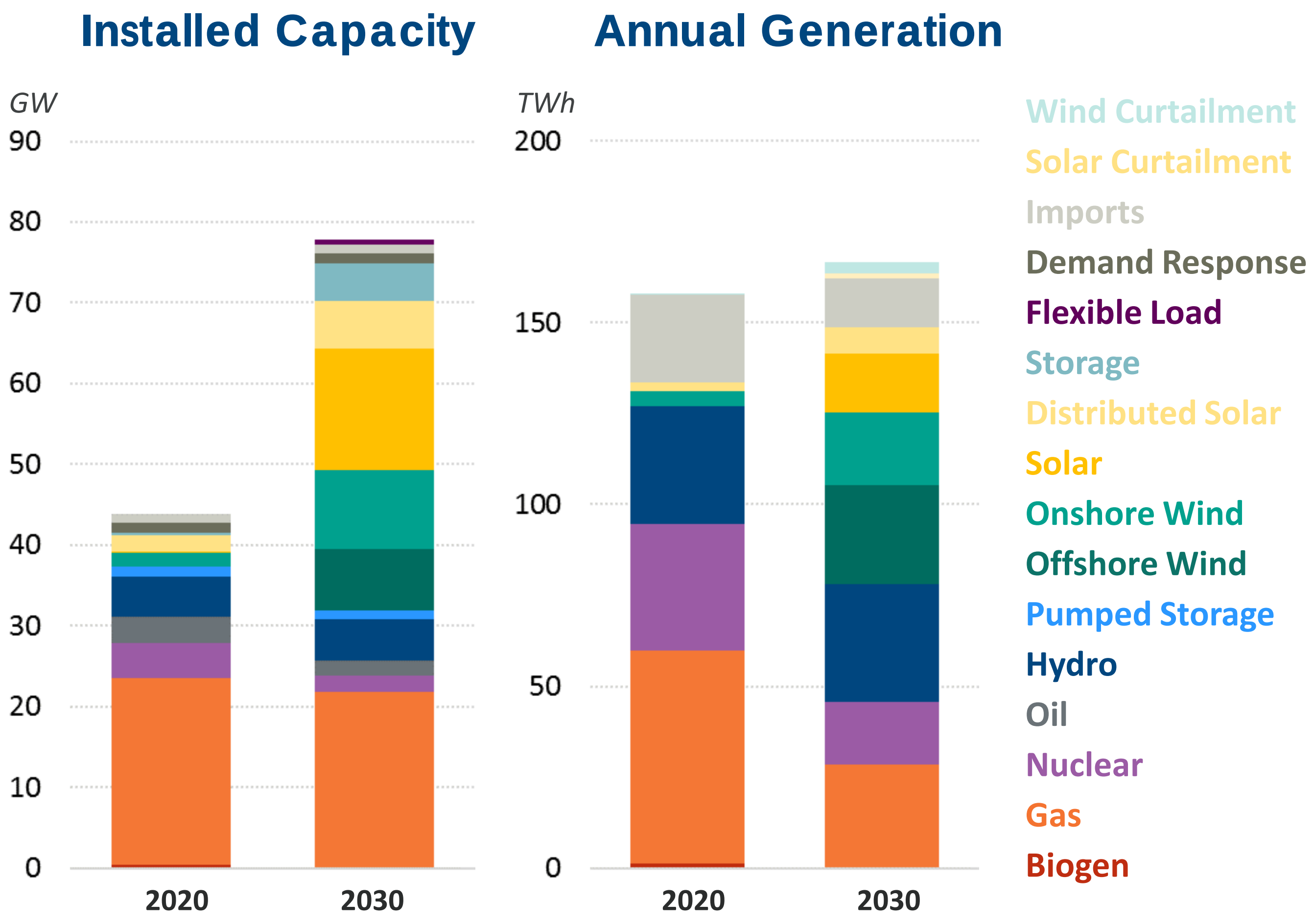
Hourly operations across 30 representative days





Mid-term (2030): Managing a 70% renewable system

Resource mix



- **Renewable resources** provide 70% of energy
  - **Solar** deployments grow to 20 GW
  - **Offshore wind** deployments grow to 8 GW
  - **Onshore wind** deployments grow to 10 GW
- **Nuclear** capacity and generation falls with 1 GW of Upstate nuclear retirement after expiration of ZEC program in 2029.
- **Energy storage** deployments grow by 4 GW with procurement mandates and provide balancing.
- **Gas-fired and oil** capacities fall due to DEC NOx rule. Gas capacity factors fall from 29% in 2020 to 15% in 2030.

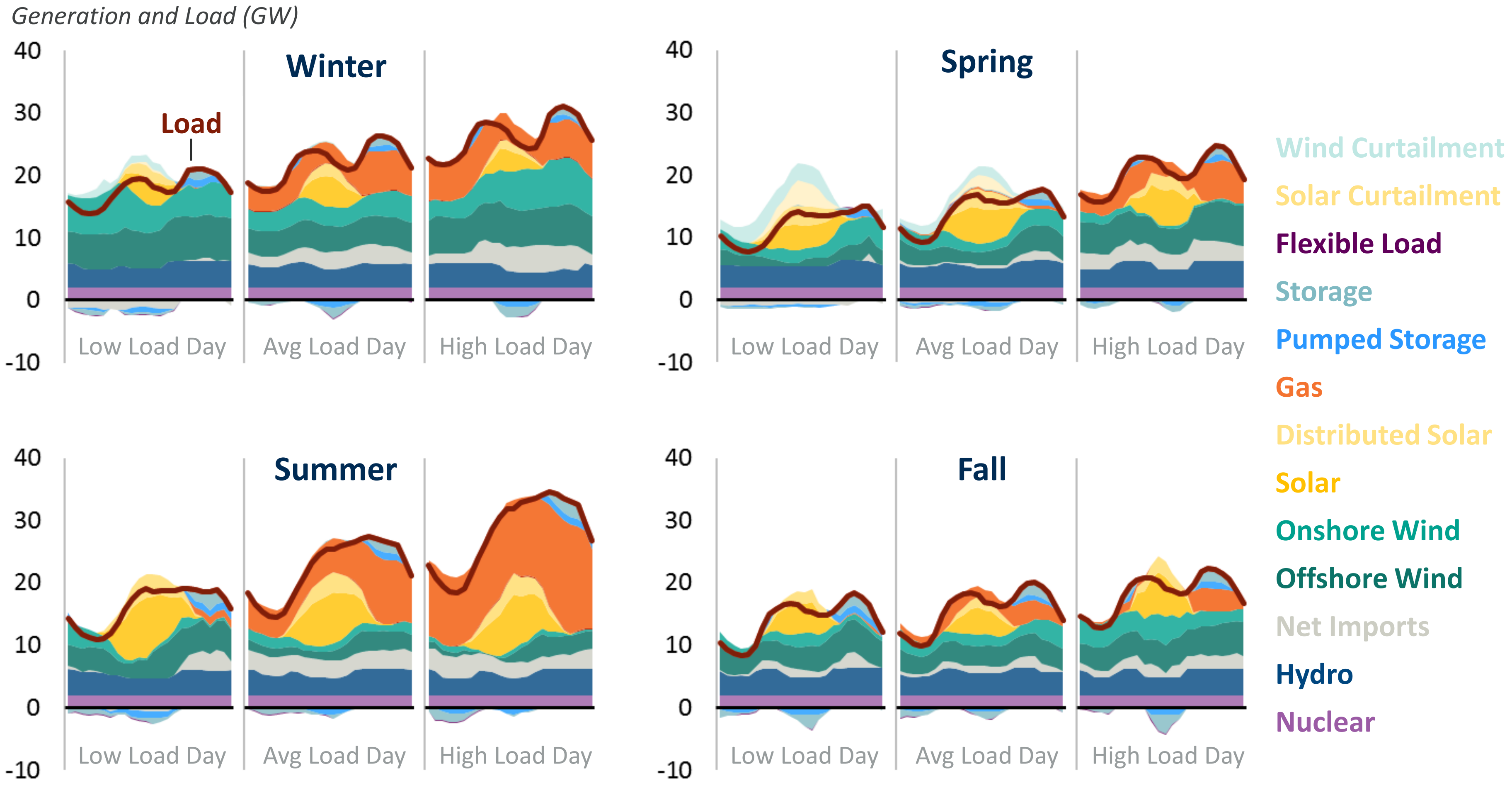
See Slide 2 Disclaimer

Mid-term (2030): Managing a 70% renewable system

Seasonal supply and demand patterns

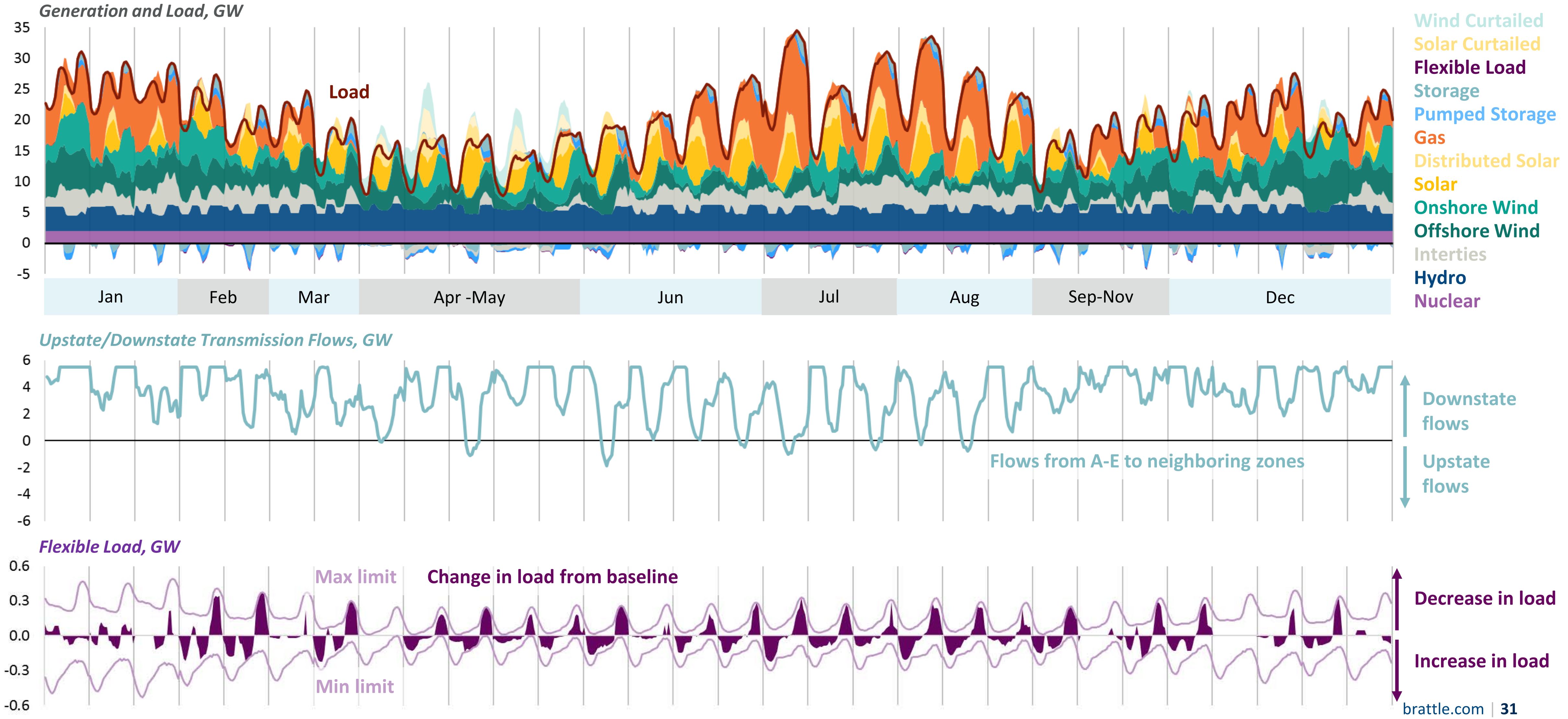
- Demand
  - System remains summer peaking
  - Storage charging generally coincident with solar generation
- Generation
  - Occasional wind and solar curtailment, predominantly in spring
  - Gas is the marginal resource in most winter, summer, and fall hours

Hourly Operations, by Season



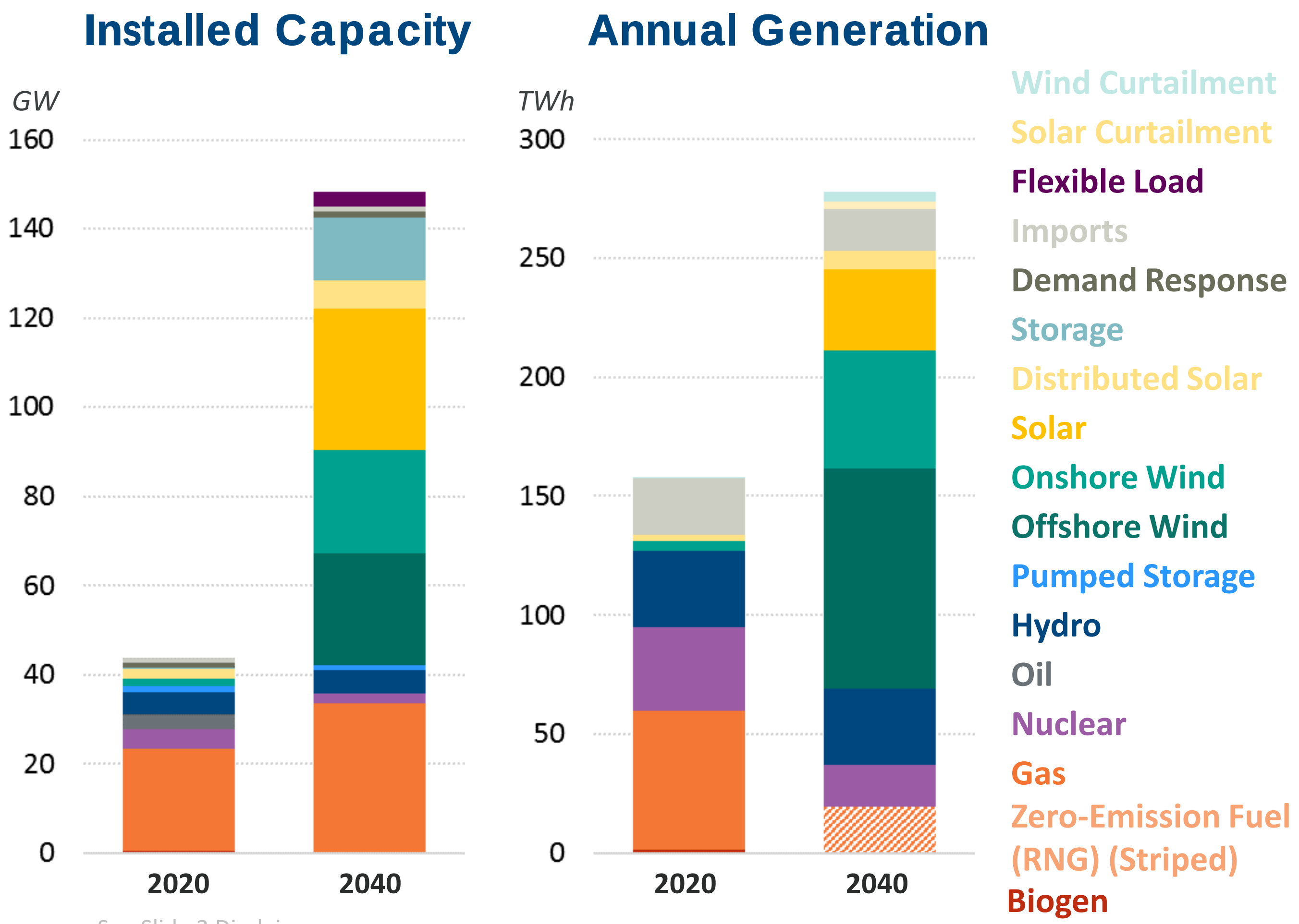
Mid-term (2030): Managing a 70% renewable system

Hourly operations across 30 representative days



Long-term (2040): Realizing a zero-emission system

Resource mix



- **Nuclear** experiences no further retirements between 2030 and 2040
- **Solar** capacity grows to 38 GW; solar generation supplies 15% of New York load in 2040
- **Offshore wind** capacity grows to 25 GW; offshore wind generation supplies 34% of New York load in 2040
- **Onshore wind** capacity grows to 23 GW; onshore wind generation supplies 18% of New York load in 2040
- **Energy storage** deployments grow to 14 GW
- **Gas-fired** capacity grows, but switches to zero-emission fuel sources (RNG). Gas capacity factors fall from 29% in 2020 to 7% in 2040

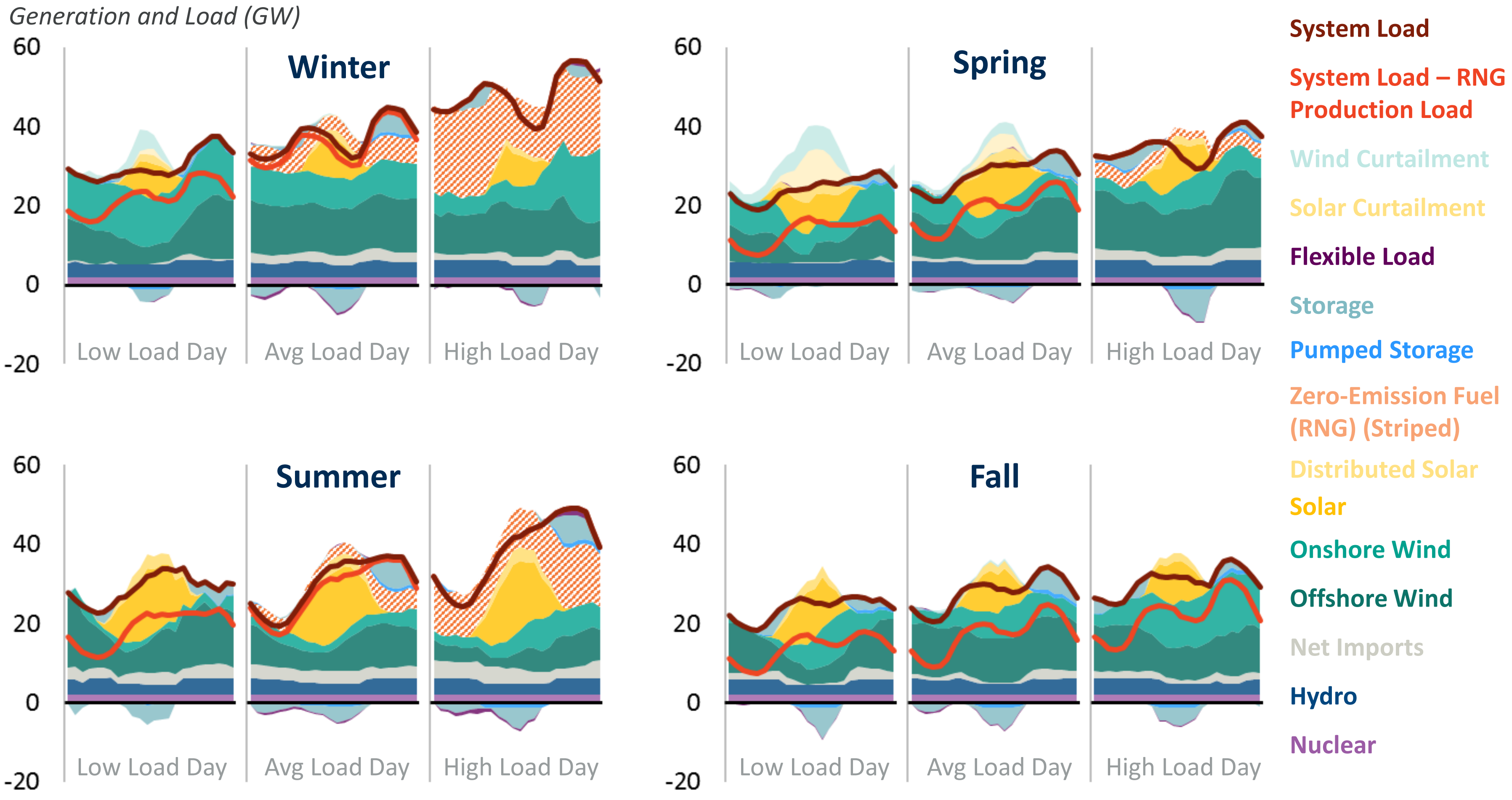
See Slide 2 Disclaimer

Long-term (2040): Realizing a zero-emission system

Seasonal supply and demand patterns

- Demand
  - System becomes winter peaking but summer peak also presents challenges
  - RNG production occurs on low load days, mostly in spring and fall
- Generation
  - Zero-emission fuels (RNG) consumed in many winter and summer hours to meet peak load
  - Storage operated to provide balancing in all seasons
  - Wind and solar curtailed predominantly in spring

Hourly Operations, by Season



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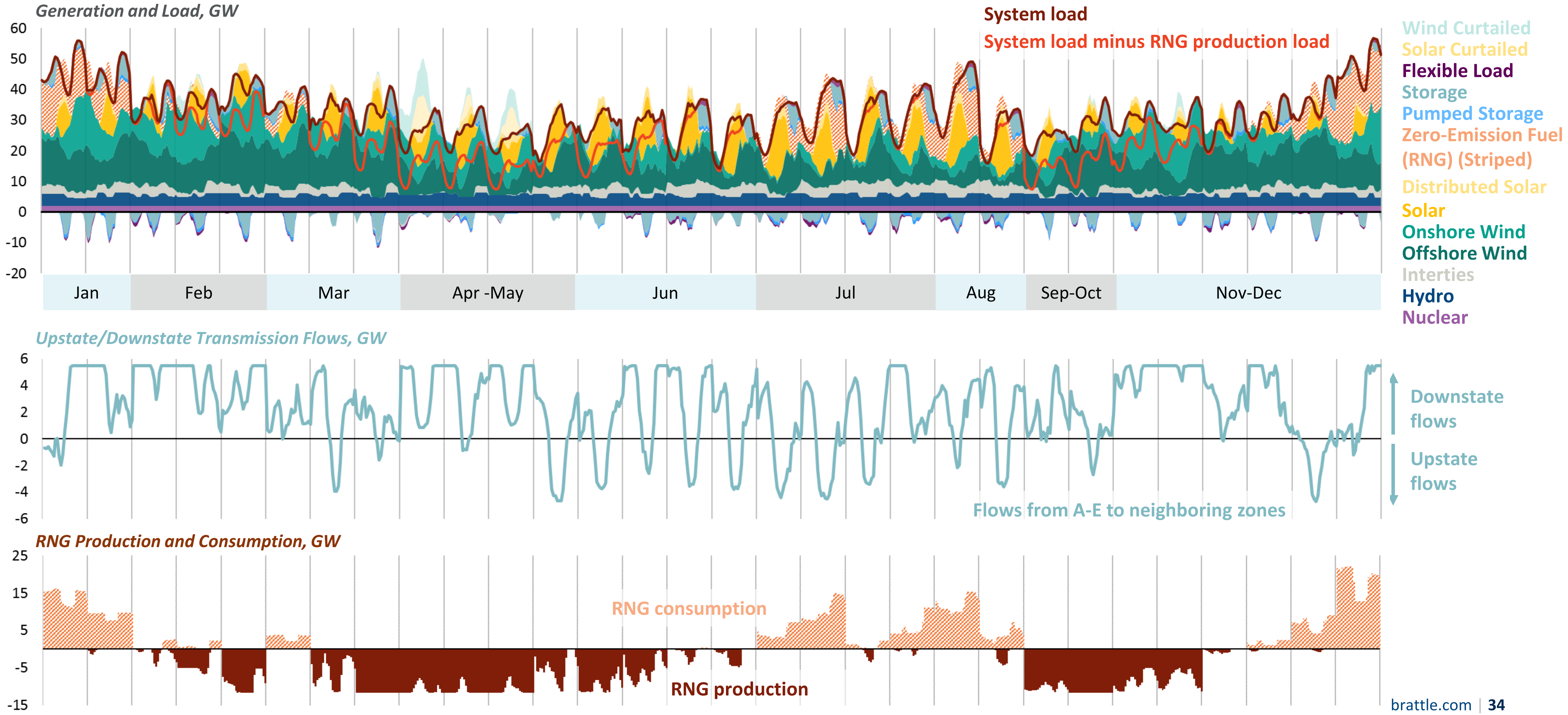
Long-term (2040): Realizing a zero-emission system

Hourly operations across 30 representative days

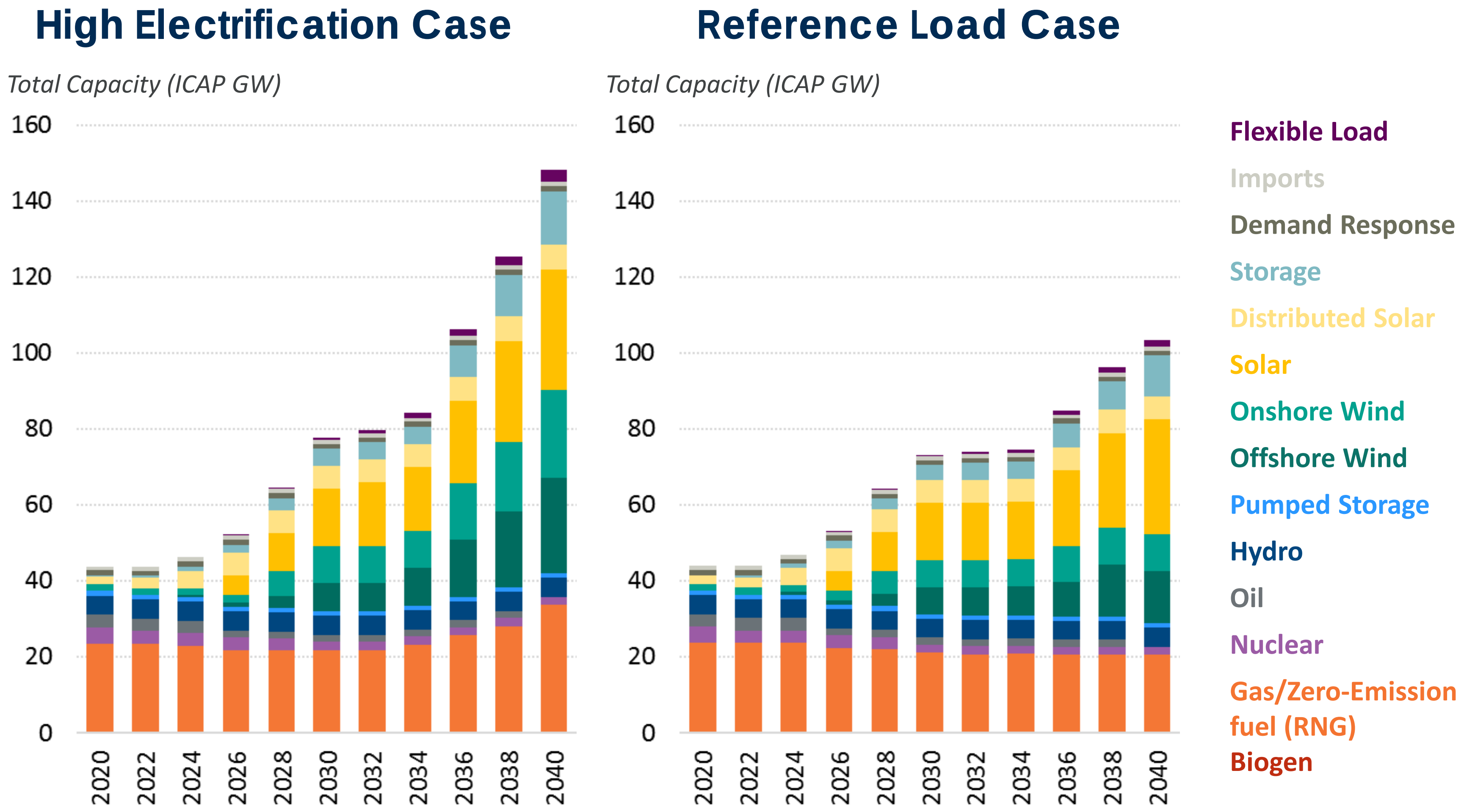


Effects of Electrification

COMPARISON OF HIGH ELECTRIFICATION AND REFERENCE LOAD CASES FROM THE CLIMATE CHANGE PHASE 1 PROJECT

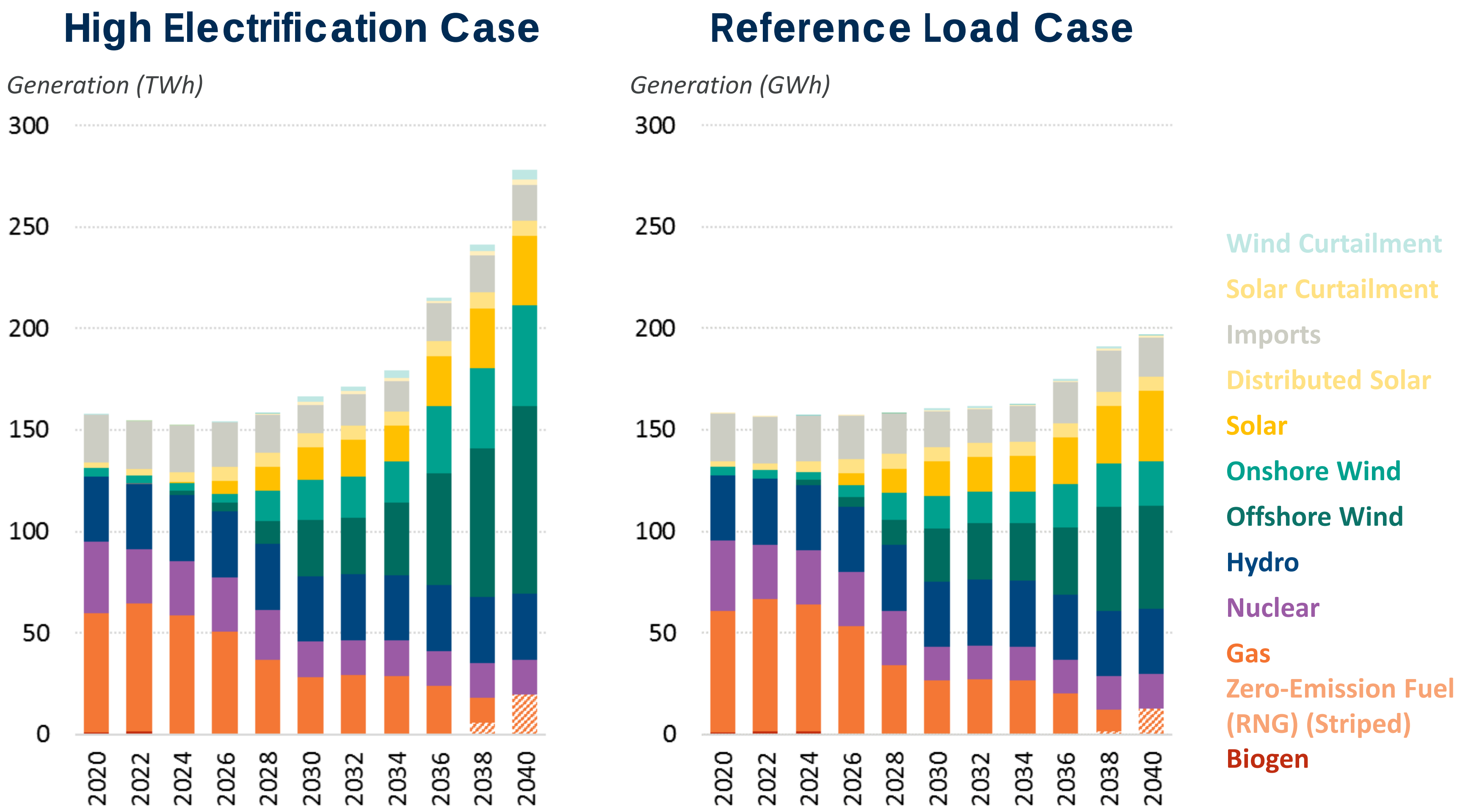
Installed capacity

- High electrification case sees **43 GW more capacity** by 2040
  - +13 GW gas
  - +11 GW offshore wind
  - +14 GW onshore wind
  - +2 GW solar
  - +3 GW storage
- More capacity needed to support electrification and RNG production loads
- **Two cases diverge starting in 2030**; before then two cases are similar



Annual generation

- Electrification and RNG production result in **75 TWh more generation** by 2040
  - **+69 TWh wind generation**
  - +7 TWh gas generation
  - -2 TWh net imports
  - Generation from other sources largely unchanged



Alternative Scenarios

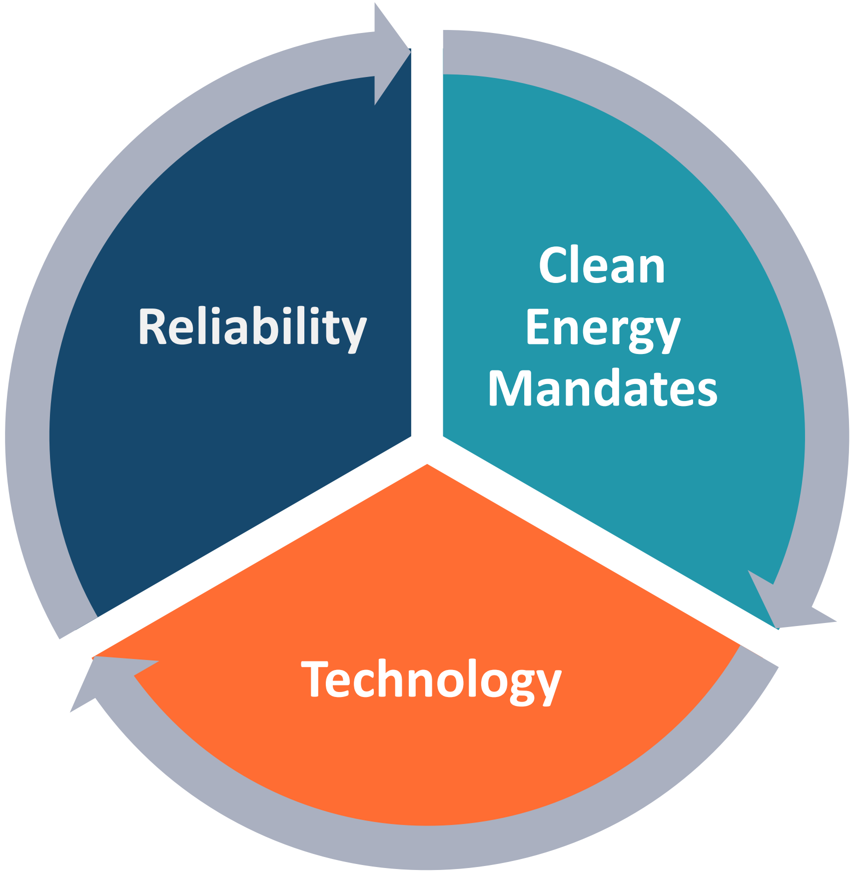
IMPACTS OF KEY MODELING ASSUMPTIONS ON RESULTS

Introduction to Alternative Scenarios

- Because future market conditions are very uncertain, we model multiple alternative future scenarios to understand key drivers of results
- Based on feedback from NYISO and stakeholders, we developed 3 scenarios to address a range of concerns
  - Existing Technologies
  - Increased Flexibility
  - Expanded Transmission
- We compared each scenario to the High Electrification Case (referred to as "Base Case"). Used "High Electrification Case" load forecast in all scenarios
- All changes to create Alternative Scenarios (e.g., expanded transmission) are fixed inputs to the model, *not* economic decisions by the model. Costs of implementing these changes are not considered.

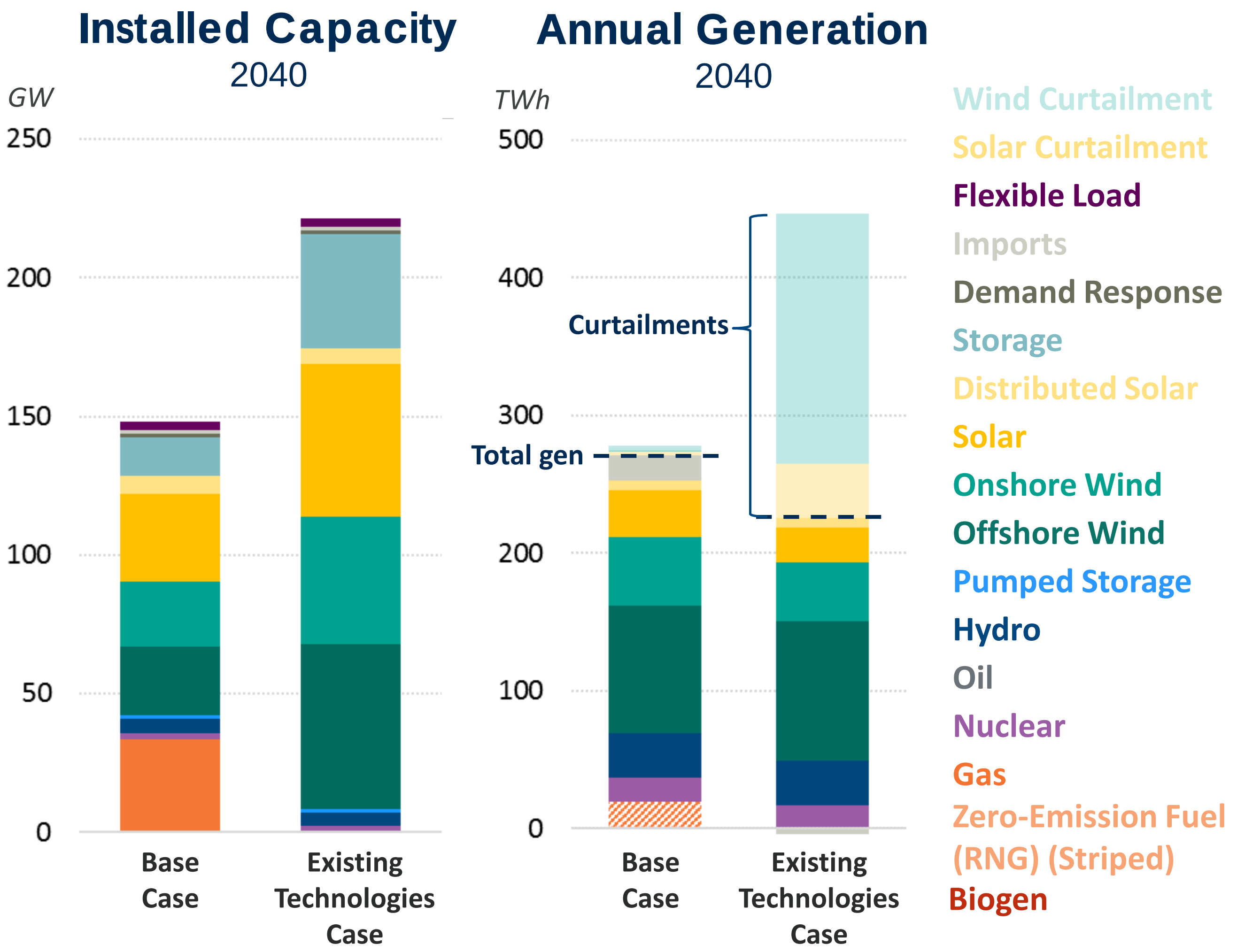
1.	**Existing Technologies**	Only existing technologies (wind, solar, storage) can be built • RNG production and consumption disallowed • All fossil plants must retire by 2040 • Capacity value of wind, solar, and storage heavily derated at high deployment levels
2.	**Increased Flexibility**	More flexibility provided by expanded interties to HQ and expanded flexible load supply • +1,300 MW intertie between HQ and Zone J • +1,500 MW import capacity (+1,000 MW export capacity) between HQ and Zone D, doubling existing capacity • +1,800 MW load shift potential from flexible EVs • +5,300 MW load shift potential from flexible HVAC
3.	**Expanded Transmission**	Expanded transmission along key corridors • +2,000 MW transmission A-E -> GHI • +2,000 MW transmission GHI -> J • +1,000 MW transmission between J & K (bidirectional)

Three aspects of the future fleet must be in alignment



Changing assumptions regarding one aspect (assuming no new technology) has consequences for other aspects (meeting clean energy and reliability mandates).

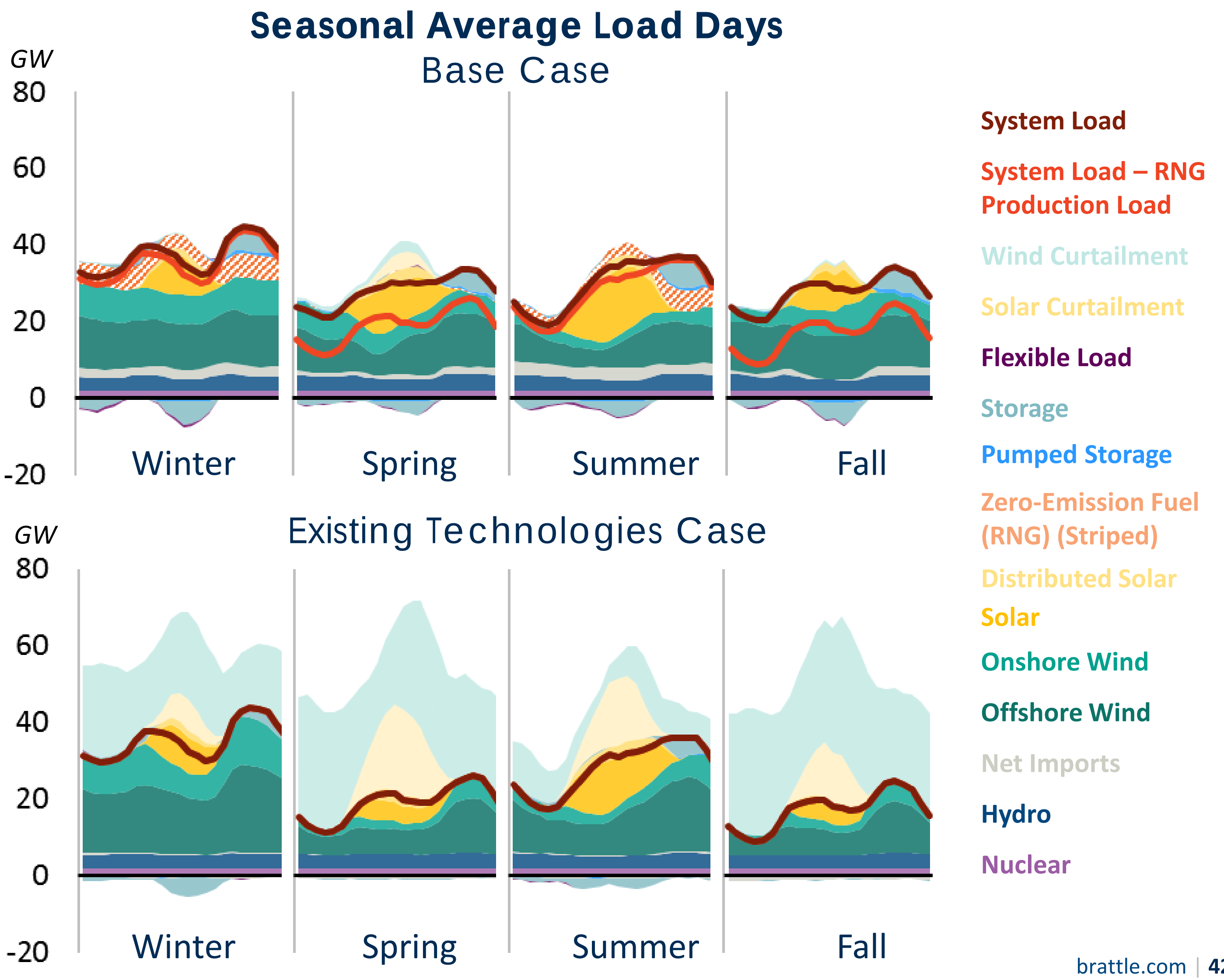
Existing Technologies Case



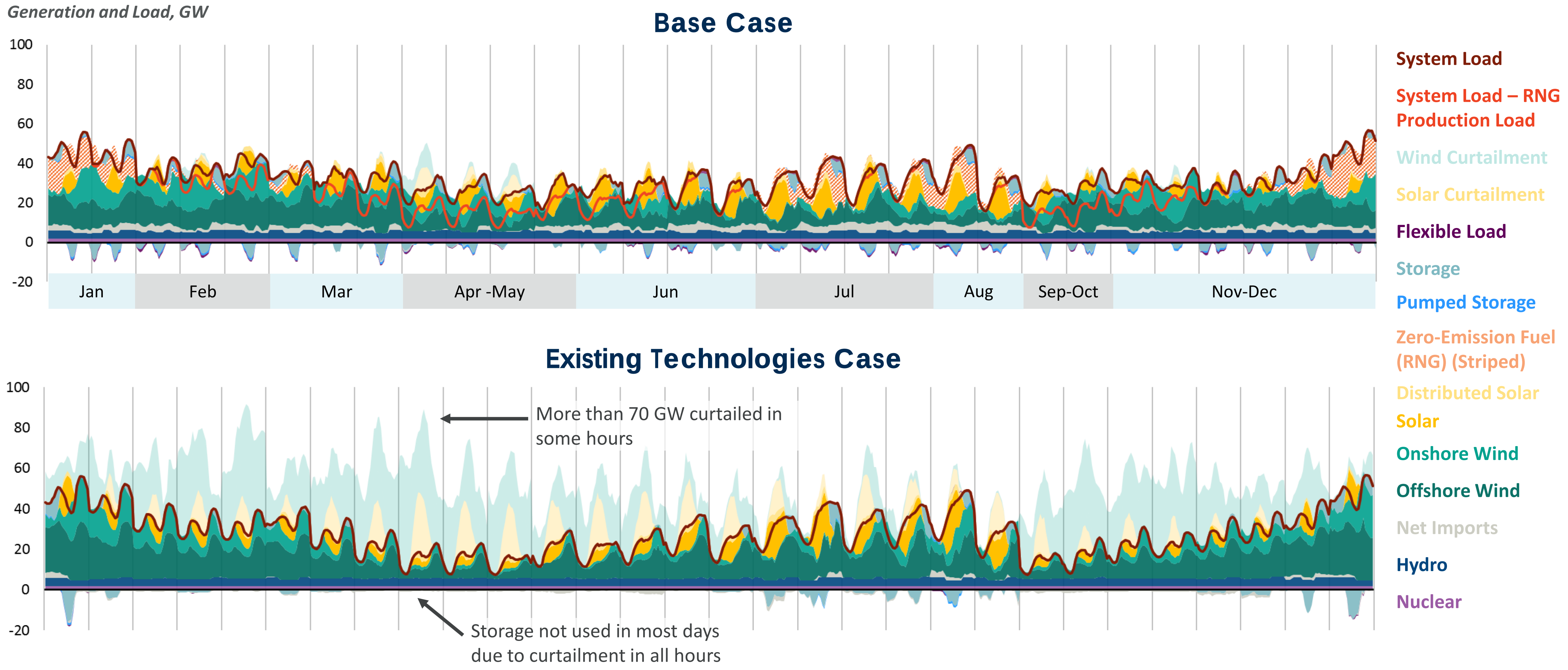
- **Changes from Base Case:** Only existing technologies (wind, solar, storage) can be built
  - RNG production and consumption disallowed
  - All fossil plants must retire by 2040
  - Capacity value of wind, solar, and storage heavily derated at high deployment levels
- **High-Level Insights**
  - **Large overbuild** of renewables (+80 GW) and storage (+27 GW) to meet load in all hours
  - **Large curtailments:** 221 TWh (50% of generation)
  - **Retirement of gas plants** by 2040 causes UCAP reserve margins to fall below planning reserve margin
  - **Load falls** by 50 TWh without in-state RNG production

Existing Technologies Case: 2040 Hourly Operations

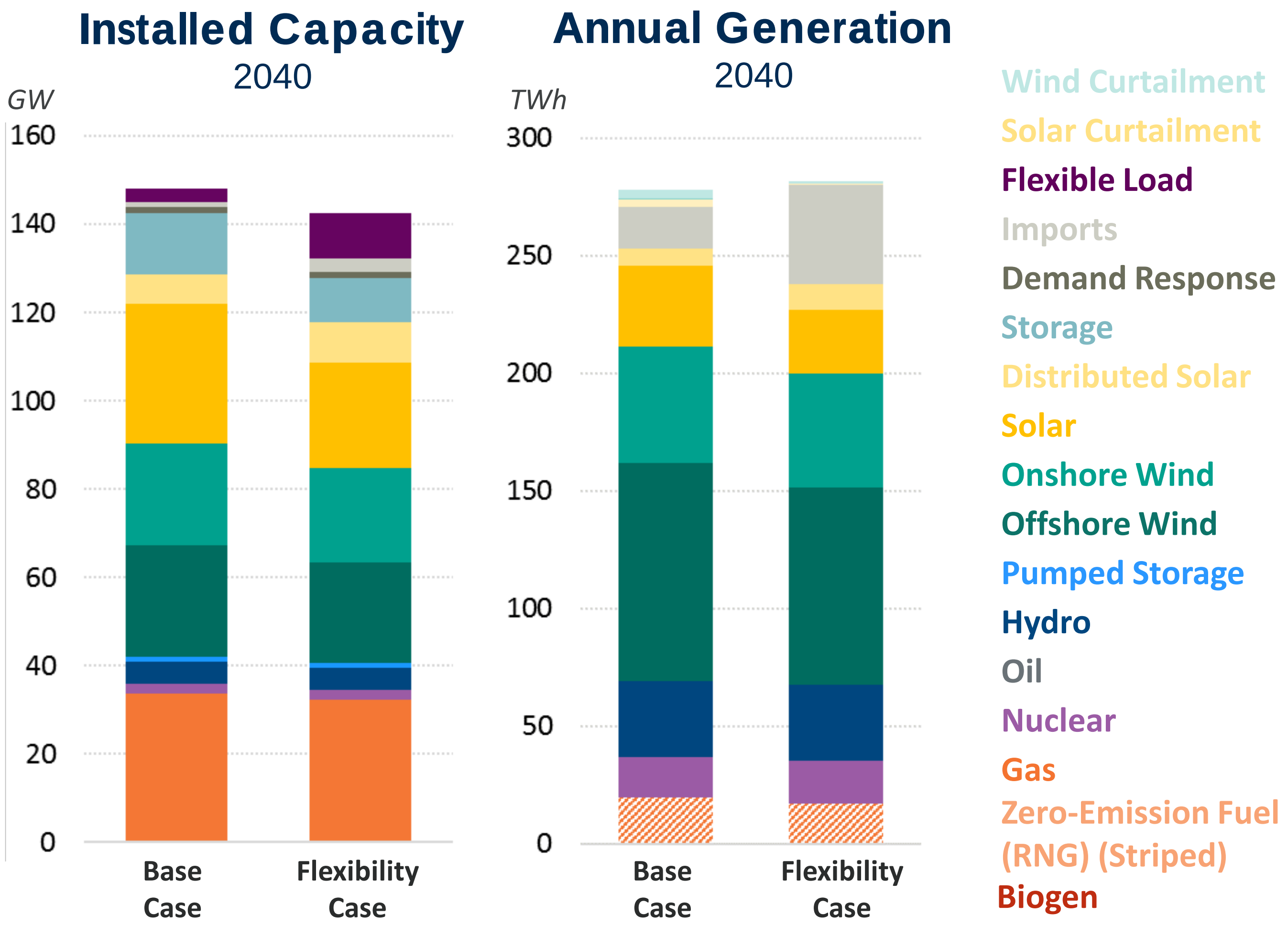
- **Curtailments** occur in all seasons due to extreme overbuild
- **Storage use** decreases relative to the Base Case, particularly in Fall and Spring when there is oversupply in almost all hours
- **Imports decrease** due to oversupply conditions



Existing Technologies Case: 2040 Hourly Operations



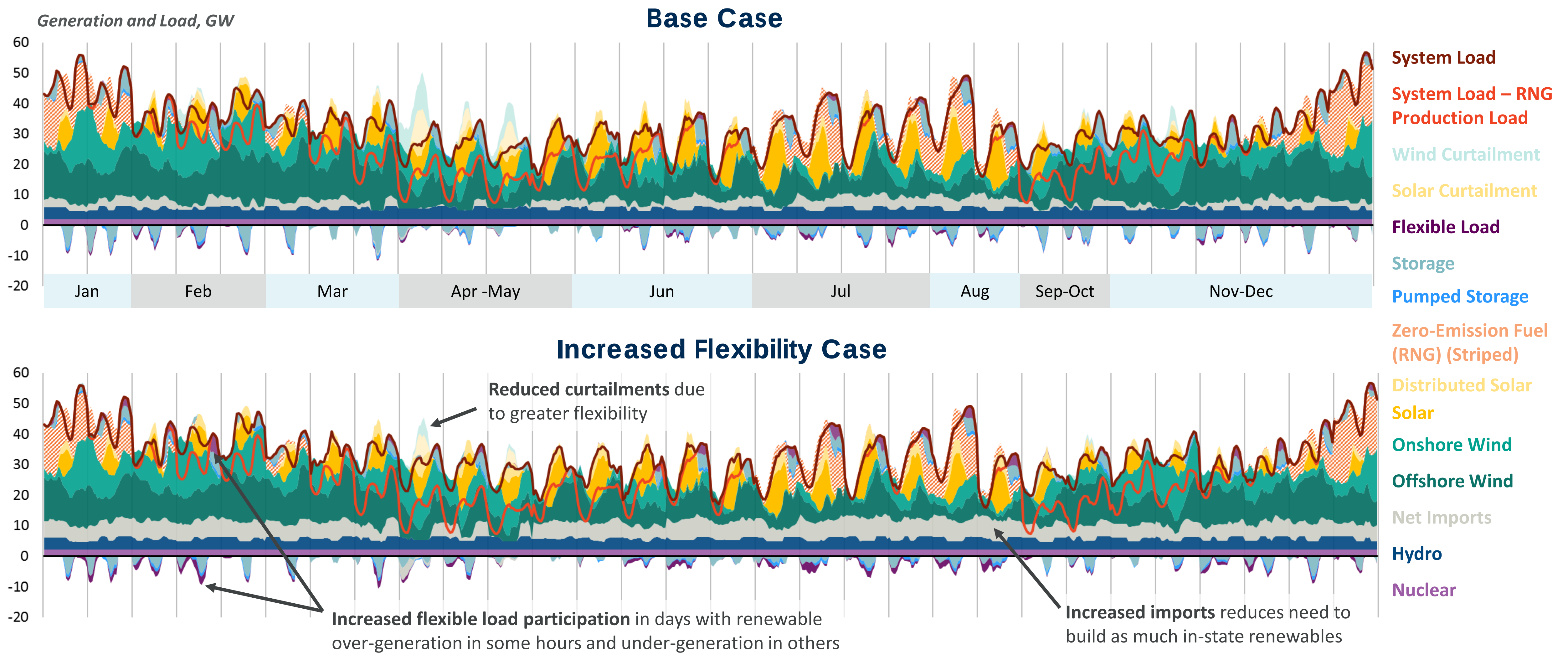
Increased Flexibility Case



- **Changes from Base Case:** More flexibility from expanded HQ interties and more flexible load (does not include costs of building transmission or flex load)
  - +1,300 MW intertie between HQ and Zone J
  - +1,500 MW import capacity (+1,000 MW export capacity) between HQ and Zone D, doubling existing capacity
  - +1,800 MW load shift potential from flexible EVs
  - +5,300 MW load shift potential from flexible HVAC
- **High-Level Insights**
  - **Increased HQ imports** (+24 TWh net) help satisfy RPS mandate, reducing in-state renewable capacity by 9 GW
  - **Zero-emission fuel generation** largely unchanged, indicating more clean imports would be necessary to displace it
  - **Increased flexible load capacity** results in less storage capacity because both provide diurnal energy shifting

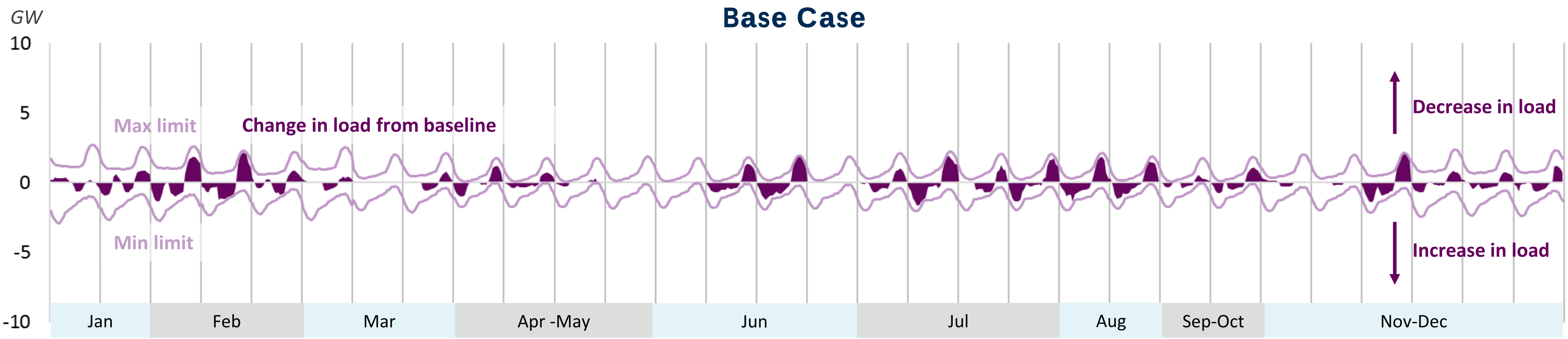
ALTERNATIVE SCENARIOS

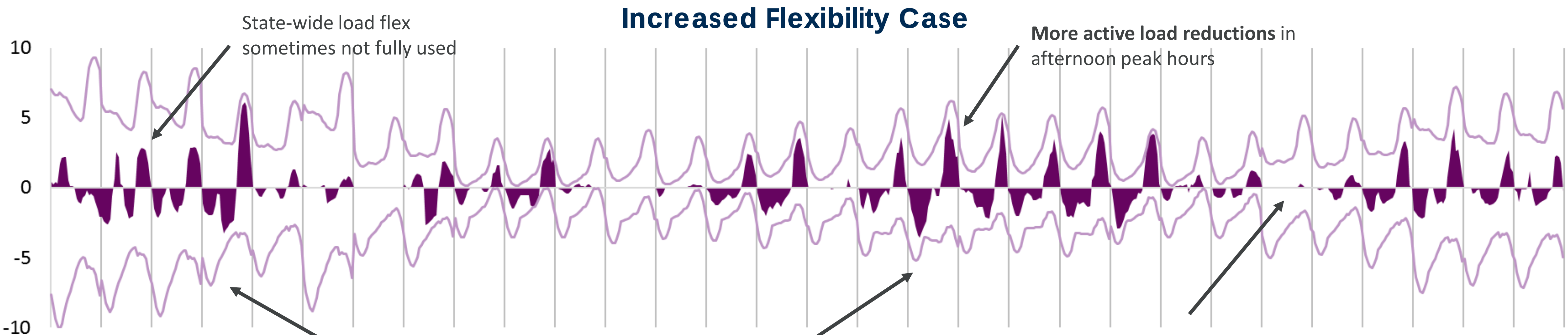
Increased Flexibility Case: 2040 Hourly Operations



ALTERNATIVE SCENARIOS

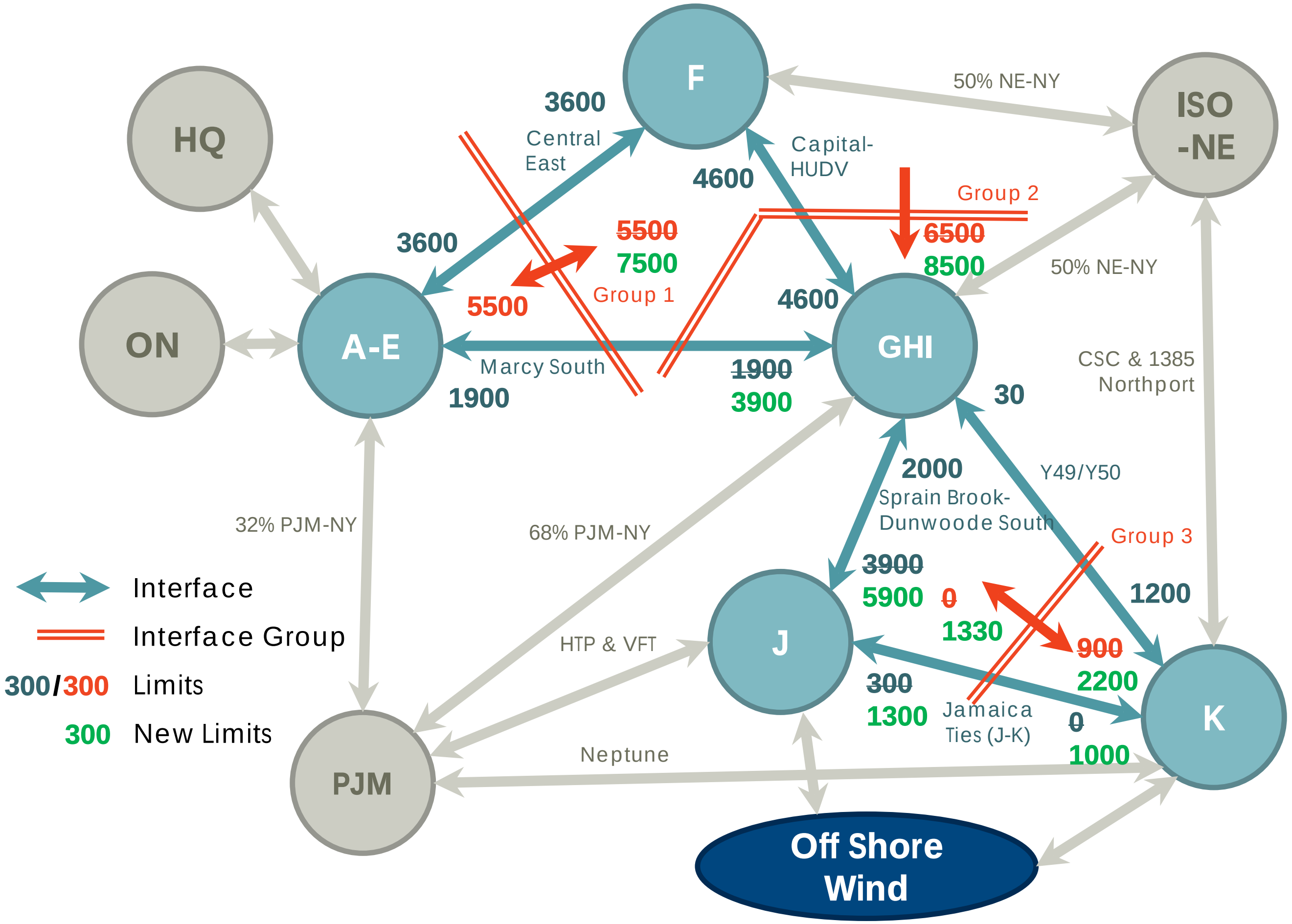
Increased Flexibility Case: 2040 Hourly Load Flex Operations



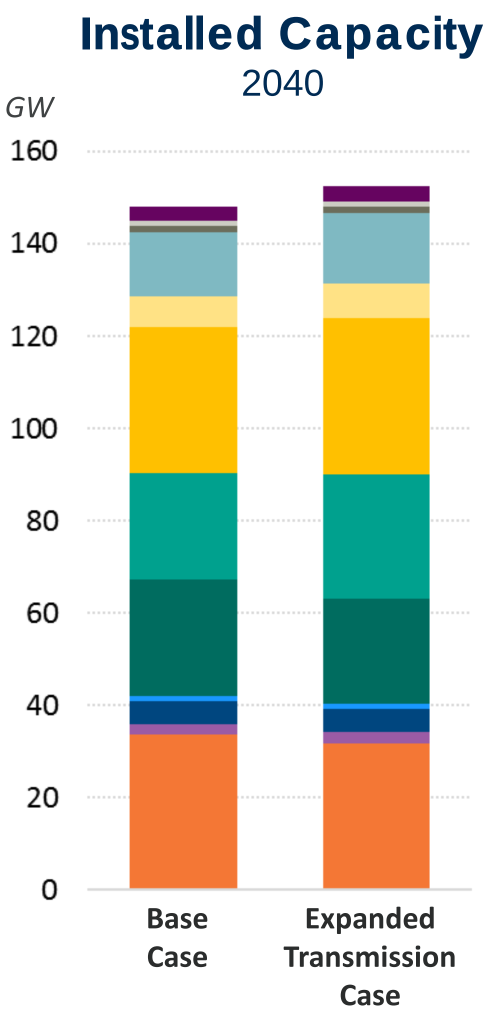


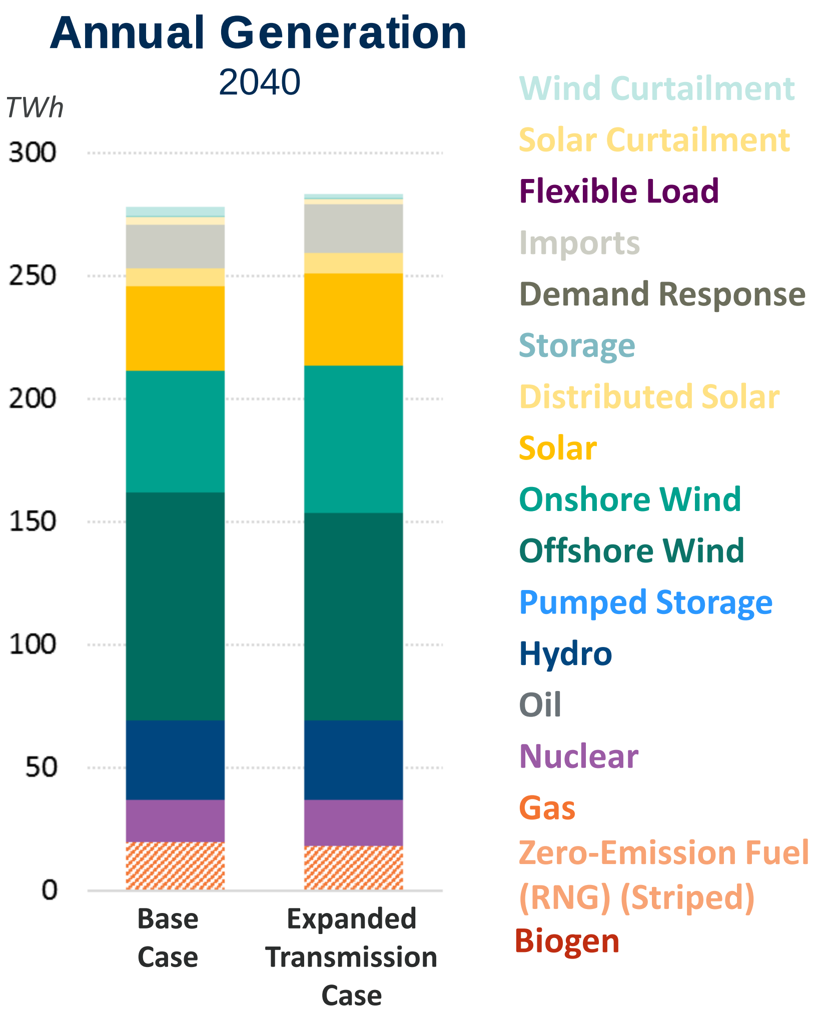
Expanded Transmission Case

- Expanded transmission along key corridors
  - +2,000 MW from A-E -> GHI
  - +2,000 MW from GHI -> J
  - +1,000 MW between J & K (bidirectional)



Expanded Transmission Case: 2040 High-Level Insights

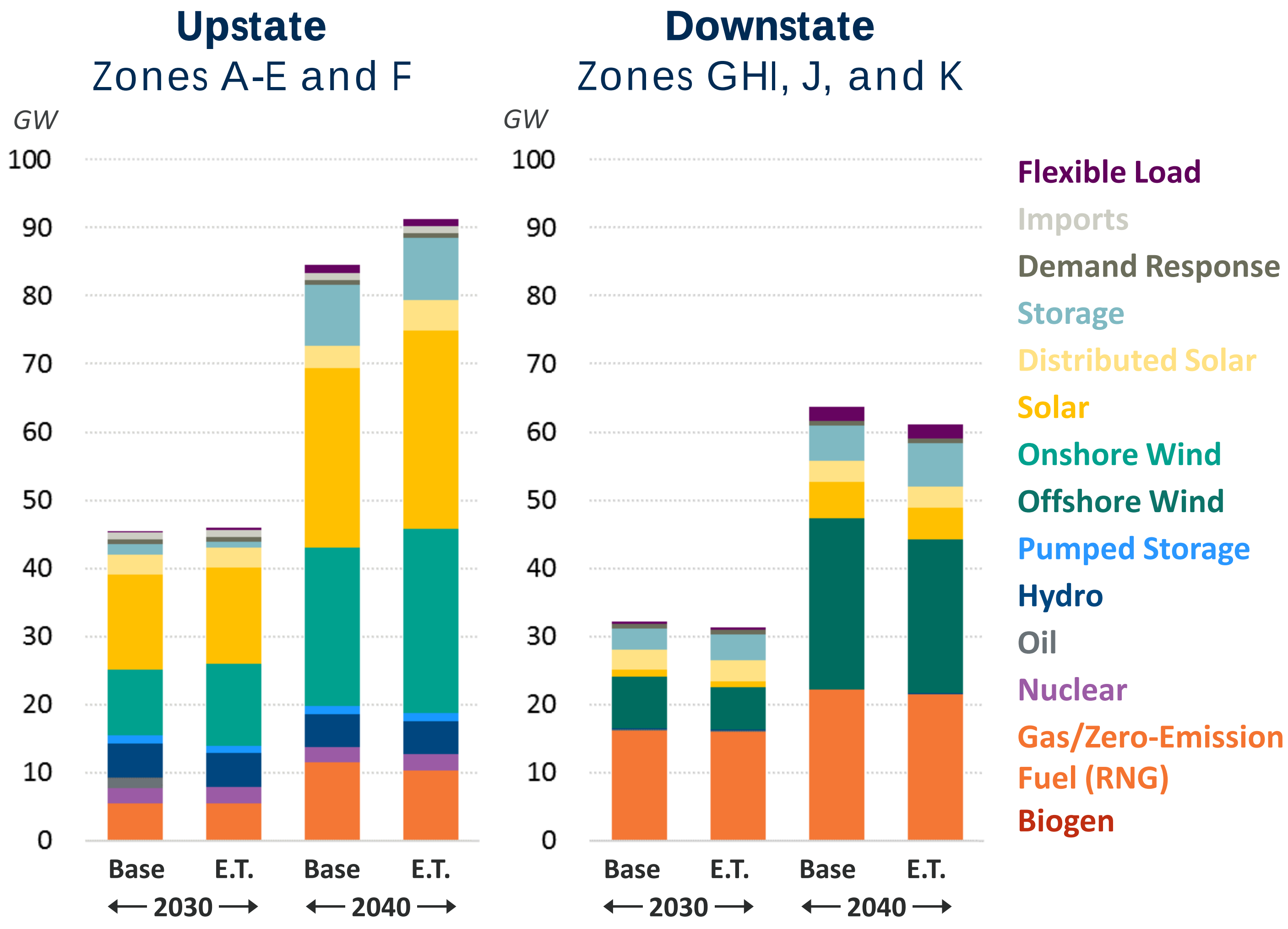




- Additional 7 TWh of Upstate generation transferred Downstate
- In general, less capacity is built Downstate and more Upstate (see next slide)
- **Offshore wind** capacity decreases (-2.4 GW), while **onshore wind** capacity increases (+3.7 GW)
- **Solar** capacity increases (+3.1 GW)
- **Gas** capacity decreases (-1.9 GW)
- **Zero-emission fuel generation** largely unchanged because of system's continued need for firm generation (or long-duration storage)

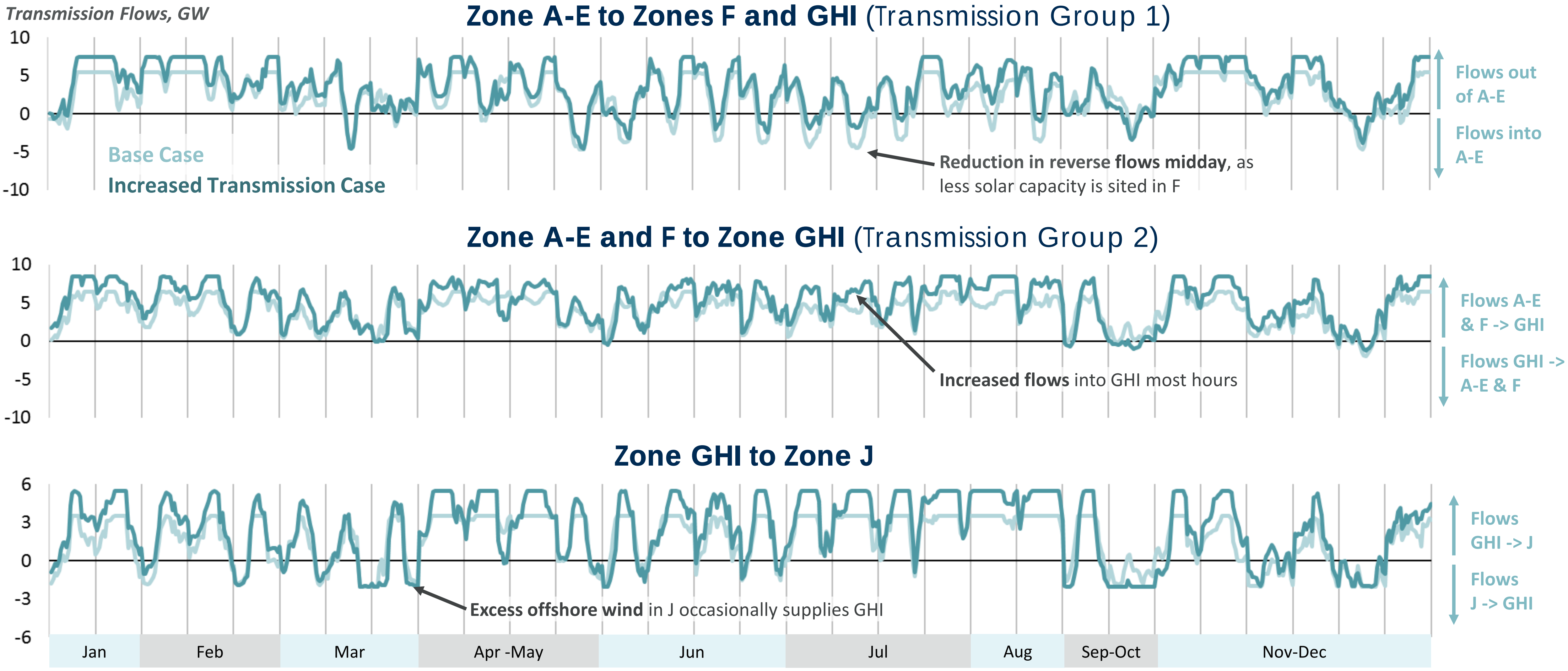
Expanded Transmission Case: Upstate and Downstate

- **Upstate capacity grows**, as increased transmission enables more capacity to be built in lower-cost areas
  - +3.7 GW upstate **onshore wind** by 2040 (2.3 GW by 2030)
  - +3.9 GW **upstate solar** by 2040
  - +3.5 GW upstate **RNG production** capacity by 2040
  - +200 MW **nuclear** capacity retained
  - Most new builds are located in Zone A-E due to expanded A-E -> J transmission
- **Downstate capacity falls**, and transmission flows from Upstate increase
  - 2.4 GW less **offshore wind** by 2040 (1.3 GW less by 2030)
  - 0.8 GW less **solar** downstate by 2040
  - 1.3 GW less **RNG production** capacity by 2040



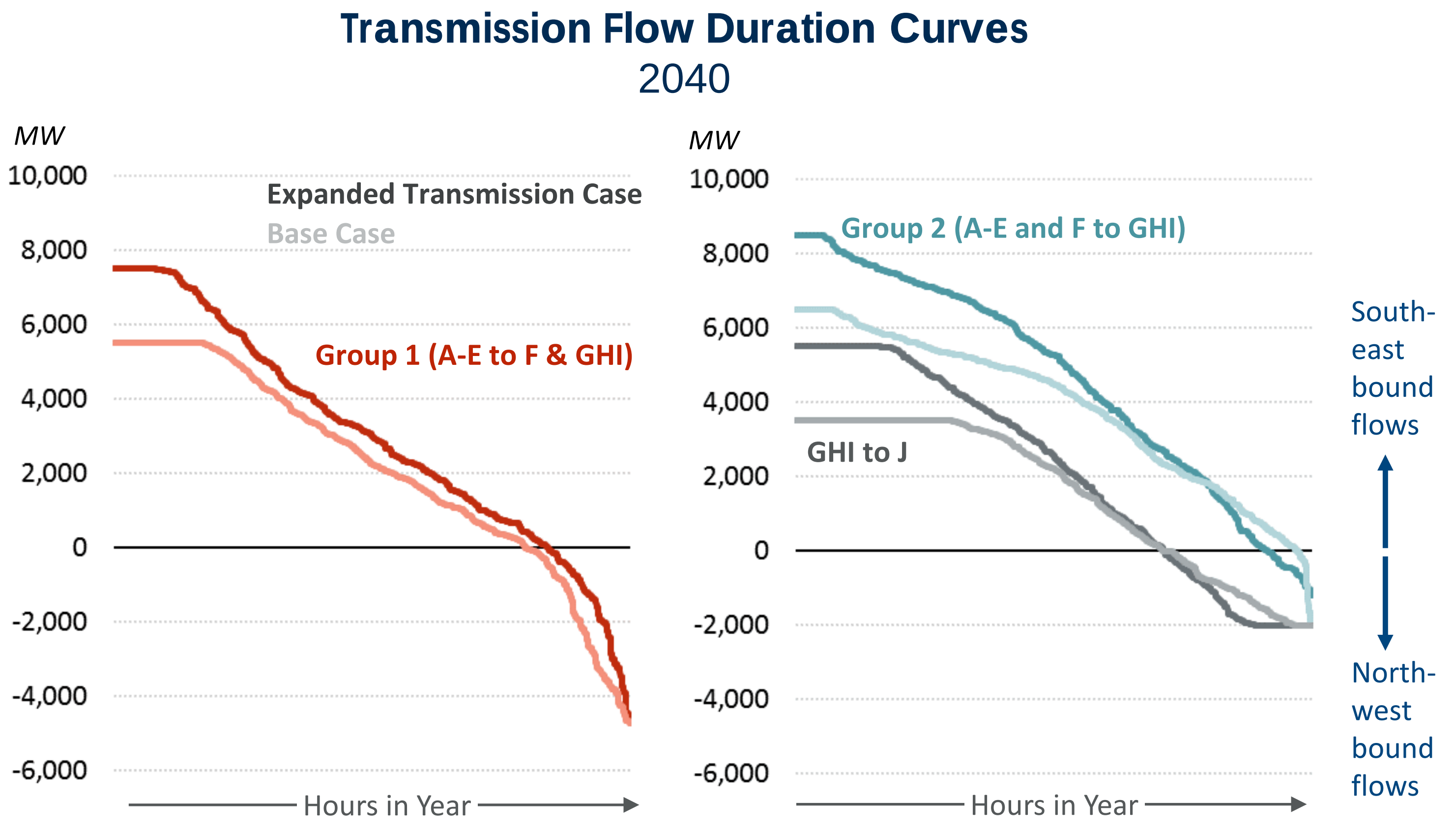
Expanded Transmission Case: 2040 Hourly Operations

Expanded Transmission Case: Hourly Flows in 2040



Expanded Transmission Case: Flows in 2040

- **South- and east-bound flows** generally higher, and hit max limits less often
  - **Annual energy transferred downstate** (across Group 2 interface) increases from 34 TWh to 41 TWh
  - **GHI-> J bottleneck partially relieved**, with flows reaching max limit for 16% of hours compared to 31% in Base Case



Alternative Scenarios: High-level Insights

1.	**Existing Technologies (Only)**	• **Large overbuild** of renewables (+80 GW) and storage (+27 GW) to meet load in all hours; likely exceeds technical limits • **Large curtailments**: 221 TWh annually (50% of renewable generation) • **Retirement of gas-fired plants** in 2040 due to zero-emission mandate causes UCAP reserve margins to fall below planning reserve margin levels
2.	**Increased Flexibility**	• **Increased HQ imports** help satisfy RPS mandate, reducing in-state renewable capacity • **Zero-emission fuel generation** largely unchanged, indicating more clean imports would be necessary to displace it • **Increased flexible load capacity** results in less storage capacity because both provide diurnal energy shifting
3.	**Expanded Transmission**	• **New resource builds shift** from Downstate to Upstate • **Offshore wind capacity decreases** (-2.4 GW), replaced by onshore wind (+3.7 GW) and solar (+2.3 GW) • **Zero-emission fuel** continues to be used, reflecting the system’s continued need for firm generation (or long-duration storage)

Areas for Further Inquiry

Consideration of Technical Resource Potential

- Three studies evaluate how much wind and solar can be built in New York without consideration of cost
  - DPS: "2030 Resource Potential" accounts for resource availability, transmission limitations, and max annual build limits
  - NYESRDA: "2030 Projected Bounded Technical Potential Electricity Generation" accounts for factors such as land use and manufacturing infrastructure
  - NREL: "Technical Potential" accounts for resource availability, land-use constraints, and transmission limitations
- Comparison of modeled builds to limits:
  - Onshore wind: 2030 builds in line with limits, 2040 builds above limits from all 3 studies
  - Offshore wind: 2030 builds in line with limits, 2040 builds exceed limits from 2 of 3 studies
  - Solar: Large variation in technical potential limits across studies

Modeled Renewable Builds vs Feasible Builds

	Base Case Results		Maximum Feasible Builds by 2030		Technical Potential
	2030	2040	DPS	NYSERDA	NREL
Onshore Wind	9.7 GW	23.3 GW	10 GW	8 GW	26 GW
Offshore Wind	7.6 GW	25.1 GW	10 GW	7 GW	146 GW
Solar	21.1 GW	38.1 GW	7 GW	48 GW	984 GW

Sources:

NYSERDA (2014). Energy Efficiency and Renewable Energy Potential Study of New York State, Provides bounds on max annual energy production (GWh), which we convert to MW assuming capacity factors of 13%, 26%, and 42% for solar, onshore wind, and offshore wind respectively. DPS (2016). Clean Energy Standard White Paper – Cost Study. Quantities estimated as maximum value of 2030 supply curves; NREL (2012). U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis.

Potential Areas for Further Study

- Additional Analyses and Scenarios
  - What is a robust approach to estimate the declining capacity value of wind, solar, and storage?
  - What is the role of technologies not considered in this study, e.g. new storage techs, small modular nuclear, and carbon capture?
  - What is New York's renewable resource potential, including transmission to offshore wind? (see previous slide)
  - Can interties provide flexibility as the broader region decarbonizes?
  - How do results change under different load forecasts?
- Implications for Market Design and Reliability
  - What operational challenges may emerge and how can ops be improved?
  - What ancillary service enhancements would be most valuable, e.g. new products or different quantities?
  - How does price formation evolve?
  - Are adjustments needed to the ICAP market?
- Questions for Policy Design
  - What types of load flexibility are most valuable, and how can it be incentivized?
  - What types of new technologies are most important to support with research and development?

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Appendix: Detailed Results

High Electrification Case

Capacity by Zone (GW) 2020

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.2	0.0	0.0	0.0	0.1	**0.4**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	4.4	0.5	0.1	0.0	0.0	**5.0**
Kerosene	0.0	0.0	0.0	0.1	0.1	**0.2**
Gas CC	2.3	3.0	1.6	3.3	0.7	**11.0**
Gas CT	0.0	0.0	0.1	2.1	0.8	**3.0**
Gas ST	0.1	0.0	2.8	3.8	2.3	**9.1**
Nuclear	3.3	0.0	1.0	0.0	0.0	**4.4**
Oil CT	0.0	0.0	0.0	0.3	1.2	**1.5**
Oil ST	1.6	0.0	0.0	0.0	0.0	**1.6**
Pumped Storage	0.0	1.2	0.0	0.0	0.0	**1.2**
Solar	0.0	0.0	0.0	0.0	0.1	**0.1**
Solar BTM	0.3	0.8	0.3	0.3	0.5	**2.1**
Storage 2-Hour	0.0	0.0	0.0	0.0	0.2	**0.2**
Storage 4-Hour	0.0	0.0	0.0	0.0	0.0	**0.0**
Wind Offshore	0.0	0.0	0.0	0.0	0.0	**0.0**
Wind Onshore	1.7	0.0	0.0	0.0	0.0	**1.7**
Capacity Imports	1.1	0.0	0.0	0.0	0.0	**1.1**
Demand Response	0.6	0.1	0.1	0.5	0.0	**1.3**
Flexible Load	0.0	0.0	0.0	0.0	0.0	**0.0**
RNG Production	0.0	0.0	0.0	0.0	0.0	**0.0**
Total	**15.9**	**5.6**	**6.0**	**10.4**	**6.0**	**43.9**

Capacity by Zone (GW) 2024

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.0	0.0	0.0	0.0	0.1	**0.1**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	4.4	0.5	0.1	0.0	0.0	**5.0**
Kerosene	0.0	0.0	0.0	0.1	0.1	**0.2**
Gas CC	2.3	3.0	1.6	3.3	0.7	**11.0**
Gas CT	0.0	0.0	0.1	2.1	0.8	**3.0**
Gas ST	0.1	0.0	2.8	3.5	2.3	**8.7**
Nuclear	3.3	0.0	0.0	0.0	0.0	**3.3**
Oil CT	0.0	0.0	0.0	0.3	1.2	**1.5**
Oil ST	1.6	0.0	0.0	0.0	0.0	**1.6**
Pumped Storage	0.0	1.2	0.0	0.0	0.0	**1.2**
Solar	0.0	0.0	0.0	0.0	0.1	**0.1**
Solar BTM	0.4	2.5	0.3	0.8	0.5	**4.5**
Storage 2-Hour	0.0	0.0	0.0	0.4	0.8	**1.2**
Storage 4-Hour	0.0	0.0	0.0	0.0	0.0	**0.0**
Wind Offshore	0.0	0.0	0.0	0.2	0.4	**0.6**
Wind Onshore	1.7	0.0	0.0	0.0	0.0	**1.7**
Capacity Imports	1.1	0.0	0.0	0.0	0.0	**1.1**
Demand Response	0.6	0.1	0.1	0.5	0.0	**1.3**
Flexible Load	0.0	0.0	0.0	0.0	0.0	**0.0**
RNG Production	0.0	0.0	0.0	0.0	0.0	**0.0**
Total	**15.7**	**7.3**	**5.0**	**11.1**	**7.1**	**46.2**

APPENDIX: DETAILED RESULTS

High Electrification Case

Capacity by Zone (GW) 2030

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.0	0.0	0.0	0.0	0.1	**0.1**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	4.4	0.5	0.1	0.0	0.0	**5.0**
Kerosene	0.0	0.0	0.0	0.0	0.1	**0.1**
Gas CC	2.3	3.0	1.6	3.3	0.7	**11.0**
Gas CT	0.0	0.0	0.1	1.0	0.8	**1.9**
Gas ST	0.1	0.0	2.8	3.5	2.3	**8.7**
Nuclear	2.2	0.0	0.0	0.0	0.0	**2.2**
Oil CT	0.0	0.0	0.0	0.0	0.2	**0.2**
Oil ST	1.6	0.0	0.0	0.0	0.0	**1.6**
Pumped Storage	0.0	1.2	0.0	0.0	0.0	**1.2**
Solar	0.0	14.1	0.9	0.0	0.1	**15.1**
Solar BTM	0.4	2.5	0.3	0.8	2.0	**6.0**
Storage 2-Hour	0.8	0.6	0.0	1.4	1.4	**4.3**
Storage 4-Hour	0.0	0.0	0.0	0.2	0.1	**0.3**
Wind Offshore	0.0	0.0	0.0	5.1	2.5	**7.6**
Wind Onshore	9.7	0.0	0.0	0.0	0.0	**9.7**
Capacity Imports	1.1	0.0	0.0	0.0	0.0	**1.1**
Demand Response	0.6	0.1	0.1	0.5	0.0	**1.3**
Flexible Load	0.2	0.0	0.1	0.2	0.1	**0.6**
RNG Production	0.0	0.0	0.0	0.0	0.0	**0.0**
Total	**23.5**	**22.0**	**6.0**	**15.9**	**10.4**	**77.8**

Capacity by Zone (GW) 2040

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.0	0.0	0.0	0.0	0.0	**0.0**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	4.4	0.5	0.1	0.0	0.0	**5.0**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	2.3	3.0	2.6	3.3	1.2	**12.5**
Gas CT	0.0	6.0	0.2	3.4	2.8	**12.5**
Gas ST	0.1	0.0	2.8	3.5	2.3	**8.7**
Nuclear	2.2	0.0	0.0	0.0	0.0	**2.2**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Pumped Storage	0.0	1.2	0.0	0.0	0.0	**1.2**
Solar	4.9	21.4	5.3	0.0	0.1	**31.7**
Solar BTM	0.5	2.8	0.3	0.8	2.0	**6.4**
Storage 2-Hour	4.1	1.2	0.1	1.4	1.4	**8.2**
Storage 4-Hour	1.8	1.8	0.2	1.2	0.9	**5.9**
Wind Offshore	0.0	0.0	0.0	17.9	7.2	**25.1**
Wind Onshore	23.3	0.0	0.0	0.0	0.0	**23.3**
Capacity Imports	1.1	0.0	0.0	0.0	0.0	**1.1**
Demand Response	0.6	0.1	0.1	0.5	0.0	**1.3**
Flexible Load	0.9	0.2	0.4	0.9	0.9	**3.2**
RNG Production	5.0	0.0	0.0	4.9	1.7	**11.6**
Total	**51.2**	**38.2**	**12.0**	**37.8**	**20.5**	**159.8**

High Electrification Case

Energy by Zone (TWh) 2020

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.6	0.1	0.0	0.0	0.5	**1.2**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	29.4	2.3	0.5	0.0	0.0	**32.3**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	13.2	8.1	8.4	18.6	4.1	**52.4**
Gas CT	0.1	0.0	0.0	1.1	1.1	**2.3**
Gas ST	0.3	0.0	0.9	1.6	1.2	**4.0**
Nuclear	26.7	0.0	8.3	0.0	0.0	**34.9**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Solar	0.0	0.0	0.0	0.0	0.1	**0.1**
Solar BTM	0.4	0.9	0.3	0.4	0.5	**2.5**
Wind Offshore	0.0	0.0	0.0	0.0	0.0	**0.0**
Wind Onshore	4.0	0.0	0.0	0.0	0.0	**4.0**
Imports	17.2	0.2	2.6	3.7	6.5	**30.2**
Exports	-0.3	-2.7	-2.9	-0.2	-0.2	**-6.3**
RNG Production Load	0.0	0.0	0.0	0.0	0.0	**0.0**
All Other Load	-53.4	-12.1	-18.5	-52.4	-21.2	**-157.6**
Total	**38.1**	**-3.3**	**-0.3**	**-27.2**	**-7.4**	0.0

Energy by Zone (TWh) 2024

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.0	0.0	0.0	0.0	0.5	**0.5**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	29.4	2.3	0.5	0.0	0.0	**32.3**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	15.4	7.5	8.9	19.0	3.3	**54.0**
Gas CT	0.1	0.0	0.0	0.8	0.8	**1.7**
Gas ST	0.2	0.0	0.6	1.1	0.7	**2.7**
Nuclear	26.7	0.0	0.0	0.0	0.0	**26.7**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Solar	0.0	0.0	0.0	0.0	0.1	**0.1**
Solar BTM	0.5	2.9	0.3	0.9	0.6	**5.3**
Wind Offshore	0.0	0.0	0.0	0.8	1.4	**2.2**
Wind Onshore	4.0	0.0	0.0	0.0	0.0	**4.0**
Imports	17.2	0.2	2.6	3.7	6.5	**30.2**
Exports	-1.6	-2.7	-2.9	-0.2	-0.2	**-7.6**
RNG Production Load	0.0	0.0	0.0	0.0	0.0	**0.0**
All Other Load	-51.3	-11.6	-18.0	-50.4	-20.8	**-152.0**
Total	**40.7**	**-1.4**	**-7.9**	**-24.2**	**-7.2**	0.0

High Electrification Case

Energy by Zone (TWh) 2030

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	**Total**
BioGen	0.0	0.0	0.0	0.0	0.3	**0.3**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	29.4	2.3	0.5	0.0	0.0	**32.3**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	7.0	2.7	4.3	10.9	1.5	**26.5**
Gas CT	0.0	0.0	0.0	0.2	0.4	**0.6**
Gas ST	0.1	0.0	0.2	0.6	0.2	**1.1**
Nuclear	17.2	0.0	0.0	0.0	0.0	**17.2**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Solar	0.0	15.1	1.0	0.0	0.1	**16.2**
Solar BTM	0.5	2.9	0.3	0.9	2.4	**7.0**
Wind Offshore	0.0	0.0	0.0	18.5	9.1	**27.5**
Wind Onshore	19.9	0.0	0.0	0.0	0.0	**19.9**
Imports	12.4	0.1	2.2	2.8	3.8	**21.2**
Exports	-1.6	-2.7	-2.9	-0.2	-0.2	**-7.6**
RNG Production Load	0.0	0.0	0.0	0.0	0.0	**0.0**
All Other Load	-54.0	-12.2	-19.4	-53.6	-23.0	**-162.2**
Total	**30.9**	**8.3**	**-13.8**	**-20.0**	**-5.5**	0.0

Energy by Zone (TWh) 2040

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	**Total**
BioGen	0.0	0.0	0.0	0.0	0.0	**0.0**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	29.4	2.3	0.5	0.0	0.0	**32.3**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	0.8	3.8	5.5	4.4	2.3	**16.9**
Gas CT	0.0	0.8	0.0	0.8	1.0	**2.6**
Gas ST	0.0	0.0	0.1	0.0	0.0	**0.1**
Nuclear	17.2	0.0	0.0	0.0	0.0	**17.2**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Solar	5.1	23.1	5.9	0.0	0.1	**34.2**
Solar BTM	0.6	3.3	0.3	0.9	2.4	**7.5**
Wind Offshore	0.0	0.0	0.0	66.5	26.2	**92.7**
Wind Onshore	49.5	0.0	0.0	0.0	0.0	**49.5**
Imports	13.3	0.2	2.5	3.4	5.7	**25.1**
Exports	-1.5	-2.7	-2.9	-0.2	-0.2	**-7.5**
RNG Production Load	-24.1	0.0	0.0	-18.5	-7.2	**-49.8**
All Other Load	-71.4	-16.0	-26.5	-72.1	-34.8	**-220.8**
Total	**19.0**	**14.8**	**-14.5**	**-14.8**	**-4.5**	0.0

Reference Load Case

Capacity by Zone (GW) 2020

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.2	0.0	0.0	0.0	0.1	**0.4**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	4.4	0.5	0.1	0.0	0.0	**5.0**
Kerosene	0.0	0.0	0.0	0.1	0.1	**0.2**
Gas CC	2.3	3.0	1.6	3.3	0.7	**11.0**
Gas CT	0.0	0.0	0.1	2.1	1.0	**3.2**
Gas ST	0.1	0.0	2.8	3.8	2.3	**9.1**
Nuclear	3.3	0.0	1.0	0.0	0.0	**4.4**
Oil CT	0.0	0.0	0.0	0.3	1.2	**1.5**
Oil ST	1.6	0.0	0.0	0.0	0.0	**1.6**
Pumped Storage	0.0	1.2	0.0	0.0	0.0	**1.2**
Solar	0.0	0.0	0.0	0.0	0.1	**0.1**
Solar BTM	0.3	0.8	0.3	0.3	0.5	**2.1**
Storage 2-Hour	0.0	0.0	0.0	0.0	0.2	**0.2**
Storage 4-Hour	0.0	0.0	0.0	0.0	0.0	**0.0**
Wind Offshore	0.0	0.0	0.0	0.0	0.0	**0.0**
Wind Onshore	1.7	0.0	0.0	0.0	0.0	**1.7**
Capacity Imports	1.1	0.0	0.0	0.0	0.0	**1.1**
Demand Response	0.6	0.1	0.1	0.5	0.0	**1.3**
Flexible Load	0.0	0.0	0.0	0.0	0.0	**0.0**
RNG Production	0.0	0.0	0.0	0.0	0.0	**0.0**
Total	**15.8**	**5.6**	**6.0**	**10.4**	**6.2**	**44.0**

Capacity by Zone (GW) 2024

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.2	0.0	0.0	0.0	0.1	**0.4**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	4.4	0.5	0.1	0.0	0.0	**5.0**
Kerosene	0.0	0.0	0.0	0.1	0.1	**0.2**
Gas CC	2.3	3.0	1.6	3.3	0.7	**11.0**
Gas CT	0.0	0.0	0.1	2.1	1.0	**3.2**
Gas ST	0.1	0.0	2.8	3.8	2.3	**9.1**
Nuclear	3.3	0.0	0.0	0.0	0.0	**3.3**
Oil CT	0.0	0.0	0.0	0.3	1.2	**1.5**
Oil ST	1.6	0.0	0.0	0.0	0.0	**1.6**
Pumped Storage	0.0	1.2	0.0	0.0	0.0	**1.2**
Solar	0.0	0.0	0.0	0.0	0.1	**0.1**
Solar BTM	0.4	2.5	0.3	0.8	0.5	**4.5**
Storage 2-Hour	0.0	0.0	0.0	0.5	0.7	**1.2**
Storage 4-Hour	0.0	0.0	0.0	0.0	0.0	**0.0**
Wind Offshore	0.0	0.0	0.0	0.1	0.5	**0.6**
Wind Onshore	1.7	0.0	0.0	0.0	0.0	**1.7**
Capacity Imports	1.1	0.0	0.0	0.0	0.0	**1.1**
Demand Response	0.6	0.1	0.1	0.5	0.0	**1.3**
Flexible Load	0.0	0.0	0.0	0.0	0.0	**0.0**
RNG Production	0.0	0.0	0.0	0.0	0.0	**0.0**
Total	**15.9**	**7.3**	**5.0**	**11.4**	**7.3**	**46.9**

Reference Load Case

Capacity by Zone (GW) 2030

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.0	0.0	0.0	0.0	0.0	**0.0**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	4.4	0.5	0.1	0.0	0.0	**5.0**
Kerosene	0.0	0.0	0.0	0.0	0.1	**0.1**
Gas CC	2.3	3.0	1.6	3.3	0.7	**11.0**
Gas CT	0.0	0.0	0.1	1.0	1.0	**2.2**
Gas ST	0.0	0.0	2.8	2.8	2.3	**8.0**
Nuclear	2.1	0.0	0.0	0.0	0.0	**2.1**
Oil CT	0.0	0.0	0.0	0.0	0.2	**0.2**
Oil ST	1.6	0.0	0.0	0.0	0.0	**1.6**
Pumped Storage	0.0	1.2	0.0	0.0	0.0	**1.2**
Solar	1.9	12.4	0.7	0.0	0.1	**15.1**
Solar BTM	0.5	2.5	0.3	0.8	2.0	**6.0**
Storage 2-Hour	0.5	0.0	0.0	1.8	1.7	**4.0**
Storage 4-Hour	0.0	0.0	0.0	0.0	0.0	**0.0**
Wind Offshore	0.0	0.0	0.0	5.3	1.8	**7.1**
Wind Onshore	7.1	0.0	0.0	0.0	0.0	**7.1**
Capacity Imports	1.1	0.0	0.0	0.0	0.0	**1.1**
Demand Response	0.6	0.1	0.1	0.5	0.0	**1.3**
Flexible Load	0.1	0.0	0.0	0.1	0.1	**0.4**
RNG Production	0.0	0.0	0.0	0.0	0.0	**0.0**
Total	**22.2**	**19.7**	**5.8**	**15.6**	**10.1**	**73.3**

Capacity by Zone (GW) 2040

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.0	0.0	0.0	0.0	0.0	**0.0**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	4.4	0.5	0.1	0.0	0.0	**5.0**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	2.3	3.0	1.6	3.3	1.1	**11.4**
Gas CT	0.0	0.0	0.1	1.0	1.6	**2.7**
Gas ST	0.0	0.0	2.1	2.1	2.3	**6.5**
Nuclear	2.1	0.0	0.0	0.0	0.0	**2.1**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Pumped Storage	0.0	1.2	0.0	0.0	0.0	**1.2**
Solar	4.8	20.8	4.4	0.0	0.1	**30.0**
Solar BTM	0.5	2.6	0.3	0.8	2.0	**6.1**
Storage 2-Hour	1.5	1.6	0.1	1.8	1.7	**6.7**
Storage 4-Hour	0.5	1.6	0.8	0.9	0.2	**4.0**
Wind Offshore	0.0	0.0	0.0	9.2	4.6	**13.8**
Wind Onshore	9.8	0.0	0.0	0.0	0.0	**9.8**
Capacity Imports	1.1	0.0	0.0	0.0	0.0	**1.1**
Demand Response	0.6	0.1	0.1	0.5	0.0	**1.3**
Flexible Load	0.5	0.1	0.2	0.4	0.6	**1.9**
RNG Production	5.0	0.0	0.0	0.4	1.5	**6.9**
Total	**33.0**	**31.6**	**9.8**	**20.4**	**15.8**	**110.5**

Reference Load Case

Energy by Zone (TWh) 2020

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.7	0.1	0.0	0.0	0.5	**1.2**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	29.4	2.3	0.5	0.0	0.0	**32.3**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	14.5	7.8	8.3	18.7	4.2	**53.5**
Gas CT	0.1	0.0	0.0	0.9	1.4	**2.4**
Gas ST	0.2	0.0	0.8	1.4	1.1	**3.5**
Nuclear	26.7	0.0	8.3	0.0	0.0	**34.9**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Solar	0.0	0.0	0.0	0.0	0.1	**0.1**
Solar BTM	0.4	0.9	0.3	0.4	0.5	**2.5**
Wind Offshore	0.0	0.0	0.0	0.0	0.0	**0.0**
Wind Onshore	4.0	0.0	0.0	0.0	0.0	**4.0**
Imports	17.2	0.1	2.6	3.5	6.4	**29.9**
Exports	-0.3	-2.7	-2.9	-0.2	-0.2	**-6.2**
RNG Production Load	0.0	0.0	0.0	0.0	0.0	**0.0**
All Other Load	-53.6	-12.1	-18.5	-52.6	-21.3	**-158.0**
Total	**39.3**	**-3.6**	**-0.6**	**-27.9**	**-7.3**	0.0

Energy by Zone (TWh) 2024

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.8	0.1	0.1	0.0	0.5	**1.4**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	29.4	2.3	0.5	0.0	0.0	**32.3**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	14.4	8.6	9.1	20.9	3.6	**56.5**
Gas CT	0.1	0.0	0.0	0.8	1.0	**2.0**
Gas ST	0.3	0.0	0.9	2.1	0.8	**4.0**
Nuclear	26.7	0.0	0.0	0.0	0.0	**26.7**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	0.1	0.0	0.0	0.0	0.0	**0.1**
Solar	0.0	0.0	0.0	0.0	0.1	**0.1**
Solar BTM	0.5	2.9	0.3	0.9	0.6	**5.3**
Wind Offshore	0.0	0.0	0.0	0.4	1.9	**2.2**
Wind Onshore	4.0	0.0	0.0	0.0	0.0	**4.0**
Imports	17.1	0.1	2.6	3.7	6.2	**29.8**
Exports	-1.6	-2.7	-2.9	-0.2	-0.2	**-7.5**
RNG Production Load	0.0	0.0	0.0	0.0	0.0	**0.0**
All Other Load	-52.9	-12.0	-18.5	-52.0	-21.4	**-156.8**
Total	**38.9**	**-0.6**	**-8.0**	**-23.3**	**-7.0**	0.0

Reference Load Case

Energy by Zone (TWh) 2030

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.0	0.0	0.0	0.0	0.0	**0.0**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	29.4	2.3	0.5	0.0	0.0	**32.3**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	7.1	2.0	3.9	9.4	1.4	**23.8**
Gas CT	0.0	0.0	0.0	0.2	0.8	**1.1**
Gas ST	0.0	0.0	0.3	0.8	0.5	**1.5**
Nuclear	16.7	0.0	0.0	0.0	0.0	**16.7**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Solar	2.2	14.2	0.8	0.0	0.1	**17.2**
Solar BTM	0.5	2.9	0.3	0.9	2.4	**7.0**
Wind Offshore	0.0	0.0	0.0	19.4	6.8	**26.2**
Wind Onshore	15.7	0.0	0.0	0.0	0.0	**15.7**
Imports	14.7	0.1	2.4	3.0	4.9	**25.1**
Exports	-1.6	-2.7	-2.9	-0.2	-0.2	**-7.6**
RNG Production Load	0.0	0.0	0.0	0.0	0.0	**0.0**
All Other Load	-53.1	-12.0	-19.1	-52.6	-22.4	**-159.2**
Total	**31.7**	**6.9**	**-13.7**	**-19.1**	**-5.7**	0.0

Energy by Zone (TWh) 2040

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.0	0.0	0.0	0.0	0.0	**0.0**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	29.4	2.3	0.5	0.0	0.0	**32.3**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	0.3	2.4	2.7	4.3	2.3	**12.0**
Gas CT	0.0	0.0	0.0	0.0	0.5	**0.5**
Gas ST	0.0	0.0	0.0	0.3	0.1	**0.4**
Nuclear	16.7	0.0	0.0	0.0	0.0	**16.7**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Solar	5.4	23.8	5.0	0.0	0.1	**34.3**
Solar BTM	0.5	3.1	0.3	0.9	2.4	**7.2**
Wind Offshore	0.0	0.0	0.0	33.9	17.0	**50.8**
Wind Onshore	22.1	0.0	0.0	0.0	0.0	**22.1**
Imports	15.6	0.1	2.4	3.2	5.6	**26.9**
Exports	-1.6	-2.7	-2.9	-0.2	-0.2	**-7.6**
RNG Production Load	-19.3	0.0	0.0	-1.5	-6.1	**-26.9**
All Other Load	-55.1	-12.5	-20.5	-54.5	-26.0	**-168.7**
Total	**14.1**	**16.5**	**-12.5**	**-13.6**	**-4.5**	0.0

Existing Technologies Case

Capacity by Zone (GW) 2020

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.2	0.0	0.0	0.0	0.1	**0.4**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	4.4	0.5	0.1	0.0	0.0	**5.0**
Kerosene	0.0	0.0	0.0	0.1	0.1	**0.2**
Gas CC	2.3	3.0	1.6	3.3	0.7	**11.0**
Gas CT	0.0	0.0	0.1	2.1	0.8	**3.0**
Gas ST	0.1	0.0	2.8	3.8	2.3	**9.1**
Nuclear	3.3	0.0	1.0	0.0	0.0	**4.4**
Oil CT	0.0	0.0	0.0	0.3	1.2	**1.5**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Pumped Storage	0.0	1.2	0.0	0.0	0.0	**1.2**
Solar	0.0	0.0	0.0	0.0	0.1	**0.1**
Solar BTM	0.3	0.3	0.3	0.8	0.5	**2.1**
Storage 2-Hour	0.0	0.0	0.0	0.0	0.2	**0.2**
Storage 4-Hour	0.0	0.0	0.0	0.0	0.0	**0.0**
Wind Offshore	0.0	0.0	0.0	0.0	0.0	**0.0**
Wind Onshore	1.7	0.0	0.0	0.0	0.0	**1.7**
Capacity Imports	1.1	0.0	0.0	0.0	0.0	**1.1**
Demand Response	0.6	0.1	0.1	0.5	0.0	**1.3**
Flexible Load	0.0	0.0	0.0	0.0	0.0	**0.0**
RNG Production	0.0	0.0	0.0	0.0	0.0	**0.0**
Total	**14.2**	**5.1**	**6.0**	**10.9**	**6.0**	**42.3**

Capacity by Zone (GW) 2024

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.0	0.0	0.0	0.0	0.1	**0.1**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	4.4	0.5	0.1	0.0	0.0	**5.0**
Kerosene	0.0	0.0	0.0	0.1	0.1	**0.2**
Gas CC	2.3	3.0	1.6	3.3	0.7	**11.0**
Gas CT	0.0	0.0	0.1	2.1	0.8	**3.0**
Gas ST	0.1	0.0	2.8	3.8	2.3	**9.1**
Nuclear	3.3	0.0	0.0	0.0	0.0	**3.3**
Oil CT	0.0	0.0	0.0	0.3	1.2	**1.5**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Pumped Storage	0.0	1.2	0.0	0.0	0.0	**1.2**
Solar	0.0	0.0	0.0	0.0	0.1	**0.1**
Solar BTM	0.5	2.4	0.3	0.8	0.5	**4.5**
Storage 2-Hour	0.0	0.0	0.0	0.1	1.1	**1.2**
Storage 4-Hour	0.0	0.0	0.0	0.0	0.0	**0.0**
Wind Offshore	0.0	0.0	0.0	0.2	0.4	**0.6**
Wind Onshore	1.7	0.0	0.0	0.0	0.0	**1.7**
Capacity Imports	1.1	0.0	0.0	0.0	0.0	**1.1**
Demand Response	0.6	0.1	0.1	0.5	0.0	**1.3**
Flexible Load	0.0	0.0	0.0	0.0	0.0	**0.0**
RNG Production	0.0	0.0	0.0	0.0	0.0	**0.0**
Total	**14.2**	**7.2**	**5.0**	**11.2**	**7.4**	**44.9**

Existing Technologies Case

Capacity by Zone (GW) 2030

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.0	0.0	0.0	0.0	0.1	**0.1**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	4.4	0.5	0.1	0.0	0.0	**5.0**
Kerosene	0.0	0.0	0.0	0.0	0.1	**0.1**
Gas CC	2.3	3.0	1.6	3.3	0.7	**11.0**
Gas CT	0.0	0.0	0.1	1.0	0.5	**1.7**
Gas ST	0.1	0.0	2.8	3.8	2.3	**9.1**
Nuclear	2.1	0.0	0.0	0.0	0.0	**2.1**
Oil CT	0.0	0.0	0.0	0.0	0.2	**0.2**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Pumped Storage	0.0	1.2	0.0	0.0	0.0	**1.2**
Solar	0.0	15.9	1.9	0.0	0.1	**17.8**
Solar BTM	0.5	2.4	0.3	0.8	2.0	**6.0**
Storage 2-Hour	1.4	1.1	0.0	0.7	1.5	**4.7**
Storage 4-Hour	0.0	0.0	0.0	0.3	0.1	**0.5**
Wind Offshore	0.0	0.0	0.0	4.4	2.3	**6.8**
Wind Onshore	9.8	0.0	0.0	0.0	0.0	**9.8**
Capacity Imports	1.1	0.0	0.0	0.0	0.0	**1.1**
Demand Response	0.6	0.1	0.1	0.5	0.0	**1.3**
Flexible Load	0.2	0.0	0.1	0.2	0.1	**0.6**
RNG Production	0.0	0.0	0.0	0.0	0.0	**0.0**
Total	**22.7**	**24.2**	**6.9**	**15.0**	**10.1**	**79.0**

Capacity by Zone (GW) 2040

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.0	0.0	0.0	0.0	0.1	**0.1**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	4.4	0.5	0.1	0.0	0.0	**5.0**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Nuclear	2.1	0.0	0.0	0.0	0.0	**2.1**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Pumped Storage	0.0	1.2	0.0	0.0	0.0	**1.2**
Solar	0.0	41.9	13.1	0.0	0.1	**55.1**
Solar BTM	0.5	2.4	0.3	0.8	2.0	**6.0**
Storage 2-Hour	5.4	6.6	7.5	4.0	1.5	**25.0**
Storage 4-Hour	4.2	5.1	2.7	3.5	0.5	**16.0**
Wind Offshore	0.0	0.0	0.0	39.0	20.6	**59.5**
Wind Onshore	45.7	0.0	0.0	0.0	0.0	**45.7**
Capacity Imports	1.1	0.0	0.0	0.0	0.0	**1.1**
Demand Response	0.6	0.1	0.1	0.5	0.0	**1.3**
Flexible Load	0.9	0.2	0.4	0.9	0.9	**3.2**
RNG Production	0.0	0.0	0.0	0.0	0.0	**0.0**
Total	**65.0**	**57.9**	**24.2**	**48.6**	**25.7**	**221.4**

Existing Technologies Case

Energy by Zone (TWh) 2020

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.6	0.1	0.0	0.0	0.5	**1.2**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	29.4	2.3	0.5	0.0	0.0	**32.3**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	13.3	8.1	8.4	18.5	4.1	**52.5**
Gas CT	0.1	0.0	0.0	1.1	1.1	**2.3**
Gas ST	0.3	0.0	0.9	1.5	1.2	**3.9**
Nuclear	26.7	0.0	8.3	0.0	0.0	**34.9**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Solar	0.0	0.0	0.0	0.0	0.1	**0.1**
Solar BTM	0.4	0.3	0.3	0.9	0.5	**2.5**
Wind Offshore	0.0	0.0	0.0	0.0	0.0	**0.0**
Wind Onshore	4.0	0.0	0.0	0.0	0.0	**4.0**
Imports	17.2	0.2	2.6	3.7	6.5	**30.2**
Exports	-0.3	-2.7	-2.9	-0.2	-0.2	**-6.3**
RNG Production Load	0.0	0.0	0.0	0.0	0.0	**0.0**
All Other Load	-53.4	-12.1	-18.5	-52.4	-21.2	**-157.6**
Total	**38.2**	**-3.7**	**-0.3**	**-26.8**	**-7.3**	**0.0**

Energy by Zone (TWh) 2024

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.0	0.0	0.0	0.0	0.5	**0.5**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	29.4	2.3	0.5	0.0	0.0	**32.3**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	15.4	7.5	8.8	18.9	3.4	**54.0**
Gas CT	0.1	0.0	0.0	0.8	0.7	**1.6**
Gas ST	0.2	0.0	0.5	1.2	0.7	**2.7**
Nuclear	26.7	0.0	0.0	0.0	0.0	**26.7**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Solar	0.0	0.0	0.0	0.0	0.1	**0.1**
Solar BTM	0.6	2.8	0.3	0.9	0.6	**5.3**
Wind Offshore	0.0	0.0	0.0	0.9	1.4	**2.2**
Wind Onshore	4.0	0.0	0.0	0.0	0.0	**4.0**
Imports	17.2	0.2	2.6	3.7	6.5	**30.2**
Exports	-1.6	-2.7	-2.9	-0.2	-0.2	**-7.6**
RNG Production Load	0.0	0.0	0.0	0.0	0.0	**0.0**
All Other Load	-51.3	-11.6	-18.0	-50.4	-20.8	**-152.0**
Total	**40.7**	**-1.5**	**-8.0**	**-24.1**	**-7.2**	**0.0**

Existing Technologies Case

Energy by Zone (TWh) 2030

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	**Total**
BioGen	0.0	0.0	0.0	0.0	0.3	**0.3**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	29.4	2.3	0.5	0.0	0.0	**32.3**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	7.0	2.3	4.3	11.2	1.7	**26.5**
Gas CT	0.0	0.0	0.0	0.1	0.3	**0.5**
Gas ST	0.1	0.0	0.1	0.7	0.3	**1.2**
Nuclear	17.1	0.0	0.0	0.0	0.0	**17.1**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Solar	0.0	16.7	2.0	0.0	0.1	**18.8**
Solar BTM	0.6	2.8	0.3	0.9	2.4	**7.0**
Wind Offshore	0.0	0.0	0.0	16.3	8.5	**24.7**
Wind Onshore	20.2	0.0	0.0	0.0	0.0	**20.2**
Imports	12.3	0.1	2.2	2.8	3.9	**21.2**
Exports	-1.6	-2.7	-2.9	-0.2	-0.2	**-7.6**
RNG Production Load	0.0	0.0	0.0	0.0	0.0	**0.0**
All Other Load	-54.0	-12.2	-19.4	-53.6	-23.0	**-162.2**
Total	**31.1**	**9.5**	**-12.9**	**-21.8**	**-5.8**	0.0

Generation by Zone (TWh) 2040

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	**Total**
BioGen	0.0	0.0	0.0	0.0	0.0	**0.0**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	29.4	2.3	0.5	0.0	0.0	**32.3**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Nuclear	17.1	0.0	0.0	0.0	0.0	**17.1**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Solar	0.0	16.8	8.4	0.0	0.0	**25.2**
Solar BTM	0.6	2.8	0.3	0.9	2.4	**7.0**
Wind Offshore	0.0	0.0	0.0	71.9	29.5	**101.4**
Wind Onshore	42.3	0.0	0.0	0.0	0.0	**42.3**
Imports	1.8	0.0	0.5	0.4	0.3	**3.0**
Exports	-1.5	-2.7	-2.9	-0.2	-0.2	**-7.5**
RNG Production Load	0.0	0.0	0.0	0.0	0.0	**0.0**
All Other Load	-71.4	-16.0	-26.5	-72.1	-34.8	**-220.8**
Total	**18.3**	**3.2**	**-19.6**	**0.9**	**-2.8**	0.0

Increased Flexibility Case

Capacity by Zone (GW) 2020

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	**Total**
BioGen	0.0	0.0	0.0	0.0	0.1	**0.1**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	4.4	0.5	0.1	0.0	0.0	**5.0**
Kerosene	0.0	0.0	0.0	0.1	0.1	**0.2**
Gas CC	2.3	3.0	1.6	3.3	0.7	**11.0**
Gas CT	0.0	0.0	0.1	2.1	0.8	**3.0**
Gas ST	0.0	0.0	2.8	3.3	2.3	**8.4**
Nuclear	3.3	0.0	1.0	0.0	0.0	**4.4**
Oil CT	0.0	0.0	0.0	0.3	1.2	**1.5**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Pumped Storage	0.0	1.2	0.0	0.0	0.0	**1.2**
Solar	0.0	0.0	0.0	0.0	0.1	**0.1**
Solar BTM	0.3	0.8	0.3	0.3	0.5	**2.1**
Storage 2-Hour	0.0	0.0	0.0	0.0	0.4	**0.4**
Storage 4-Hour	0.0	0.0	0.0	0.0	0.0	**0.0**
Wind Offshore	0.0	0.0	0.0	0.0	0.0	**0.0**
Wind Onshore	1.7	0.0	0.0	0.0	0.0	**1.7**
Capacity Imports	2.2	0.0	0.0	1.0	0.0	**3.2**
Demand Response	0.6	0.1	0.1	0.5	0.0	**1.3**
Flexible Load	0.0	0.0	0.0	0.0	0.0	**0.0**
RNG Production	0.0	0.0	0.0	0.0	0.0	**0.0**
Total	**15.0**	**5.6**	**6.0**	**10.8**	**6.2**	**43.6**

Capacity by Zone (GW) 2024

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	**Total**
BioGen	0.0	0.0	0.0	0.0	0.1	**0.1**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	4.4	0.5	0.1	0.0	0.0	**5.0**
Kerosene	0.0	0.0	0.0	0.1	0.1	**0.2**
Gas CC	2.3	3.0	1.6	3.3	0.7	**11.0**
Gas CT	0.0	0.0	0.1	2.1	0.8	**3.0**
Gas ST	0.0	0.0	2.8	3.0	2.3	**8.1**
Nuclear	3.3	0.0	0.0	0.0	0.0	**3.3**
Oil CT	0.0	0.0	0.0	0.3	1.2	**1.5**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Pumped Storage	0.0	1.2	0.0	0.0	0.0	**1.2**
Solar	0.0	0.0	0.0	0.0	0.1	**0.1**
Solar BTM	0.3	2.6	0.3	0.8	0.5	**4.5**
Storage 2-Hour	0.0	0.0	0.0	0.3	0.9	**1.2**
Storage 4-Hour	0.0	0.0	0.0	0.0	0.0	**0.0**
Wind Offshore	0.0	0.0	0.0	0.2	0.4	**0.6**
Wind Onshore	1.7	0.0	0.0	0.0	0.0	**1.7**
Capacity Imports	2.2	0.0	0.0	1.0	0.0	**3.2**
Demand Response	0.6	0.1	0.1	0.5	0.0	**1.3**
Flexible Load	0.0	0.0	0.0	0.0	0.0	**0.0**
RNG Production	0.0	0.0	0.0	0.0	0.0	**0.0**
Total	**14.9**	**7.4**	**5.0**	**11.5**	**7.2**	**46.0**

Increased Flexibility Case

Capacity by Zone (GW) 2030

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.0	0.0	0.0	0.0	0.1	**0.1**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	4.4	0.5	0.1	0.0	0.0	**5.0**
Kerosene	0.0	0.0	0.0	0.0	0.1	**0.1**
Gas CC	2.3	3.0	1.6	3.3	0.7	**11.0**
Gas CT	0.0	0.0	0.1	1.0	0.7	**1.8**
Gas ST	0.0	0.0	2.8	3.0	2.3	**8.1**
Nuclear	2.3	0.0	0.0	0.0	0.0	**2.3**
Oil CT	0.0	0.0	0.0	0.0	0.2	**0.2**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Pumped Storage	0.0	1.2	0.0	0.0	0.0	**1.2**
Solar	0.0	6.7	0.2	0.0	0.1	**6.9**
Solar BTM	0.3	2.6	0.3	0.8	2.0	**6.0**
Storage 2-Hour	0.5	0.0	0.0	1.8	1.9	**4.1**
Storage 4-Hour	0.0	0.0	0.0	0.0	0.0	**0.0**
Wind Offshore	0.0	0.0	0.0	2.5	2.5	**5.0**
Wind Onshore	6.3	0.0	0.0	0.0	0.0	**6.3**
Capacity Imports	2.2	0.0	0.0	1.0	0.0	**3.2**
Demand Response	0.6	0.1	0.1	0.5	0.0	**1.3**
Flexible Load	0.5	0.1	0.2	0.4	0.3	**1.5**
RNG Production	0.0	0.0	0.0	0.0	0.0	**0.0**
Total	**19.4**	**14.2**	**5.3**	**14.3**	**10.9**	**64.1**

Capacity by Zone (GW) 2040

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.0	0.0	0.0	0.0	0.0	**0.0**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	4.4	0.5	0.1	0.0	0.0	**5.0**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	2.3	3.0	1.6	3.3	1.0	**11.3**
Gas CT	0.1	4.8	0.9	3.7	3.5	**12.8**
Gas ST	0.0	0.0	2.8	3.0	2.3	**8.1**
Nuclear	2.3	0.0	0.0	0.0	0.0	**2.3**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Pumped Storage	0.0	1.2	0.0	0.0	0.0	**1.2**
Solar	0.8	17.0	6.1	0.0	0.1	**24.0**
Solar BTM	0.5	5.6	0.3	0.8	2.0	**9.2**
Storage 2-Hour	1.5	0.7	0.0	1.8	1.9	**5.9**
Storage 4-Hour	1.7	1.0	0.4	0.8	0.1	**4.0**
Wind Offshore	0.0	0.0	0.0	15.2	7.5	**22.7**
Wind Onshore	21.3	0.0	0.0	0.0	0.0	**21.3**
Capacity Imports	2.2	0.0	0.0	1.0	0.0	**3.2**
Demand Response	0.6	0.1	0.1	0.5	0.0	**1.3**
Flexible Load	3.1	0.7	1.2	3.0	2.3	**10.2**
RNG Production	8.2	0.0	0.0	3.6	1.8	**13.6**
Total	**49.0**	**34.6**	**13.4**	**36.7**	**22.4**	**156.1**

Increased Flexibility Case

Energy by Zone (TWh) 2020

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.0	0.0	0.0	0.0	0.5	**0.5**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	29.4	2.3	0.5	0.0	0.0	**32.3**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	8.4	2.5	5.6	12.4	3.9	**32.8**
Gas CT	0.1	0.0	0.0	1.4	1.4	**2.9**
Gas ST	0.0	0.0	0.4	0.4	1.3	**2.1**
Nuclear	26.7	0.0	8.3	0.0	0.0	**34.9**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Solar	0.0	0.0	0.0	0.0	0.1	**0.1**
Solar BTM	0.4	0.9	0.3	0.4	0.5	**2.5**
Wind Offshore	0.0	0.0	0.0	0.0	0.0	**0.0**
Wind Onshore	4.0	0.0	0.0	0.0	0.0	**4.0**
Imports	29.3	0.1	2.1	14.3	6.0	**51.9**
Exports	-0.3	-2.7	-2.9	-0.2	-0.2	**-6.3**
RNG Production Load	0.0	0.0	0.0	0.0	0.0	**0.0**
All Other Load	-53.4	-12.1	-18.5	-52.4	-21.2	**-157.6**
Total	**44.5**	**-8.9**	**-4.1**	**-23.7**	**-7.7**	0.0

Energy by Zone (TWh) 2024

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.0	0.0	0.0	0.0	0.4	**0.4**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	29.4	2.3	0.5	0.0	0.0	**32.3**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	8.2	2.7	6.1	11.8	3.1	**31.9**
Gas CT	0.0	0.0	0.0	1.2	1.1	**2.3**
Gas ST	0.0	0.0	0.1	0.2	0.6	**0.9**
Nuclear	26.7	0.0	0.0	0.0	0.0	**26.7**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Solar	0.0	0.0	0.0	0.0	0.1	**0.1**
Solar BTM	0.4	3.0	0.3	0.9	0.6	**5.3**
Wind Offshore	0.0	0.0	0.0	0.6	1.6	**2.2**
Wind Onshore	4.0	0.0	0.0	0.0	0.0	**4.0**
Imports	29.8	0.2	2.6	14.8	6.1	**53.5**
Exports	-1.6	-2.7	-2.9	-0.2	-0.2	**-7.6**
RNG Production Load	0.0	0.0	0.0	0.0	0.0	**0.0**
All Other Load	-51.3	-11.6	-18.0	-50.4	-20.8	**-152.0**
Total	**45.8**	**-6.1**	**-11.2**	**-21.1**	**-7.4**	0.0

Increased Flexibility Case

Energy by Zone (TWh) 2030

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	**Total**
BioGen	0.0	0.0	0.0	0.0	0.3	**0.3**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	29.4	2.3	0.5	0.0	0.0	**32.3**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	7.3	2.3	4.5	10.0	1.5	**25.6**
Gas CT	0.0	0.0	0.0	0.1	0.3	**0.5**
Gas ST	0.0	0.0	0.2	0.3	0.2	**0.7**
Nuclear	18.4	0.0	0.0	0.0	0.0	**18.4**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Solar	0.0	7.8	0.2	0.0	0.1	**8.1**
Solar BTM	0.4	3.0	0.3	0.9	2.4	**7.0**
Wind Offshore	0.0	0.0	0.0	9.3	9.3	**18.6**
Wind Onshore	14.5	0.0	0.0	0.0	0.0	**14.5**
Imports	24.7	0.1	2.2	13.2	3.8	**43.9**
Exports	-1.8	-2.7	-2.9	-0.2	-0.2	**-7.8**
RNG Production Load	0.0	0.0	0.0	0.0	0.0	**0.0**
All Other Load	-54.0	-12.2	-19.4	-53.6	-23.0	**-162.2**
Total	**39.0**	**0.7**	**-14.4**	**-20.0**	**-5.2**	0.0

Energy by Zone (TWh) 2040

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	**Total**
BioGen	0.0	0.0	0.0	0.0	0.0	**0.0**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	29.4	2.3	0.5	0.0	0.0	**32.3**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	0.9	4.0	3.3	4.3	1.8	**14.3**
Gas CT	0.0	0.7	0.2	0.7	1.2	**2.7**
Gas ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Nuclear	18.4	0.0	0.0	0.0	0.0	**18.4**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Solar	0.9	19.3	7.0	0.0	0.1	**27.2**
Solar BTM	0.6	6.6	0.3	0.9	2.4	**10.8**
Wind Offshore	0.0	0.0	0.0	56.4	27.2	**83.6**
Wind Onshore	48.4	0.0	0.0	0.0	0.0	**48.4**
Imports	27.3	0.2	2.6	14.5	5.8	**50.5**
Exports	-2.3	-2.7	-2.9	-0.3	-0.2	**-8.4**
RNG Production Load	-36.6	0.0	0.0	-14.8	-7.7	**-59.1**
All Other Load	-71.4	-16.0	-26.5	-72.1	-34.8	**-220.8**
Total	**15.7**	**14.3**	**-15.4**	**-10.4**	**-4.2**	0.0

Expanded Transmission Case

Capacity by Zone (GW) 2020

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.2	0.0	0.0	0.0	0.1	**0.4**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	4.4	0.5	0.1	0.0	0.0	**5.0**
Kerosene	0.0	0.0	0.0	0.1	0.1	**0.2**
Gas CC	2.3	3.0	1.6	3.3	0.7	**11.0**
Gas CT	0.1	0.0	0.1	2.1	0.8	**3.0**
Gas ST	0.1	0.0	2.8	3.8	2.3	**9.1**
Nuclear	3.3	0.0	1.0	0.0	0.0	**4.4**
Oil CT	0.0	0.0	0.0	0.3	1.2	**1.5**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Pumped Storage	0.0	1.2	0.0	0.0	0.0	**1.2**
Solar	0.0	0.0	0.0	0.0	0.1	**0.1**
Solar BTM	0.3	0.8	0.3	0.3	0.5	**2.1**
Storage 2-Hour	0.0	0.0	0.0	0.0	0.2	**0.2**
Storage 4-Hour	0.0	0.0	0.0	0.0	0.0	**0.0**
Wind Offshore	0.0	0.0	0.0	0.0	0.0	**0.0**
Wind Onshore	1.7	0.0	0.0	0.0	0.0	**1.7**
Capacity Imports	1.1	0.0	0.0	0.0	0.0	**1.1**
Demand Response	0.6	0.1	0.1	0.5	0.0	**1.3**
Flexible Load	0.0	0.0	0.0	0.0	0.0	**0.0**
RNG Production	0.0	0.0	0.0	0.0	0.0	**0.0**
Total	**14.2**	**5.6**	**6.0**	**10.4**	**6.0**	**42.3**

Capacity by Zone (GW) 2024

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.0	0.0	0.0	0.0	0.1	**0.1**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	4.4	0.5	0.1	0.0	0.0	**5.0**
Kerosene	0.0	0.0	0.0	0.1	0.1	**0.2**
Gas CC	2.3	3.0	1.6	3.3	0.7	**11.0**
Gas CT	0.1	0.0	0.1	2.1	0.8	**3.0**
Gas ST	0.1	0.0	2.8	3.5	2.3	**8.8**
Nuclear	3.3	0.0	0.0	0.0	0.0	**3.3**
Oil CT	0.0	0.0	0.0	0.3	1.2	**1.5**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Pumped Storage	0.0	1.2	0.0	0.0	0.0	**1.2**
Solar	0.0	0.0	0.0	0.0	0.1	**0.1**
Solar BTM	0.4	2.5	0.3	0.8	0.5	**4.5**
Storage 2-Hour	0.0	0.0	0.0	0.0	1.2	**1.2**
Storage 4-Hour	0.0	0.0	0.0	0.0	0.0	**0.0**
Wind Offshore	0.0	0.0	0.0	0.6	0.0	**0.6**
Wind Onshore	1.7	0.0	0.0	0.0	0.0	**1.7**
Capacity Imports	1.1	0.0	0.0	0.0	0.0	**1.1**
Demand Response	0.6	0.1	0.1	0.5	0.0	**1.3**
Flexible Load	0.0	0.0	0.0	0.0	0.0	**0.0**
RNG Production	0.0	0.0	0.0	0.0	0.0	**0.0**
Total	**14.1**	**7.3**	**5.0**	**11.2**	**7.1**	**44.6**

Expanded Transmission Case

Capacity by Zone (GW) 2030

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.0	0.0	0.0	0.0	0.1	**0.1**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	4.4	0.5	0.1	0.0	0.0	**5.0**
Kerosene	0.0	0.0	0.0	0.0	0.1	**0.1**
Gas CC	2.3	3.0	1.6	3.3	0.7	**11.0**
Gas CT	0.1	0.0	0.1	1.0	0.5	**1.7**
Gas ST	0.1	0.0	2.8	3.5	2.3	**8.8**
Nuclear	2.4	0.0	0.0	0.0	0.0	**2.4**
Oil CT	0.0	0.0	0.0	0.0	0.2	**0.2**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Pumped Storage	0.0	1.2	0.0	0.0	0.0	**1.2**
Solar	0.8	13.3	0.8	0.0	0.1	**15.0**
Solar BTM	0.4	2.5	0.3	0.8	2.0	**6.0**
Storage 2-Hour	0.8	0.0	0.0	0.9	2.8	**4.5**
Storage 4-Hour	0.0	0.0	0.0	0.1	0.0	**0.2**
Wind Offshore	0.0	0.0	0.0	5.1	1.2	**6.3**
Wind Onshore	12.0	0.0	0.0	0.0	0.0	**12.0**
Capacity Imports	1.1	0.0	0.0	0.0	0.0	**1.1**
Demand Response	0.6	0.1	0.1	0.5	0.0	**1.3**
Flexible Load	0.2	0.0	0.1	0.2	0.1	**0.6**
RNG Production	0.0	0.0	0.0	0.0	0.0	**0.0**
Total	**25.2**	**20.7**	**5.9**	**15.5**	**10.2**	**77.4**

Capacity by Zone (GW) 2040

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.0	0.0	0.0	0.0	0.0	**0.0**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	4.4	0.5	0.1	0.0	0.0	**5.0**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	2.3	3.0	2.3	3.3	0.7	**11.7**
Gas CT	0.1	4.8	0.2	2.8	3.5	**11.3**
Gas ST	0.1	0.0	2.8	3.5	2.3	**8.8**
Nuclear	2.4	0.0	0.0	0.0	0.0	**2.4**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Pumped Storage	0.0	1.2	0.0	0.0	0.0	**1.2**
Solar	10.1	19.1	4.5	0.0	0.1	**33.8**
Solar BTM	0.5	3.9	0.3	0.8	2.0	**7.5**
Storage 2-Hour	5.0	1.0	0.0	0.9	2.8	**9.7**
Storage 4-Hour	1.9	1.1	0.5	2.1	0.0	**5.8**
Wind Offshore	0.0	0.0	0.0	16.2	6.5	**22.7**
Wind Onshore	27.0	0.0	0.0	0.0	0.0	**27.0**
Capacity Imports	1.1	0.0	0.0	0.0	0.0	**1.1**
Demand Response	0.6	0.1	0.1	0.5	0.0	**1.3**
Flexible Load	0.9	0.2	0.4	0.9	0.9	**3.2**
RNG Production	8.5	0.0	0.0	3.8	1.5	**13.8**
Total	**64.9**	**34.9**	**11.2**	**34.8**	**20.3**	**166.2**

Expanded Transmission Case

Energy by Zone (TWh) 2020

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.7	0.1	0.0	0.0	0.3	**1.1**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	29.4	2.3	0.5	0.0	0.0	**32.3**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	13.6	8.9	8.9	19.0	2.9	**53.3**
Gas CT	0.2	0.0	0.0	1.3	0.4	**1.9**
Gas ST	0.3	0.0	1.3	1.6	0.4	**3.6**
Nuclear	26.7	0.0	8.3	0.0	0.0	**34.9**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Solar	0.0	0.0	0.0	0.0	0.1	**0.1**
Solar BTM	0.4	0.9	0.3	0.4	0.5	**2.5**
Wind Offshore	0.0	0.0	0.0	0.0	0.0	**0.0**
Wind Onshore	4.0	0.0	0.0	0.0	0.0	**4.0**
Imports	17.2	0.2	2.6	3.7	6.5	**30.2**
Exports	-0.3	-2.7	-2.9	-0.2	-0.2	**-6.3**
RNG Production Load	0.0	0.0	0.0	0.0	0.0	**0.0**
All Other Load	-53.4	-12.1	-18.5	-52.4	-21.2	**-157.6**
Total	**38.7**	**-2.4**	**0.6**	**-26.5**	**-10.3**	0.0

Energy by Zone (TWh) 2024

	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	Total
BioGen	0.0	0.0	0.0	0.0	0.3	**0.3**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	29.4	2.3	0.5	0.0	0.0	**32.3**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	15.9	7.9	8.9	19.0	2.8	**54.4**
Gas CT	0.2	0.0	0.0	1.0	0.3	**1.4**
Gas ST	0.3	0.0	0.7	1.5	0.2	**2.6**
Nuclear	26.7	0.0	0.0	0.0	0.0	**26.7**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Solar	0.0	0.0	0.0	0.0	0.1	**0.1**
Solar BTM	0.5	2.9	0.3	0.9	0.6	**5.3**
Wind Offshore	0.0	0.0	0.0	2.2	0.0	**2.2**
Wind Onshore	4.0	0.0	0.0	0.0	0.0	**4.0**
Imports	17.2	0.2	2.6	3.7	6.5	**30.2**
Exports	-1.6	-2.7	-2.9	-0.2	-0.2	**-7.6**
RNG Production Load	0.0	0.0	0.0	0.0	0.0	**0.0**
All Other Load	-51.3	-11.6	-18.0	-50.4	-20.8	**-152.0**
Total	**41.3**	**-1.0**	**-7.8**	**-22.3**	**-10.3**	0.0

See Slide 2 Disclaimer

Expanded Transmission Case

Energy by Zone (TWh) 2030

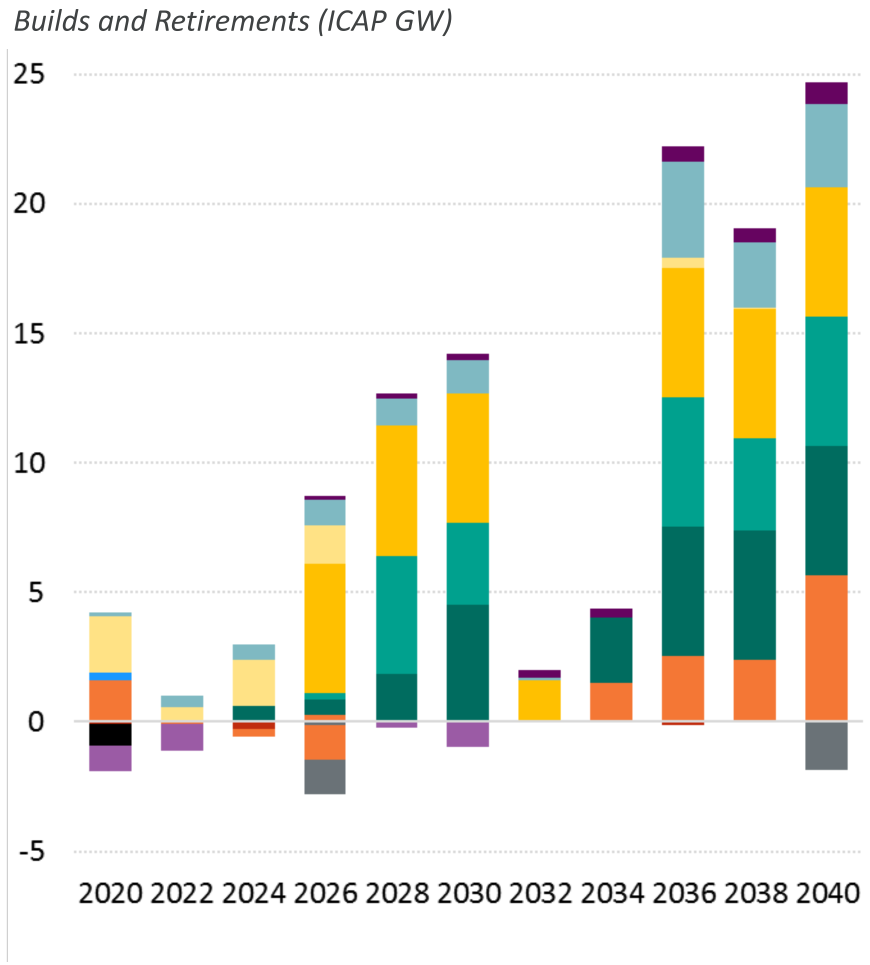
	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	**Total**
BioGen	0.0	0.0	0.0	0.0	0.2	**0.2**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	29.4	2.3	0.5	0.0	0.0	**32.3**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	7.4	3.0	4.1	9.8	1.1	**25.4**
Gas CT	0.1	0.0	0.0	0.2	0.1	**0.4**
Gas ST	0.1	0.0	0.2	0.5	0.1	**0.9**
Nuclear	18.9	0.0	0.0	0.0	0.0	**18.9**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Solar	0.8	14.3	0.8	0.0	0.1	**16.0**
Solar BTM	0.5	2.9	0.3	0.9	2.4	**7.0**
Wind Offshore	0.0	0.0	0.0	18.4	4.3	**22.7**
Wind Onshore	24.7	0.0	0.0	0.0	0.0	**24.7**
Imports	12.7	0.1	2.2	2.7	3.6	**21.2**
Exports	-1.6	-2.7	-2.9	-0.2	-0.2	**-7.6**
RNG Production Load	0.0	0.0	0.0	0.0	0.0	**0.0**
All Other Load	-54.0	-12.2	-19.4	-53.6	-23.0	**-162.2**
Total	**38.9**	**7.8**	**-14.1**	**-21.3**	**-11.3**	**0.0**

Energy by Zone (TWh) 2040

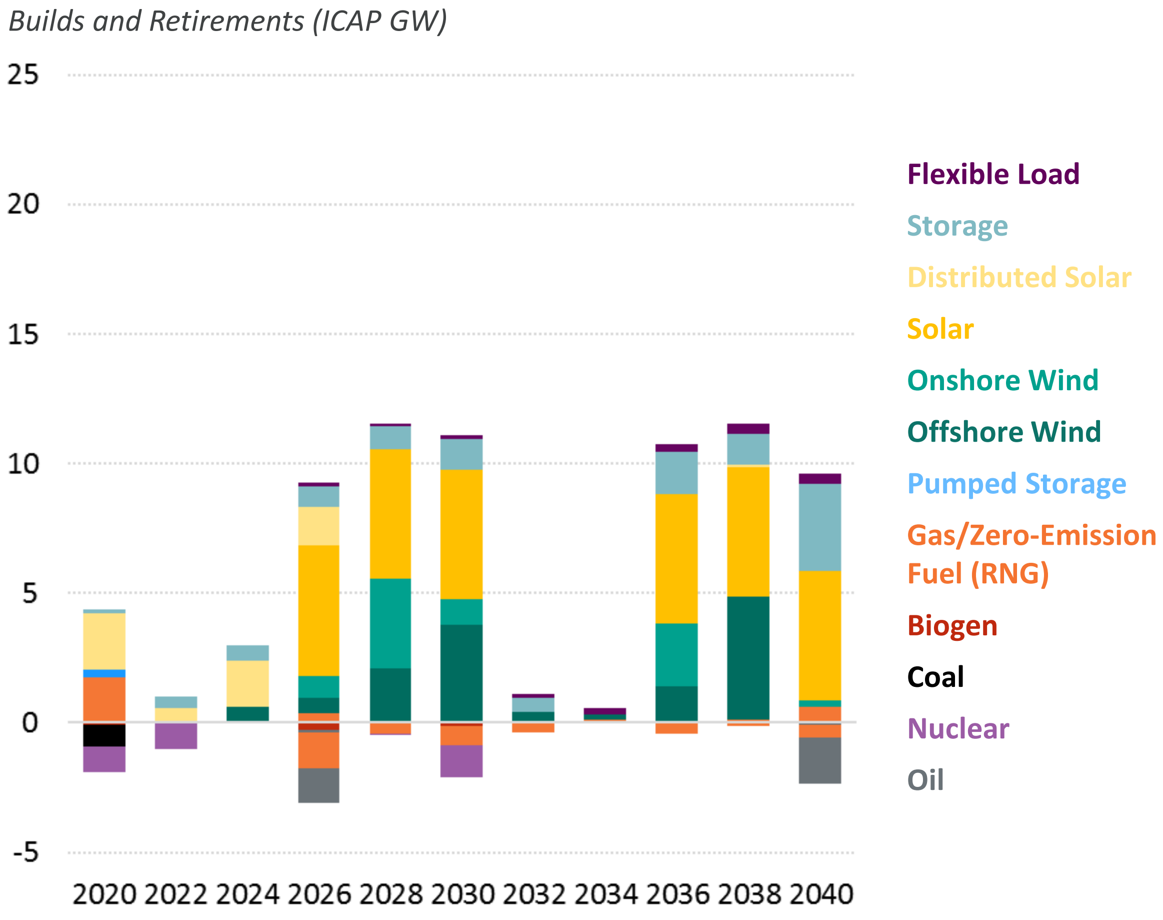
	Zone A-E	Zone F	Zone GHI	Zone J	Zone K	**Total**
BioGen	0.0	0.0	0.0	0.0	0.0	**0.0**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**
Hydro	29.4	2.3	0.5	0.0	0.0	**32.3**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	1.0	4.0	5.0	4.4	1.4	**15.8**
Gas CT	0.0	0.8	0.0	0.6	1.0	**2.4**
Gas ST	0.0	0.0	0.1	0.0	0.0	**0.1**
Nuclear	18.9	0.0	0.0	0.0	0.0	**18.9**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	0.0	0.0	0.0	0.0	0.0	**0.0**
Solar	11.2	21.1	5.1	0.0	0.1	**37.5**
Solar BTM	0.6	4.5	0.3	0.9	2.4	**8.8**
Wind Offshore	0.0	0.0	0.0	60.0	24.0	**83.9**
Wind Onshore	59.8	0.0	0.0	0.0	0.0	**59.8**
Imports	15.1	0.2	2.6	3.5	5.8	**27.1**
Exports	-1.5	-2.7	-2.9	-0.2	-0.2	**-7.5**
RNG Production Load	-36.6	0.0	0.0	-15.3	-6.3	**-58.2**
All Other Load	-71.4	-16.0	-26.5	-72.1	-34.8	**-220.8**
Total	**26.5**	**14.1**	**-15.6**	**-18.2**	**-6.8**	**0.0**

Annual Builds and Retirements

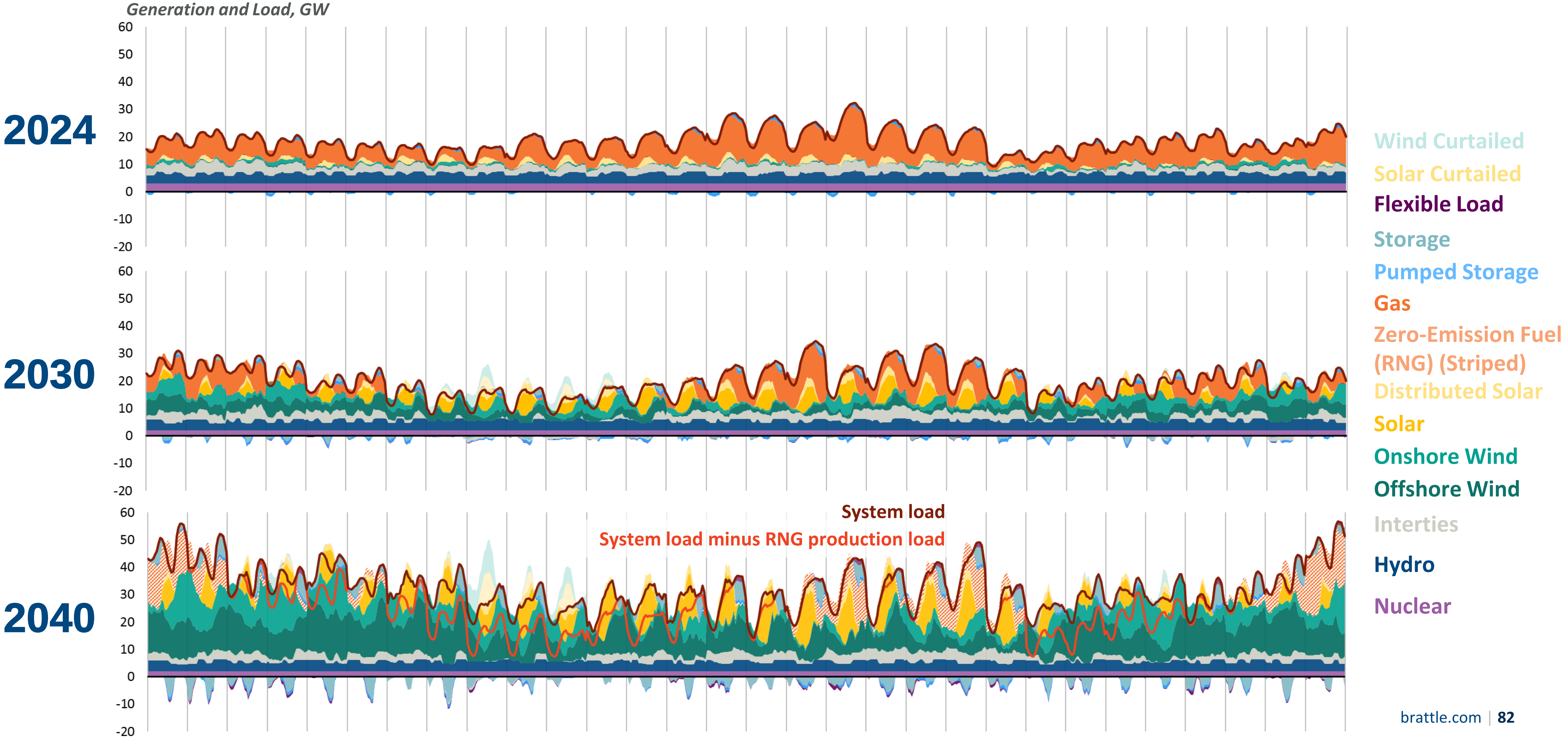
High Electrification Case



Reference Load Case

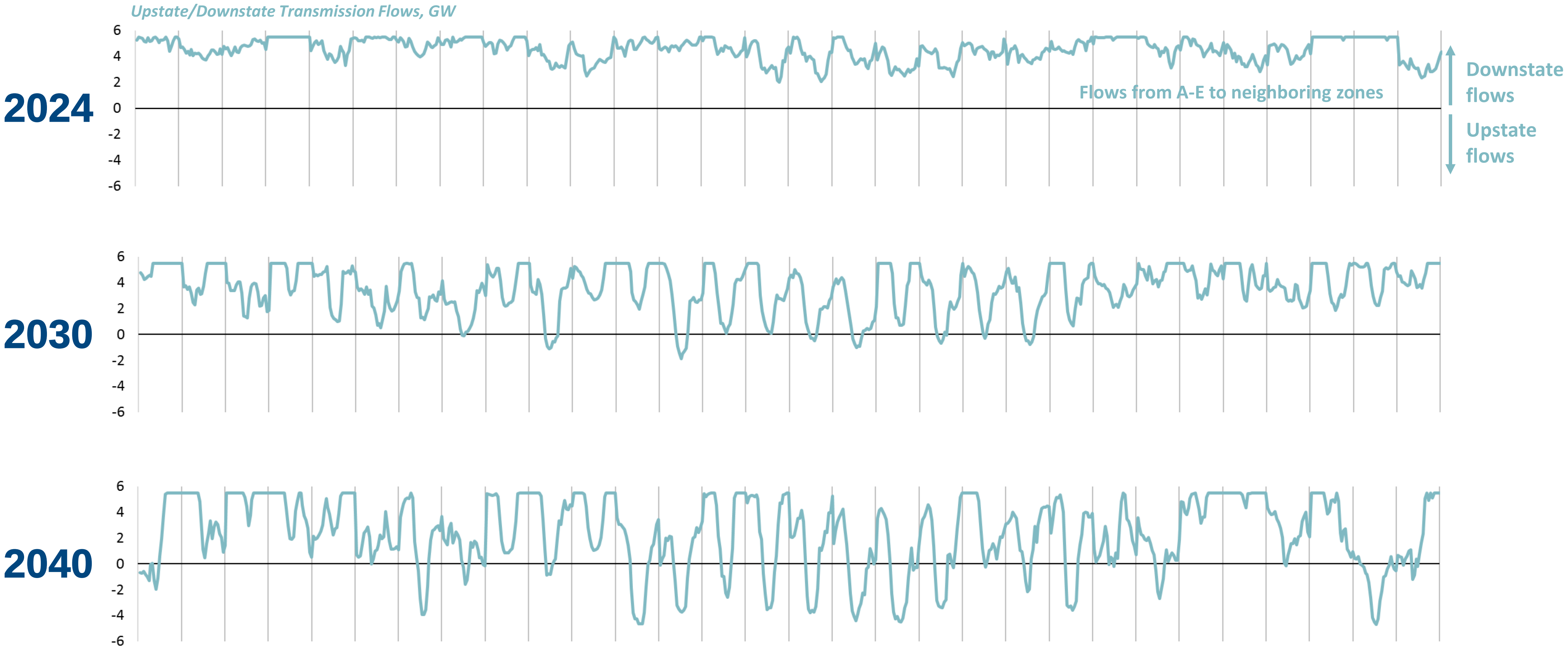


High Electrification Case: Hourly Generation



High Electrification Case: Hourly Transmission Flows

Flows from A-E to neighboring zones



RNG production and consumption, 2040

- In both cases, more than half of the RNG consumed by gas-fired generation is produced in-state.
- RNG production adds 18% to system load, utilizing renewable generation that would otherwise be curtailed.
- Note: RNG is utilized for the purposes of this analysis solely as a proxy for potential future zero-emission technology development.

RNG Production in 2040

		High Electrification Case	Reference Load Case
RNG Production and Consumption			
Total RNG Produced	*(Million MMBTu)*	99	53
Total RNG Consumed	*(Million MMBTu)*	149	95
% RNG Demand Produced in NY	*(%)*	66%	56%
Impacts on Load			
Annual Load from RNG Production	*(TWh)*	50	27
as a % of Gross Load	*(%)*	18%	14%

Appendix: Modeling Approach and Assumptions

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)

Sources and Notes:

RGGI Auction Allowance Price and Volumes Results

New York Public Service Commission Order Adopting a Clean Energy Standard. August 1, 2016

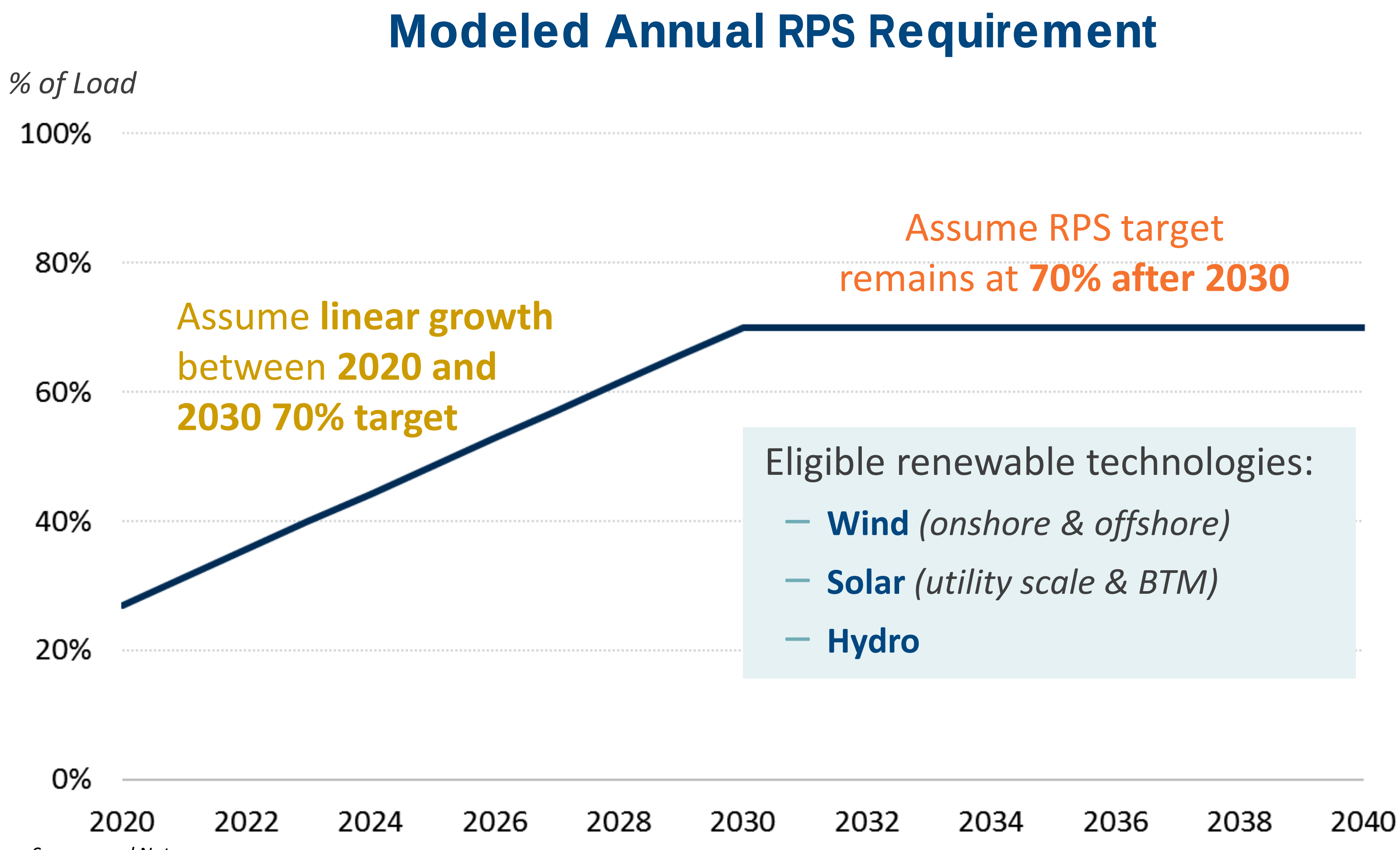
New York DEC Adopted Subpart 227-3

New York Senate Bill S6599

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

70% Renewable Portfolio Standard



Sources and Notes:
New York Senate Bill S6599

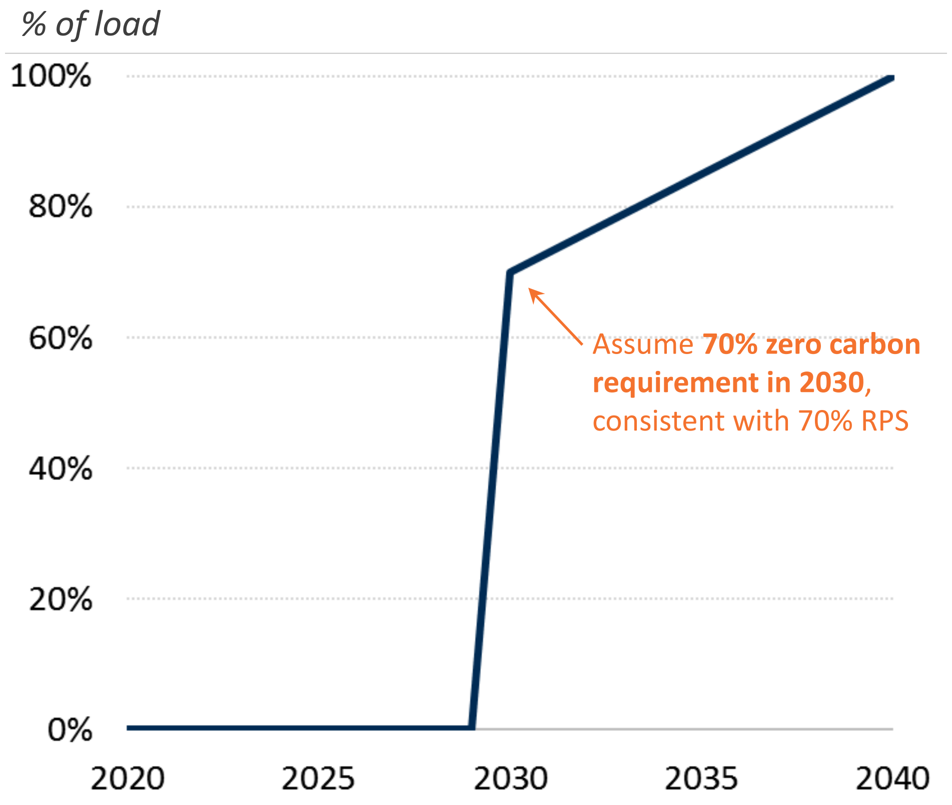
100% zero emissions mandate

Eligible "zero emissions" generation technologies

- **Renewables**
- **Nuclear**
- **Renewable natural gas**
- **Clean imports from HQ**

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

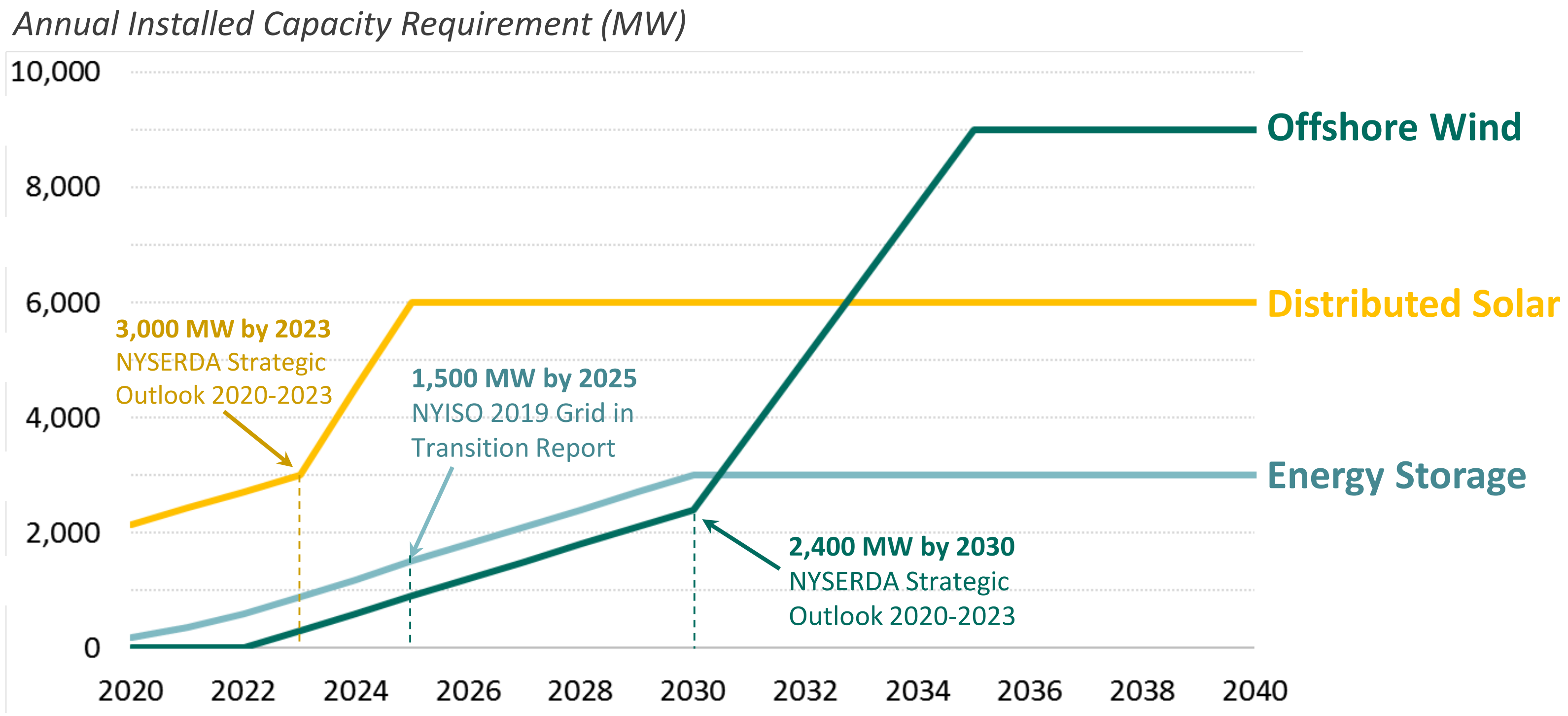
Modeled Annual Zero Emissions Requirement



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).

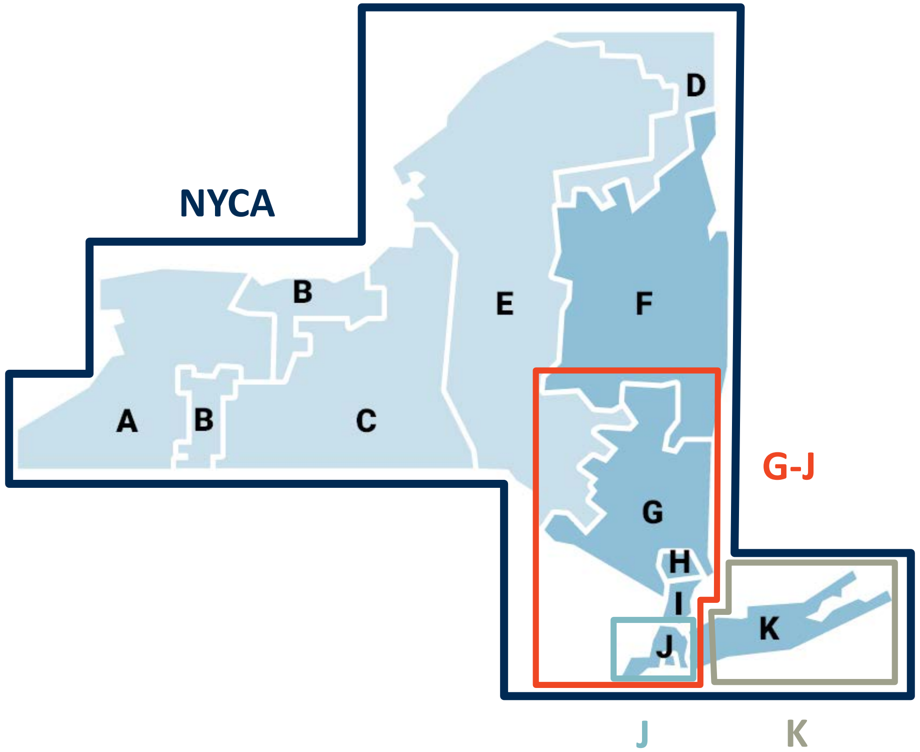


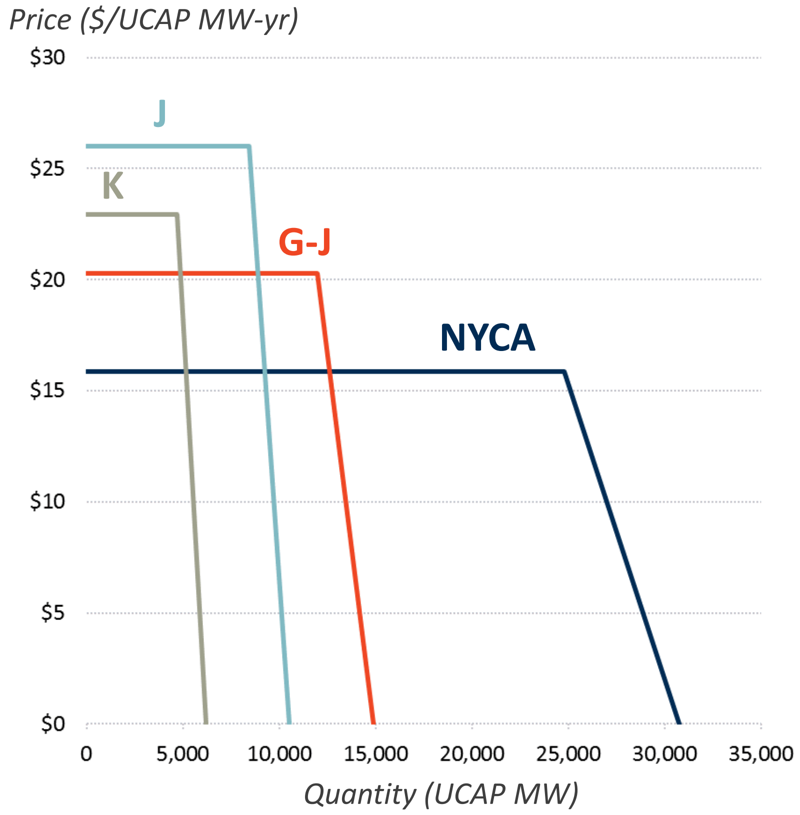
Sources and Notes:

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**.





Sources and Notes:

NYISO ICAP/UCAP Translation of the Demand Curve – Summer 2018 Capability Period

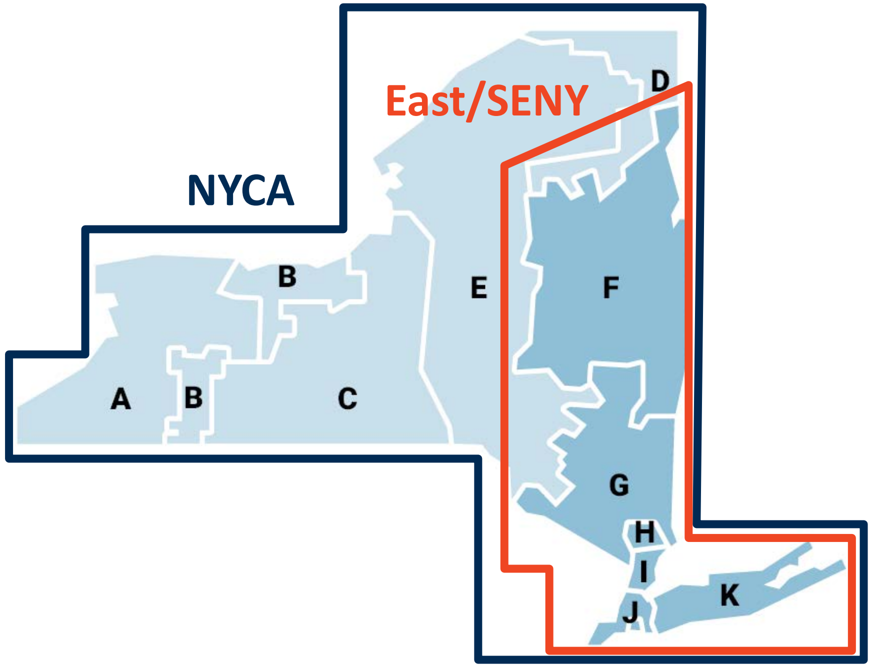
NYISO ICAP/UCAP Translation of the Demand Curve – Winter 2018-2019 Capability Period

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

Product	NYCA Quantity (MW)	NYCA Shortage Price ($/MWh)	EAST/SENY (G-K) Quantity (MW)	EAST/SENY (G-K) Shortage Price ($/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.

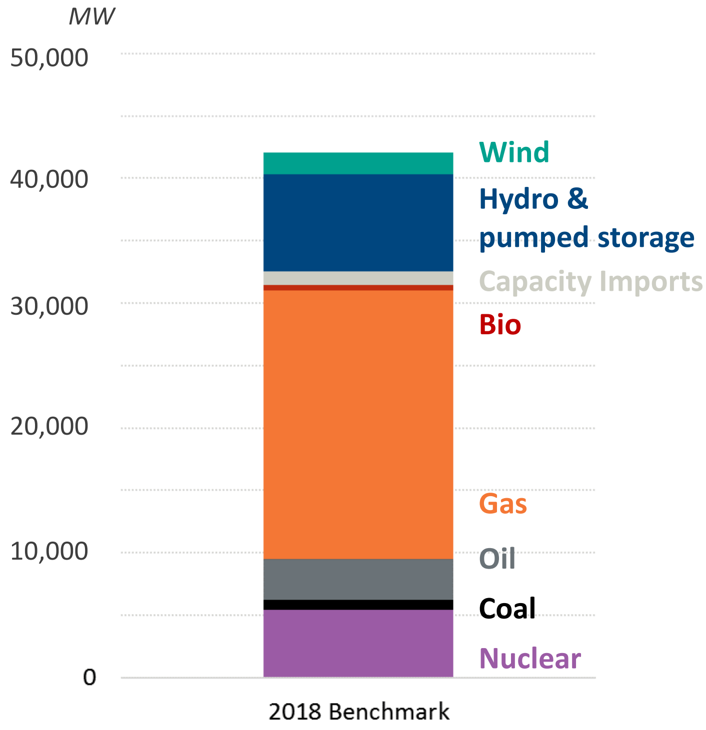
Supply Assumptions

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

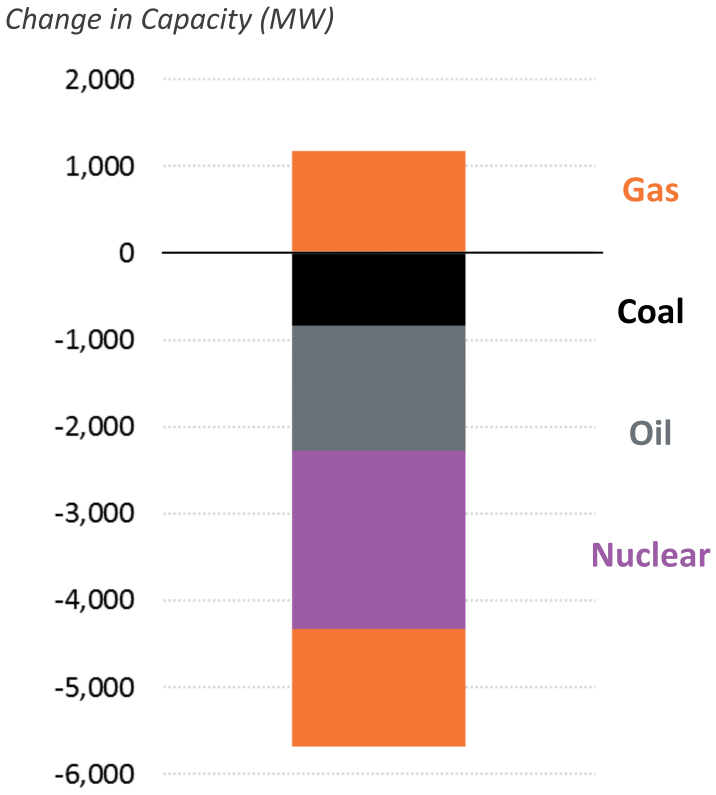


Planned builds and retirements

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)

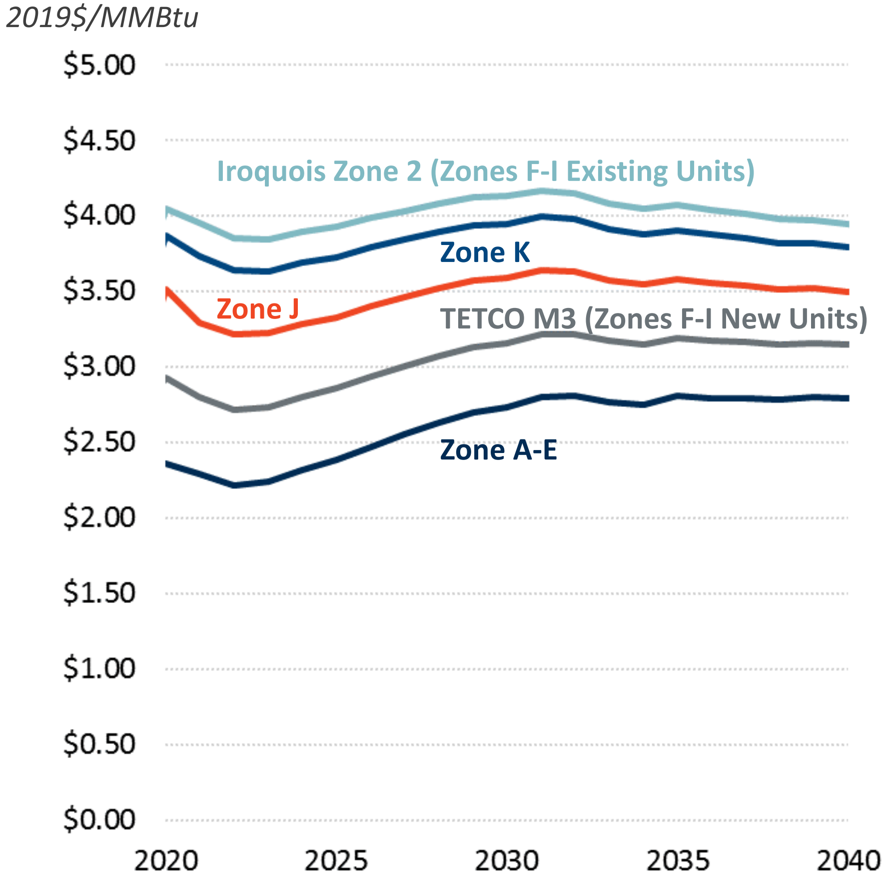
Cumulative Planned Capacity Changes 2020-2030



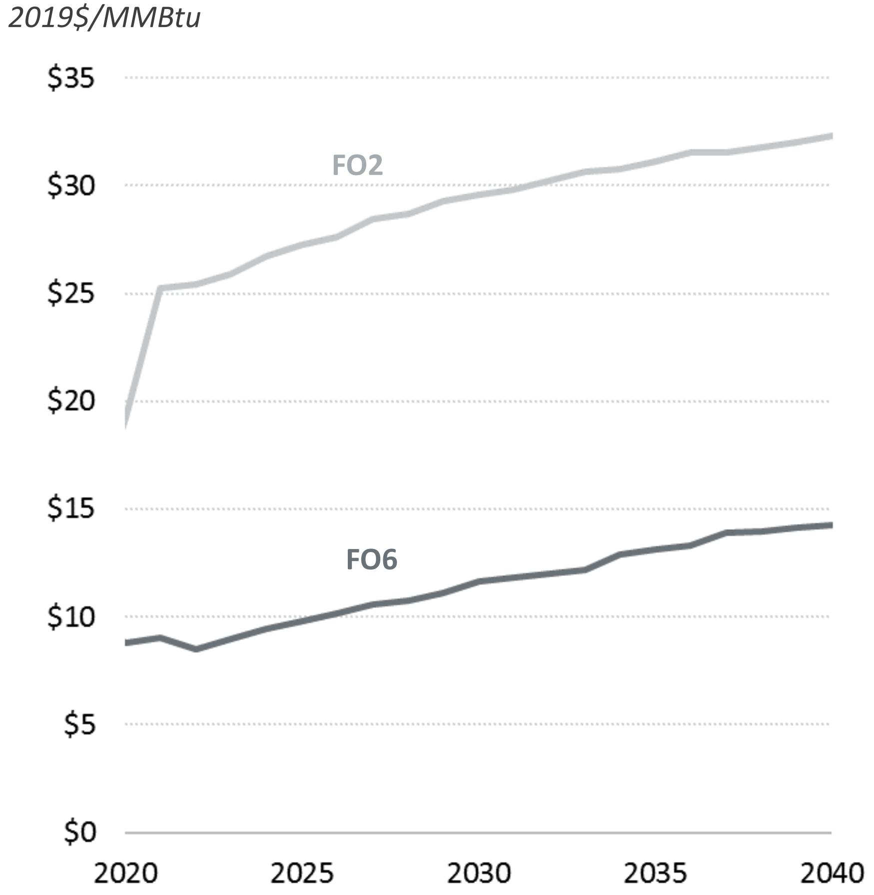
Sources and Notes:
ABB Velocity Suite. NOx retirement assumptions derived from NYDEC NOx Revised Regulatory Impact Statement Summary and conversations with NYISO
NYISO Grid in Transition Report. 2019

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

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
Load flexibility	• Model **controllable EV charging** and **HVAC loads** • Amount of participation assumed (not endogenously determined) • Modeling flexibility over 24-hour period
Renewable natural gas (RNG)	• Assume supply from interstate pipelines at a price of $38-$43/MMBtu • Model potential in-state RNG production from excess renewable energy

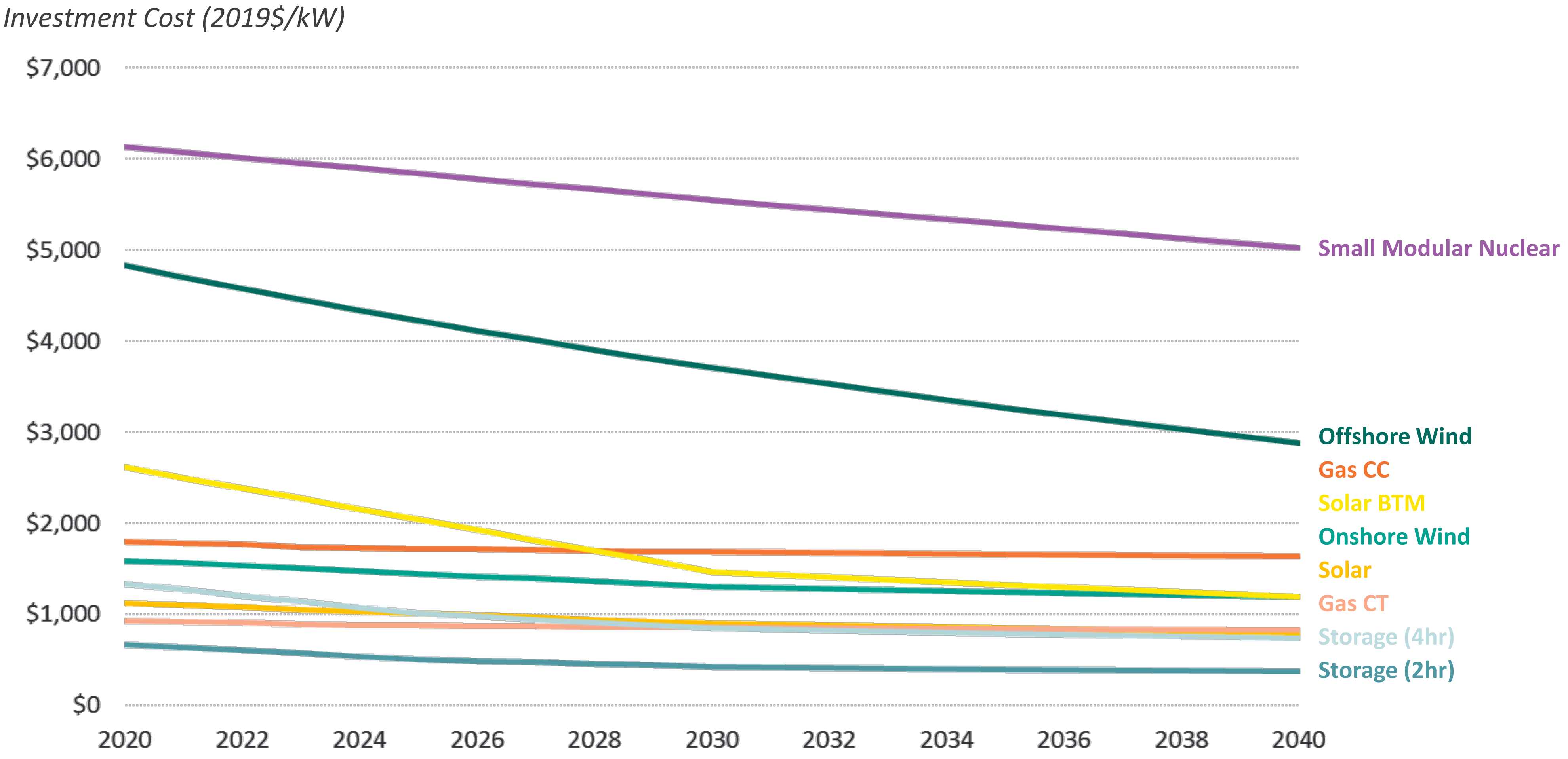
New generators and storage

- **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
- Downstate costs higher, per EIA and DCR

	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%

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

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

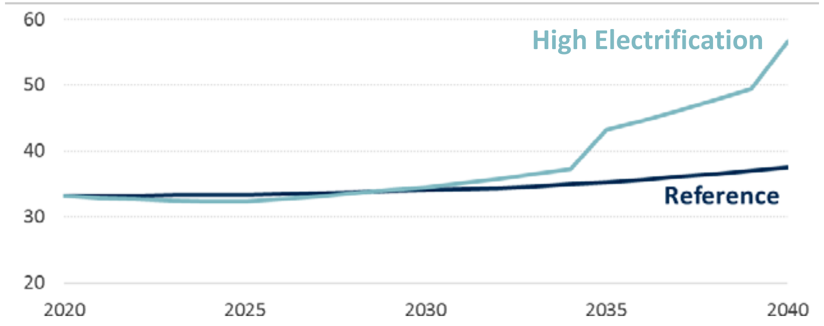
Load forecasts

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

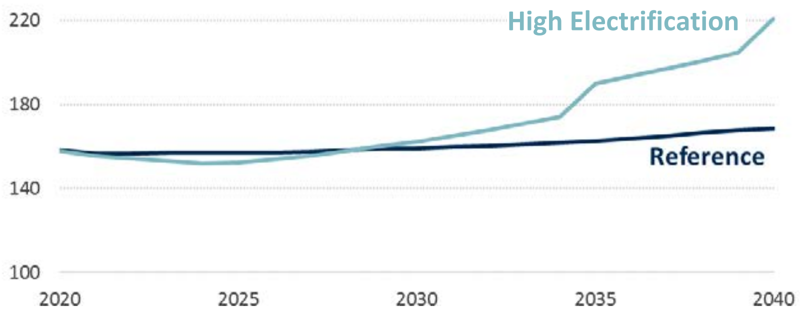
- **Reference Case:** Gold Book assumptions plus 0.7 ^{o}F warming per decade
- **High Electrification Case:** Aggressive electrification and energy efficiency

Gross Load Forecast

Annual Peak (GW)



Annual Energy (TWh)



Components of 2040 Gross Load

Annual Energy (TWh)

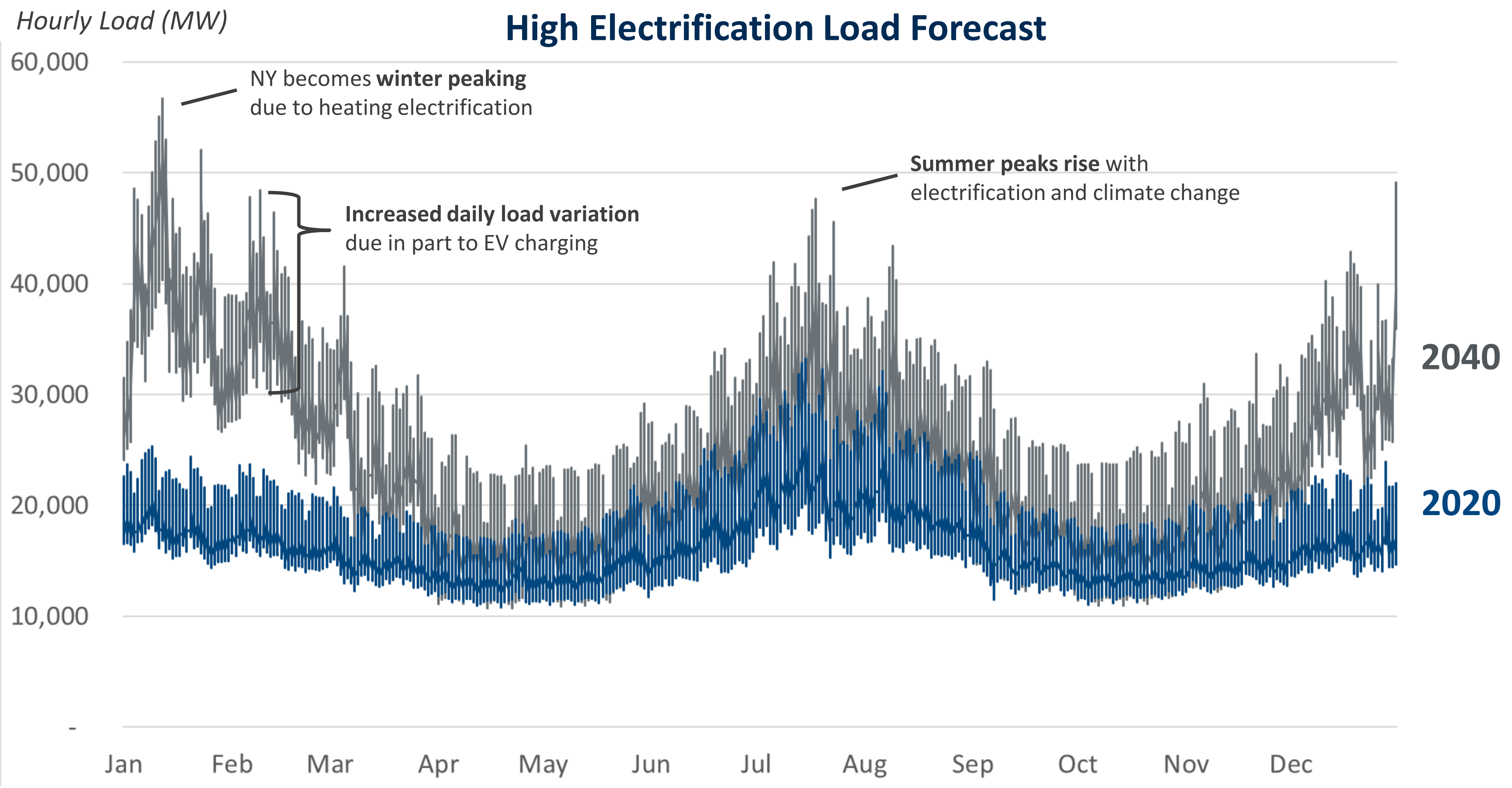
	Reference Case	High Electrification Case
Base load ***(excluding energy efficiency)***	156	175
EV adoption	13	16
Additional electrification	--	76
Energy efficiency	--	-46
Total 2040 gross load	169	221

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.

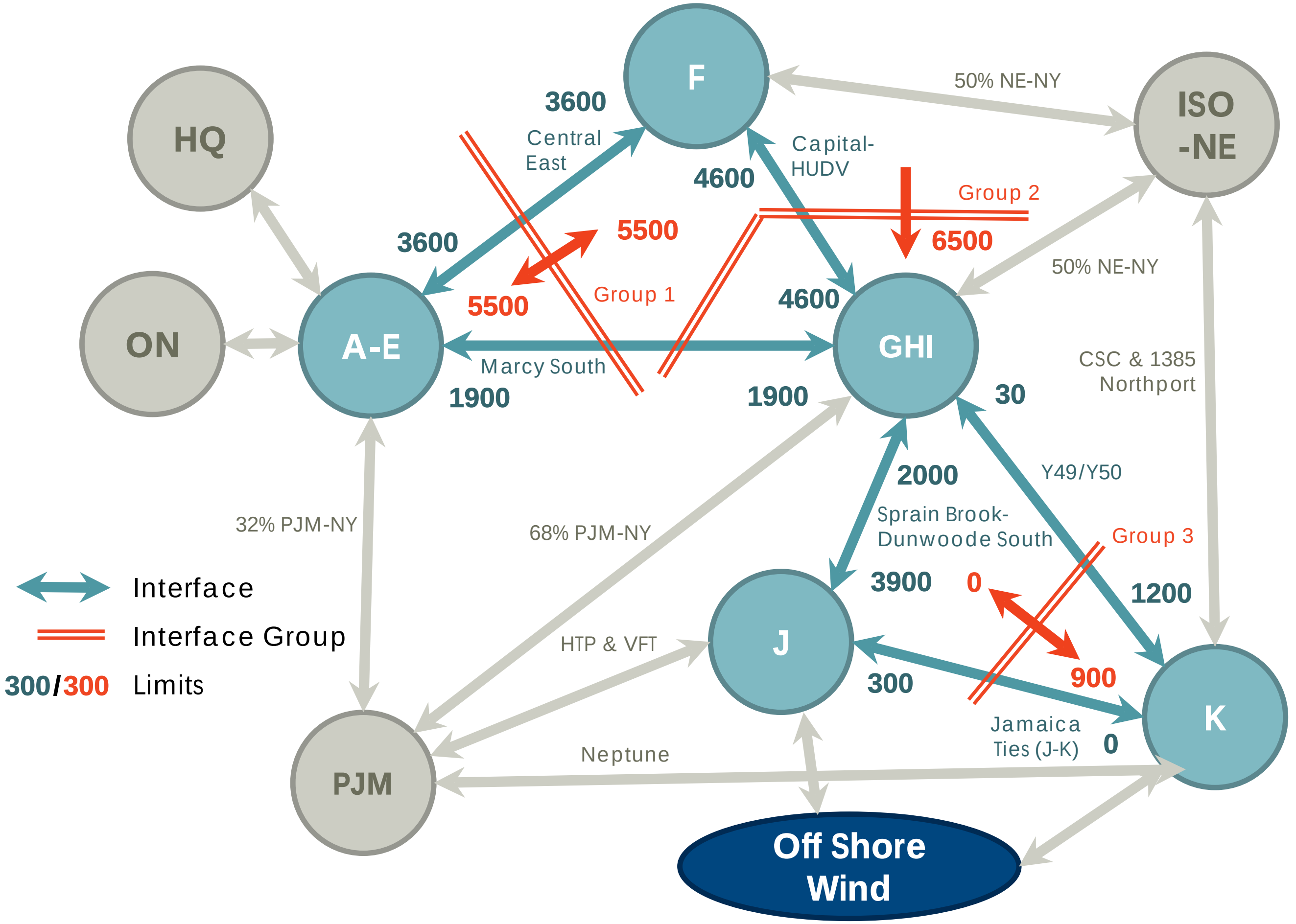


Sources and Notes:
Load forecasts from Climate Change and Resilience Study - Phase I, ICAP WG December 17, 2019.

Transmission Assumptions

Transmission topology

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



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.

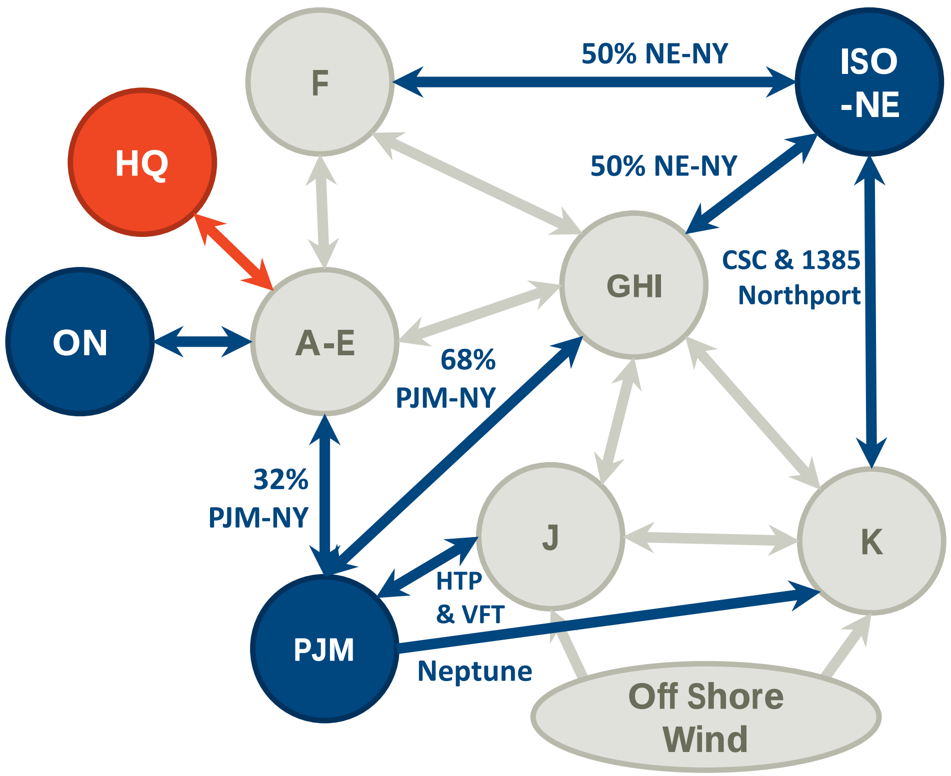
Hydro Quebec modeled as flexible

- 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 each year

We select and weight representative days for each year to reflect NYISO's forecasted hourly net demand.

Identify 30 days to represent a year's variety of conditions

- 30 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 across years

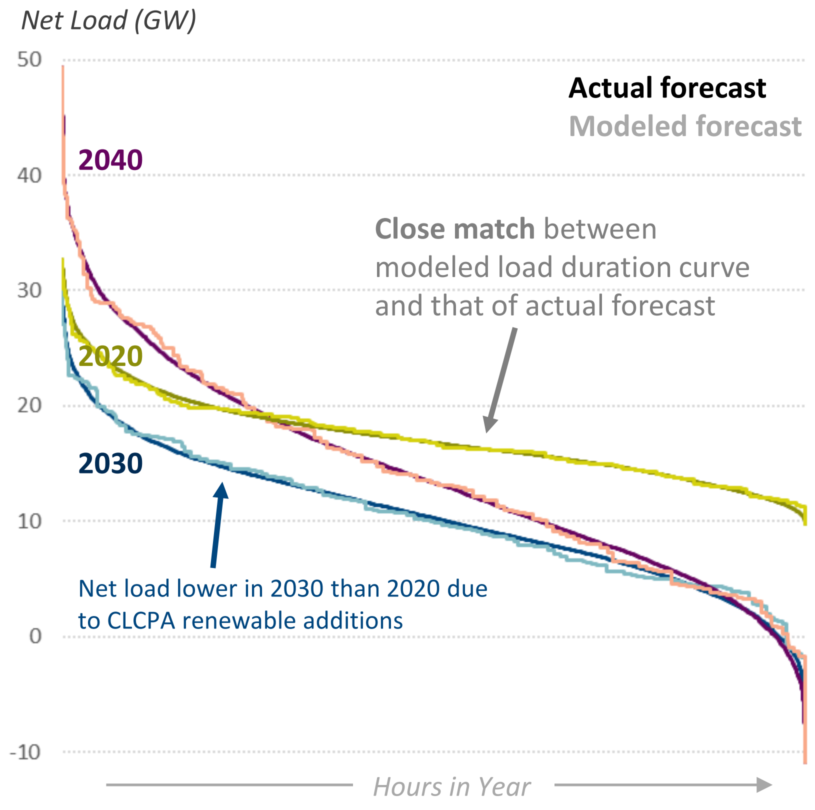
Each year, we select and weight new representative days to capture evolving net load shapes.

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

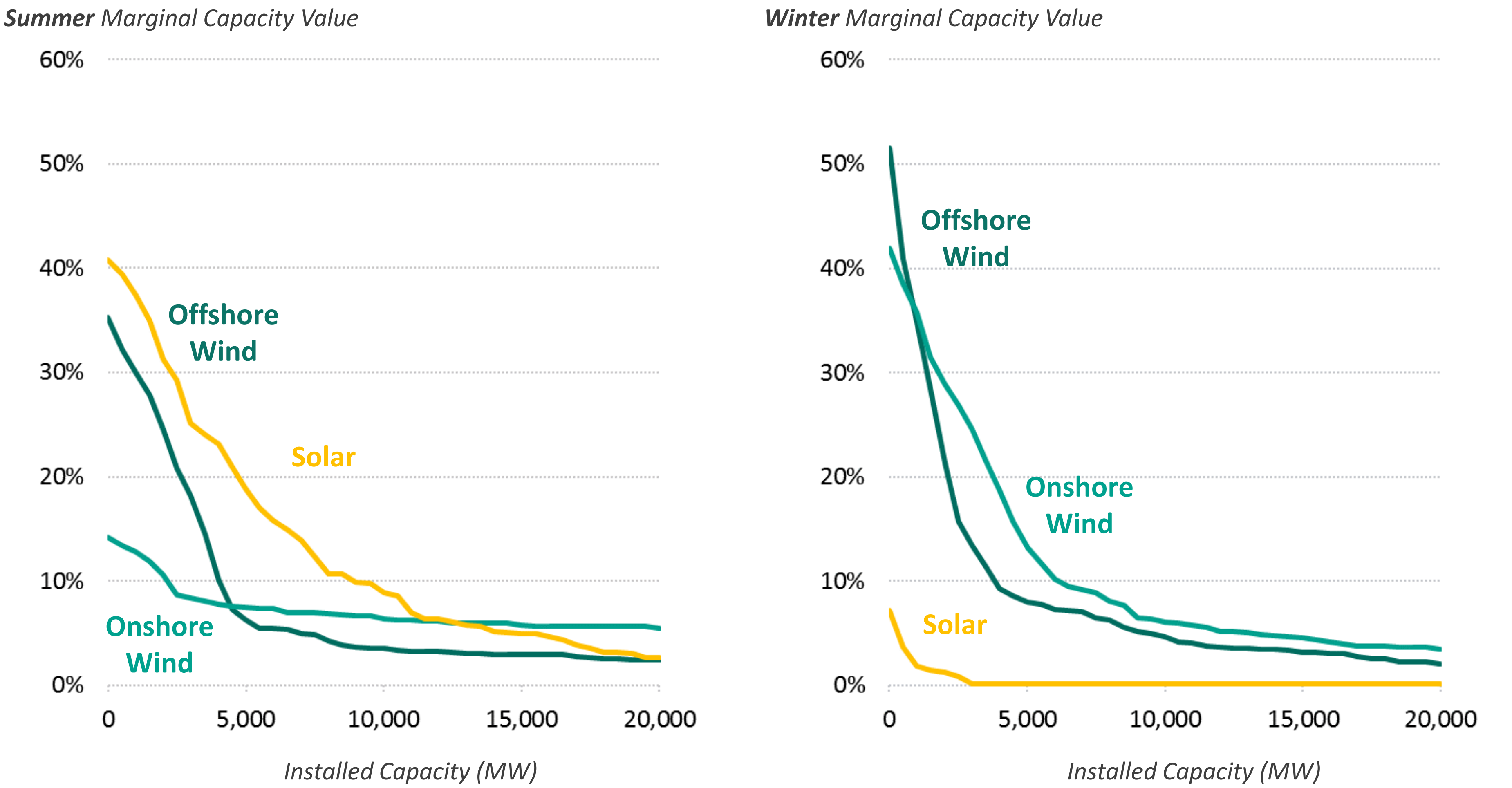
- Does not account for **variability in conditions across many years**, like GE MARS
- Does not account for impacts of **internal transmission constraints**

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

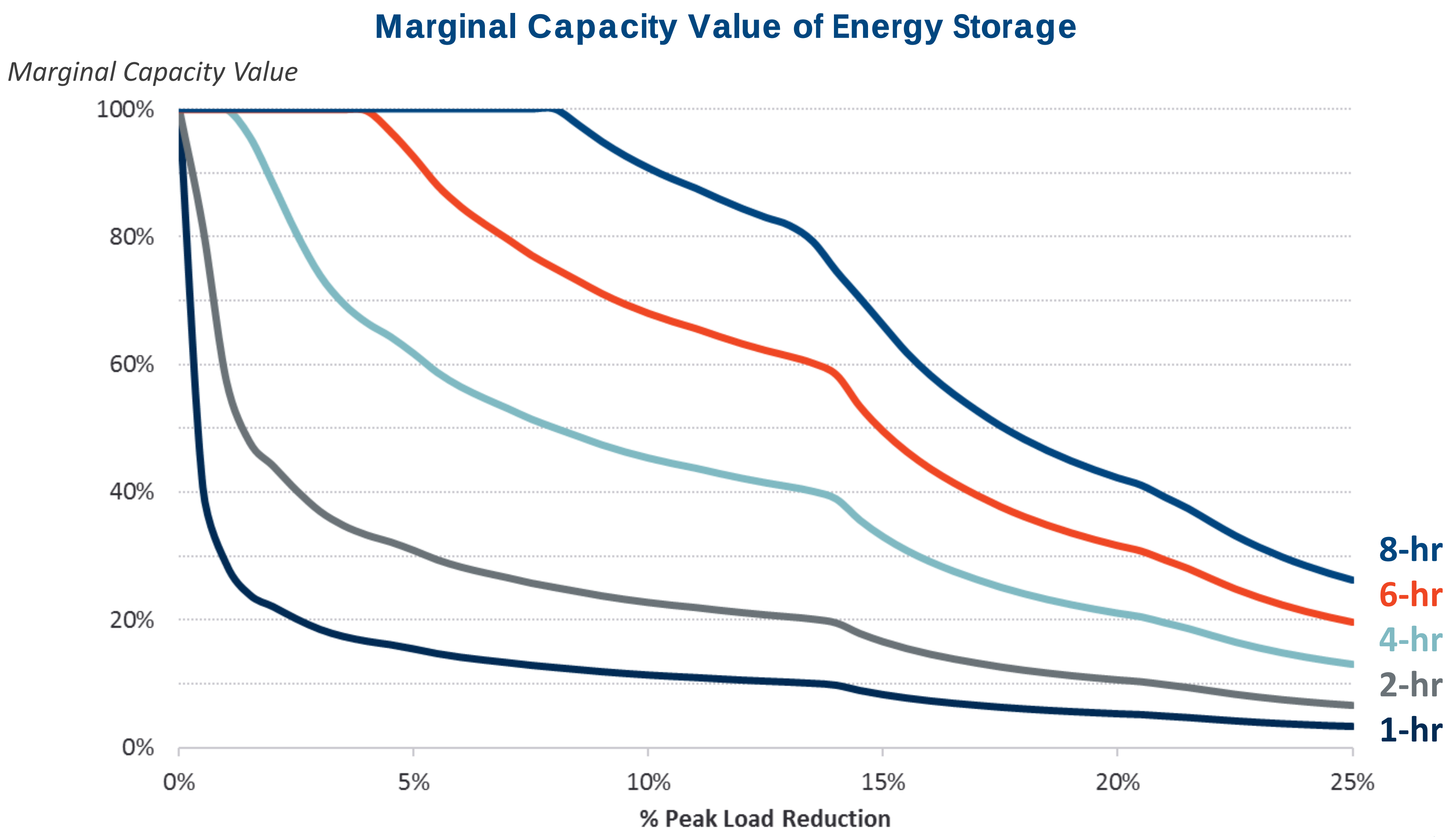
Supply Resource	Concept	Methodology
Wind and Solar Resources	Generation of new wind and solar additions is correlated with previously deployed resources. New resources therefore provide less marginal capacity value than previously added resources.	1. Across 8760 hours, identify 20-100 top NYCA net load 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



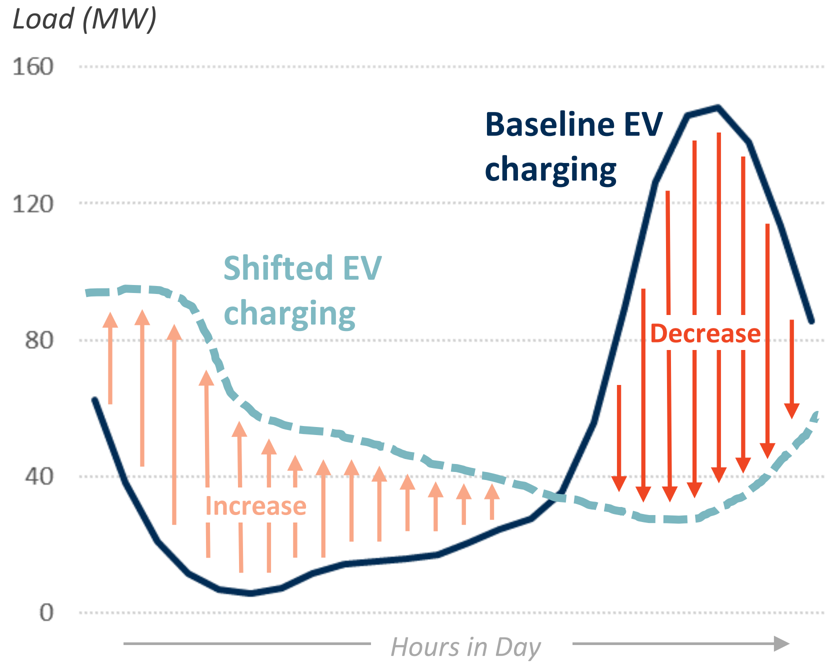
Capacity value of storage



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 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

Example of Electric Vehicle Flexibility



Renewable natural gas (RNG)

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

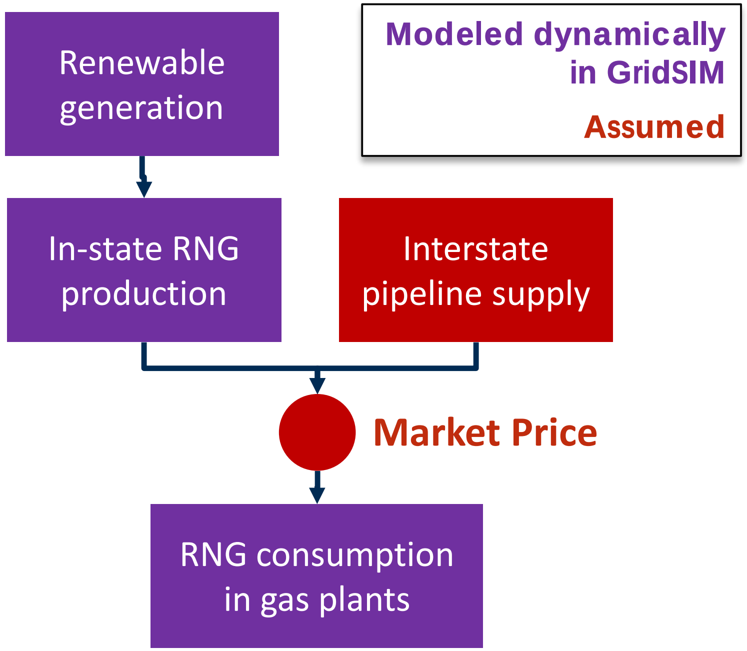
- In this context, RNG refers to gas created via electrolysis + methanation
  - Can also refer to methane from agriculture or landfills
- Producing RNG is a multi-step process
  - **Electrolysis** utilizes grid electricity (likely curtailed renewables) to create hydrogen
  - **Direct air capture** uses 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** informed by the costs of production and with a buy/sell price spread to account for transmission and pipeline charges

Treatment of RNG in GridSIM



RNG production

- GridSIM builds and operates RNG production capacity if revenues from RNG sales exceed the plant's levelized investment costs and RNG production costs (including costs of electricity).
- Note: RNG is utilized for the purposes of this analysis solely as a proxy for potential future zero-emission technology development.

Cost Assumption	Value in 2040 *(2020 dollars)*	Description
Capital Cost	$1,080/kW* ($101/kW-yr levelized)	• Future **electrolyzer** and **methanizer** costs are estimated from 2020 costs and projected cost declines in the future
Fixed Cost	$4/kW-yr	• Assumed as 4% of capital costs
Non-Electric Variable Cost	$10/MWh	• **CO_2**: CO_2 is an input for methanation. We assume CO_2 is captured from industrial processes (e.g., cement) and directly from the air at an average cost of $62/ton. • **Hydrogen storage**: We assume hydrogen is stored between the electrolysis and methanation. Cost of hydrogen storage assumed to be $1.6/MMBtu.
Electric Variable Cost	Endogenous to model	• Cost of electricity to power electrolysis and methanation • Includes cost of electricity and purchase of RECs to cover load
Market Price for RNG	$38/MMBtu	• Plants sell RNG at a regional market price. Market price determined using same cost assumptions and an average electricity price of $37.5/MWh.

* All Watt-based units are in terms of the electrical load of the RNG production plant

Detailed generator assumptions

Type	New/Existing	EFORd *(%)*	Heat Rate *(MMBTU/MWh)*	Minimum Generation Level *(% of ICAP)*	Startup Cost *$/MW-start*	Variable O&M *($/MWh)*	FOM & Capex *($/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%