New York's Evolution to a Zero Emission Power System

MODELING OPERATIONS AND INVESTMENT THROUGH 2040

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THE Brattle GROUP

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Note: Updated on 5/18 from initial posting with minor adjustments to text and formatting, no substantive changes.

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
- **Key Issues in Decarbonizing Systems:** Meeting demand in low wind and solar periods
- **Analytical Approach:** Modeling the grid's evolution with GridSIM
- **Insights into the Future New York Fleet**
  - **Evolution of the Grid through 2040**
  - **Stages of Decarbonization:** Fleet composition and operations in 2024, 2030, and 2040
  - **Effects of Electrification:** Comparison of high electrification and reference load cases
- **Alternative Scenarios and Next Steps**

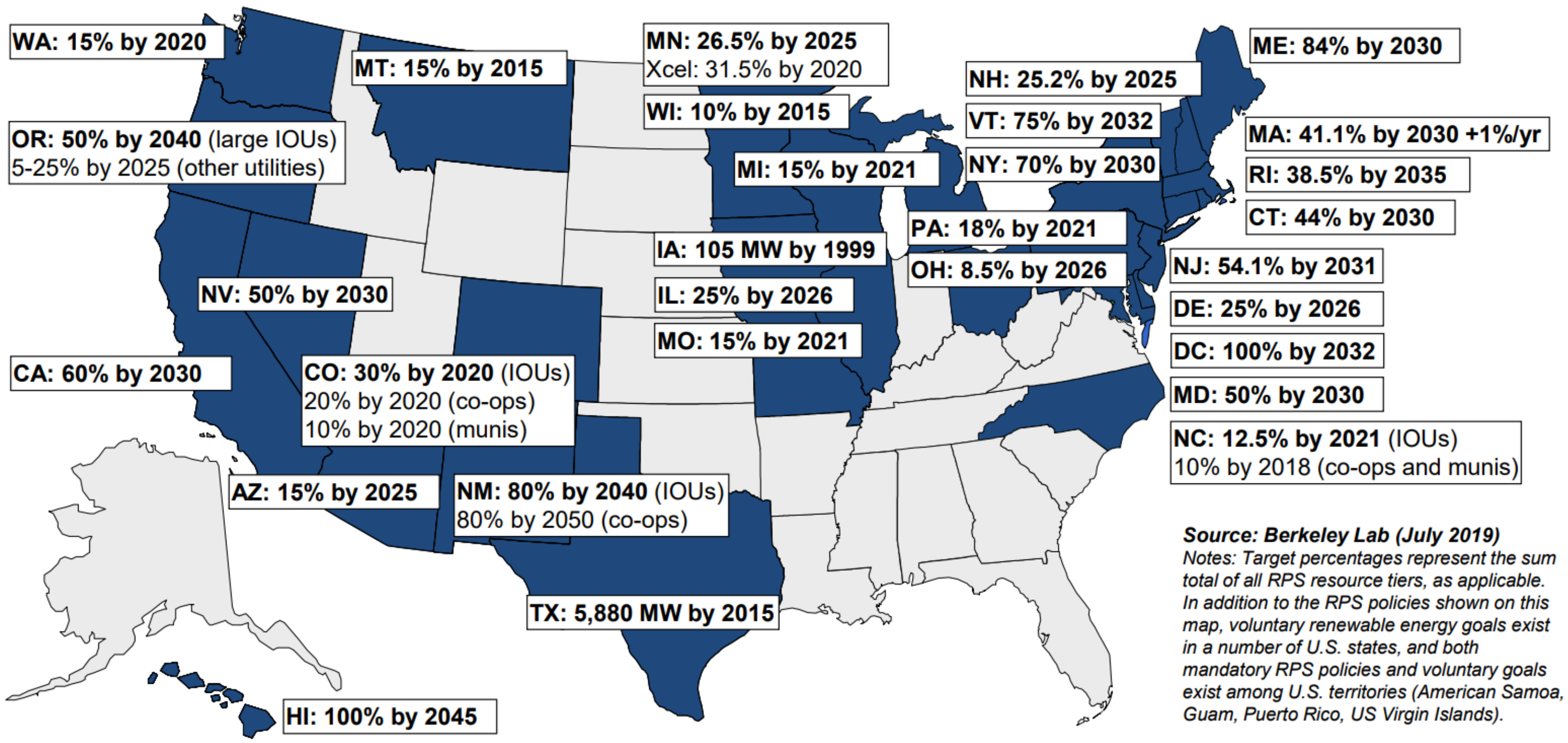
The Policy Context

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

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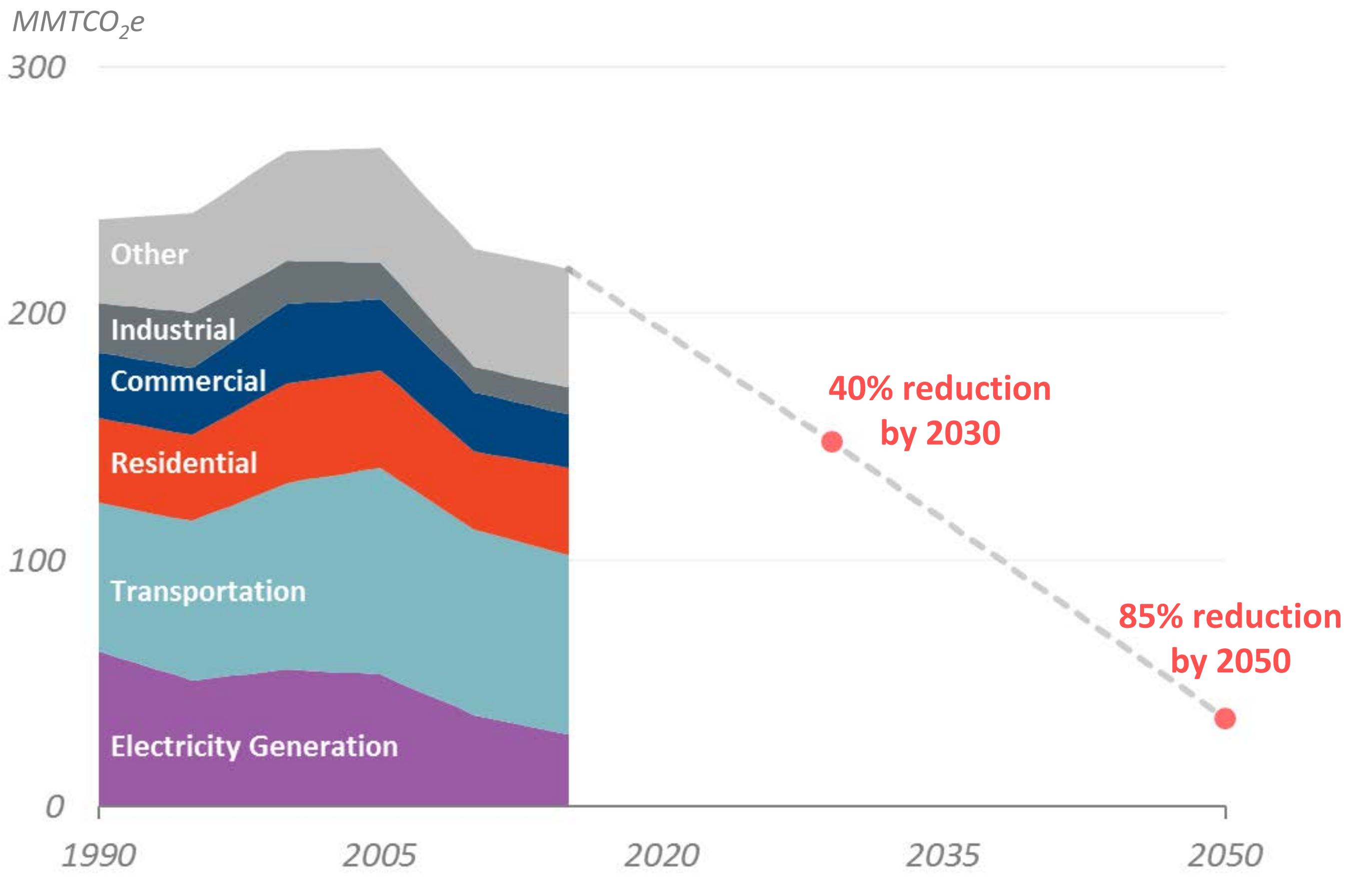
New York's economy-wide decarbonization trajectory

- 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

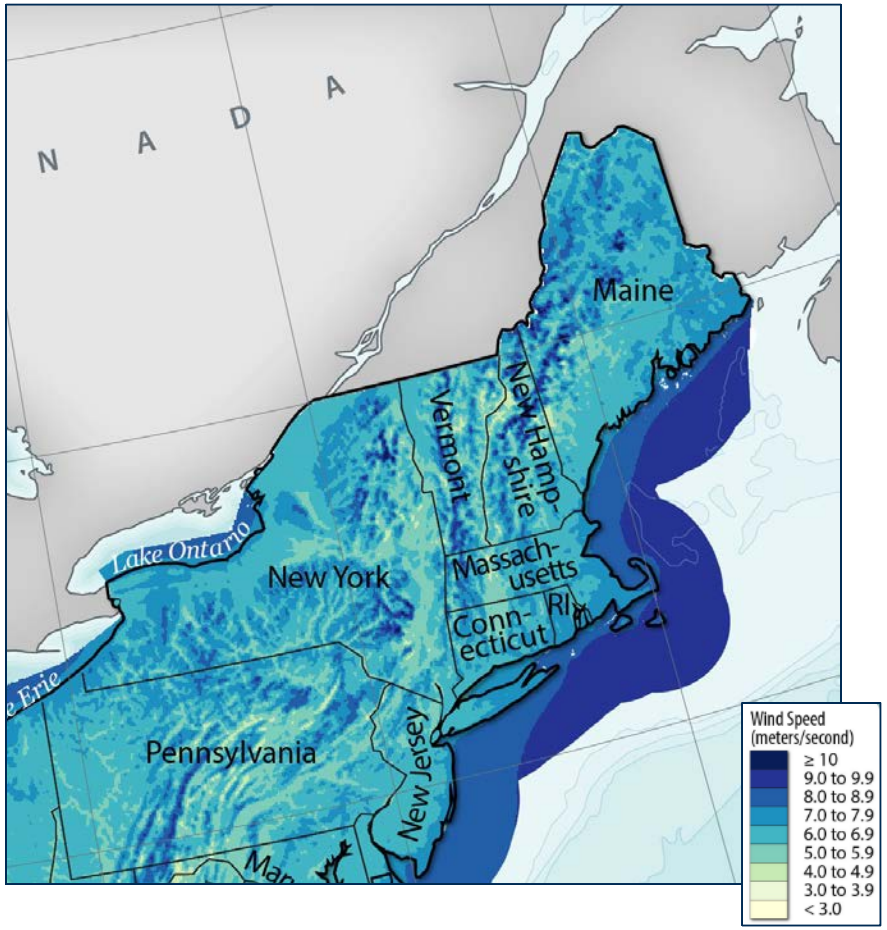
Challenge: Meeting demand when wind and solar are low, hour-to-hour and seasonally

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

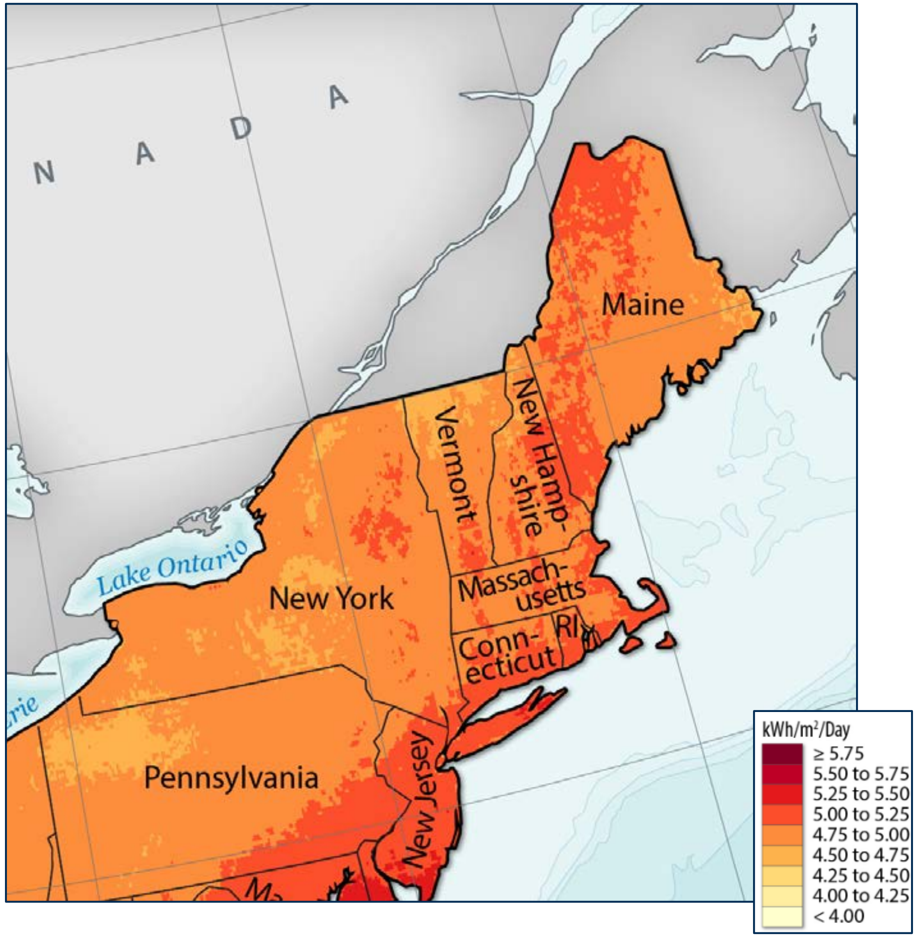
Wind Resources

Average Annual Wind Speed 100 Meters Above Surface Level



Solar Resources

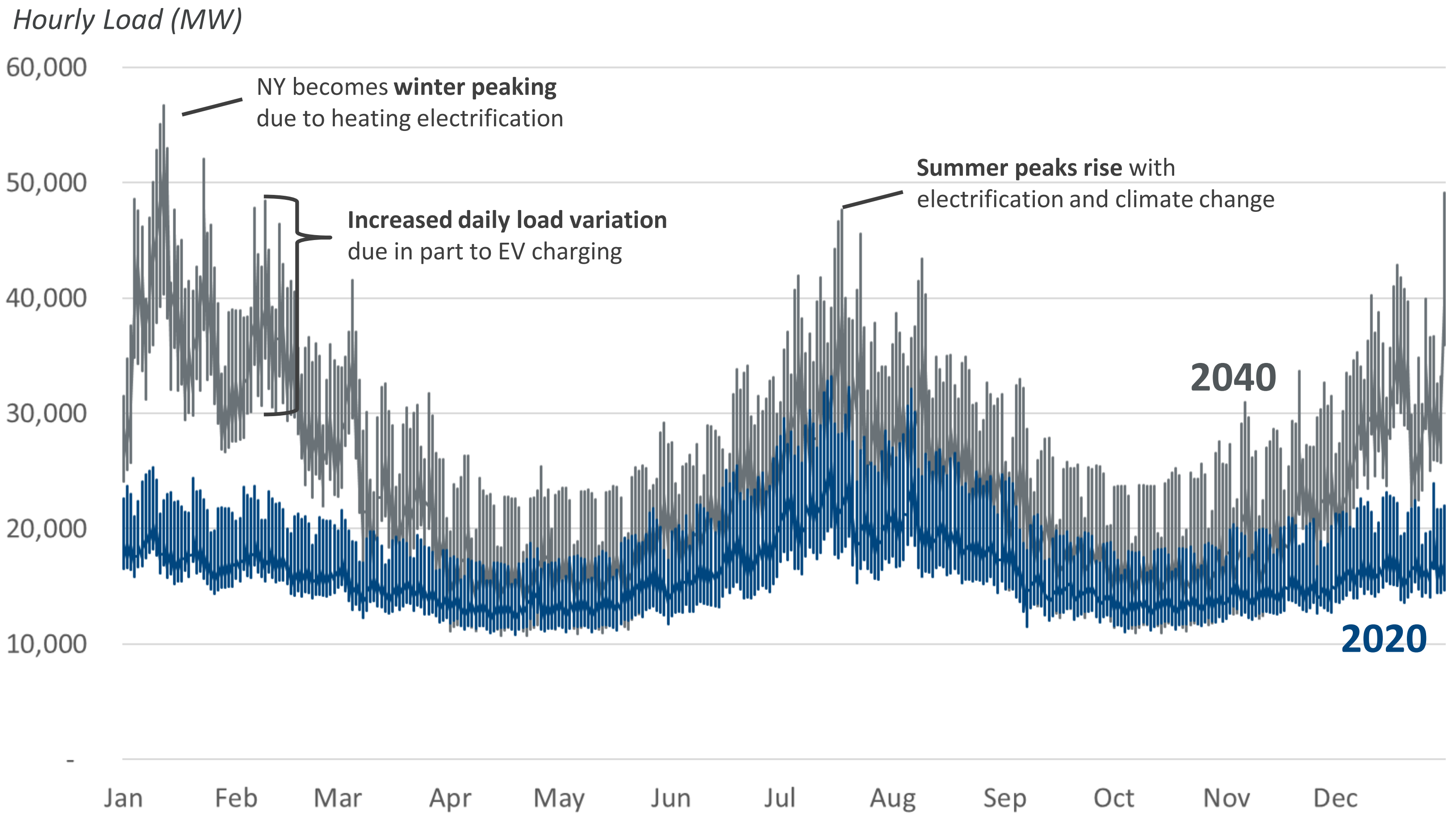
Global Horizontal Solar Irradiance in April



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

Growing loads will enable the economy's 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.

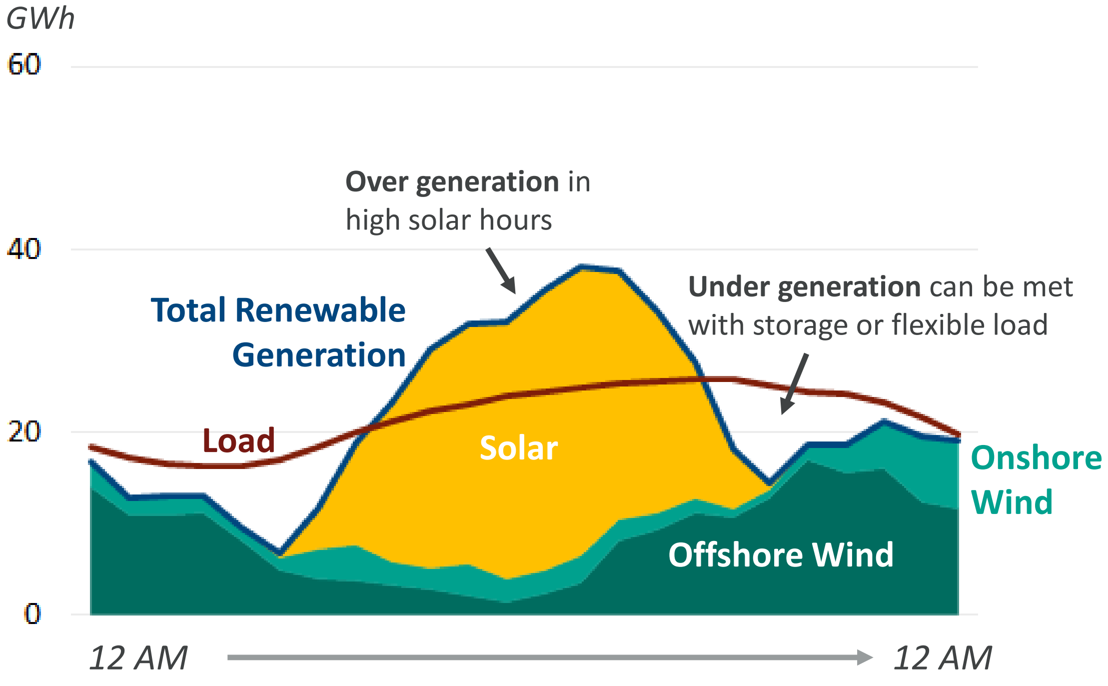
Flexibility needed to always balance supply and demand when wind and solar are low

- **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 more 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.

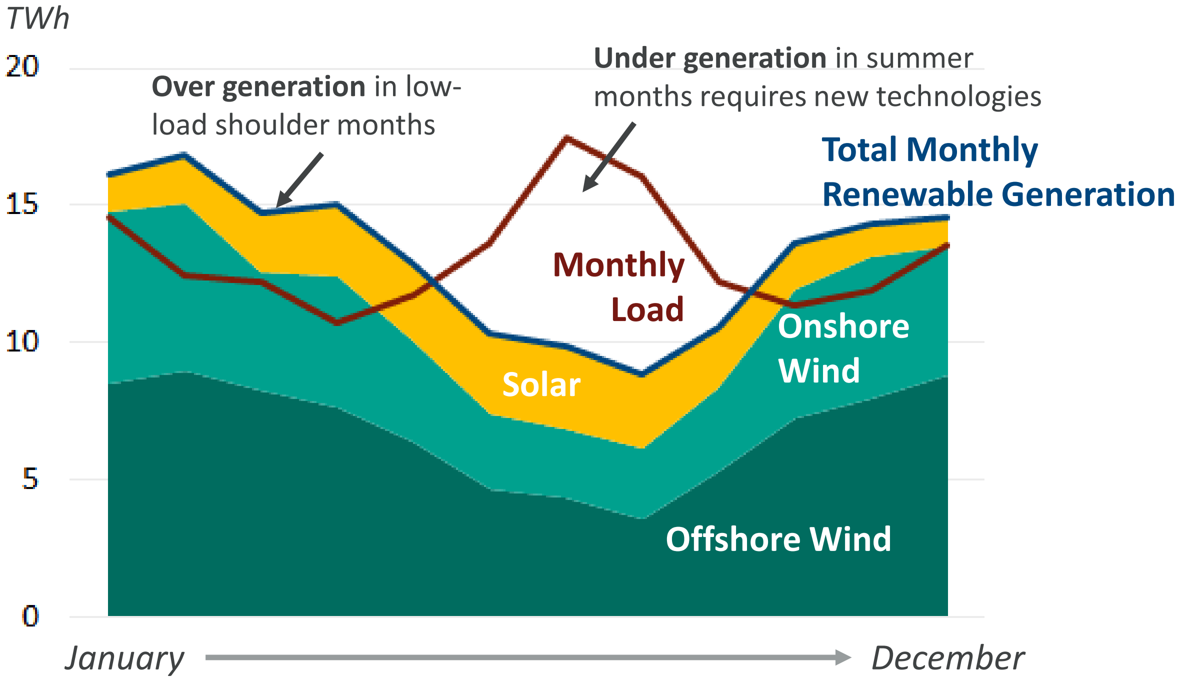
The balancing challenge is across multiple timescales

Hourly Balancing Challenge



Batteries and load flexibility can provide short-term balancing.

Seasonal Balancing Challenge



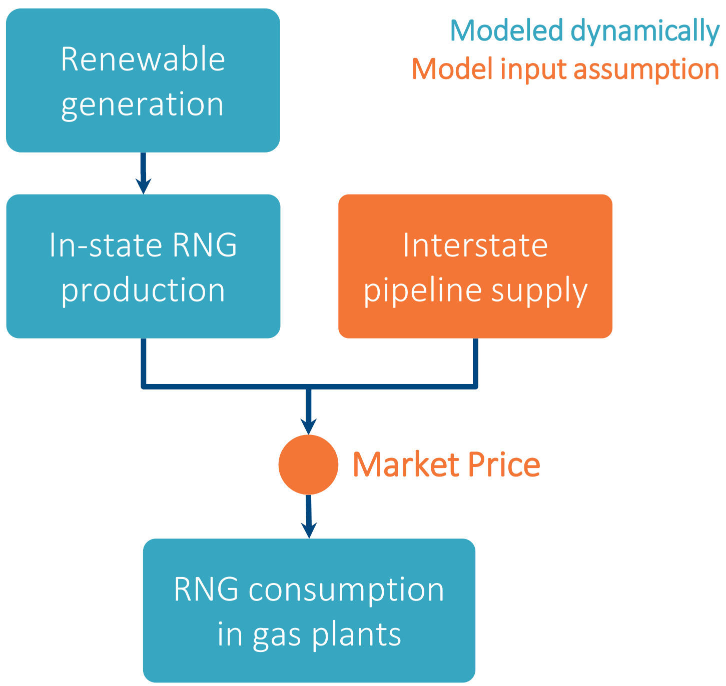
Seasonal balancing is the more difficult challenge, requiring new technologies such as seasonal storage or zero-emission dispatchable generation.

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.

Treatment of Renewable Natural Gas in GridSIM



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 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

gridSIM

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 Brattle GROUP

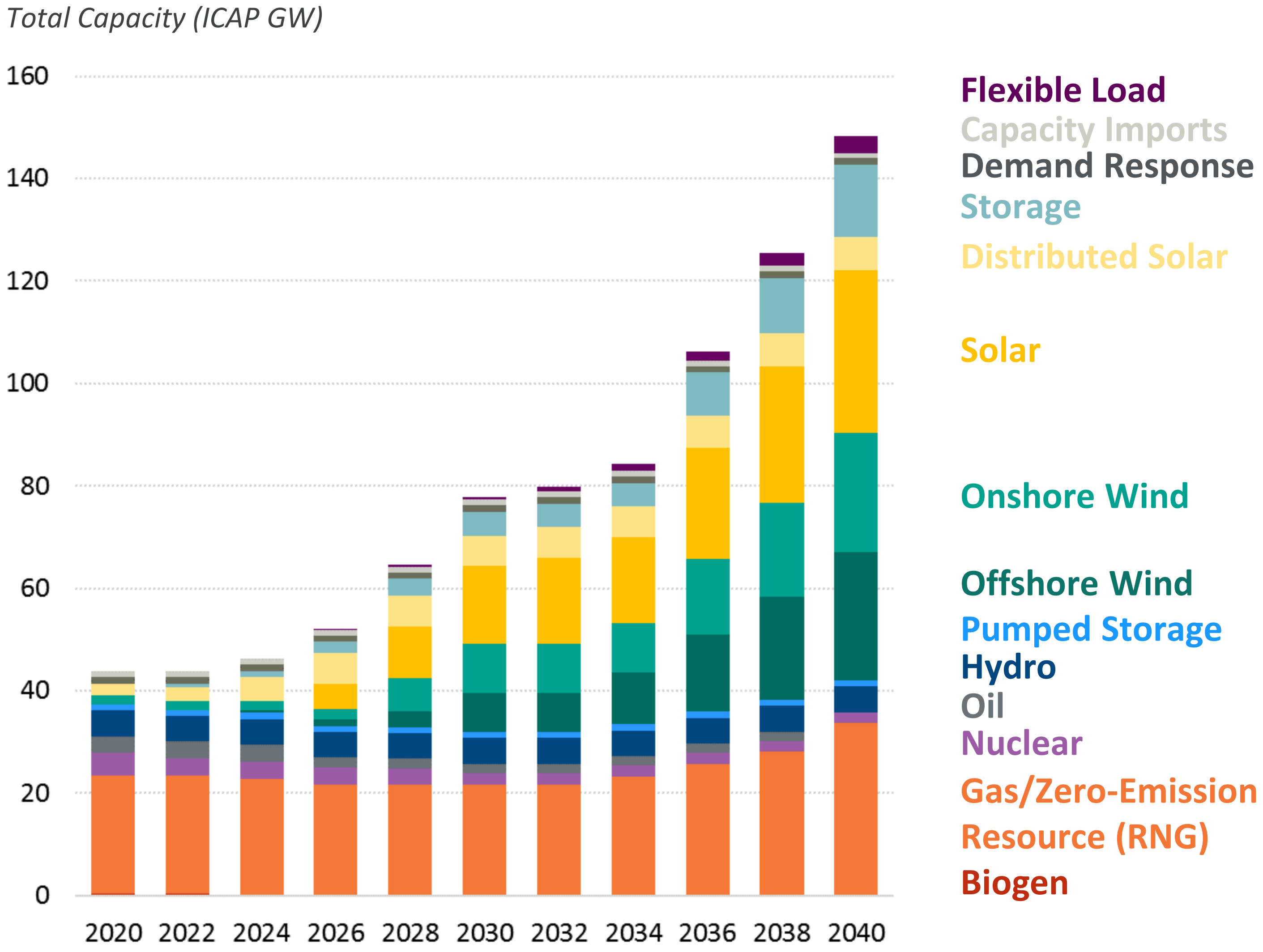
The value of modeling the grid’s evolution

The value in studying the future grid is not the ability to predict very particular resource mix scenarios.

Rather, the value is providing illustrative outcomes of how the grid may evolve 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 (RNG):** Prior gas-fired generators converted to produce using zero-carbon fuel sources in 2040.

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

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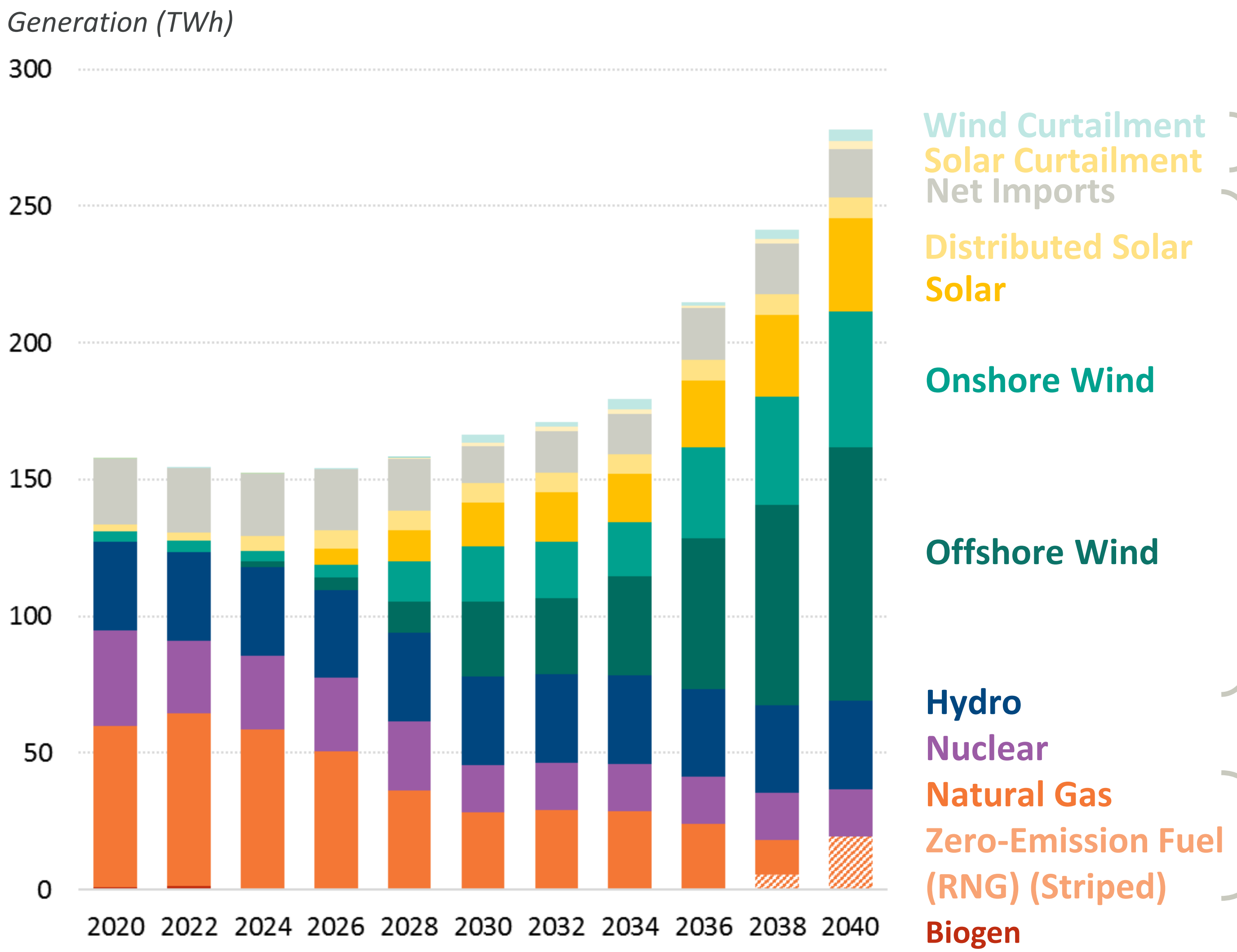
The transition to zero emissions generation



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)

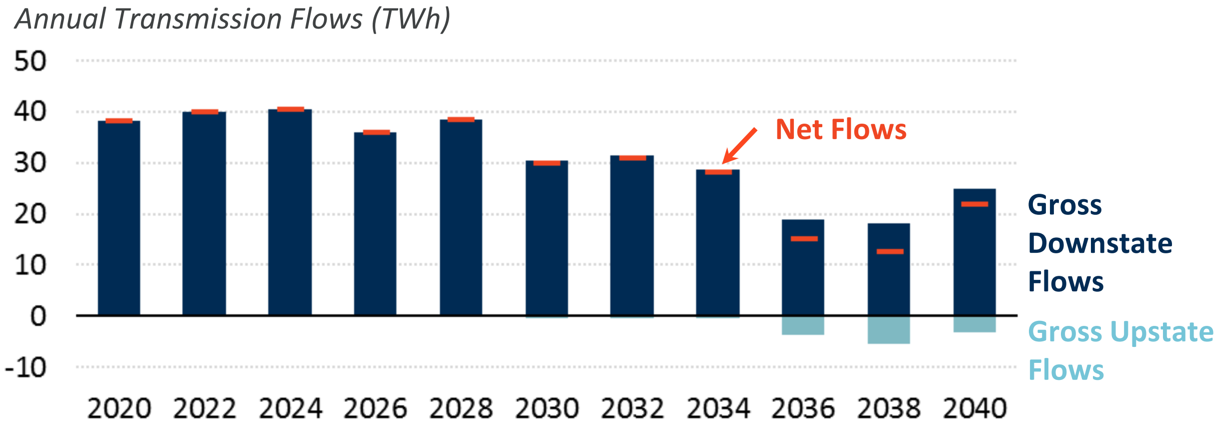
Transmission flows reflect an evolving fleet

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

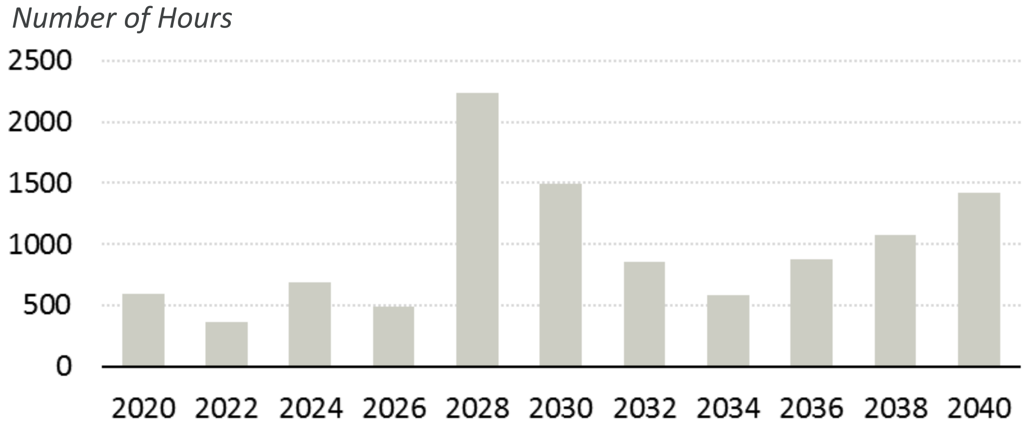
In the future, flow patterns become more variable, with flows occasionally reversing direction.

The frequency of constrained hours southbound generally increases.

Gross Annual Upstate/Downstate Flows



Number of Hours with Constrained Downstate Flows



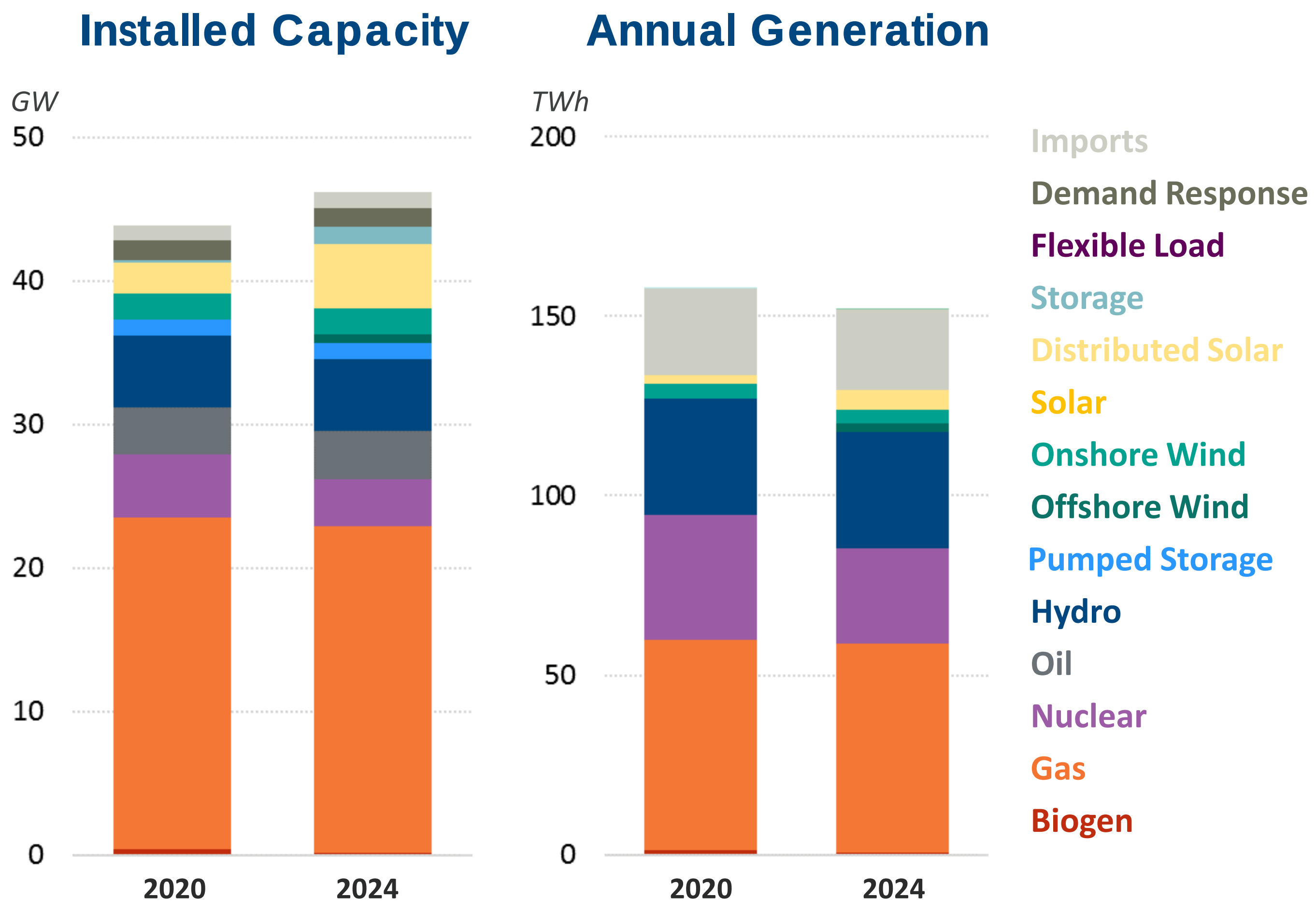
Notes: Measured as total flows between A-E and neighboring zones (GHI and F)

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

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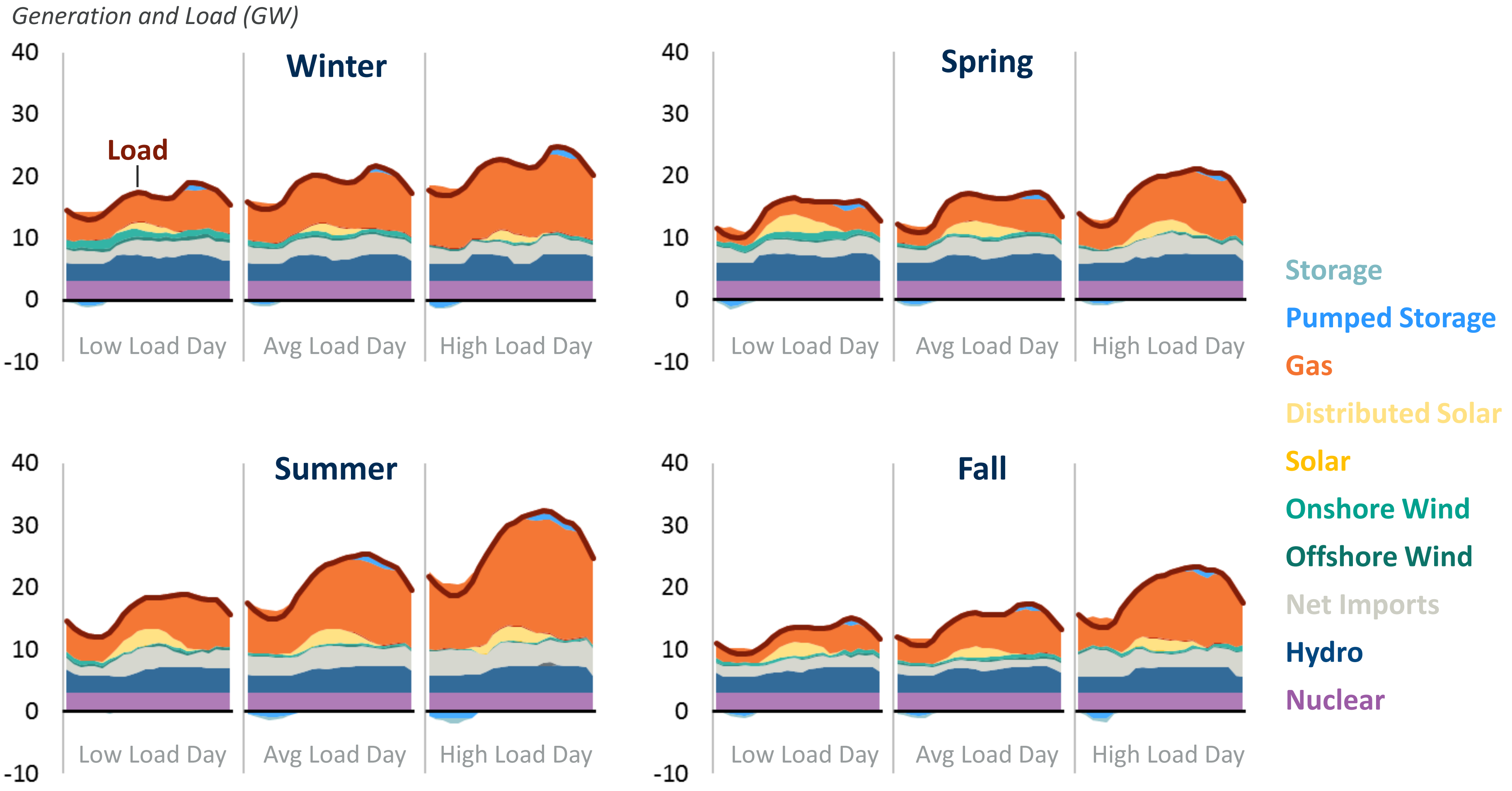
Near term (2024): Supply mix and operations similar to today

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



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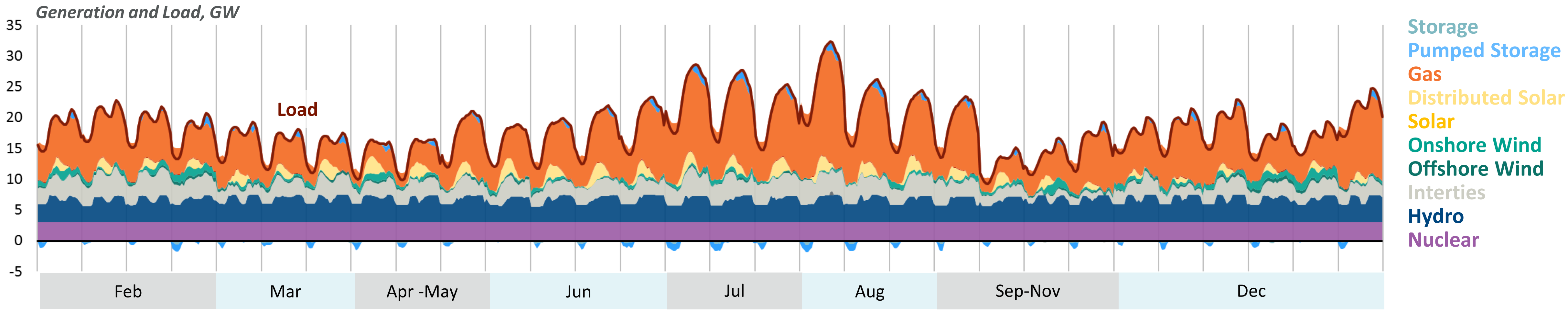
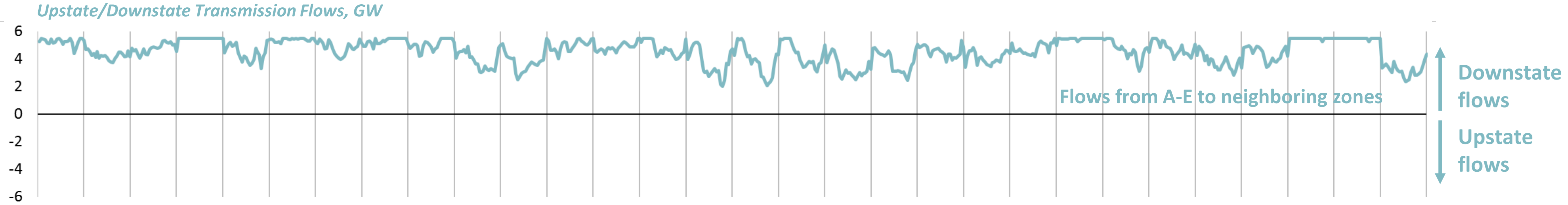
STAGES OF DECARBONIZATION

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

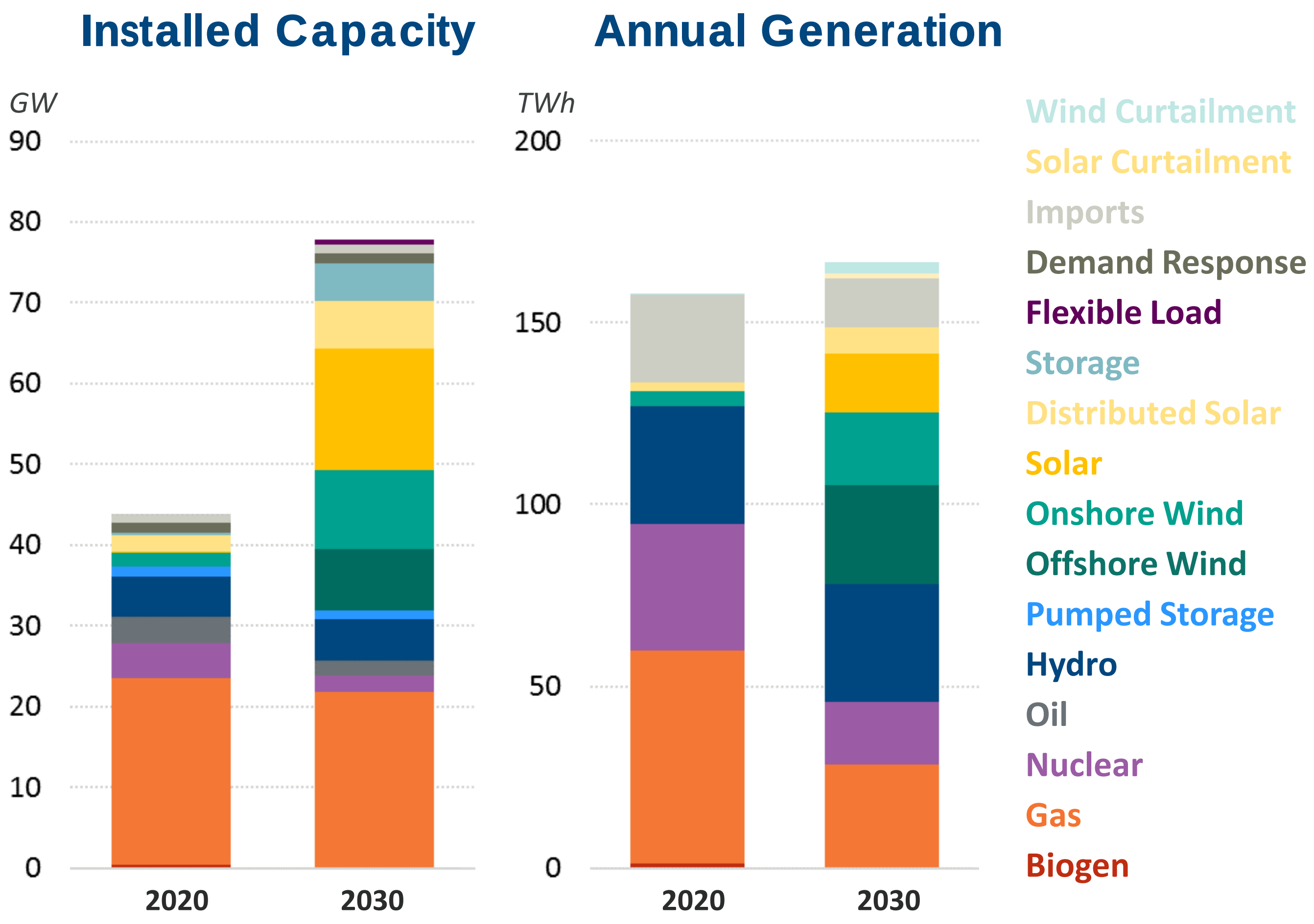
Hourly operations across 30 representative days





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.

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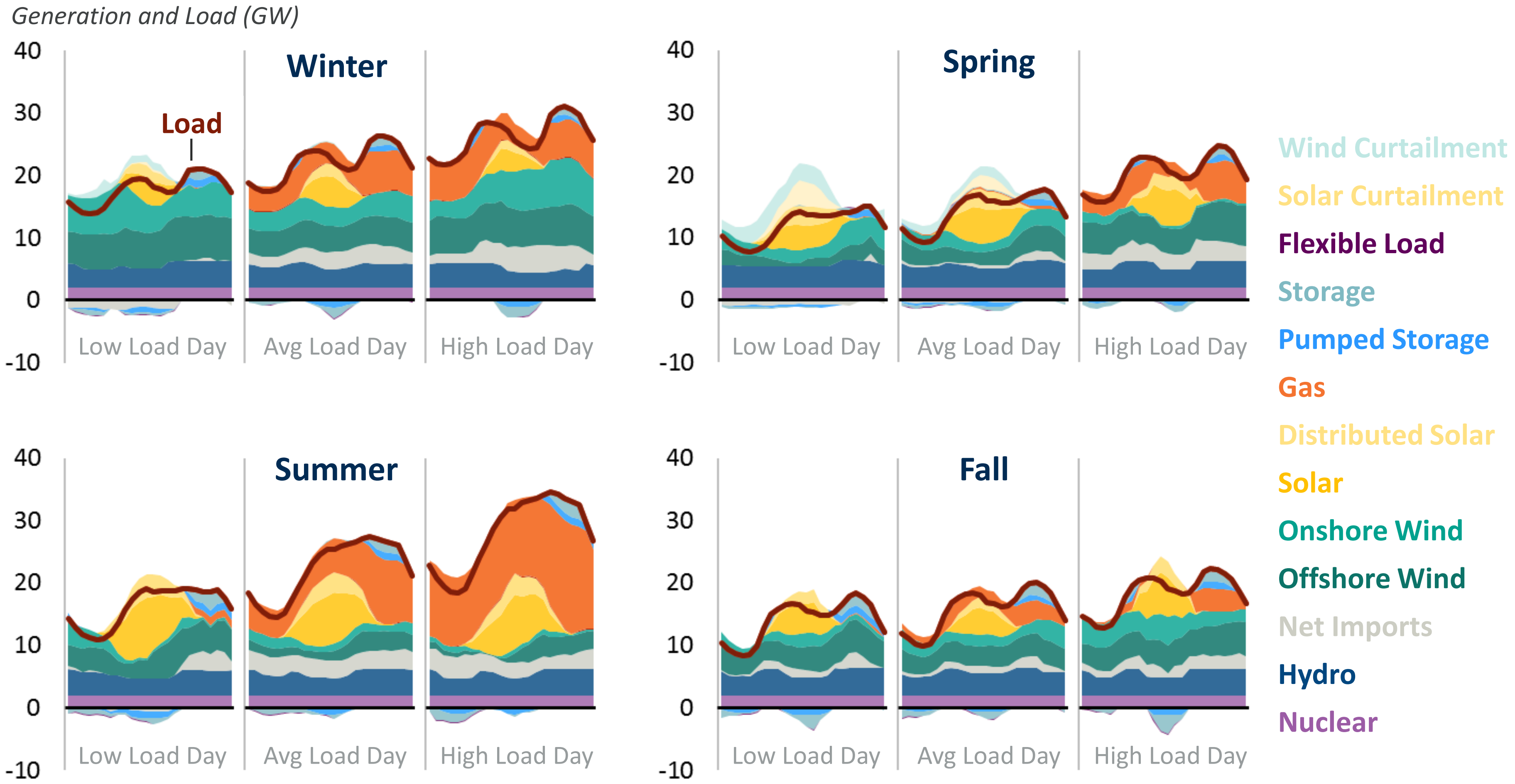
Mid-term (2030): Managing a 70% renewable system

Seasonal supply and demand patterns

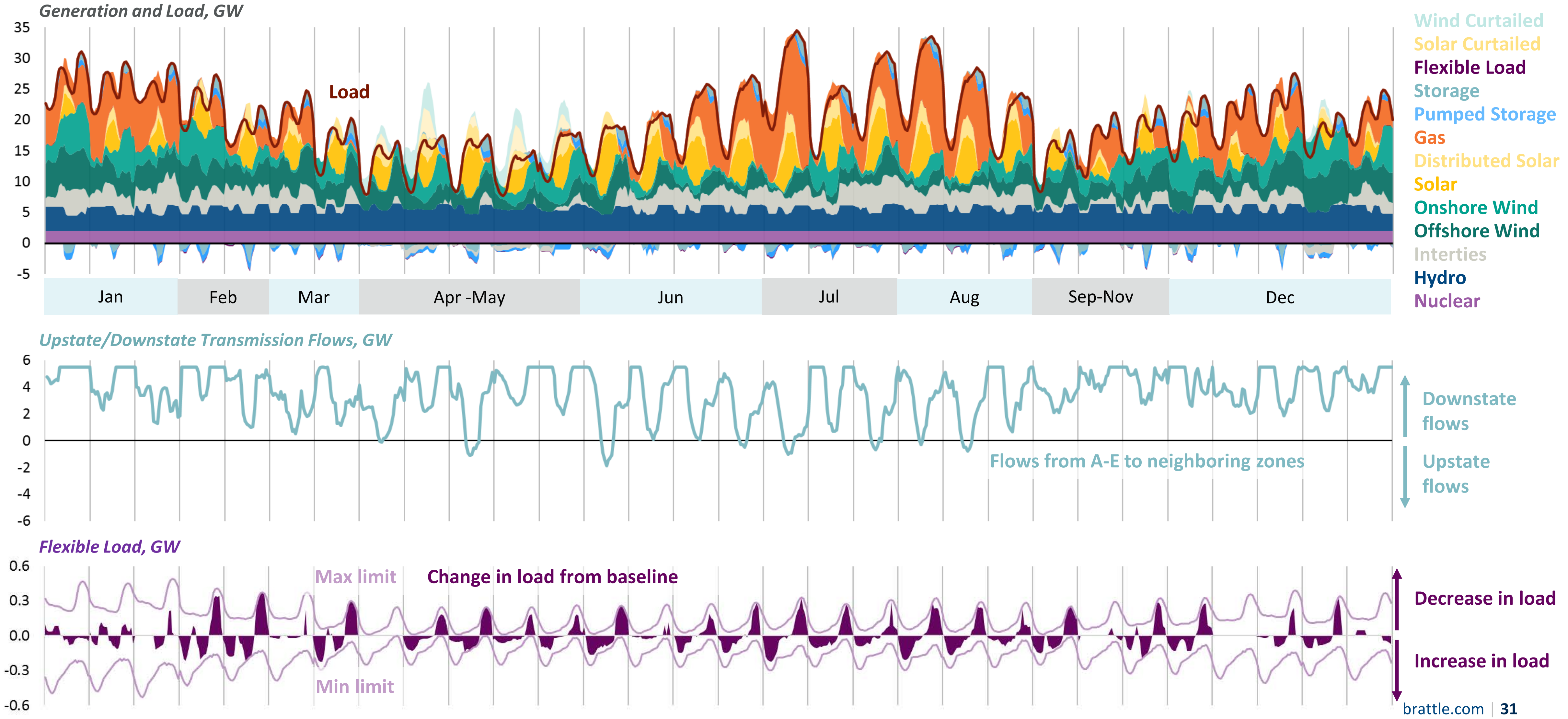
- **Demand**
  - System remains summer peaking
  - Storage charging generally coincident with solar generation
- **Generation**
  - Occasional wind and solar curtailment, predominantly in spring
  - Gas is the marginal resource in most winter, summer, and fall hours

Hourly Operations, by Season



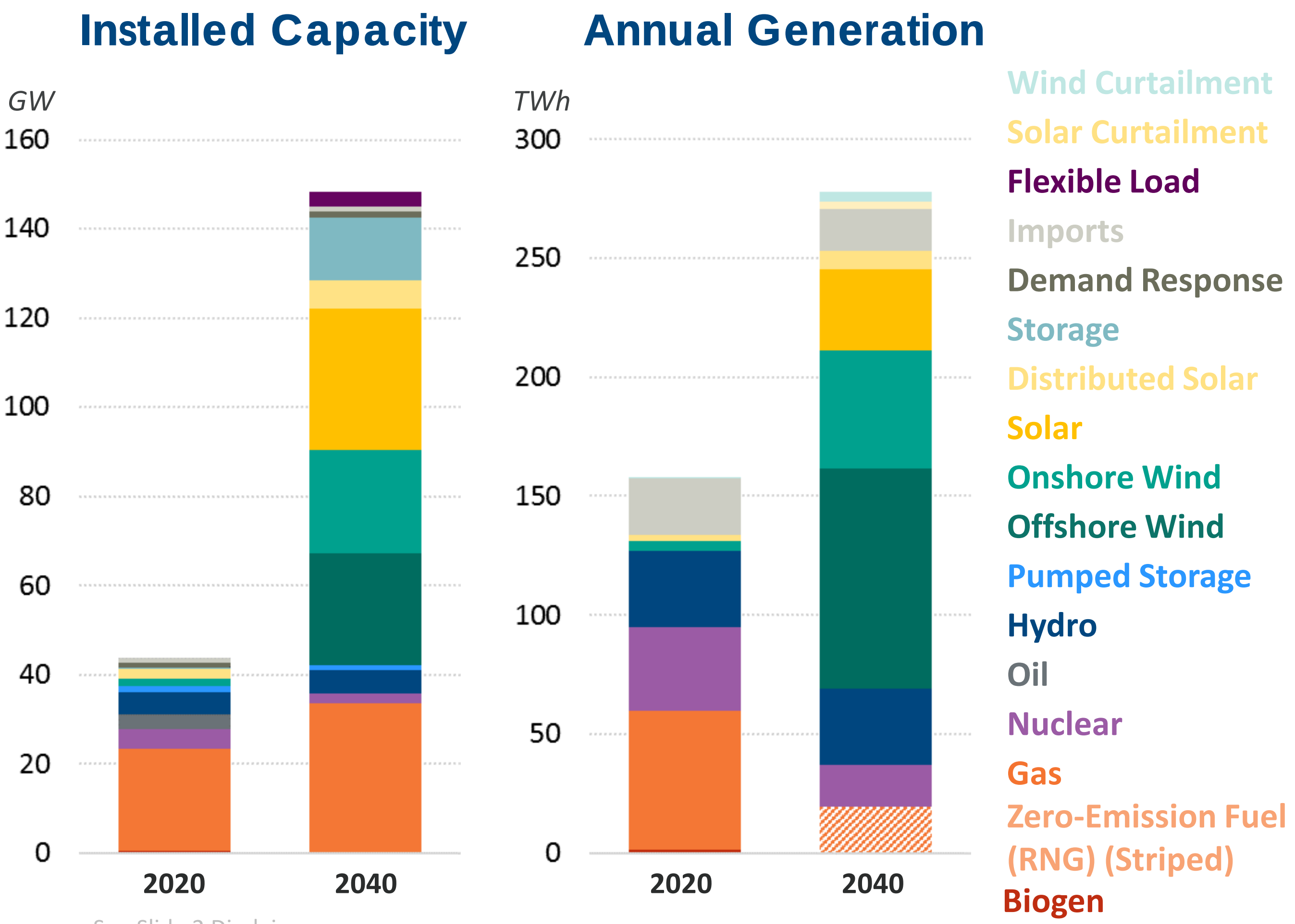
Mid-term (2030): Managing a 70% renewable system

Hourly operations across 30 representative days



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

Resource mix



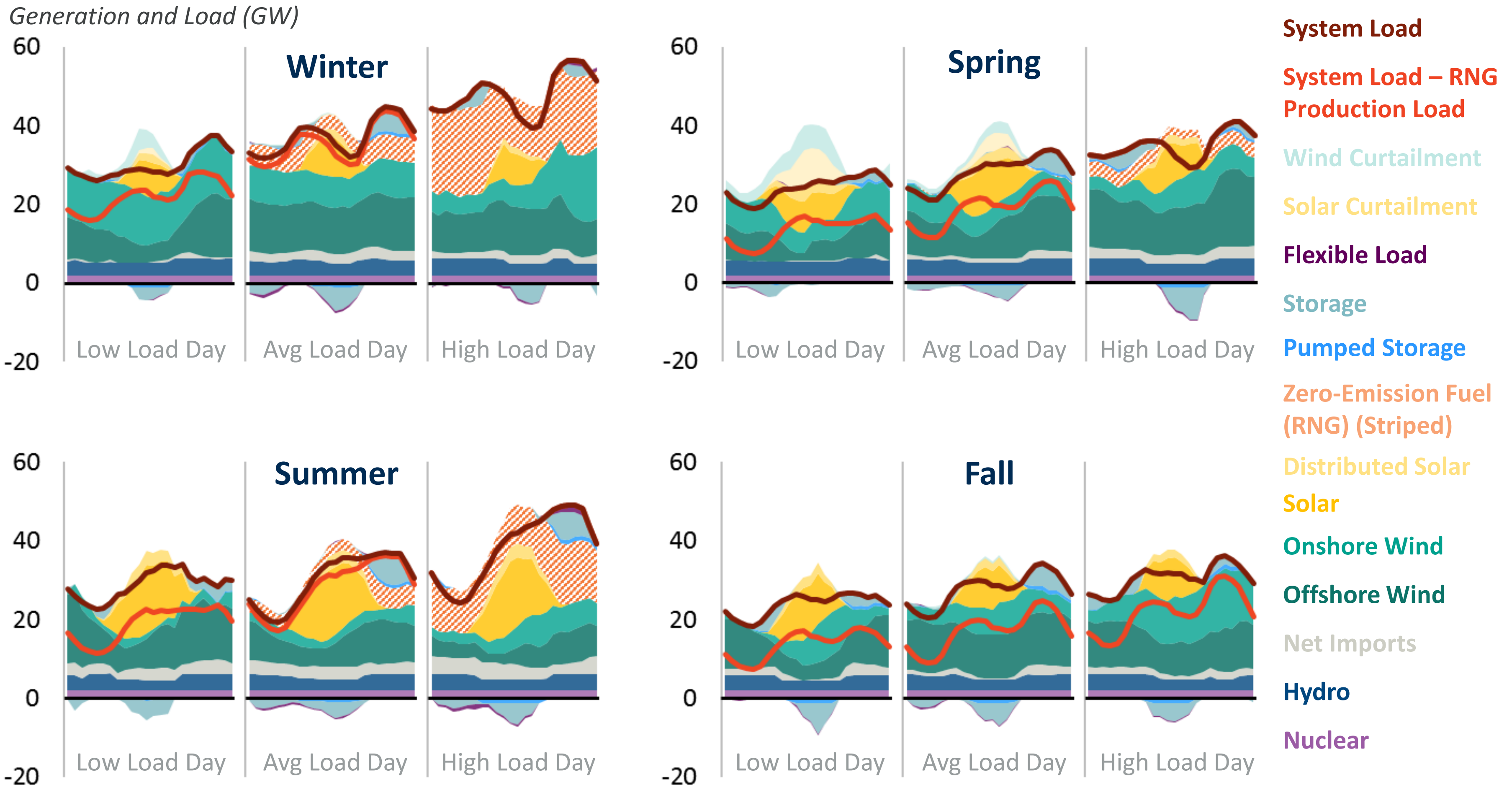
- **Nuclear** experiences no further retirements between 2030 and 2040
- **Solar** capacity grows to 38 GW; solar generation supplies 15% of New York load in 2040
- **Offshore wind** capacity grows to 25 GW; offshore wind generation supplies 34% of New York load in 2040
- **Onshore wind** capacity grows 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

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

Seasonal supply and demand patterns

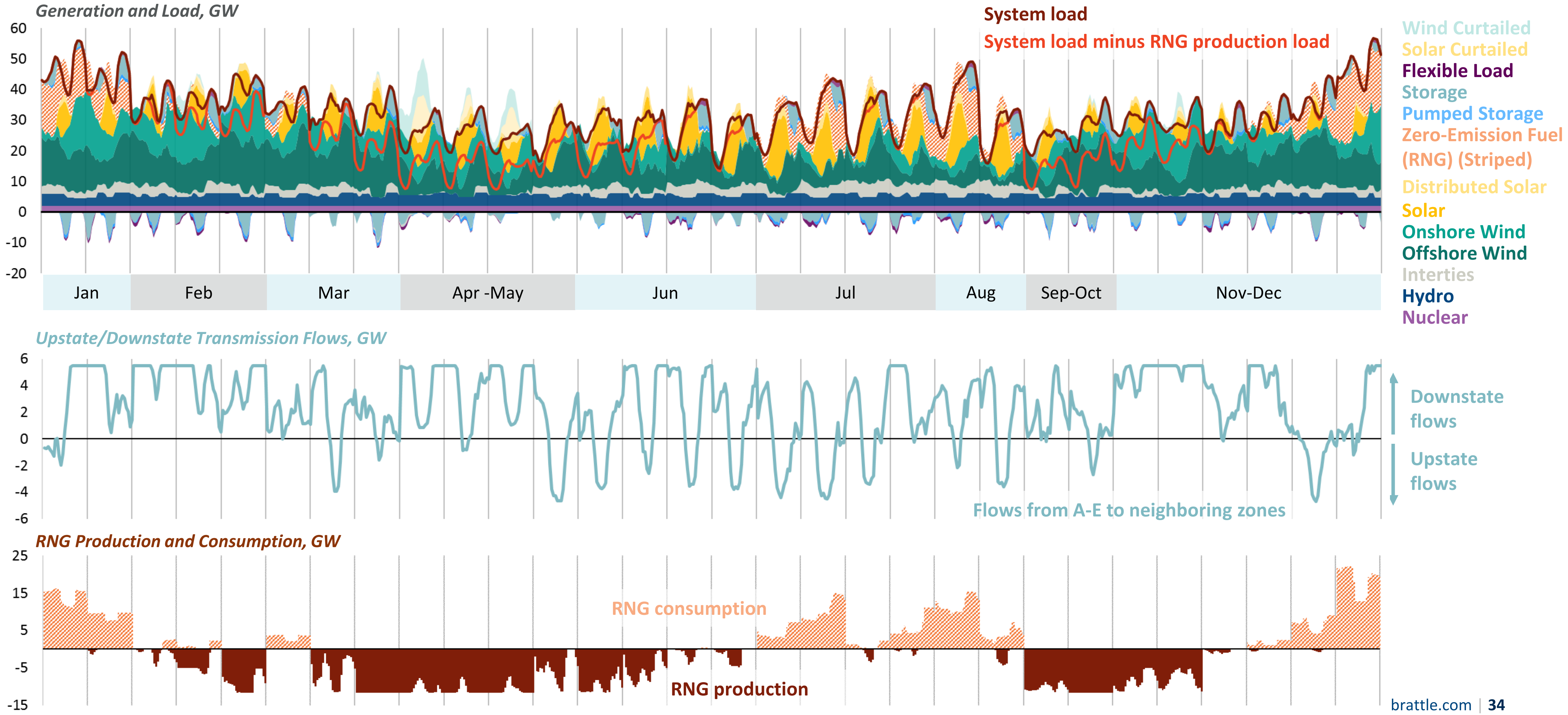
- **Demand**
  - System becomes winter peaking but summer peak also presents challenges
  - RNG production occurs on low load days, mostly in spring and fall
- **Generation**
  - Zero-emission fuels (RNG) consumed in many winter and summer hours to meet peak load
  - Storage operated to provide balancing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

Hourly Operations, by Season



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

Hourly operations across 30 representative days

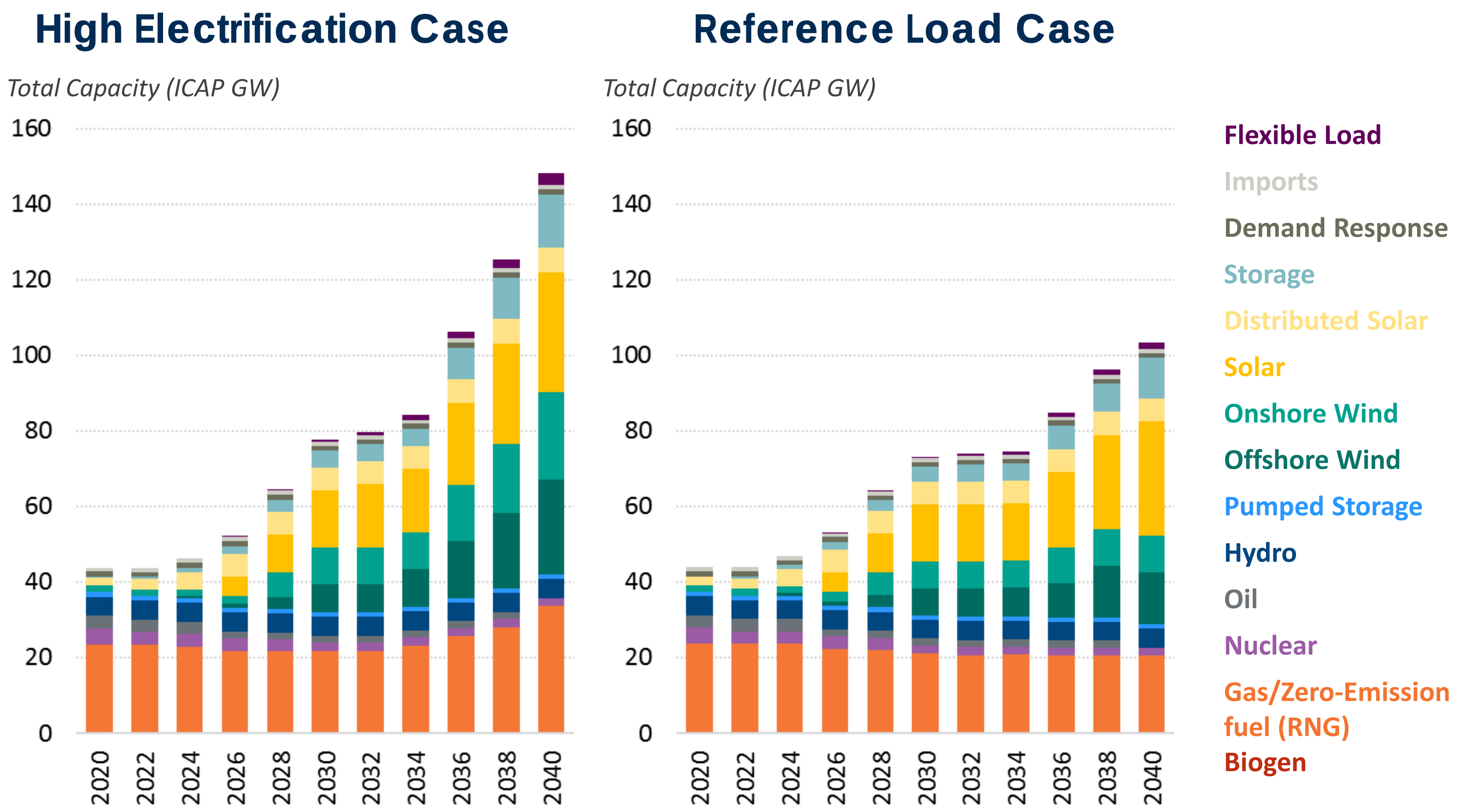


Effects of Electrification

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

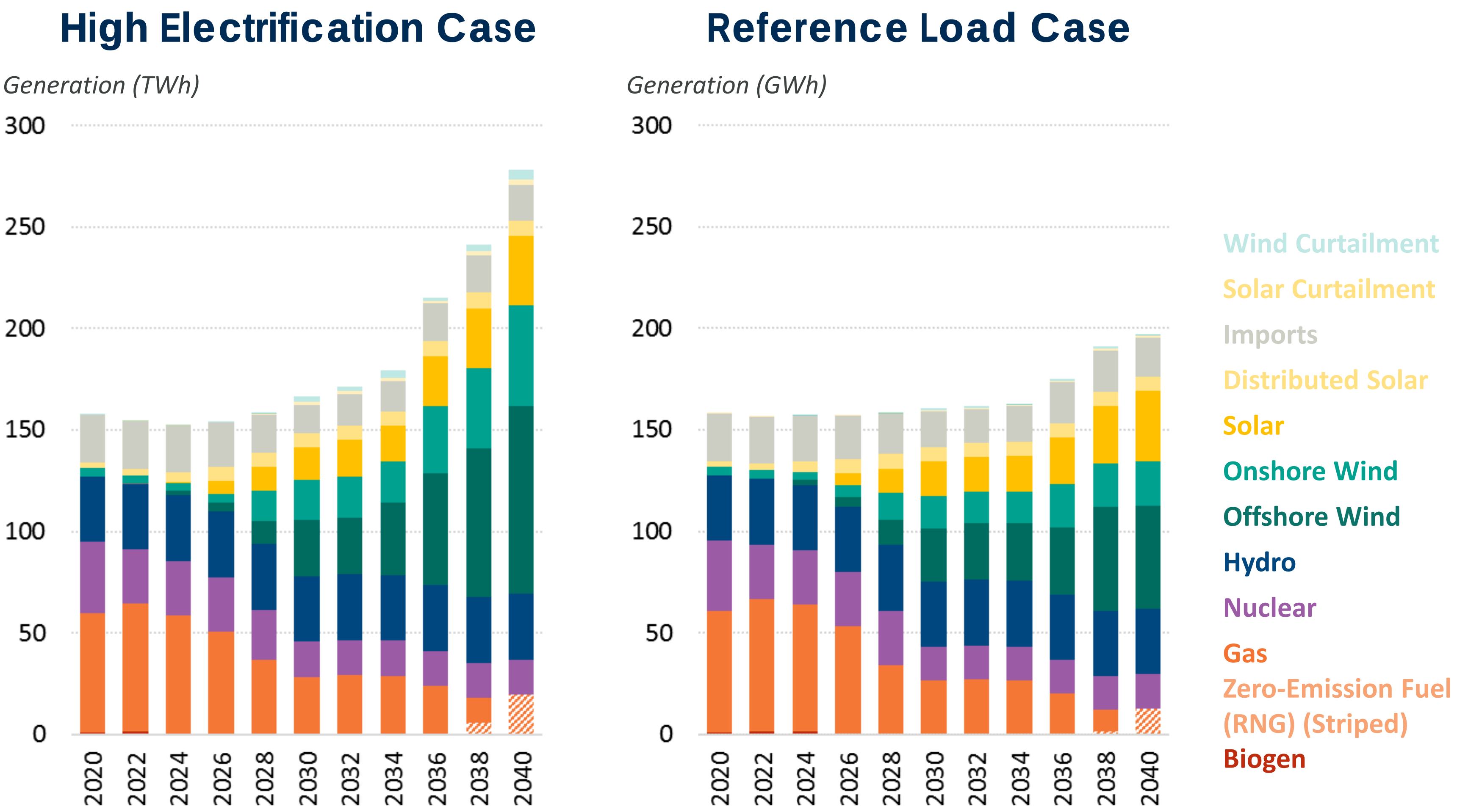
Installed capacity

- 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 and Next Steps

Initial proposed scenarios developed based on stakeholder comments and input from March 6 and March 30 meetings

1. Existing Technologies Only

- No zero-emission technology development or other long-duration storage technologies
- High Electrification load forecast

2. Alternative Flexibility Options

- Different types of flexible resources
- Increased transmission to HQ
- More flexible load
- High Electrification load forecast

3. Increased Transmission

- Increased Upstate/Downstate transmission
- High Electrification load forecast

Next Steps

- Gather stakeholder feedback
- Develop alternative scenarios
- Present final study results at June stakeholder meeting

Appendix: Detailed Results

Installed Capacity by Zone: 2024

2024 Capacity by Zone (GW)

	High Electrification Case						Reference Load Case						Difference in Capacity (High Electrification Case - Reference Load Case)					
	A-E	F	GHI	J	K	Total	A-E	F	GHI	J	K	Total	A-E	F	GHI	J	K	Total
BioGen	0.0	0.0	0.0	0.0	0.1	**0.1**	0.2	0.0	0.0	0.0	0.1	**0.4**	(0.2)	(0.0)	(0.0)	0.0	(0.0)	**(0.3)**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	**0.0**	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**	4.4	0.5	0.1	0.0	0.0	**5.0**	0.0	0.0	0.0	0.0	0.0	**0.0**
Kerosene	0.0	0.0	0.0	0.1	0.1	**0.2**	0.0	0.0	0.0	0.1	0.1	**0.2**	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	2.3	3.0	1.6	3.3	0.7	**11.0**	2.3	3.0	1.6	3.3	0.7	**11.0**	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CT	0.0	0.0	0.1	2.1	0.8	**3.0**	0.0	0.0	0.1	2.1	1.0	**3.2**	0.0	(0.0)	(0.0)	(0.0)	(0.1)	**(0.1)**
Gas ST	0.1	0.0	2.8	3.5	2.3	**8.7**	0.1	0.0	2.8	3.8	2.3	**9.1**	(0.0)	0.0	0.0	(0.4)	(0.0)	**(0.4)**
Nuclear	3.3	0.0	0.0	0.0	0.0	**3.3**	3.3	0.0	0.0	0.0	0.0	**3.3**	(0.0)	0.0	0.0	0.0	0.0	**(0.0)**
Oil CT	0.0	0.0	0.0	0.3	1.2	**1.5**	0.0	0.0	0.0	0.3	1.2	**1.5**	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	1.6	0.0	0.0	0.0	0.0	**1.6**	1.6	0.0	0.0	0.0	0.0	**1.6**	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**	0.0	1.2	0.0	0.0	0.0	**1.2**	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**	0.0	0.0	0.0	0.0	0.1	**0.1**	(0.0)	(0.0)	(0.0)	0.0	(0.0)	**(0.0)**
Solar BTM	0.4	2.5	0.3	0.8	0.5	**4.5**	0.4	2.5	0.3	0.8	0.5	**4.5**	0.0	0.0	(0.0)	(0.0)	(0.0)	**0.0**
Storage 2-Hour	0.0	0.0	0.0	0.4	0.8	**1.2**	0.0	0.0	0.0	0.5	0.7	**1.2**	(0.0)	(0.0)	(0.0)	(0.1)	0.1	**(0.0)**
Storage 4-Hour	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	**0.0**	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**	0.0	0.0	0.0	0.1	0.5	**0.6**	0.0	0.0	0.0	0.1	(0.1)	**0.0**
Wind Onshore	1.7	0.0	0.0	0.0	0.0	**1.7**	1.7	0.0	0.0	0.0	0.0	**1.7**	0.0	(0.0)	(0.0)	0.0	0.0	**0.0**
Capacity Imports	1.1	0.0	0.0	0.0	0.0	**1.1**	1.1	0.0	0.0	0.0	0.0	**1.1**	0.0	0.0	0.0	0.0	0.0	**0.0**
Demand Response	0.6	0.1	0.1	0.5	0.0	**1.3**	0.6	0.1	0.1	0.5	0.0	**1.3**	0.0	0.0	0.0	0.0	0.0	**0.0**
Flexible Load	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	**0.0**	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)**	(0.0)	0.0	0.0	(0.0)	(0.0)	**(0.0)**	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**	**15.9**	**7.3**	**5.0**	**11.4**	**7.3**	**46.9**	**(0.2)**	**(0.0)**	**(0.0)**	**(0.3)**	**(0.2)**	**(0.8)**

Installed Capacity by Zone: 2030

2030 Capacity by Zone (GW)

	High Electrification Case						Reference Load Case						Difference in Capacity (High Electrification Case - Reference Load Case)					
	A-E	F	GHI	J	K	Total	A-E	F	GHI	J	K	Total	A-E	F	GHI	J	K	Total
BioGen	0.0	0.0	0.0	0.0	0.1	**0.1**	0.0	0.0	0.0	0.0	0.0	**0.0**	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**	0.0	0.0	0.0	0.0	0.0	**0.0**	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**	4.4	0.5	0.1	0.0	0.0	**5.0**	0.0	0.0	0.0	0.0	0.0	**0.0**
Kerosene	0.0	0.0	0.0	0.0	0.1	**0.1**	0.0	0.0	0.0	0.0	0.1	**0.1**	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CC	2.3	3.0	1.6	3.3	0.7	**11.0**	2.3	3.0	1.6	3.3	0.7	**11.0**	0.0	0.0	0.0	0.0	0.0	**0.0**
Gas CT	0.0	0.0	0.1	1.0	0.8	**1.9**	0.0	0.0	0.1	1.0	1.0	**2.2**	0.0	(0.0)	(0.0)	(0.0)	(0.2)	**(0.2)**
Gas ST	0.1	0.0	2.8	3.5	2.3	**8.7**	0.0	0.0	2.8	2.8	2.3	**8.0**	0.1	0.0	0.0	0.6	(0.0)	**0.8**
Nuclear	2.2	0.0	0.0	0.0	0.0	**2.2**	2.1	0.0	0.0	0.0	0.0	**2.1**	0.1	0.0	0.0	0.0	0.0	**0.1**
Oil CT	0.0	0.0	0.0	0.0	0.2	**0.2**	0.0	0.0	0.0	0.0	0.2	**0.2**	0.0	0.0	0.0	0.0	0.0	**0.0**
Oil ST	1.6	0.0	0.0	0.0	0.0	**1.6**	1.6	0.0	0.0	0.0	0.0	**1.6**	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**	0.0	1.2	0.0	0.0	0.0	**1.2**	0.0	(0.0)	0.0	0.0	0.0	**(0.0)**
Solar	0.0	14.1	0.9	0.0	0.1	**15.1**	1.9	12.4	0.7	0.0	0.1	**15.1**	(1.9)	1.7	0.2	0.0	(0.0)	**(0.0)**
Solar BTM	0.4	2.5	0.3	0.8	2.0	**6.0**	0.5	2.5	0.3	0.8	2.0	**6.0**	(0.0)	0.0	(0.0)	(0.0)	(0.0)	**(0.0)**
Storage 2-Hour	0.8	0.6	0.0	1.4	1.4	**4.3**	0.5	0.0	0.0	1.8	1.7	**4.0**	0.3	0.6	(0.0)	(0.3)	(0.3)	**0.2**
Storage 4-Hour	0.0	0.0	0.0	0.2	0.1	**0.3**	0.0	0.0	0.0	0.0	0.0	**0.0**	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**	0.0	0.0	0.0	5.3	1.8	**7.1**	0.0	0.0	0.0	(0.2)	0.7	**0.5**
Wind Onshore	9.7	0.0	0.0	0.0	0.0	**9.7**	7.1	0.0	0.0	0.0	0.0	**7.1**	2.6	0.0	0.0	0.0	0.0	**2.6**
Capacity Imports	1.1	0.0	0.0	0.0	0.0	**1.1**	1.1	0.0	0.0	0.0	0.0	**1.1**	0.0	0.0	0.0	0.0	0.0	**0.0**
Demand Response	0.6	0.1	0.1	0.5	0.0	**1.3**	0.6	0.1	0.1	0.5	0.0	**1.3**	0.0	0.0	0.0	0.0	0.0	**0.0**
Flexible Load	0.2	0.0	0.1	0.2	0.1	**0.6**	0.1	0.0	0.0	0.1	0.1	**0.4**	0.1	0.0	0.0	0.1	0.0	**0.2**
RNG Production	(0.0)	0.0	0.0	(0.0)	(0.0)	**(0.0)**	(0.0)	0.0	0.0	(0.0)	(0.0)	**(0.0)**	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**	**22.2**	**19.7**	**5.8**	**15.6**	**10.1**	**73.3**	**1.3**	**2.4**	**0.2**	**0.3**	**0.4**	**4.6**

Installed Capacity by Zone: 2040

2040 Capacity by Zone (GW)

	High Electrification Case						Reference Load Case						Difference in Capacity (High Electrification Case - Reference Load Case)					
	A-E	F	GHI	J	K	Total	A-E	F	GHI	J	K	Total	A-E	F	GHI	J	K	Total
BioGen	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	**0.0**	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**	0.0	0.0	0.0	0.0	0.0	**0.0**	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**	4.4	0.5	0.1	0.0	0.0	**5.0**	0.0	0.0	0.0	0.0	0.0	**0.0**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	**0.0**	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**	2.3	3.0	1.6	3.3	1.1	**11.4**	0.0	0.0	1.0	0.0	0.1	**1.1**
Gas CT	0.0	6.0	0.2	3.4	2.8	**12.5**	0.0	0.0	0.1	1.0	1.6	**2.7**	0.0	6.0	0.1	2.4	1.2	**9.8**
Gas ST	0.1	0.0	2.8	3.5	2.3	**8.7**	0.0	0.0	2.1	2.1	2.3	**6.5**	0.1	0.0	0.6	1.4	(0.0)	**2.2**
Nuclear	2.2	0.0	0.0	0.0	0.0	**2.2**	2.1	0.0	0.0	0.0	0.0	**2.1**	0.1	0.0	0.0	0.0	0.0	**0.1**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	**0.0**	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**	0.0	0.0	0.0	0.0	0.0	**0.0**	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**	0.0	1.2	0.0	0.0	0.0	**1.2**	0.0	(0.0)	0.0	0.0	0.0	**(0.0)**
Solar	4.9	21.4	5.3	0.0	0.1	**31.7**	4.8	20.8	4.4	0.0	0.1	**30.0**	0.1	0.5	1.0	0.0	(0.0)	**1.6**
Solar BTM	0.5	2.8	0.3	0.8	2.0	**6.4**	0.5	2.6	0.3	0.8	2.0	**6.1**	0.1	0.2	0.0	(0.0)	(0.0)	**0.3**
Storage 2-Hour	4.1	1.2	0.1	1.4	1.4	**8.2**	1.5	1.6	0.1	1.8	1.7	**6.7**	2.6	(0.5)	0.0	(0.3)	(0.3)	**1.5**
Storage 4-Hour	1.8	1.8	0.2	1.2	0.9	**5.9**	0.5	1.6	0.8	0.9	0.2	**4.0**	1.3	0.2	(0.6)	0.3	0.7	**1.9**
Wind Offshore	0.0	0.0	0.0	17.9	7.2	**25.1**	0.0	0.0	0.0	9.2	4.6	**13.8**	0.0	0.0	0.0	8.8	2.6	**11.3**
Wind Onshore	23.3	0.0	0.0	0.0	0.0	**23.3**	9.8	0.0	0.0	0.0	0.0	**9.8**	13.5	0.0	0.0	0.0	0.0	**13.5**
Capacity Imports	1.1	0.0	0.0	0.0	0.0	**1.1**	1.1	0.0	0.0	0.0	0.0	**1.1**	0.0	0.0	0.0	0.0	0.0	**0.0**
Demand Response	0.6	0.1	0.1	0.5	0.0	**1.3**	0.6	0.1	0.1	0.5	0.0	**1.3**	0.0	0.0	0.0	0.0	0.0	**0.0**
Flexible Load	0.9	0.2	0.4	0.9	0.9	**3.2**	0.5	0.1	0.2	0.4	0.6	**1.9**	0.4	0.1	0.2	0.4	0.3	**1.3**
RNG Production	5.0	0.0	0.0	4.9	1.7	**11.6**	5.0	0.0	0.0	0.4	1.5	**6.9**	0.0	0.0	0.0	4.5	0.2	**4.7**
Total	**51.2**	**38.2**	**12.0**	**37.8**	**20.5**	**159.8**	**33.0**	**31.6**	**9.8**	**20.4**	**15.8**	**110.5**	**18.3**	**6.6**	**2.2**	**17.4**	**4.8**	**49.3**

Generation by Zone: 2024

2024 Generation by Zone (TWh)

	High Electrification Case						Reference Load Case						Difference in Generation (High Electrification Case-Reference Load Case)					
	A-E	F	GHI	J	K	Total	A-E	F	GHI	J	K	Total	A-E	F	GHI	J	K	Total
BioGen	0.0	0.0	0.0	0.0	0.5	**0.5**	0.8	0.1	0.1	0.0	0.5	**1.4**	(0.8)	(0.1)	(0.1)	0.0	0.0	**(0.9)**
Coal	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	**0.0**	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**	29.4	2.3	0.5	0.0	0.0	**32.3**	(0.0)	0.0	0.0	0.0	0.0	**0.0**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	**0.0**	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**	14.4	8.6	9.1	20.9	3.6	**56.5**	1.0	(1.1)	(0.2)	(2.0)	(0.3)	**(2.5)**
Gas CT	0.1	0.0	0.0	0.8	0.8	**1.7**	0.1	0.0	0.0	0.8	1.0	**2.0**	(0.0)	(0.0)	(0.0)	(0.1)	(0.2)	**(0.3)**
Gas ST	0.2	0.0	0.6	1.1	0.7	**2.7**	0.3	0.0	0.9	2.1	0.8	**4.0**	(0.1)	0.0	(0.3)	(1.0)	(0.1)	**(1.4)**
Nuclear	26.7	0.0	0.0	0.0	0.0	**26.7**	26.7	0.0	0.0	0.0	0.0	**26.7**	(0.0)	0.0	0.0	0.0	0.0	**(0.0)**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	**0.0**	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**	0.1	0.0	0.0	0.0	0.0	**0.1**	(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**	0.0	0.0	0.0	0.0	0.1	**0.1**	(0.0)	(0.0)	(0.0)	0.0	(0.0)	**(0.0)**
Solar BTM	0.5	2.9	0.3	0.9	0.6	**5.3**	0.5	2.9	0.3	0.9	0.6	**5.3**	0.0	0.0	(0.0)	(0.0)	(0.0)	**0.0**
Wind Offshore	0.0	0.0	0.0	0.8	1.4	**2.2**	0.0	0.0	0.0	0.4	1.9	**2.2**	0.0	0.0	0.0	0.5	(0.5)	**(0.0)**
Wind Onshore	4.0	0.0	0.0	0.0	0.0	**4.0**	4.0	0.0	0.0	0.0	0.0	**4.0**	(0.0)	(0.0)	(0.0)	0.0	0.0	**(0.0)**
Imports	17.2	0.2	2.6	3.7	6.5	**30.2**	17.1	0.1	2.6	3.7	6.2	**29.8**	0.1	0.1	0.1	(0.0)	0.3	**0.4**
Exports	(1.6)	(2.7)	(2.9)	(0.2)	(0.2)	**(7.6)**	(1.6)	(2.7)	(2.9)	(0.2)	(0.2)	**(7.5)**	(0.0)	0.0	0.0	(0.0)	0.0	**(0.0)**
Total	**91.9**	**10.2**	**10.0**	**26.2**	**13.6**	**152.0**	**91.8**	**11.3**	**10.5**	**28.8**	**14.4**	**156.8**	**0.2**	**(1.1)**	**(0.5)**	**(2.6)**	**(0.8)**	**(4.8)**

Generation by Zone: 2030

2030 Generation by Zone (TWh)

	High Electrification Case						Reference Load Case						Difference in Generation (High Electrification Case-Reference Load Case)					
	A-E	F	GHI	J	K	Total	A-E	F	GHI	J	K	Total	A-E	F	GHI	J	K	Total
BioGen	0.0	0.0	0.0	0.0	0.3	**0.3**	0.0	0.0	0.0	0.0	0.0	**0.0**	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**	0.0	0.0	0.0	0.0	0.0	**0.0**	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**	29.4	2.3	0.5	0.0	0.0	**32.3**	(0.0)	0.0	(0.0)	0.0	0.0	**(0.0)**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	**0.0**	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**	7.1	2.0	3.9	9.4	1.4	**23.8**	(0.1)	0.7	0.4	1.5	0.1	**2.6**
Gas CT	0.0	0.0	0.0	0.2	0.4	**0.6**	0.0	0.0	0.0	0.2	0.8	**1.1**	0.0	(0.0)	0.0	(0.1)	(0.5)	**(0.5)**
Gas ST	0.1	0.0	0.2	0.6	0.2	**1.1**	0.0	0.0	0.3	0.8	0.5	**1.5**	0.1	0.0	(0.1)	(0.2)	(0.2)	**(0.4)**
Nuclear	17.2	0.0	0.0	0.0	0.0	**17.2**	16.7	0.0	0.0	0.0	0.0	**16.7**	0.5	0.0	0.0	0.0	0.0	**0.5**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	**0.0**	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**	0.0	0.0	0.0	0.0	0.0	**0.0**	(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**	2.2	14.2	0.8	0.0	0.1	**17.2**	(2.1)	0.9	0.2	0.0	(0.0)	**(1.1)**
Solar BTM	0.5	2.9	0.3	0.9	2.4	**7.0**	0.5	2.9	0.3	0.9	2.4	**7.0**	(0.0)	0.0	(0.0)	(0.0)	(0.0)	**(0.0)**
Wind Offshore	0.0	0.0	0.0	18.5	9.1	**27.5**	0.0	0.0	0.0	19.4	6.8	**26.2**	0.0	0.0	0.0	(0.9)	2.3	**1.4**
Wind Onshore	19.9	0.0	0.0	0.0	0.0	**19.9**	15.7	0.0	0.0	0.0	0.0	**15.7**	4.2	(0.0)	(0.0)	0.0	0.0	**4.2**
Imports	12.4	0.1	2.2	2.8	3.8	**21.2**	14.7	0.1	2.4	3.0	4.9	**25.1**	(2.3)	0.0	(0.2)	(0.2)	(1.2)	**(3.9)**
Exports	(1.6)	(2.7)	(2.9)	(0.2)	(0.2)	**(7.6)**	(1.6)	(2.7)	(2.9)	(0.2)	(0.2)	**(7.6)**	(0.0)	0.0	0.0	(0.0)	0.0	**0.0**
Total	**84.9**	**20.5**	**5.5**	**33.7**	**17.5**	**162.2**	**84.7**	**18.9**	**5.3**	**33.5**	**16.7**	**159.2**	**0.2**	**1.6**	**0.2**	**0.1**	**0.9**	**3.0**

Generation by Zone: 2040

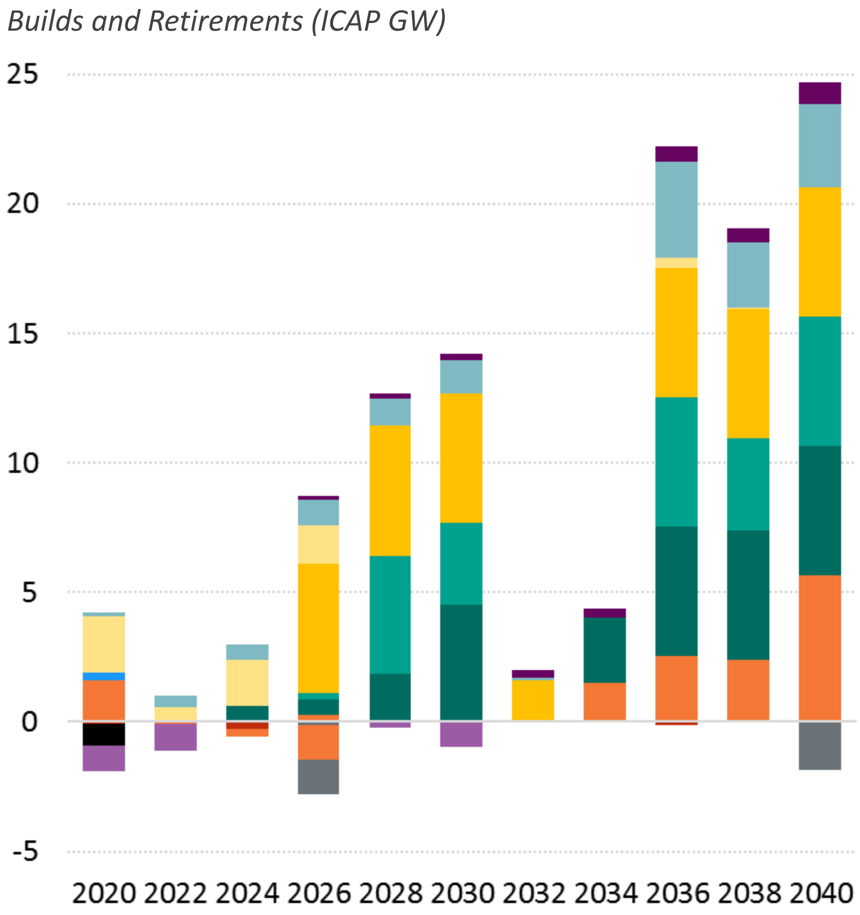
2040 Generation by Zone (TWh)

	High Electrification Case						Reference Load Case						Difference in Generation (High Electrification Case-Reference Load Case)					
	A-E	F	GHI	J	K	Total	A-E	F	GHI	J	K	Total	A-E	F	GHI	J	K	Total
BioGen	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	**0.0**	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**	0.0	0.0	0.0	0.0	0.0	**0.0**	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**	29.4	2.3	0.5	0.0	0.0	**32.3**	(0.0)	0.0	(0.0)	0.0	0.0	**(0.0)**
Kerosene	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	**0.0**	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**	0.3	2.4	2.7	4.3	2.3	**12.0**	0.5	1.4	2.8	0.2	0.0	**4.9**
Gas CT	0.0	0.8	0.0	0.8	1.0	**2.6**	0.0	0.0	0.0	0.0	0.5	**0.5**	0.0	0.8	0.0	0.8	0.5	**2.2**
Gas ST	0.0	0.0	0.1	0.0	0.0	**0.1**	0.0	0.0	0.0	0.3	0.1	**0.4**	0.0	0.0	0.1	(0.3)	(0.1)	**(0.3)**
Nuclear	17.2	0.0	0.0	0.0	0.0	**17.2**	16.7	0.0	0.0	0.0	0.0	**16.7**	0.5	0.0	0.0	0.0	0.0	**0.5**
Oil CT	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	**0.0**	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**	0.0	0.0	0.0	0.0	0.0	**0.0**	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**	5.4	23.8	5.0	0.0	0.1	**34.3**	(0.3)	(0.8)	0.9	0.0	0.0	**(0.2)**
Solar BTM	0.6	3.3	0.3	0.9	2.4	**7.5**	0.5	3.1	0.3	0.9	2.4	**7.2**	0.1	0.3	0.0	(0.0)	(0.0)	**0.4**
Wind Offshore	0.0	0.0	0.0	66.5	26.2	**92.7**	0.0	0.0	0.0	33.9	17.0	**50.8**	0.0	0.0	0.0	32.6	9.3	**41.8**
Wind Onshore	49.5	0.0	0.0	0.0	0.0	**49.5**	22.1	0.0	0.0	0.0	0.0	**22.1**	27.4	(0.0)	(0.0)	0.0	0.0	**27.4**
Imports	13.3	0.2	2.5	3.4	5.7	**25.1**	15.6	0.1	2.4	3.2	5.6	**26.9**	(2.3)	0.1	0.1	0.2	0.1	**(1.8)**
Exports	(1.5)	(2.7)	(2.9)	(0.2)	(0.2)	**(7.5)**	(1.6)	(2.7)	(2.9)	(0.2)	(0.2)	**(7.6)**	0.1	0.0	0.0	0.0	0.0	**0.1**
Total	**114.4**	**30.8**	**12.0**	**75.8**	**37.5**	**270.6**	**88.5**	**29.0**	**8.0**	**42.4**	**27.6**	**195.6**	**26.0**	**1.8**	**4.0**	**33.4**	**9.9**	**75.1**

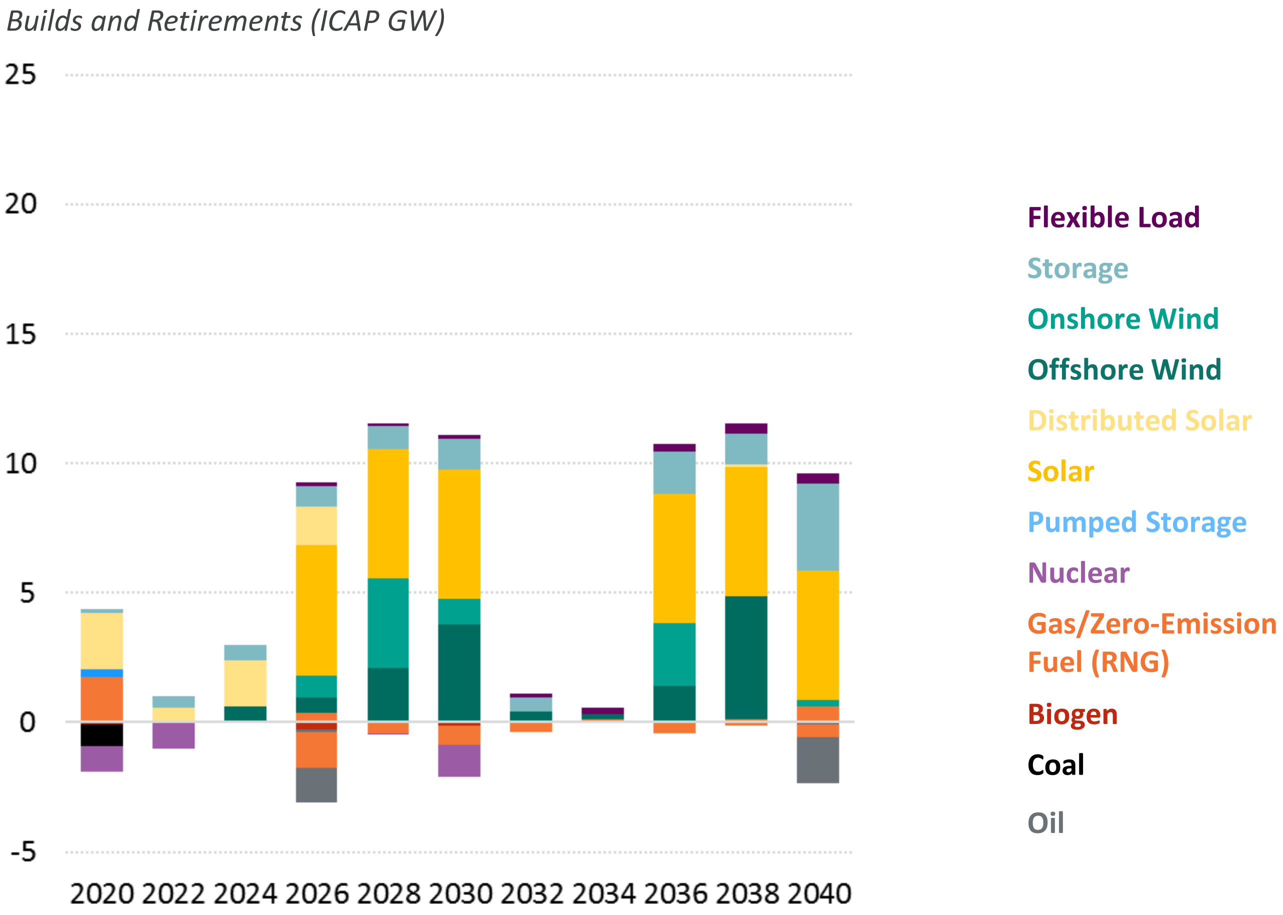
Note: Production from gas-fired generation in 2040 is based on use of a zero-emission fuel source (RNG).

Annual Builds and Retirements

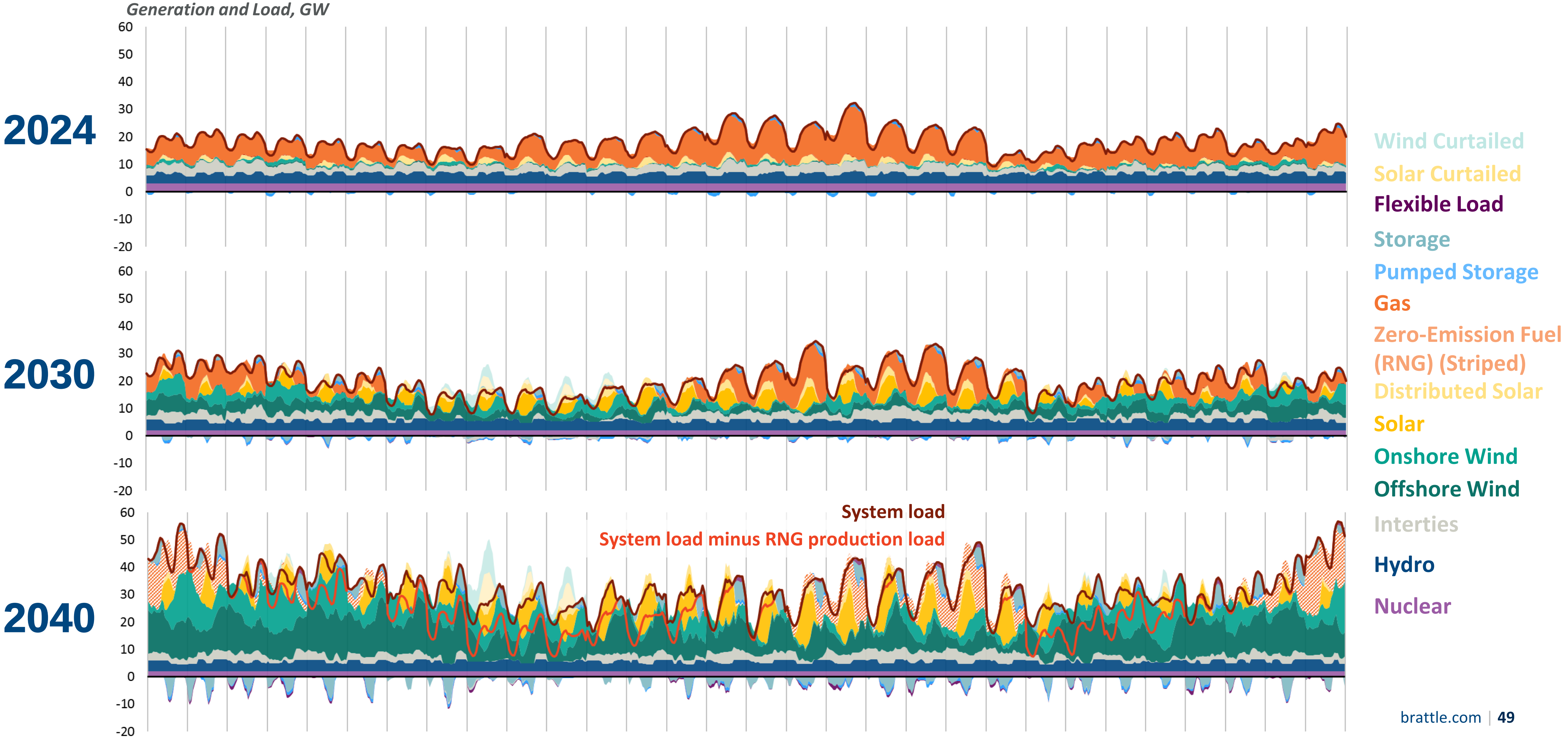
High Electrification Case



Reference Load Case

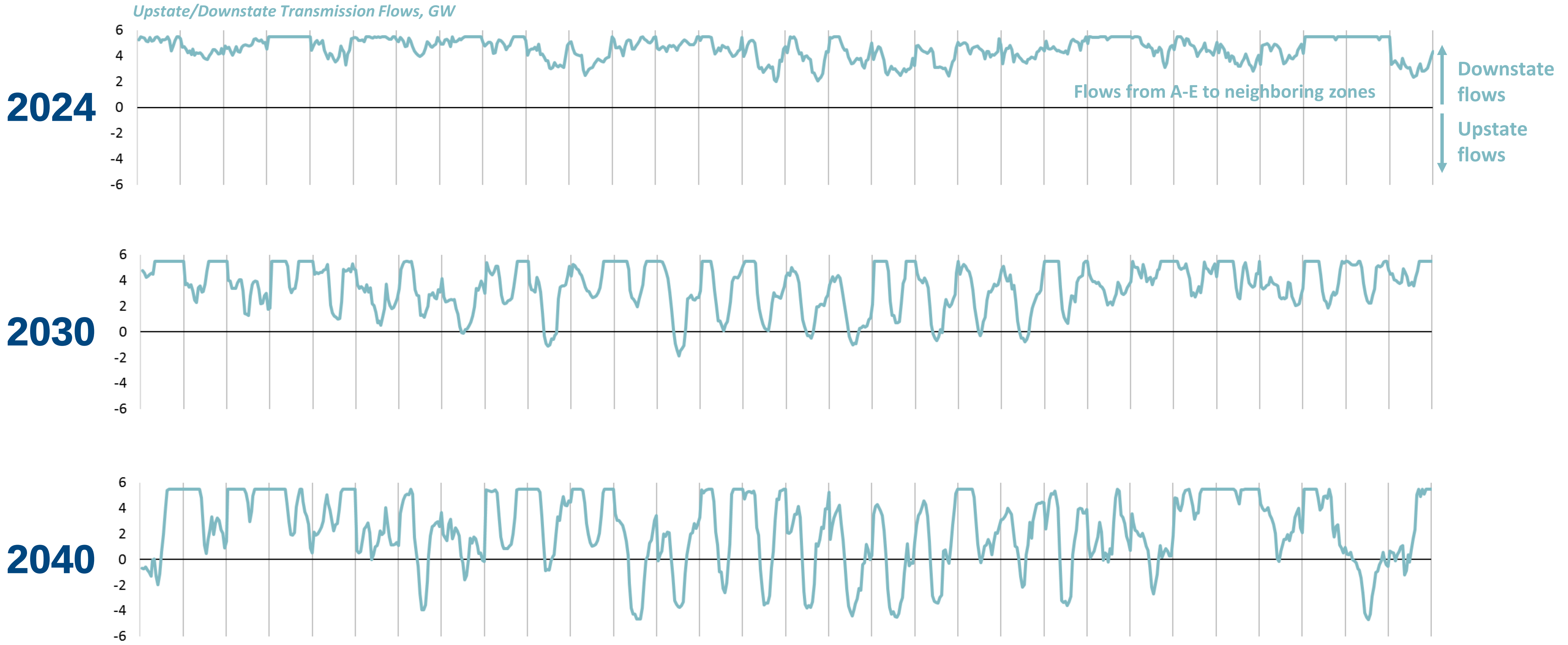


Hourly generation and load: 2024, 2030, and 2040



Hourly transmission flows: 2024, 2030, and 2040

Flows from A-E to neighboring zones



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

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 more than 10% 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%

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