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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
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.

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 NOₓ rule**
- DEC rule to reduce NOₓ 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
  - **NOₓ 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:  
- New York Senate Bill S6599
THE POLICY CONTEXT

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

Key Issues in Decarbonizing Systems

MEETING DEMAND IN LOW WIND AND SOLAR PERIODS
KEY ISSUES IN DECARBONIZING SYSTEMS

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.
KEY ISSUES IN DECARBONIZING SYSTEMS

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](http://brattle.com)
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.*
**KEY ISSUES IN DECARBONIZING SYSTEMS**

**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**

- **Total Renewable Generation**
- **Load**
- **Solar**
- **Offshore Wind**

**Seasonal Balancing Challenge**

- **Onshore Wind**
- **Solar**
- **Offshore Wind**

Batteries and load flexibility can provide short-term balancing.

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.
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.

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<table>
<thead>
<tr>
<th></th>
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<tr>
<td>1.</td>
<td><strong>Construct Scenarios</strong></td>
<td>Develop model inputs and vet assumptions with stakeholders. Previously discussed at <a href="https://example.com">March 30 ICAP working group</a>.</td>
</tr>
<tr>
<td>2.</td>
<td><strong>Base Case GridSIM Modeling</strong></td>
<td>Use GridSIM to identify cost-effective investment path through 2040</td>
</tr>
<tr>
<td>3.</td>
<td><strong>Alternative Cases</strong></td>
<td>Simulate operations and investments under different future scenarios.</td>
</tr>
</tbody>
</table>

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?
ANALYTICAL APPROACH

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 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
The transition to zero emissions generation

- **Wind and solar** become primary source of energy
- **Gas-fired generation** falls, eventually switches to zero-emission fuel sources (RNG)
- **Minimal curtailments** due to short- and long-term balancing (including RNG production)
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.
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
Near term (2024): Supply mix and operations similar to today

*Seasonal supply and demand patterns*

**STAGES OF DECARBONIZATION**

- **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**

- **Winter**
- **Spring**
- **Summer**
- **Fall**

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

### Installed Capacity

![Bar chart showing installed capacity for different resources in 2020 and 2030.]

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<th>Resource</th>
<th>2020</th>
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<tr>
<td>Biogen</td>
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</table>

### Annual Generation

![Bar chart showing annual generation for different resources in 2020 and 2030.]

- **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.
STAGES OF DECARBONIZATION

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

Seasonal supply and demand patterns

**Hourly Operations, by Season**

- **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
STAGES OF DECARBONIZATION

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

Hourly operations across 30 representative days

Load

Generation and Load, GW

Upstate/Downstate Transmission Flows, GW

Flexible Load, GW

Wind Curtailed
Solar Curtailed
Flexible Load
Storage
Pumped Storage
Gas
Distributed Solar
Solar
Onshore Wind
Offshore Wind
Interties
Hydro
Nuclear

Max limit
Change in load from baseline
Min limit

Downstate flows
Upstate flows

Decrease in load
Increase in load
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
STAGES OF DECARBONIZATION

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

See Slide 2 Disclaimer
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
EFFECTS OF ELECTRIFICATION

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
EFFECTS OF ELECTRIFICATION

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
**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)

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<th>High Electrification Case</th>
<th>Reference Load Case</th>
<th>Difference in Capacity</th>
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## Installed Capacity by Zone: 2030

### 2030 Capacity by Zone (GW)

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<td>Demand Response</td>
<td>0.2</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td>Flexible Load</td>
<td>(0.0)</td>
<td>(0.0)</td>
<td>(0.0)</td>
</tr>
<tr>
<td>RNG Production</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Total</td>
<td>23.5</td>
<td>22.0</td>
<td>6.0</td>
</tr>
</tbody>
</table>
## APPENDIX: DETAILED RESULTS

### Installed Capacity by Zone: 2040

<table>
<thead>
<tr>
<th></th>
<th>High Electrification Case</th>
<th>Reference Load Case</th>
<th>Difference in Capacity (High Electrification Case - Reference Load Case)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A-E F GHI J K Total</td>
<td>A-E F GHI J K Total</td>
<td>A-E F GHI J K Total</td>
</tr>
<tr>
<td>BioGen</td>
<td>0.0 0.0 0.0 0.0 0.0 0.0</td>
<td>0.0 0.0 0.0 0.0 0.0 0.0</td>
<td>0.0 0.0 0.0 0.0 0.0 0.0</td>
</tr>
<tr>
<td>Coal</td>
<td>0.0 0.0 0.0 0.0 0.0 0.0</td>
<td>0.0 0.0 0.0 0.0 0.0 0.0</td>
<td>0.0 0.0 0.0 0.0 0.0 0.0</td>
</tr>
<tr>
<td>Hydro</td>
<td>4.4 0.5 0.1 0.0 0.0 0.0</td>
<td>5.0 4.4 0.5 0.1 0.0 0.0</td>
<td>5.0 0.0 0.0 0.0 0.0 0.0</td>
</tr>
<tr>
<td>Kerosene</td>
<td>0.0 0.0 0.0 0.0 0.0 0.0</td>
<td>0.0 0.0 0.0 0.0 0.0 0.0</td>
<td>0.0 0.0 0.0 0.0 0.0 0.0</td>
</tr>
<tr>
<td>Gas CC</td>
<td>2.3 3.0 2.6 3.3 1.2 0.0</td>
<td>12.5 2.3 3.0 1.6 3.3 1.1</td>
<td>11.4 0.0 1.0 0.1 1.0 1.1</td>
</tr>
<tr>
<td>Gas CT</td>
<td>0.0 6.0 0.2 3.4 2.8 0.0</td>
<td>12.5 0.0 0.1 1.0 1.6 2.7</td>
<td>6.0 0.1 2.4 1.2 9.8</td>
</tr>
<tr>
<td>Gas ST</td>
<td>0.1 0.0 2.8 3.5 2.3 0.0</td>
<td>8.7 0.0 2.1 2.1 2.3 6.5</td>
<td>0.1 0.0 0.6 1.4 (0.0) 2.2</td>
</tr>
<tr>
<td>Nuclear</td>
<td>2.2 0.0 0.0 0.0 0.0 0.0</td>
<td>2.2 2.1 0.0 0.0 0.0 0.0</td>
<td>2.1 0.1 0.0 0.0 0.0 0.1</td>
</tr>
<tr>
<td>Oil CT</td>
<td>0.0 0.0 0.0 0.0 0.0 0.0</td>
<td>0.0 0.0 0.0 0.0 0.0 0.0</td>
<td>0.0 0.0 0.0 0.0 0.0 0.0</td>
</tr>
<tr>
<td>Oil ST</td>
<td>0.0 0.0 0.0 0.0 0.0 0.0</td>
<td>0.0 0.0 0.0 0.0 0.0 0.0</td>
<td>0.0 0.0 0.0 0.0 0.0 0.0</td>
</tr>
<tr>
<td>Pumped Storage</td>
<td>0.0 1.2 0.0 0.0 0.0 0.0</td>
<td>1.2 0.0 1.2 0.0 0.0 0.0</td>
<td>1.2 0.0 0.0 0.0 0.0 0.0</td>
</tr>
<tr>
<td>Solar</td>
<td>4.9 21.4 5.3 0.0 0.1 0.1</td>
<td>31.7 4.8 20.8 4.4 0.1 30.0</td>
<td>0.1 0.5 1.0 0.0 (0.0) 1.6</td>
</tr>
<tr>
<td>Solar BTM</td>
<td>0.5 2.8 0.3 0.8 2.0 0.0</td>
<td>6.4 0.5 2.6 0.3 0.8 2.0</td>
<td>6.1 0.1 0.2 0.0 (0.0) 0.3</td>
</tr>
<tr>
<td>Storage 2-Hour</td>
<td>4.1 1.2 0.1 1.4 1.4 1.4</td>
<td>8.2 1.5 1.6 0.1 1.6 1.7</td>
<td>6.7 2.6 (0.5) 0.0 (0.3) 0.3</td>
</tr>
<tr>
<td>Storage 4-Hour</td>
<td>1.8 1.8 0.2 1.2 0.9 0.9</td>
<td>5.9 0.5 1.6 0.8 0.9 0.2</td>
<td>4.0 1.3 0.2 (0.6) 0.3 0.7</td>
</tr>
<tr>
<td>Wind Offshore</td>
<td>0.0 0.0 0.0 17.9 7.2 0.0</td>
<td>25.1 0.0 0.0 9.2 4.6 13.8</td>
<td>0.0 0.0 0.0 8.8 2.6 11.3</td>
</tr>
<tr>
<td>Wind Onshore</td>
<td>23.3 0.0 0.0 0.0 0.0 0.0</td>
<td>23.3 9.8 0.0 0.0 0.0 9.8</td>
<td>13.5 0.0 0.0 0.0 13.5</td>
</tr>
<tr>
<td>Capacity Imports</td>
<td>1.1 0.0 0.0 0.0 0.0 0.0</td>
<td>1.1 0.0 0.0 0.0 0.0 0.0</td>
<td>1.1 0.0 0.0 0.0 0.0 0.0</td>
</tr>
<tr>
<td>Demand Response</td>
<td>0.6 0.1 0.1 0.5 0.0 0.0</td>
<td>1.3 0.6 0.1 0.1 0.5 0.0</td>
<td>1.3 0.0 0.0 0.0 0.0 0.0</td>
</tr>
<tr>
<td>Flexible Load</td>
<td>0.9 0.2 0.4 0.9 0.9 0.0</td>
<td>3.2 0.5 0.1 0.2 0.6 1.9</td>
<td>1.9 0.4 0.1 0.2 0.4 0.3</td>
</tr>
<tr>
<td>RNG Production</td>
<td>5.0 0.0 0.0 4.9 1.7 1.1</td>
<td>11.6 5.0 0.0 0.4 1.5 6.9</td>
<td>0.0 0.0 0.0 4.5 0.2 4.7</td>
</tr>
<tr>
<td>Total</td>
<td>51.2 38.2 12.0 37.8 20.5 159.8</td>
<td>33.0 31.6 9.8 20.4 15.8 110.5</td>
<td>18.3 6.6 2.2 17.4 4.8 49.3</td>
</tr>
</tbody>
</table>
## Generation by Zone: 2024

### 2024 Generation by Zone (TWh)

<table>
<thead>
<tr>
<th></th>
<th>High Electrification Case</th>
<th>Reference Load Case</th>
<th>Difference in Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A-E</td>
<td>F</td>
<td>GHI</td>
</tr>
<tr>
<td>BioGen</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Coal</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Hydro</td>
<td>29.4</td>
<td>2.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Kerosene</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Gas CC</td>
<td>15.4</td>
<td>7.5</td>
<td>8.9</td>
</tr>
<tr>
<td>Gas CT</td>
<td>0.1</td>
<td>0.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Gas ST</td>
<td>0.2</td>
<td>0.0</td>
<td>0.6</td>
</tr>
<tr>
<td>Nuclear</td>
<td>26.7</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Oil CT</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Oil ST</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Solar</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Solar BTM</td>
<td>0.5</td>
<td>2.9</td>
<td>0.3</td>
</tr>
<tr>
<td>Wind Offshore</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Wind Onshore</td>
<td>4.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Imports</td>
<td>17.2</td>
<td>0.2</td>
<td>2.6</td>
</tr>
<tr>
<td>Exports</td>
<td>(1.6)</td>
<td>(2.7)</td>
<td>(2.9)</td>
</tr>
<tr>
<td>Total</td>
<td>91.9</td>
<td>10.2</td>
<td>10.0</td>
</tr>
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</table>
## Generation by Zone: 2030

### Appendix: Detailed Results

<table>
<thead>
<tr>
<th>2030 Generation by Zone (TWh)</th>
<th>High Electrification Case</th>
<th>Reference Load Case</th>
<th>Difference in Generation (High Electrification Case-Reference Load Case)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A-E</td>
<td>F</td>
<td>GHI</td>
</tr>
<tr>
<td>BioGen</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Coal</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Hydropower</td>
<td>29.4</td>
<td>2.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Kerosene</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Gas CC</td>
<td>7.0</td>
<td>2.7</td>
<td>4.3</td>
</tr>
<tr>
<td>Gas CT</td>
<td>0.0</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td>Gas ST</td>
<td>0.1</td>
<td>0.2</td>
<td>0.6</td>
</tr>
<tr>
<td>Nuclear</td>
<td>17.2</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Oil CT</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Oil ST</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Solar</td>
<td>0.0</td>
<td>15.1</td>
<td>1.0</td>
</tr>
<tr>
<td>Solar BTM</td>
<td>0.5</td>
<td>2.9</td>
<td>0.3</td>
</tr>
<tr>
<td>Wind Offshore</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Wind Onshore</td>
<td>19.9</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Imports</td>
<td>12.4</td>
<td>0.1</td>
<td>2.2</td>
</tr>
<tr>
<td>Exports</td>
<td>(1.6)</td>
<td>(2.7)</td>
<td>(2.9)</td>
</tr>
<tr>
<td>Total</td>
<td>84.9</td>
<td>20.5</td>
<td>5.5</td>
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</table>
# Generation by Zone: 2040

## 2040 Generation by Zone (TWh)

<table>
<thead>
<tr>
<th>High Electrification Case</th>
<th>Reference Load Case</th>
<th>Difference in Generation (High Electrification Case-Reference Load Case)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-E GHI J K Total</td>
<td>A-E GHI J K Total</td>
<td>A-E GHI J K Total</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>BioGen</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Coal</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Hydro</td>
<td>29.4</td>
<td>2.3</td>
</tr>
<tr>
<td>Kerosene</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Gas CC</td>
<td>0.8</td>
<td>3.8</td>
</tr>
<tr>
<td>Gas ST</td>
<td>0.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Nuclear</td>
<td>17.2</td>
<td>0.0</td>
</tr>
<tr>
<td>Oil CT</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Oil ST</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Solar</td>
<td>5.1</td>
<td>23.1</td>
</tr>
<tr>
<td>Solar BTM</td>
<td>0.6</td>
<td>3.3</td>
</tr>
<tr>
<td>Wind Offshore</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Wind Onshore</td>
<td>49.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Imports</td>
<td>13.3</td>
<td>0.2</td>
</tr>
<tr>
<td>Exports</td>
<td>(1.5)</td>
<td>(2.7)</td>
</tr>
<tr>
<td>Total</td>
<td>114.4</td>
<td>30.8</td>
</tr>
</tbody>
</table>

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

Annual Builds and Retirements

**High Electrification Case**

**Reference Load Case**

*Builds and Retirements (ICAP GW)*

- Flexible Load
- Storage
- Onshore Wind
- Offshore Wind
- Distributed Solar
- Solar
- Pumped Storage
- Nuclear
- Gas/Zero-Emission Fuel (RNG)
- Biogen
- Coal
- Oil

See Slide 2 Disclaimer
APPENDIX: DETAILED RESULTS

Hourly generation and load: 2024, 2030, and 2040
APPENDIX: DETAILED RESULTS

Hourly transmission flows: 2024, 2030, and 2040

Flows from A-E to neighboring zones

2024

2030

2040
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.

<table>
<thead>
<tr>
<th>Cost Assumption</th>
<th>Value in 2040 (2020 dollars)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Cost</td>
<td>$1,080/kW* ($101/kW-yr levelized)</td>
<td>• Future electrolyzer and methanizer costs are estimated from 2020 costs and projected cost declines in the future</td>
</tr>
<tr>
<td>Fixed Cost</td>
<td>$4/kW-yr</td>
<td>• Assumed as 4% of capital costs</td>
</tr>
</tbody>
</table>
| Non-Electric Variable Cost | $10/MWh                      | • CO₂: CO₂ is an input for methanation. We assume CO₂ 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/MBtu. |
| 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/MBtu                      | • 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
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

<table>
<thead>
<tr>
<th></th>
<th>High Electrification Case</th>
<th>Reference Load Case</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RNG Production and Consumption</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total RNG Produced</td>
<td>(Million MMBTu)</td>
<td>99</td>
</tr>
<tr>
<td>Total RNG Consumed</td>
<td>(Million MMBTu)</td>
<td>149</td>
</tr>
<tr>
<td>% RNG Demand Produced in NY</td>
<td>(%)</td>
<td>66%</td>
</tr>
<tr>
<td><strong>Impacts on Load</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Load from RNG Production</td>
<td>(TWh)</td>
<td>50</td>
</tr>
<tr>
<td>as a % of Gross Load</td>
<td>(%)</td>
<td>18%</td>
</tr>
</tbody>
</table>
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