

EXPLORING NEW YORK CITY'S PATH TO DECARBONIZATION

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Abstract

The June 2019 passage of the Climate Leadership and Community Protection Act (CLCPA) in New York state set ambitious carbon reduction goals over the 2030-2050 time horizon. Removal of carbon from the electric system and decarbonization of the New York state economy becomes increasingly challenging when taking timeline, cost and reliability constraints into account. New York City (NYISO Zone J) is a unique part of the NYISO system, as this region is currently comprised of aging generation infrastructure, experiences challenges with importing sufficient energy to serve peak demand and is subject to geographic limitations. As carbon reductions become a focal point in generation resource planning, the integration of the societal cost of carbon is an increasingly central component of generation resource selection. A 20-year revenue requirement model has been utilized to evaluate the impact of carbon pricing on the levelized cost of energy (LCOE) and levelized cost of capacity across various fuel types. Taking into consideration affordability, emission intensity and operational parameters to maintain grid reliability, both short and long-term carbon reduction strategies must be deployed. In the short-term horizon renewable integration in New York City is best supported through gas flexibility and the replacement of Zone J's older peaking units with dispatchable high-efficiency combustion turbines. In the long-term horizon, the region will need to increase transmission investments and begin exploring applicable energy storage to align carbon-free energy with load demands. It is important to ensure that the short and long-term strategies complement each other and provide avenues for the energy industry to improve these tools over the state's journey to decarbonization.

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Executive Summary

In June 2019, New York state passed the Climate Leadership and Community Protection Act (CLCPA), setting ambitious carbon reduction goals for the state over the 2030-2050 time horizon. This legislation outlines specific resource addition goals including: 6 GW of solar capacity by 2025, 9 GW offshore wind capacity by 2035, and 3 GW energy storage capacity by 2030. In order to integrate an unprecedented volume of renewable generation over such a short time horizon, New York passed the Accelerated Renewable Energy Growth and Community Benefit Act in February 2020 which streamlines a lengthy and involved permitting and approvals processes to site and build generation resources. As 90% of generation in upstate New York is already generated by carbon-free energy, much of the investment needs to be concentrated in transmission infrastructure. Currently, transmission constraints prevent upstate renewable energy from being transported downstate to heavy load centers.

Due to the erratic nature of renewable resources, increasing levels of intermittent renewable assets present reliability challenges; these resources are unable to reliably contribute to peak energy needs. Energy storage can serve as a complementary capacity addition by shifting low-carbon generation to high-demand periods, but under the current design limitations the most cost-effective energy storage product is constrained to a four-hour dispatch period. As each region looks to transition to low carbon and ultimately carbon-free energy, New York City (NYISO Zone J) needs to import increased renewable generation or site renewable resources within the Zone J footprint. Currently the region relies on local fossil generation and imported energy from other NYISO (New York Independent System Operator) regions. Siting renewable generation in Zone J can present a challenge due to rising local property cost and the region's

high population density. As New York state looks to increase renewable generation to meet CLCPA, NYC will face three key challenges: transmission constraints, aging peaking units, and geographic constraints.

Carbon reductions have become a focal point in generation resource planning. The integration of the societal cost of carbon is becoming an increasingly central component of generation resource selection. Wholesale markets are designed to provide electricity to optimize cost and reliability. As regional emission requirements are incorporated into resource planning the cost of carbon will begin to impact market energy costs. When generic natural gas assets (combustion turbine and combined cycle), utility scale wind and utility scale solar assets are modeled over a 20-year period the results illustrates four key characteristics: renewable assets are competitive on an energy basis with and without federal subsidies, capacity accreditation associated with intermittent resources decreases resource value from a capacity basis, heat rate efficiencies and low emission levels of natural gas make natural gas a competitive low emission resource, and combustion turbines are the most affordable capacity resource addition.

As the resource mix shifts in the State of New York and in NYISO Zone J, multiple operational tools need to be deployed to increase the volume of renewable energy available, while reliably serving New York City at an affordable price. To achieve 70% renewable electricity by 2030, the grid needs to accommodate increased renewable resources in the short-term horizon (current-10 years) by increasing gas flexibility and replacing older peaking units with dispatchable high-efficiency combustion turbines. In the long-term horizon of achieving the 2040 goal of 100% carbon-free electricity, the region will have to increase transmission investment and begin exploring applicable energy storage, allowing renewable resources to shift to peak demand periods.

New York Renewable Policy

State renewable energy targets and generation portfolio standards have been ambitiously increasing since 2000, with a more recent resurgence in 2017 as the United States (US) announced its intent to withdraw from the Paris Agreement. State-level renewable energy standards allow for a localized stance on emissions as these mechanisms establish a regional level of control over the electricity resource mix and regional emission standards. As of 2019, 29 states and Washington D.C. have renewable energy targets, three states have a renewable portfolio standard (RPS) and eight states have renewable energy goals (Knaub, 2019).

New York's RPS was established in 2004 and was strengthened in 2009 through Executive Order 24, which established a 2050 goal of an 80% carbon reduction below 1990 emission levels. In addition to the emission reduction, Executive Order 24 went on to call for the establishment of a New York State Climate Action Council (SAC) with the charge of creating a state climate action plan. These refinements strengthened New York State's commitment to climate change mitigation through formalizing emission management. In August 2011 further reductions were established when Chapter 388 was signed into law. Later, in "August 2016, the New York State Public Service Commission (PSC) adopted a Clean Energy Standard (CES), requiring that 50% of the energy consumed in New York State be generated from renewable resources by 2030 (50-by-30 goal)" (NYISO, 2018, p.32). Over time, New York state has refined and increased its commitment to driving emissions down through policy initiatives and regulation.

As part of its' climate legislation evolution, New York's climate legislation has incorporated meaningful and consistent consideration of the impact of inequities across social and economic demographics as emission management and climate change mitigation is instituted. This social

consideration is evident in the Climate Leadership and Community Protection Act (CLCPA) passed in 2019, which furthers the state’s carbon reduction goals to 70% renewables by 2030 and 100% carbon-free electricity by 2040. The CLCPA sets a further goal to decarbonize the entire New York State economy by 2050, while considering disadvantaged communities and small business. The detailed and holistic legislation is a reflection of “more than three years of grassroots organizing, [to establish] economy-wide and electric sector targets for reducing [greenhouse gas] (GHG) emissions and scaling up clean energy” (Morris, 2019).

The CLCPA outlines detailed targets for renewable generation, including;

- 6 GW of solar capacity by 2025,
- 9 GW offshore wind capacity by 2035, and
- 3 GW energy storage capacity by 2030.

“From 2011 to 2019, wind capacity in the continental United States has grown at a compounded annual growth rate (CAGR) of roughly 11%”, where wind growth in NYISO has lagged in comparison, reflecting 5% annually over the same period (Drennen, 2019). Based on New York Independent System Operator’s (NYISO) 2019 capacity data, New York State only had 32 MW of installed utility scale solar and no offshore wind or battery capacity in 2019, as illustrated below in Table 1. To achieve the CLCPA goals, the state will have to make meaningful increases to installed renewable capacity over the next decade. The state has recently awarded the construction of 1,278 MW of renewable capacity additions in New York State, at a weighted average price of \$18.59/MWh over a 20-yr horizon, all of which is expected to be installed by 2024 (NYSERDA, 2020).

**Table 1. Current Renewable Capacity and 2030 Goals
(NYISO, 2019a).**

	2019 Capacity (MWh)		State Goals	Annual Additions Needed from 2020-2030
	New York City (NYISO Zone J)	New York State		
Solar	-	32	6,000	597
Wind	-	1,729		
Offshore Wind	-	-	9,000	900
Battery	-	-	3,000	300

There are several challenges with installing these large volumes of wind, solar and energy storage at such as rapid pace, to meet the 2030 goals outlined in CLCPA. As New York state looks to integrate large volumes of renewables over the next decade, maintaining affordability and reliability needs to be addressed. There are also challenges with existing policy and procedure, such as the permitting and siting processes to install new capacity in New York, codified in Article 10 of Chapter 388. This New York State code outlines a centralized and involved permitting process of energy additions, in an effort to minimize the impact of new energy projects on local communities, local ecology, regional economies and residential culture. To adequately address the interest of these various stakeholders the process outlined in Chapter 388 involves a cumbersome and lengthy schedule to protect social equality and maximize opportunities for engagement. In the effort to streamline renewable energy project permitting to meet the CLCPA targets, New York state’s Governor proposed the Accelerated Renewable Energy Growth and Community Benefit Act, which was signed into law in February 2020. This Act streamlined “environmental review and permitting of renewable projects of 25 MW and above, while allowing projects of 10 MW up to 25 MW to opt into the new process” (Knaub, 2020). This importance of community involvement is carefully ingrained in much of New York’s climate and energy policy and provides a process to ensure social equity in citing

infrastructure. As new renewable installations are approved and installed on an accelerated basis it will be important for the state to ensure appropriate stakeholder representation.

In considering affordability of the renewable generation outlined in the recent CLCPA, the current proposed capacity additions will come with a big price tag. In models completed by Energy Ventures Analysis (EVA), capacity additions to decarbonize the electric system in New York state will require the current generation capacity to more than double, resulting in generation investment of \$115 billion (EVA, 2019). The \$115 billion estimate formulated by EVA is exclusive to generation additions and does not include transmission investment.

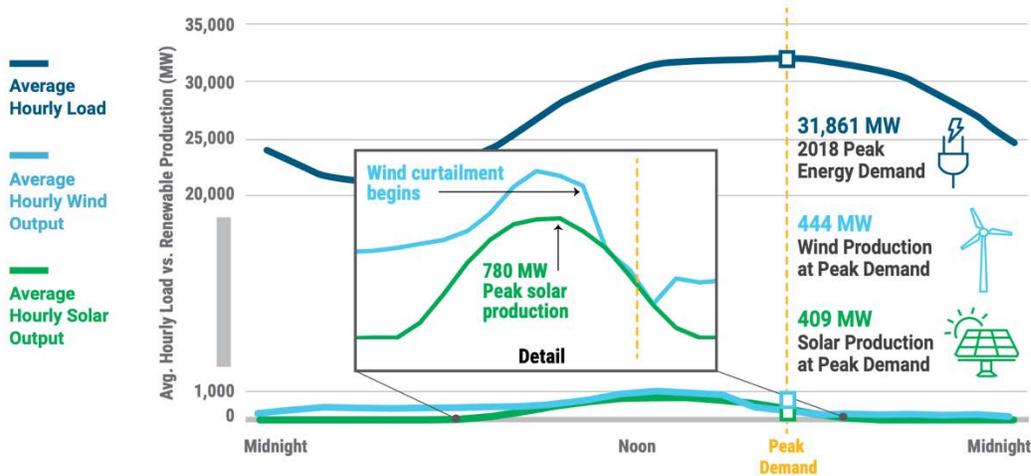
Transmission will be an additional expense in renewable growth throughout New York state as NYISO has identified existing transmission grid constraints (NYISO, 2018, p.11). Large investment will be required to reduce the carbon intensity of downstate NYISO, as 90% of generation in upstate New York is already generated by carbon-free assets (NYISO, 2019b, p.10). Due to limitations of the NYISO bulk power grid “investment in renewables in upstate load zones runs the risk of bringing diminishing returns in terms of progress toward both renewable energy production and carbon dioxide emissions reduction goals” (NYISO, 2019b, p.10). As the government looks to increase carbon-free generation across the state, there is a need to add transmission investment to transfer renewable generation from upstate to downstate or increased local renewable generation downstate to serve localized load.

Current and Planned Capacity and Energy Resources

As energy efficiency efforts have taken hold across the country load growth has experienced stagnation, as customer load intensity (MWh/customer) reductions have been experienced throughout the country. New York is no exception to this phenomenon, as “the combined effects of energy efficiency and distributed energy resources are expected to reduce demand from the

bulk power system by nearly 3,700 MW by 2028” (NYISO, 2018, p.9). Despite decreases in load, these changes do not reduce the system challenges of meeting energy and capacity requirements with renewable resources. Renewable resources are non-dispatchable, energy limited resources, meaning that generation from these intermittent resources does not always align with load requirements (i.e. customer energy demands). Figure 1 provides an illustration of wind and solar generation compared to peak load demand during NYISO’s system peak in 2018. Due to the nature of wind patterns, wind generation is seasonally variable with the lowest production output in summer months. Solar generation output also varies based on fuel availability within the day as the production aligns with sunlight and clear skies. The 2018 peak demand on the NYISO system occurred on August 29th at 4:00 pm, allowing the daily down ramp of the solar production to contribute to meeting peak load requirements, but with marginal contribution of wind resources to serve peak load, as shown in Figure 1.

Figure 1. Intermittent Resource Contribution to Load on 2018 Peak Demand Day (August 29) (NYISO, 2019b, p.29).



These intermittent renewable resources are unable to reliably contribute to peak energy needs, due to the inconsistent nature of their fuel source. Energy storage additions can complement

intermittent resources by shifting carbon-free energy to high-demand periods; however, under the current design limitations the most cost-effective energy storage resource (i.e. lithium-ion batteries) are constrained to a four-hour dispatch period. In NYISO's 2019 annual Power Trends report, the Independent System Operator (ISO) identified the role of battery storage in the future grid design to support renewable integration, but also noted the importance of additional dispatchable generation to secure reliability needs.

“Battery storage can contribute to meeting operational needs and is often discussed as a necessary tool to balance the intermittent nature of renewable resources. However, battery storage is insufficient to fully meet peak demand, even at penetration levels envisioned by policymakers over the next decade, due to technological constraints limiting their contribution to meeting the full duration of peak demand periods” (NYISO, 2019b, p.29).

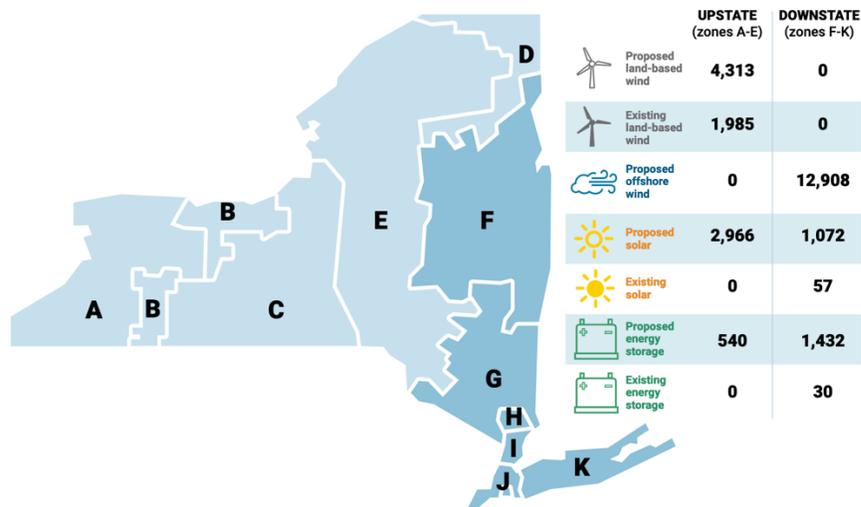
Renewable generation can contribute to meeting peak energy needs but are discounted from their installed capacity value when discussing system resource adequacy due to their undependable nature (i.e. inconsistent fuel supply). Currently there is no industry standard on identifying capacity contribution to system adequacy related to intermittent resources; however, presently, the east coast of the United States, encompassing NYISO, NE-ISO and PJM, takes into consideration capacity markets when assessing resource adequacy (Bothwell, 2016). In NYISO under the current market tariffs, intermittent resources can participate in the NYISO capacity market, where the resource's capacity value is based on the unforced capacity (UCAP) multiplied times a derate to account for the resource's contribution to system peak. The NYISO Open Access Transmission Tariff (OATT) describes the methodology to calculate intermittent resource capacity, utilizing EFORd (equivalent forced outage rate – demand) and resource type

(i.e. technology) to determine the resource's dependable capacity as a function of system peak demand (NYISO, 2020a, p.96-97). The methodology employed in NYISO of applying EFORd accounts for the generation resource's contribution to high-demand periods across varying fuel types, reflecting operational characteristics of the respective resource and a discounted capacity contribution for renewable resources.

Planned Generation Additions

Intermittent resources pose unique challenges in managing grid reliability compared to traditionally dispatchable resources, as intermittent fuel resources create a disconnect between generation supply and load demands. An intermittent resource's ability to serve peak load differs based on location and fuel type. Due to the inherent limitations of intermittent renewable fuel sources, increased renewable resources in a system result in marginal contribution to capacity (i.e. diminishing returns) creating instigating a reduction in value at increasing levels of intermittent resource penetration. Despite these operational and value challenges, the majority of planned generation resource additions in New York are renewable resources. This increase in renewables is due to climate change pressures, renewable tax incentives and regional legislation to achieve emission reduction goals. The downstate region planned resource additions, shown in dark blue in Figure 2, are dominated by renewable generation, with 12,908 MW of offshore wind, 1,072 MW of solar and 1,432 MW of energy storage capacity additions (NYISO, 2019b, p.47). Transmission considerations and investment will also have to be addressed to accommodate these resource additions, as the planned offshore wind would interconnect through Long Island (Zone K) and New York City (Zone J).

Figure 2. Existing and Proposed Intermittent Resources in New York State (NYISO, 2019b, p.47).



Current Capacity and Energy in New York City (Zone J)

New York City (Zone J) is a unique section of NYISO, as New York City is the most populous city in the US (8.5 M) as well as the most densely populated city in the US (28,211 people/sq mile) (Macaig, 2017). During summer peak, Zone J relies on local fossil-fuel generation resources and imported energy from other NYISO zones to serve regional load, as illustrated below in Table 2. Zone J’s resources only provide 83% of the region’s peak energy needs, meaning the region is a net importer and relies on transmission interconnections with other zones to meet their peak energy demands. The deficit of local capacity to serve peak demands in Zone J is reflected in capacity clearing prices, as 2017 capacity prices in Zone J reflected \$9/kW-month, where the remainder of the system maintained \$3/kW-month (Piper, 2017). It is difficult to determine the energy resources that are being imported into Zone J due to the proprietary nature of generation data; however, S&P Global has identified in the past that the majority of the

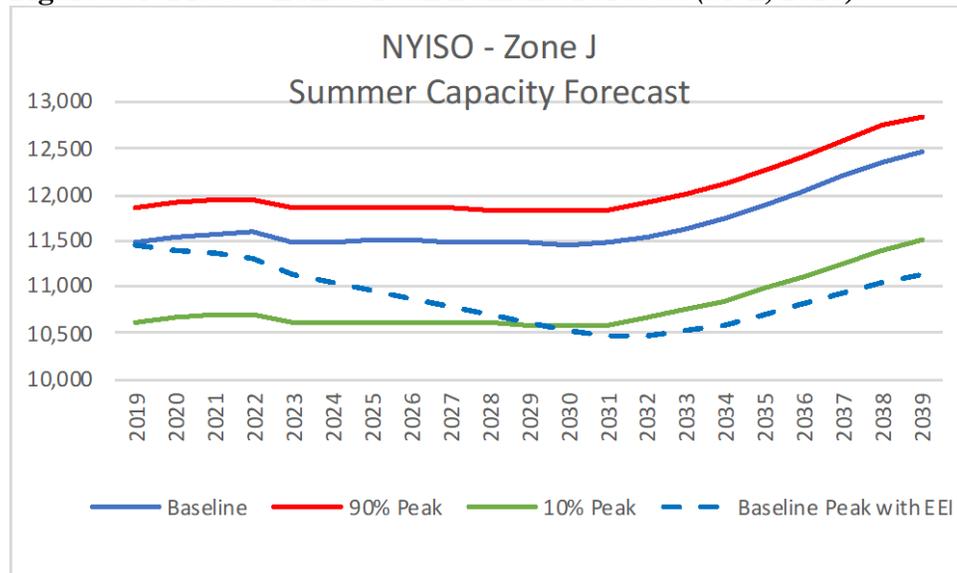
summer generation capacity deficit in Zone G-J was “provided by CPV Valley and Cricket Valley combined cycle plants” (Piper, 2017).

Table 2.
2019 Summer Capacity Volume by Fuel Type, Zone J
(NYISO, 2019a).

Fuel Type	2019 Summer Capacity (MW)
Natural Gas	5,464
Fuel Oil (#2)	848
Fuel Oil (#6)	2,462
Kerosene	541
Other	243
Total Zone J Summer Capacity	9,559
2019 Zone J, Coincident Peak Summer Capacity	11,496
Imports Needed to Serve Summer Peak	1,937

Based on NYISO’s forecasted energy needs for Zone J, without energy efficiency impacts (EEI) the region’s capacity demand could rise by 1,000 MW in 2039, to 12,500 MW at peak demand conditions. Without the addition of local generation resources and the forecasted increases in regional demand, Zone J will become increasingly dependent on imported energy from neighboring NYISO zones and transmission interconnections.

Figure 3. NYISO – Zone J Peak Demand Forecast (SNL, 2020).



New York City (NYC) Grid Challenges

In 2019 New York City's local electricity was powered by natural gas and fuel oil. The generation in Zone J consists of 78% natural gas powered generation and 12% fuel oil powered generation (NYISO, 2019a). As each region looks to transition to low carbon and ultimately carbon-free energy, NYISO Zone J will need to import increased renewable generation or site renewable resources within the Zone J footprint. Currently there is no utility scale renewable generation in Zone J (shown in Table 2), as this region has limited geographic opportunity to site renewable generation. NYC has experienced eight straight years of rising increases in property values, with an annual market value increase of 8.8% across New York City's boroughs in the 2019 fiscal year (NYC, 2019).

State public policy initiatives paired with technology advancements are resulting in a dynamic environment and increasing pressure to shift energy supply to carbon-free generation. The challenges faced by the state to integrate increased renewable generation by 2030 becomes more complicated when evaluating NYC (i.e. Zone J). As New York state looks to increase renewable generation to meet CLCPA, NYC has three unique challenges to reliably and affordably serve load with increasing renewable generation;

- transmission constraints,
- aging peaking units, and
- geographic constraints.

Transmission Constraints

New York City is interconnected with the larger New York state (NYISO) grid; however, Zone J remains a load pocket that experiences challenges with importing sufficient energy at the time of peak demand. “Load pockets represent transmission-constrained geographic areas where energy needs in that area can only be served by local generators due to the inability to import energy over the transmission system during certain high-demand conditions” (NYISO, 2018, p.35). To address the load pocket considerations of Zone J, the region will have to evaluate if it is more cost effective to add additional transmission or add localized generators to serve the New York City area.

The addition of renewables without sufficient transmission will put “downward pressure on wholesale energy prices, placing upward pressure on the cost of the state’s out-of-market incentive payments” thus reducing the effectiveness of the ISO market to provide affordable and reliable power (NYISO, 2019b, p.11). In an effort to improve system transmission and renewable integration, NYISO is currently working on two transmission expansion projects; Western New York and AC Public Policy Transmission projects. Both of the Western New York and AC Public Policy projects were included in the NYISO 2018-2019 Comprehensive Reliability Plan, published in July 2019. This study identified that the “New York State Bulk Power Transmission Facilities will meet applicable Reliability Criteria over the 2019 through 2028” period (NYISO, 2019c, p.4).

Western New York Transmission Project: Located in NYISO Zone A, this project was awarded to NextEra in October 2017, with a targeted in-service date of June 2022. This project will alleviate hydro constraints from Niagara and Ontario imports to the NYISO system.

AC Public Policy Transmission Project: Stretching over three NYISO Zones (E, F and G) the project consists of two separate segments. Segment A consists of 350MW addition to increase transmission capacity between eastern and western New York, which was awarded to North American Transmission in 2019. Segments B consists of a 900 MW addition to interconnect Albany and Hudson Valley, which was awarded to National Grid and New York Transco in 2019. Both segments have a targeted in-service date of December 2023. The construction of this project will allow for additional renewable energy to be transmitted to downstate zones.

In addition to the approved Western New York and AC Public Policy Transmission projects, there are additional projects in the NYISO transmission queue process, seeking review of necessity and approval to be constructed within the NYISO footprint. The Empire State Connector is one of the many transmission projects in the NYISO transmission planning queue, which has been gaining publicity as transmission projects are discussed that will enable the transmission of renewable generation to Zone J. The Empire State Connector is a proposed “1,000 MW high-voltage direct current (HVDC) line from Utica to Brooklyn”, that would be instrumental in delivering upstate renewable generation to Zone J (Empire State Connector Corp, 2019). Transmission projects such as the Empire State Connector are vital to reaching the carbon goals outlined in the CLCPA.

[Aging Steam Turbine Units with Increasing Emission Constraints](#)

New York City’s system peak demand occurs in the summer. This summer peak is met by generation from older steam turbine units (natural gas and fuel oil powered) cited in New York City boroughs. Of the peaking units located in Zone J, many of these units are in the 95 percentile of asset age in the country (NYISO, 2019b, p.16). These aging units were mostly

commissioned before 1980, with the average age of generators in Zone J being 40 years old (NYISO, 2019a). In addition to providing electricity, these steam turbines also provide steam services to 1,500 buildings over 100 miles of pipe, for heating, cooling, cooking and sterilizing needs (Brown, 2018).

Table 3.
NYISO Zone J Asset Age
(NYISO, 2019a).

Fuel Type	Sum of 2019 Summer Capacity (MW)	Sum of 2018 Net Energy (GWh)	Average of In- Service Year
Fuel Oil #2	848	89	1971
Fuel Oil #6	2,464	3,040	1962
Kerosene	541	46	1970
Natural Gas	5,464	19,641	1994
Other	243	2,141	1987
Grand Total	9,559	24,956	1980

The age of these units causes reliability concerns when “peak demand surges—most common during heat waves, such as the ones that struck the region in 2006 and 2011—[where] the older, less efficient generating stations have a harder time keeping up, and brownouts or blackouts become more likely” (Bogost, 2019). The localized capacity needs of each region are accounted for by the NYISO market through locational capacity requirements (LCRs), which are annually established for Hudson Valley, New York City and Long Island (Zones G-J). As of “May 1, 2019, the LCR for New York City (Zone J) is 82.8%”, illustrating the dependence of Zone J on the localized capacity resources outlined in Table 2 and imports from other regions (NYISO, 2019b p. 24).

Despite their relatively limited operation throughout the year to serve peak demand, Zone J’s steam turbines are a “significant contributor to ozone-forming pollutants because their operation is typically concentrated during hot weather conditions - when smog formation is most likely to occur” (NYISO, 2018, p.35). In order to comply with the New York Residual Oil Elimination

regulation the 2,946 MW of capacity that utilizes fuel oil #6 and fuel oil #4 will be required to retire or complete retrofits to transition to an alternative fuel source by 2020 and 2025, respectively (NYISO, 2018, p.33). This policy was developed by the NYC Department of Environmental Protection (DEP) to address particulate matter below 2.5 microns (PM 2.5), which impacts the health of residents through lung and heart complications. The New York Residual Oil Elimination regulation will predominantly impact buildings that currently utilize fuel oil #6 and fuel oil #4 to provide building heat throughout the boroughs; however, as shown in Table 3, some generators that continue to utilize fuel oil to generate electricity will also be impacted.

In addition to the Residual Oil Elimination regulation, New York City generation will be impacted by the Ozone Season Oxides of Nitrogen (NO_x) Emission Limits proposed in February 2019 by the Department of Environmental Conservation (DEC). This NO_x emission limit (i.e. 'Peaker Rule') address smog generated from peaking units and "could impact approximately 3,300 MW of simple-cycle turbines in New York City and Long Island" which maintain transmission reliability for the region (NYISO, 2019b p. 11). In NYISO's 2019-2028 reliability study, the impact of the DEC 'Peaker Rule' was evaluated and it was determined that; "if all of the generators affected by the peaker rule were to deactivate without the addition of replacement resources or system reinforcements, the transmission system would be unable to reliably serve the forecasted load within specific pockets in New York City and Long Island, as well as across Southeast New York" (NYISO, 2019c, p.5). NYISO estimates that implementation of the DEC rule in 2023 (the first phase of the DEC 'Peaker Rule') will result in a 14-hour 240 MW deficiency in New York City, increasing to a 660MW deficit in 2025 at full implementation of the rule (NYISO, 2019c, p.5). The New York Residual Oil Elimination regulation and the

Ozone Season Oxides of NO_x Emission Limits are forcing the aging peaking units in NYC to either invest in retrofit technology or be replaced with new technology.

As these fuel oil and peaker units are retired or transitioned to alternative fuel sources, the generation fleet in New York City will become increasingly dependent on natural gas or imports from other NYISO zones via transmission interconnections. Single fuel generators that utilize natural gas can cause increased stress on natural gas supplies and infrastructure in cold seasons, as the added electricity from a natural gas fuel source will compete against natural gas resources availability to maintain customer heating. In periods of time where there is insufficient gas supply to provide heating and fuel for electricity, generators without firm gas supply can be curtailed - impacting reliability. Currently, “The New York State Reliability Council (NYSRC) has a minimum oil-burn requirement rule that is intended to provide assurance that electric system reliability can be maintained in the event of gas supply interruptions during winter months, when gas is also needed for heating, and peak electric demand conditions during the summer” (NYISO, 2019b, p. 39). Alternative generation needs to be established in NYISO Zone J to serve peak load demands, recognizing that without additional natural gas infrastructure natural gas generation could be constrained in instances of natural gas interruptions and/or curtailments.

As many of these peaking units in the New York City area are older and facing increasing levels of environmental regulation, it is challenging to make a business case around investing capital to retrofit older units. As the fuel oil and DEC rules continue to be evaluated and implemented, one must keep in mind that Zone J will require a replacement mechanism for these peaking units in the form of new generation assets or increased transmission investment by the 2023-2025 time period, under the current regulation implementation schedule.

Geographic Constraints

New York City has the highest population density of any metropolitan area in the United States, with 27,000 people per square mile (NYC Planning, 2020). Despite geographic constraints, New York City is installing solar arrays on rooftops. In June 2019, New York City Council passed an ordinance requiring rooftops of new buildings to be “topped with solar panels or roofs covered in grass or other vegetation” (McGeehan, 2019). Blackstone Group, one of the leading real estate groups in the world, has added 9,000 solar panels to 56 roofs in Manhattan, doubling the borough’s solar capacity. Despite the volume of solar panels installed by the Blackstone Group, this solar addition provides a mere 3.9 MW of capacity. When compared to the annual peak capacity of Zone J (11,496 MW), this solar install reflects only 0.03% of system demand in New York City.

Table 4.
Blackstone 2019 Manhattan Solar Installation
(McGeehan, 2019).

Blackstone Solar Capacity	3.9 MW
Average Solar Capacity Factor ¹	15.5%
Annual Production	5,121,379 MWh
Average Household Usage	6,000 kWh
Annual Households Fully Supplied by Solar	854

References and Notes:

1. Solar capacity factor calculated based on NREL, PVWatts tool. Generation was calculated specific to New York City, based on a fixed solar array, 20° array tilt, 180° array azimuth. (NREL, 2020).

Table 4 illustrates that this \$10 million solar investment generates local carbon-free energy for 854 households. The cost of Blackstone’s solar installation in NYC resulted in a total build cost of approximately \$2,500/kW. For comparison, the current overnight capital cost of a natural gas combustion turbine is \$700-900/kW. The capital cost of the recent solar addition by Blackstone in Manhattan was 3.5 times a natural gas alternative. In addition to the costly nature of this installation, the power generated represents less than 10% of the company’s local residences

owned by the Blackstone Group in New York City. These solar additions provide fuel diversity to the generation mix but are incurred at a significantly higher cost than a natural gas alternative. It is also worth noting that \$2.3 million of the \$10 million Blackstone solar project was subsidized through the New York State Energy and Resource Development Department, to support local renewable integration.

Inclusion of Carbon in Resource Planning

As carbon reductions become a focal point in generation resource planning, the integration of the societal cost of carbon is an increasingly central component of generation resource selection. Currently, the societal cost of carbon and the realized market cost of carbon are far from aligned. “New York Public Service Commission’s (NYPSC’s) adoption of the Social Cost of Carbon (SCC) as estimated by the U.S. Interagency Working Group on the Social Cost of Carbon [is] \$43/ton CO₂ today and rising to \$65/ton by 2029” compared to the most recent RGGI carbon auction price of \$5.65/ton CO₂ (Newell, 2017, p.22 & RGGI, 2020). The disparity between the carbon cost used for planning purposes and the carbon cost dictated by the market creates a disconnect between resource selection and market value.

Wholesale markets are designed to provide electricity to optimize cost and reliability, and as regional emission requirements and targets are incorporated into resources planning considerations the planning cost of energy will begin to impact market costs. NYISO has evaluated and published an opinion that the introduction of “a carbon price into wholesale markets will reduce the cost of [renewable energy credits] RECs and [zero emission credits] ZECs as facilities eligible for these subsidies are able to realize greater revenues from the NYISO’s energy markets” (NYISO, 2020b). As a “carbon charge increases clearing prices for wholesale energy according to the emissions rate of the marginal, price-setting resources in the

market ... the cost of higher wholesale energy prices is partially offset by carbon revenues collected from internal fossil generation and imported energy” that are assumed to be returned to customers via their load serving entity (LSE) (i.e. utility provider) (Newell, 2017, p.vii). Based on this analysis on carbon pricing returning revenues to customers can serve to counteract the increased cost of generation and transmission driven by applying carbon pricing.

Leveraging NYISO data and industry data, listed in Table 5, the impact of carbon pricing on the levelized cost of energy (LCOE) and levelized cost of capacity across various fuel types has been assessed in a 20-year revenue requirement model¹.

Table 5.
Assumptions Leveraged in Carbon Impact to LCOE.

Technology (Fuel Type)	Combustion Turbine (Natural Gas)	Combined Cycle (Natural Gas)	Utility Scale Wind	Utility Scale Solar
Life of Asset (years)	30	30	20	20
Capital Build \$/kW ₁	710	954	1,319	1,331
Build Capital (\$000s)	142,000	715,500	263,800	199,650
Annual O&M (\$000s) ₁	1,394	5,200	5,244	2,279
Annual Capital (\$000s)	1,500	6,000	500	500
Variable O&M (\$/MWh) ₁	4.48	1.86	-	-
Heat Rate ₁	9,905	6,370	-	-
Carbon Intensity (lbs/MWh) ₂	1,159	745	-	-
Size (MW)	237	1,083	200	150
MACRS ₃	20-Years - Half	20-Years - Half	5-Years - Half	5-Years - Half
Capacity Factor	10.0%	45.0%	50.0%	40.0%
Capacity Accreditation	100%	100%	15%	40%

References and Notes:

1. Capital and O&M assumptions were sourced from the EIA’s Annual Energy Outlook 2020 (EIA, 2020a, p.6)
2. Carbon intensity based on EIA CO2 emissions per energy output ratio (EIA, 2020b).
3. MACRS (Modified Accelerated Cost Recovery System) based on the IRS 946 guidelines (IRS, 2020)
4. All other inputs were developed using broad industry research and knowledge base

As shown in Figures 4 and 5, regardless of federal tax credits, wind is a more cost-effective resources on an energy basis. On a capacity basis, combustion turbines and combined cycles are more cost effective than wind or solar capacity resource additions, even with a \$100/ton cost of carbon applied. When evaluating electric cost, it is important to consider the resource from an

¹ This revenue requirement model was developed as a unique work product for this report, utilizing inputs identified in Table 5.

energy and capacity basis; different resources have different operating characteristics and serve different roles in balancing grid demands. Certain resources will be required to provide baseload energy levels that will be needed throughout the year and other resources will be predominantly dispatched to meet peak demand needs (i.e. capacity). All levelized costs provided in Figures 4 and 5 are based on a 20-year period.

Evaluating these resources without federal tax incentives (i.e. production tax credit and investment tax credit), which are planned to be phased out by 2022, result in a different level of sensitivity. As shown in Figure 5, with the federal subsidies, accelerated depreciation and no cost of carbon, solar energy and a generic combined cycle resource have similar LCOE; however, as the cost of carbon increases these resources diverge with the fossil based combined cycle becoming incrementally more expensive as the cost of carbon burdens the fossil asset. Conversely on a capacity basis, dispatchable fossil assets have lower levelized cost of capacity compared to solar and wind resources due to the discounted capacity accreditation of intermittent resources. Under a subsidized and unsubsidized analysis wind is the lowest cost energy asset and a combustion turbine is the lowest cost capacity asset, across the span of a \$0-\$100/ton cost of carbon.

Figure 4. Subsidized Levelized Cost of Energy and Capacity of Technology, with Cost of Carbon

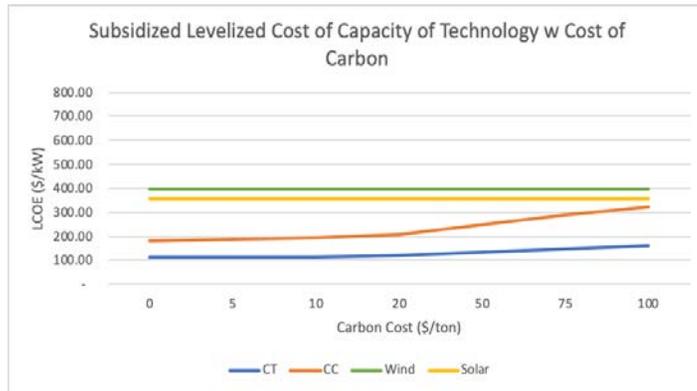
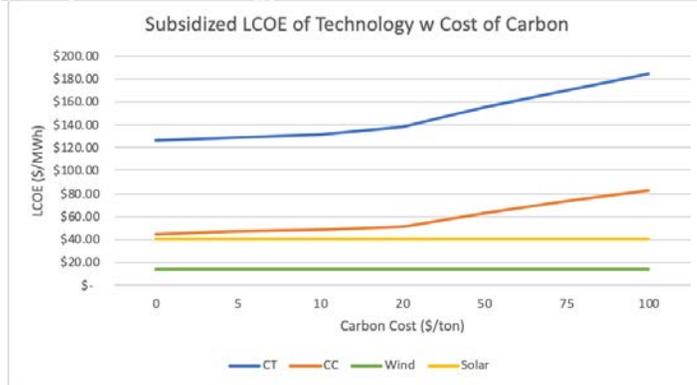
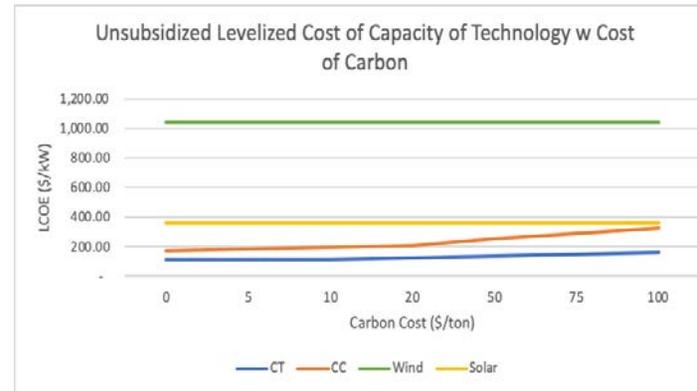
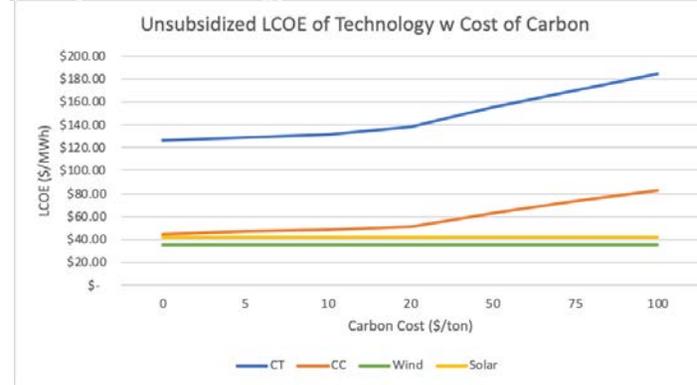


Figure 5. Unsubsidized Levelized Cost of Energy and Capacity of Technology, with Cost of Carbon



Notes:

Capital structure assumed reflects 55/45 D/E ratio with assumed ROE of 9.8% and debt service of 5.0%, resulting in an after-tax weighted average cost of capital (WACC) of 7.1%. A 9.8% ROE is in line with ConEd's 2017 approved ROE in its' 2017 rate case before the NY Department of Public Service (13-00197).

This cost analysis illustrates the following characteristics when evaluating cost of electricity across different generation technologies;

- ***Federal subsidies do provide cost benefits for renewable resources but renewable assets are still competitive on an energy basis without tax credits.*** The production tax credits (PTC), investment tax credits (ITC) and accelerated depreciation afforded renewable technology have allowed these emerging technologies the time required to bring the equipment cost down. As these tax credits approach discontinuation, wind and solar continues to compete with the lowest cost fossil assets on an energy basis.
- ***Capacity accreditation associated with intermittent resources decreases value of non-dispatchable assets from a capacity basis.*** The cost analysis shown in Figure 4 and 5 reflect 15% capacity accreditation for wind and 40% for solar resources, requiring more than 6.5 times the capacity additions for wind and 2.5 times the capacity additions for solar to equate the same system capacity contribution to demand as a dispatchable resource with the same installed capacity. As penetration of specific renewable resources increases in a region, the degradation of a resources contribution to capacity will impact the resource's capacity accreditation, further decreasing the resources ability to contribute to meeting system demand as a stand-alone asset (disregarding solar+battery and wind+battery configurations).
- ***Heat rate efficiencies and low emission levels of natural gas make natural gas a competitive low emission resource.*** Taking into account the heat rate efficiency of natural gas combustion units (6,000-10,000) and the low carbon intensity of natural gas combustion (117 lbs CO₂/MMBtu), natural gas is able to provide electricity at a low

carbon intensity level. Due to the carbon efficiency of natural gas generation, the application of carbon cost has a marginal impact on the LCOE of the CT and CC assets, reflecting a \$0.58/MWh and \$0.37/MWh increase to the technology's levelized cost for each \$1.00/ton of carbon cost applied.

- ***Dispatchable natural gas combustion turbines are the most affordable capacity addition.*** Fossil generation cost is heavily dependent on fuel commodity cost. Based on the EIA's 2020 Annual Energy Outlook, the reference case forecast that gas prices will remain below \$4.00/MMBtu through 2050. The cost analysis incorporated in Figures 4 and 5 assume a natural gas price of \$2.02/MMBtu in 2020 based on the Henry Hub index in January 2020, increasing to a \$3.40/MMBtu gas price in 2040 based on the EIA's 2020 Annual Energy Outlook (EIA, 2020c). Using these recent bearish gas price forecasts, the low carbon intensity of natural gas and dispatchability of gas turbine assets results in combustion turbines being the lowest cost option to provide system capacity, even with a \$100/ton cost of carbon.

Considerations of Carbon Cost Shifts Resource Mix

In the transition to a low carbon future, the basic tenants of affordability and reliability need to be considered. The electric power sector serves as crucial infrastructure that supports the US economy as a fundamental requirement that must be dependable and affordable for residents and businesses alike.

Affordability

Affordability of carbon mitigation is a sensitive topic as the forecasted cost associated with carbon mitigation are astronomical. For example, in 2019 New York City enacted legislation to reduce emissions of the 50,000 buildings in NYC that are greater than 25,000 square feet in size.

This legislation to reduce the emissions in the largest buildings in New York City is estimated to have a price tag of \$4 billion (Kim, 2019). To further climate change adaptation and mitigation, the City of New York Mayor's Office has formed the Office of Resilience to prepare the City of New York for climate change challenges. As discussions are had on the cost of climate change mitigation through transitioning to carbon-free energy resources, it is important to take into account the impact of these changes have to residents and their utility rates. How will the cost of carbon and increased investment impact customer rates?

Three of New York City's five boroughs are ranked as the most expensive cities in the US; Queens at number nine, Brooklyn at number four and Manhattan at number one with a cost of living at 87% above the US average (Burrows, 2019). From a national perspective "New York State had the seventh-highest residential prices for electricity in the United States, at 18.28 cents per kilowatt-hour", according to the United States Energy Information Administration. In an area where the price of electricity "is more than 40 percent higher than the national average" it is important to pay attention to any additional cost that will inflate customer's electric rate (McGeehan, 2019).

Currently NYISO is exploring the integration of carbon cost, in order to incorporate carbon into market dispatch considerations. "NYISO views open markets as an essential, effective platform for pursuing those public policy goals in an economically efficient manner" (NYISO, 2018, p. 10). As carbon cost are integrated into the cost of electricity the "carbon taxes tend to reduce inequality through the changes in factor prices and tend to increase inequality through the changes in commodity prices. Hence, we find a non-monotonic (U-shaped) relationship between carbon taxes and inequality." (Dissou, 2014). As carbon cost increases and generation additions

become more costly in the final stages of carbon reductions required to obtain a carbon-free system, cost can reach unsustainable levels for retail customers to pay.

“Although the incremental emissions reductions induced by a carbon charge could be used to produce greater environmental benefit, they could alternatively be used to meet a fixed emissions target at lower cost by replacing costlier carbon abatement measures. For example, if RECs were being procured beyond the [clean energy standard] CES targets in order to meet economy-wide carbon reduction goals, the carbon-charge-induced reductions could avoid buying 6.3 TWh of RECs per year. This could save roughly \$120 million per year in total economic costs per year, assuming the price-induced abatement measures cost \$19/MWh less than the RECs” (Newell, 2017, p.37). As the state works towards decarbonization it is important to consider multiple options and applications in order to minimize cost associated with reaching this milestone, recognizing the impact these decarbonization investments will have on customers.

Reliability

As renewable generation penetration increases, this shift in generation resources “will create a more dynamic grid where supply is heavily influenced by weather. This necessitates a look at what types of incentives for flexible resources are needed to balance intermittent renewables” (NYISO, 2018, p. 10). As dispatchable units are retired and replaced with intermittent resources the ancillary service markets will be increasingly relied on to meet required capacity needs within energy balancing markets. “The NYISO’s markets have maintained this balance through price signals that sustain reliability in an economically efficient manner. However, power plant deactivations can present challenges to electric system reliability” (NYISO, 2018, p. 18). Due to fuel irregularity, intermittent resource are “able to displace energy requirements—and capacity to a lesser extent—other essential reliability services traditionally provided by conventional

generation must also be replaced” (NERC, 2013, p. 15). As peaking and dual fuel oil units are retired and replaced due to growing environmental regulations and policy initiatives, reliability concerns related to fuel security and ability to meet peak system demand must be addressed while working to achieve New York State’s carbon goals.

Concerns have also been raised related to renewable resources’ ability to provide system inertia. Inertia maintains the system power factor and protects the grid infrastructure from damage as the system experiences fluctuations in demand and supply. This electric property is generated from the rotation of heavy generating equipment operating at the grid frequency, also known as reactive power. Inertia aids the grid in balancing changes in demand and supply, as the frequency shifts and the inertia (rotating mass of large generators) acts as a shock absorber (Robb, 2019). In absence of large fossil generating assets, synchronous condensers can provide “inertia – following a disturbance in frequency [by releasing] the kinetic energy that is stored in their rotating masses as an inertia response” (Rezkalla, 2018). As renewable generation continues to dominate energy additions in resource plans (as illustrated in Figure 2), the concepts of inertia floors to manage reactive power and emulated inertia (using pooled renewable resources) are being explored. For example, The Republic of Ireland “established a minimum value of rotational kinetic energy in the system as an operational constraint during the dispatch phase (i.e. 20 GWs) and they refer to it as inertia floor” (Rezkalla, 2018). NERC has stated that “PV solar generation offers no inertia and no frequency response, and wind generation offers virtually none”; however, the industry has continued to explore the concept of emulated inertia, which utilizes “control algorithms, renewable energy resources, energy storage systems and power electronics” to mimic conventional inertia (NERC, 2013, p.15; Rezkalla, 2018). As NYISO integrates increased amount of intermittent renewable resources onto its’ system

capacity dispatchability, inertia, reactive power and transmission constraints will have to be part of the conversation to continue to reliability serve customers.

Methods to Incorporate Increased Renewables

As the resource mix shifts in the State of New York and in NYISO Zone J, multiple operational tools need to be deployed to increase the volume of renewable energy used to serve New York City's electric requirements, while maintaining grid reliability at an affordable price. To achieve 70% renewable electricity by 2030, the grid must accommodate increased renewable resources in the short-term horizon by increasing gas flexibility and replacing older peaking units with dispatchable high-efficiency combustion turbines. In the long-term horizon of achieving the 2040 goal of 100% carbon-free electricity, the region will need to increase transmission investments and begin exploring applicable energy storage to allow renewable resources to be shifted to serve load demands. It is important to note that these methods complement each other and provide avenues for the energy industry to leverage these tools as it grows into the new energy mix of achieving carbon reductions over time, in a safe, reliable and cost-effective manner.

Flexibility

Resource flexibility is defined as “the ability to respond rapidly to dynamic system conditions, provide controllable ramping capability with fast response rates, and the ability to startup and shutdown quickly and frequently in response to system needs” (NYISO, 2019b p. 46).

Flexibility is the most effective method to integrate increasing volumes of renewable generation, in the absence of a cost-effective and operationally deployable energy storage solution.

Increased dispatchable resource flexibility is a short-term (i.e. current-10 year) solution to decreasing carbon intensity of the electric grid. Natural gas combustion turbines (frame and aeroderivative) and hydro resources (as geographically available) are able to provide the quickest response time to changing operational demands, as detailed in Figure 6. In 2019 the fossil electric energy mix in the US was comprised of predominantly natural gas (38.4%), followed by coal (23.5%) and marginal amounts of petroleum (0.5%) fired generation (EIA, 2020d). Of these fuel sources natural gas provides the most flexibility. Within the configuration options commercially available (at utility scale) for natural gas, the “technology with the fastest cycle time for hot and cold starts is the Aero-GT (45 min), followed by the heavy-duty, frame gas turbine in simple cycle (90 min) and in combined cycle (120–280 min, respectively)” (Gonzalez-Salazar, 2018, p.1504). Increasing renewable generation into energy portfolios across the world has engaged the original equipment manufactures (OEMs) in developing products that increase operational flexibility of generators to respond to shifting load demands through increased

turndown, fast-start optionality and fast-ramp products. Aero-derivative gas turbines have the highest operating flexibility with ramping capabilities of 80-100% of full load/minute and start-up times of 2 minutes. The flexibility benefit of the

Figure 6.
Flexibility Characteristics of Various Power Generator Technologies
(Gonzalez-Salazar, 2018, p.1499).

Technology	Minimum load (% full load)	Ramping rate (% full load/min)	Hot start-up time (h)
Hydro reservoir	5	15	0,1
Simple cycle gas turbine	15	20	0,16
Geothermal	15	5	1,5
Gas turbine combined cycle	20	8	2
Concentrated solar power	25	6	2,5
Steam plants (gas, oil)	30	7	3
Coal power	30	6	3
Bioenergy	50	8	3
Lignite	50	4	6
Nuclear	50	2	24

aeroderivative technology comes with the cost of higher carbon emissions when compared to a large frame combustion turbine or combined cycle configuration. Large frame gas combustion turbines provide valuable operational flexibility in a simple cycle configuration, with ramp rates ranging from 8-15% full load/minute and start up time of 11 minutes at lower emission levels. Flexible improvements are projected to continue as flexible operations become increasingly critical to the health and viability of fossil generators on the electric market. Future operational improvements are depicted by black bars in Figure 7.

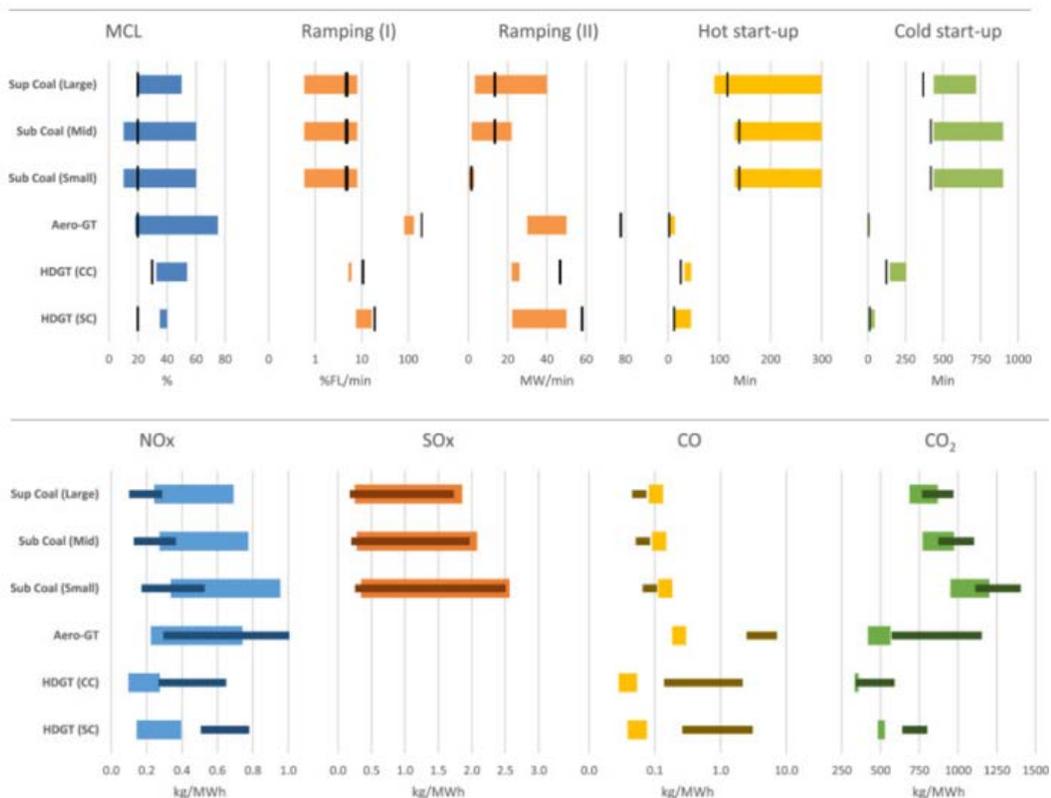
In a 2018 report, NYISO recognized the need for highly flexible resources “to balance the traditional variability of load and emerging variability of new intermittent supply resources. Operating characteristics such as availability, flexibility, and willingness to cycle are important to long-term grid stability and will need to be incentivized” (NYISO, 2018, p. 37). In an effort to encourage the generator development and value fast-ramping capabilities FERC developed a “pay for performance” order in 2011, recognizing the value of ramping capabilities. As resource flexibility becomes critical to incorporating increased volumes of intermittent carbon-free resources, revenue adequacy through market products will become paramount to encouraging investment in flexibility upgrades and additions.

Replacement of Zone J Existing Peaker Units with Natural Gas

Providing the citizens of New York City with improved air quality, with reductions to NO_x and particulate matter benefits the health and well-being of the community. To accommodate this improved air quality, 3,300 MW of generation in Zone J must be retired or retrofitted to operate with a natural gas fuel source. As Zone J currently relies on these aging peaker units (i.e. steam turbines) and imports from neighboring zones to meet its regional peak demand requirements, replacement capacity will need to be considered. This capacity replacement need and goal of

improved air quality “translate into customer benefits in two ways: (1) incremental investment in new CCs reduces wholesale capacity and energy prices relative to those estimated in the static analysis; and (2) the emissions reductions can translate to customer cost savings by relieving the need to undertake more costly carbon abatement measures, such as additional REC purchases, to achieve a given carbon reduction goal” (Newell, 2017). As shown in Figure 7 natural gas combined cycle configurations provide the lowest emission levels of all fossil generation and has the lowest LCOE of the fossil resources (\$44-68/MWh) (Lazard, 2019). Simple cycle gas combustion turbines (i.e. CT) provide fast start, fast ramping capabilities and relatively low emissions at a low cost of capacity. Replacing the current aging steam units in New York with simple cycle gas combustion turbines for capacity needs and combined cycle assets for energy needs at the current steam turbine brownfield sites are a cost effective way to provide reliable and affordable generation to Zone J, while improving local air quality by the 2022-2025 period, outlined in the current environmental regulation schedules by the NY DEP and NY DEC.

Figure 7.
Operational flexibility and emissions at minimum load and full load capabilities
(Gonzalez-Salazar, 2018, p.1508-1509).



Notes:

In operating parameter graphic, black bars represent possible future values. In emissions graphic, light thicker bars represent emission factors at full load, dark narrower bars represent emission factors at minimum compliant load.

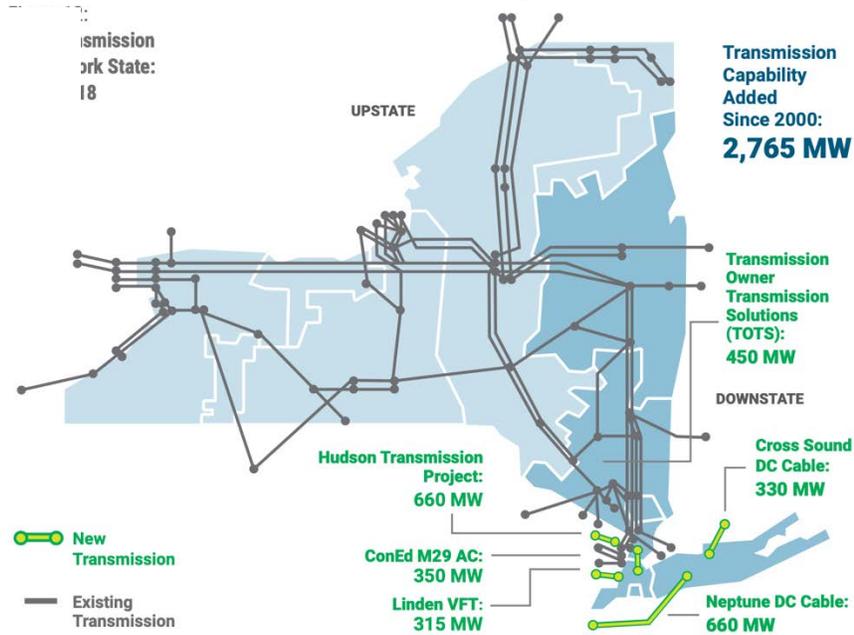
Increased Transmission Investment

Despite the resource constraints of Zone J, NYISO has ample renewable generation with upstate New York serving up to 90% of load demands with renewable resources (NYISO, 2019b, p.45).

The need for transmission expansion to move renewable generation from upstate New York to downstate zones is required to maximize the renewable generation produced and minimize renewable curtailment due to insufficient transmission capabilities. The “power demands of the downstate region have attracted the development of various transmission projects, primarily to

serve southeastern New York, including New York City and Long Island” (NYISO, 2019b, p.18). The current Western New York Transmission project planned for completion in 2022 will allow for increased NYISO imports of hydro energy and the AC Public Policy Transmission project will increase transmission capabilities from northwest NYISO to the Hudson Valley and New York City load centers. In addition to these large transmission additions currently in progress, new transmission that was completed from 2000-2018 has increased import capabilities to Zone J, as shown in Figure 8 (NYISO, 2019b p. 44).

Figure 8.
New Transmission in New York State: 2000-2018
(NYISO, 2019b p.19).



The transmission improvements in progress and completed since 2010 currently provide increased renewable generation and transmission capabilities across the ISO and bring additional imports to current load pockets (such as Zone J). The transmission additions noted are small improvements in comparison to the transmission additions needed to interconnect the 12 GW of proposed offshore wind resources planned for NYISO Zones F-K or at a minimum the 9 GW of

offshore wind capacity to be installed by 2035, per the CLCPA legislation. In August 2019, the New York Power Authority published a study that assessed the offshore wind resources in Europe, in an effort to leverage Europe's offshore wind experience in guiding New York's development of offshore wind resources and grid interconnection. It was identified by the New York Power Authority that 25% of the capital cost for offshore wind development is driven by transmission cost, which can vary significantly, "between 15-30% of total cost based on water depth, distance from shore, etc." (New York Power Authority, 2019, p.9). It is estimated that transmission and interconnection cost in New York for 10 GW of offshore wind could "require \$6 billion to \$8 billion in capital investment" without accounting for on-shore upgrades to transmit this wind generation to load centers within NYISO (Lefevre-Marton, 2019).

Energy Storage

Energy storage technology continues to demonstrate improvements in cost year-over-year. Declining cost in lithium-ion battery technologies have outpaced improvements in lead and flow batteries (Lazard, 2019). Project economics of utility scale energy storage is still heavily dependent on "subsidized revenues and related incentives" which vary based on regional market structures and legislation (Lazard, 2019). As New York works towards the state goal outlined in CLCPA legislation of "1,500 MW of storage capacity to be installed by 2025, [combined with] a commitment of \$200 million in storage-related investments from the NY Green Bank to support this goal, the NYISO anticipates investments in both behind- and in front-of-the-meter storage resources" (NYISO, 2018, p. 39). In 2019, Enel X installed a 4.8 MW/16.4MWh lithium ion battery, the largest grid battery in New York City which is dispatched by ConEd in front-of-the-meter to manage congestion and differ system upgrades (Spector, 2019). Energy storage will

play a crucial role in the decarbonized energy market, and ConEd is currently in the procurement process of adding 300MW/1,200MWh of battery storage in 2022 (Spector, 2019).

The opinion of what role energy storage plays in a deep decarbonization future is varied, and the value of duration and size of energy storage can be drastically different based on the regional load and resource mix available. In an MIT study that evaluated energy storage in Texas, it was identified that “the value delivered by energy storage with a 2-hour storage capacity only exceeds current technology costs under strict emissions limits...[where] in contrast, storage resources with a 10-hour storage capacity deliver value consistent with the current cost of pumped hydroelectric storage” (de Sisternes, 2016). As energy storage capital cost continues to decrease and renewable generation penetration increase, the challenge of integrating energy storage has become identifying which technology will allow large volumes of energy storage and sufficient storage duration at an affordable cost.

Long-term energy storage advancements are being explored, including but not limited to; compressed air energy storage (CAES), molten salt and hydrogen storage. The use of hydrogen as a long-term energy storage technology allows blending of hydrogen fuel with natural gas fuel in combustion turbines. Currently combustion turbine technology and retrofits are available to allow up to 40% hydrogen integration in combustion turbine generators and tests are being performed to achieve 100% hydrogen fuel integration. Based on these advancements, as Zone J replaces existing peaking units with new combustion turbine equipment, opportunity exists to integrate carbon-free hydrogen into Zone J’s natural gas fuel mix as the grid reaches increased levels of decarbonization.

Conclusion

The passage of CLCPA puts New York at the forefront of solutioning grid decarbonization in the next several decades. The CLCPA outlines carbon reduction goals by increasing the state energy and climate goals to achieve 70% renewables by 2030, 100% carbon-free electricity by 2040, followed by decarbonization of the state by 2050. Incorporating increased renewables can create operational challenges as non-dispatchable generators with intermittent fuel resources establish a disconnect between generation supply and load demands. The reliance on intermittent resources to provide instantaneous energy makes balancing grid supply and demand increasingly challenging. New York City (Zone J) is currently a net importer of peak energy and relies on transmission interconnections with other zones to meet its regional peak energy demands. A unique challenge in implementing CLCPA will be the decarbonization of New York City as this load pocket has large load demands and limited affordable geography combined with aging generation infrastructure.

As New York State and New York City look to transition to carbon-free electricity, it is important that affordability and reliability remain key considerations. As it stands, the political and regulatory structures have already begun incorporating carbon pricing into resource planning, creating a divergence between the carbon cost used for planning purposes and the carbon cost established by the market. This creates a disconnect between resource selection and market value. Considering that New York state has the seventh highest residential electric rates in the nation, it is imperative that the impact of imposing carbon costs on customer rates is closely monitored. Throughout this report it has been demonstrated that with or without current federal subsidies wind resources are the lowest cost energy asset (\$13.60-\$35.70/MWh) and a combustion turbine represents the lowest cost capacity asset (\$110-\$160/kW-yr), across the span

of a \$0-\$100/ton cost of carbon. Electric service is a critical input to the US economy and society; affordability and reliability are a cornerstone consideration of the system's transitions to a carbon-free grid.

Multiple operational deployment tools will be needed to increase the volume of renewable energy used to serve New York City's electric requirements and maintain affordable grid reliability. It is important that both short and long-term applications are integrated into the strategy to decarbonize the NYISO system and NYISO Zone J. In the short-term, Zone J would benefit from replacing aging steam units with combustion turbine and combined cycle technology ensuring affordable, reliable and flexible energy. The replacement of the existing steam units, that have been taken past their standard useful life, will provide regional benefits in the form of improved air quality and allow for flexible regional resources to aid in the integration of intermittent renewable resources. In the long-term horizon, Zone J will benefit from investing in transmission infrastructure to increase its interconnection capabilities with other NYISO zones and integrating offshore wind that is planned in the downstate region. As energy storage technology evolves and matures, NYISO can manage transmission constraints through the integration of battery storage and application of extended duration energy storage resources.

The journey to deep decarbonization of the electric grid provides unique challenges, which vary greatly based on regional load demands, existing generation mix, transmission constraints and natural resources available. Through exploring the short-term and long-term challenges with deep decarbonization of New York City it is clear that deep decarbonization is operationally possible, but becomes more challenging when taking timeline, cost and reliability constraints into account. As innovation and technology cost curves continue to decrease capital cost and

improve operational flexibility, effective low-cost carbon-free solutions become increasingly more attainable within the confines of economic and operational requirements.

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