New York City’s Aging Power Plants: Risks, Replacement Options, and the Role of Energy Storage

STRATEGEN CONSULTING

Prepared For: NY-BEST

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Executive Summary

New York City's aging electric generation fleet presents a significant challenge and opportunity that must be addressed over the next few years. Existing generation units located in New York City are critical for meeting local grid reliability needs, but face pressures due to their advanced age and significant contribution to air quality problems in the region. Within the next five years, plant owners, system operators, and policy makers will need to make important decisions to address these interrelated concerns. As these decisions are made, it is critical to understand that battery energy storage can provide an effective solution for simultaneously addressing both air quality and reliability needs. This study explores the issues related to New York City's aging fleet with a particular focus on peaking plants and the role that energy storage can play in addressing the imminent challenges they face. Below are some of the key takeaways from this analysis.

Key Takeaways from the Analysis

Reliability Issues Associated with New York City's Aging Generation Fleet:

- Within 5 years, 2,860 MW of old steam and combustion turbines in Zone J will be past their normal retirement age, representing 30% of New York City's current generation fleet.
- The transmission system in the New York metro area is highly constrained, requiring that enough local generation resources be installed to serve ~80% New York City's 11,600 MW forecasted peak load in order to ensure reliability.
- Only 456 MW of new local generation projects in development have advanced to the Facilities Study stage, which would be insufficient to meet a potential 642 MW local capacity shortfall as early as 2021 (if old peaker plants are decommissioned).

Air Quality Impacts of New York City's Old Peaker Plants:

- Air pollution, including ozone and particulate matter, is a major public health problem for the New York metro area.
- Ozone above background levels causes New Yorkers to suffer annually from over 400 premature deaths, 850 hospitalizations for asthma and 4,500 emergency department visits for asthma.[1]
- The cost to the local economy from NYC power plants emissions is estimated to be at least $62 million annually, but is likely much higher.
- There are a small number of older peaking plants in New York City without NOx controls that contribute significantly to ozone-forming NOx emissions in the region.
- Many of these plants run very infrequently, and typically do so on hot summer days that are likely to have higher ozone concentrations.
- On average, these few plants contribute 51% of the NOx emissions from in-city plants during ozone season, while generating only 4% of the power consumed.
- The closure of Indian Point is likely to increase the utilization and emissions from fossil fuel plants – particularly those located in NYC (Zone J).

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[1] Source: NYC Dept. of Health and Mental Hygiene: Air Pollution and the Health of New Yorkers https://www1.nyc.gov/assets/doh/downloads/pdf/eode/eode-air-quality-impact.pdf

Evaluation of Energy Storage as a Potential Solution:

- Deployment of battery energy storage facilities in lieu of old peakers could be an effective strategy for controlling NOx emissions and ozone pollution, while contributing to local grid reliability.
- Deploying 4-hours of energy storage at or near the highest NOx emitting combustion turbine plants may be sufficient to reduce NOx emissions at these plants by 62-66%.
- Studies conducted in other regions of the U.S. power grid (e.g. Texas and California) have confirmed the ability of energy storage to contribute substantially to the reliability of the grid.
- As solar PV penetration increases, NYC peak load hours will shift into the evening and become much narrower, thereby reducing the need for long-duration generator output and enhancing the ability of limited duration energy storage to meet system peak load.

Economic Evaluation of Storage Versus Conventional Solutions:

- New York City electricity customers currently pay over $268 M annually in capacity payments to support old peaker plants that run less than 10% of the time.
- Energy storage is increasingly cost-competitive with new natural gas peakers in NYC and could be an economically viable option for replacing or supplementing existing generation capacity in the region.
- Energy storage can provide system level benefits that are not compensated under NYISO's current market design. Accounting for these system-wide benefits could make storage even more cost effective than new natural gas peakers.
- Like many other energy resources recently developed in New York (e.g. renewables, natural gas), long-term contracts are needed to make storage projects financeable.
- A relatively small set-aside for flexible capacity resources could provide the financial certainty necessary to allow energy storage to effectively be deployed as a supplement or replacement for old peakers.
- We estimate that a small capacity set-aside (<5%) for storage each year in Zone J could help attract investment in 450 MW of new energy storage resources over the next 5 years, helping to supplement or replace the least utilized peakers with minimal impact in total cost to customers.
- Adapting the proposed VDER tariff to provide revenue certainty may also be an effective option for deploying storage, especially for distributed storage resources.

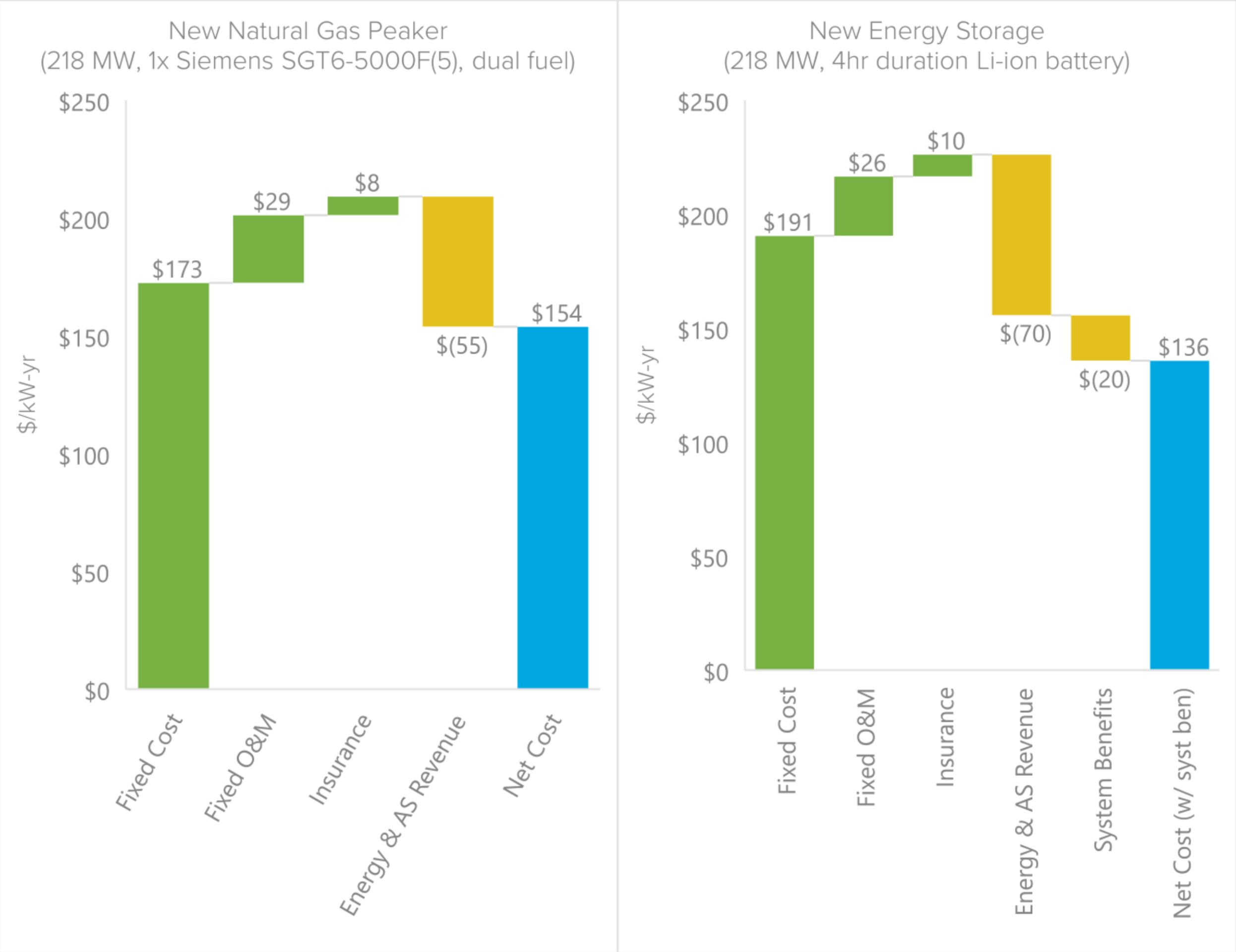

Figure ES-1. Net CONE comparison between a new natural gas peaker and a new battery energy storage unit, including system benefits. The type of natural gas unit illustrated here reflects the proxy unit selected by the NYISO for its ICAP demand curve. Fixed costs for storage reflects the current forecast of cost of a new Li-ion battery installation (these costs may decline in coming years). System benefits (e.g. avoided startup costs) are not compensated under current NYISO market design but would accrue to all customers.

Potential Pathways for New York City's Generation Fleet

Based on the analysis in this study, we can envision several hypothetical scenarios that could unfold over the coming years for New York City's generation fleet. Of the scenarios outlined below, we believe that "Status Quo" is relatively unlikely given potential technical challenges and policy preferences at the state and local level. Of the remaining two scenarios, the final one (Proactive Procurement) is clearly a preferable option. We recommend that state and local authorities take appropriate steps to ensure this outcome and we have provided some suggested recommendations in the following section.

- Status Quo: Under this scenario, New York City's aging generation fleet continues to operate indefinitely. Older generators overcome the technical barriers to continued operation, despite surpassing the age of all other similar generators in the country. No additional steps are taken to address emissions from local generators and their health impacts perpetuate. Capacity market revenues support continued operation of older generators and eventually attract minimal investments in new capacity resources in the city. New York City stalls in meeting its clean energy goals due to continued investment solely in fossil fuel resources.

- Capacity Crisis: Several older generators in New York City soon retire due to a combination of new environmental rules and technical challenges due to age. This leads to a local capacity shortfall that is exacerbated by the retirement of Indian Point. Prospective new generation and transmission projects are unable to be completed on time due to unanticipated cost overruns, local opposition, lack of long-term contracts to secure financing, and NY DEC rejection of new pipeline projects. Energy efficiency and distributed generation efforts are ramped up, but still insufficient to meet local capacity requirements. Emergency steps must be taken to secure New York City's grid reliability, but few new capacity options are available.
- Proactive Procurement for Reliability and Environmental Benefits: New York seeks proactive steps to simultaneously 1) address the environmental damages from old generators and 2) stave off local reliability issues should any of these generators be forced to retire. A policy is adopted to procure low-emissions capacity resources. Energy storage is found to be an important component of implementing a new clean local generation portfolio. This results in meaningful deployment of energy storage resources which simultaneously serve to reduce local criteria pollutants, advance the City's GHG goals, and contribute to local grid reliability.

Recommendations for Action:

- *Establish a flexible capacity target for local resources* – An incremental annual 5% set-aside in New York City (Zone J) capacity market could help support the long-term contracts necessary to attract investment in over 450 MW of new energy storage resources over the next 5 years with very little impact (<1%) in total cost to New York City customers.
- *Establish a fair and effective VDER tariff for storage* —a near-term modification to the proposed VDER tariff could create certainty around a long-term revenue stream for distributed energy storage. Tariff development should explore local environmental values and accommodate a variety of system sizes and configurations.
- *Complete the state's "storage roadmap" study* – Through NYSERDA, New York has begun to embark on a storage roadmap study that will help identify need and potential benefits of storage for the state. We recommend the timely completion of this study and that it include some focus on the role of storage for meeting New York City's local capacity needs.
- *Conduct a technical study on storage's contribution to grid reliability* – Like what has been done in Texas and California, we recommend that NYISO work with stakeholders to define and conduct a study on the ability of energy storage (of

various durations) to contribute to its resource adequacy criteria (i.e. Loss of Load Expectation).

- *Explore procurement options under the Clean Energy Standard* – Given the ability for energy storage to aid renewable energy integration (e.g. reduced curtailment) and contribute to underlying goals of reduced greenhouse gas and criteria pollutants, it may warrant special consideration under the Clean Energy Standard. NYSERDA and NYPA should consider ways to leverage their procurement processes to include the full benefits of potential storage resources.

Section 1 – Meeting New York City's Future Reliability Needs with an Aging Generation Fleet

1.1 Overview of New York City's Generation Fleet

The New York Independent System Operator (NYISO) is largely responsible for maintaining reliable operations for New York's power grid. In their most recent annual Power Trends report, NYISO identifies a major challenge to grid reliability that the state will be facing over the coming decade: "nearly 2,000 MW of steam-turbine and gas-turbine capacity [is already] of an age at which 95% of capacity using these technologies retires."[2] While this is a statewide issue, it's worth noting that approximately 80% (~1,600 MW) of the generators that NYISO has identified as nearing retirement age exist within a single load zone – Zone J, which corresponds to New York City. Moreover, the amount of generation in New York City of retirement age will grow considerably over the next decade (see Figure 1). Within 5 years, 2,860 MW of Zone J generation will be at retirement age, comprising 30% of NYC's fleet. Within 10 years, the number will grow to approximately 4,000 MW, or 41% of the city's fleet.

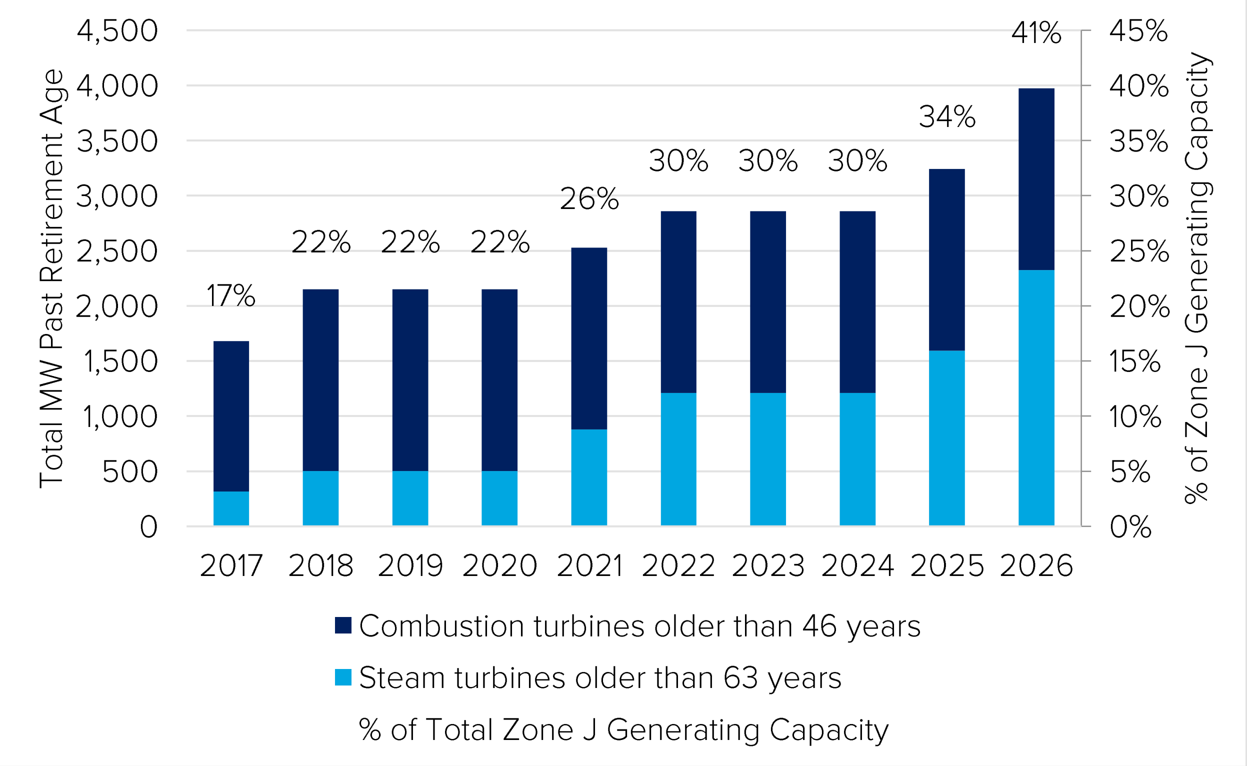

Figure 1. Capacity Outlook for NYISO Load Zone J (N.Y.C.). Retirement age is defined as the age at which 95% of capacity using these technologies retires nationally. This equates to 46 years for combustion turbines and 63 years for steam turbines. (Source: NYISO 2017 Load & Capacity Data aka "Gold Book").

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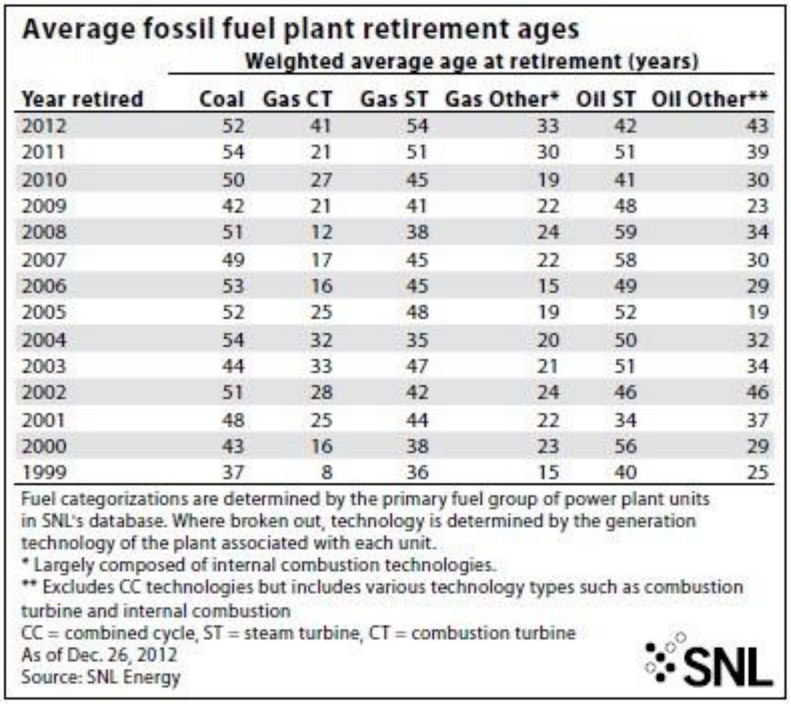
[2] NYISO Power Trends 2017

New York City's generation fleet is comprised of three primary technologies: steam turbines (STs), combustion turbines (CTs), and combined cycle plants (CCs). Most of the ST units in Zone J commenced operation in the late 1950s and early 1960s, while most of the CT units commenced operation in the late 1960s and early 1970s. As indicated in the NYISO's recent Power Trends report, STs generally have a lifespan of 63 years or less, while CTs typically have a lifespan of 46 years or less (95th percentile). Other analyses have shown that average retirement ages are often much shorter than this (see Figure 2).



Average fossil fuel plant retirement ages

Year retired	Coal	Gas CT	Gas ST	Gas Other*	Oil ST	Oil Other**
	Weighted average age at retirement (years)					
2012	52	41	54	33	42	43
2011	54	21	51	30	51	39
2010	50	27	45	19	41	30
2009	42	21	41	22	48	23
2008	51	12	38	24	59	34
2007	49	17	45	22	58	30
2006	53	16	45	15	49	29
2005	52	25	48	19	52	19
2004	54	32	35	20	50	32
2003	44	33	47	21	51	34
2002	51	28	42	24	46	46
2001	48	25	44	22	34	37
2000	43	16	38	23	56	29
1999	37	8	36	15	40	25

Fuel categorizations are determined by the primary fuel group of power plant units in SNL's database. Where broken out, technology is determined by the generation technology of the plant associated with each unit.

* Largely composed of internal combustion technologies.

** Excludes CC technologies but includes various technology types such as combustion turbine and internal combustion

CC = combined cycle, ST = steam turbine, CT = combustion turbine

As of Dec. 26, 2012

Source: SNL Energy

Figure 2. Average plant retirement ages by year for fossil units. Source: http://www.powermag.com/americas-aging-generation-fleet/

After a steady buildout of CTs in the 1960s and 1970s no generation was added in Zone J for about 20 years. However, beginning in 1992, several new CCs were added through 2012. Generally, these units are not at risk since they were built more recently, have pollution controls, are more efficient, and run at high capacity factors.

Figure 3 provides more detail on each unit installed in Zone J based its in-service date and summer rated capacity. This illustrates that some of the older STs built in the 1950s and most of the CTs built in the 1960s are already at the 95th percentile for retirement age or will be within the next few years. The CTs typically operate at very low capacity factors (<10%) and rely heavily on capacity market revenues to maintain operation. Additionally, several of the older CT units are of the "jet engine" variety and lack any direct form of pollution control. These units may be at risk as new emissions rules are implemented by NY Department of Environmental Conservation (DEC) to address ozone pollution. The NY metro area is currently in non-attainment for federal ozone standards and DEC has proposed implementing new rules to address the contribution of older CTs. This could affect ~1,775 MW of CT generators in Zone J within the 2023 timeframe.

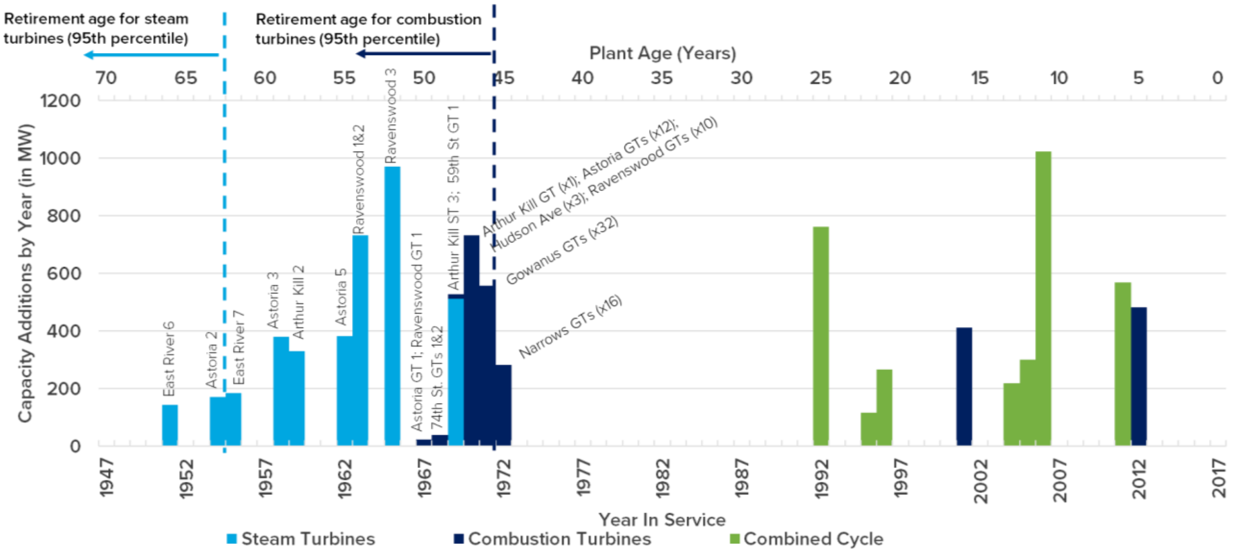


Figure 3. Installed Generation Capacity in Zone J - N.Y.C.
(Source: NYISO 2017 Load and Capacity Data aka "Gold Book")

Several of the older ST and CT units are also "dual fuel" units, meaning they have both a primary source of fuel (typically natural gas) and a secondary fuel source of fuel that can be used as a backup. In some cases, this is required for reliability purposes. For some of these units the backup fuel type is #6 or #4 fuel oil. #6 is the heaviest type of fuel oil (followed by #4 and #2, respectively) and is associated with emissions of SO_2 and black carbon which can be health hazards. In order to improve air quality, New York City has implemented a local law mandating the phase out of #6 fuel oil by 2020 and #4 fuel oil by 2030.[3] Additionally, there is a proposed City Council resolution that could accelerate the phase out of #4 oil to 2025.[4] While some of these dual fuel plants may be able to switch to a cleaner backup fuel (e.g. #2 fuel oil) this phase out could potentially have an impact on approximately 2,800 MW of ST units in Zone J that NYISO currently lists as using #6 oil.[5]

1.2 New York City's Load Forecast and Local Capacity Requirements

Each year, NYISO produces an official load forecast for each of its load zones as part of its annual Load & Capacity Data Report (aka the "Gold Book"). The 2017 Gold Book forecasted a summer peak load for 2017 in Zone J of ~11,600 MW. This reflects the inclusion of about 300 MW of energy efficiency and distributed generation resources (e.g. rooftop solar PV), which grows over time in the forecast. Meeting this demand can be a significant challenge since the transmission system in the NYC metro area is highly constrained and there is a limit to the amount of energy that can be imported from other parts of the grid. As such, the NYISO has specified a Local Capacity Requirement (LCR) for Zone J, which is the amount of generation that must be physically located within the Zone J load zone to reliably operate the grid. The NYISO's most recent LCR analysis for 2017-

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[3] Local Law 38 of 2015
[4] Res. No. 320, Constantinides
[5] NYISO 2017 Load and Capacity Data (aka "Gold Book")

2018 specified a requirement of 81.5% (or about ~9,400 MW).[6] In total there is about 9,612 MW of generation installed in Zone J, or about 83% of the 2017 forecasted peak load.

Table 1. Summary of Local Capacity Installed in Zone J.
(Source: NYISO 2017 Load & Capacity Data aka "Gold Book").

Generation Type	MW Installed (NYC)	Average Plant Age
Combined Cycle	3,258	14
Combustion Turbine	2,543	40
Steam Turbine	3,811	57
Total	9,612	--
% of Zone J Peak Load (2017 Forecast)	83.0%	--

NYISO is currently exploring changes to its methodology for computing the LCR. If these changes are adopted it may decrease the LCR in Zone J to 77.5%.[7] We estimate this would lower the in-city generation requirement by about 400 MW. In addition to local generation, Zone J can also help meet its needs through demand response resources known as Special Case Resources (SCR) as well as specialized controllable import capability known as Unforced Capacity Deliverability Rights (UDR). Together these account for ~1,360 MW.[8]

Figure 4 illustrates the outlook for local capacity resources in Zone J in comparison to the overall peak load forecast and LCR requirement (both at the current 81.5% level and proposed 77.5% level). The lightest blue portion indicates the generation capacity that is over retirement age (defined as above the 95th percentile as described above). If this capacity were to retire in the coming years, New York City will be at risk of having insufficient local capacity to meet its reliability needs. Figure 5 illustrates the same outlook if the generation past retirement age were removed under the 77.5% LCR scenario. In this case, Zone J would still have a 642 MW shortfall by 2021.

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[6] NYISO Locational Minimum Installed Capacity Requirements Study - 2017-2018 Capability Year, (Jan 2017). Note that the results of this study were issued after the recent TOTS AC transmission projects were placed in service in June 2016.
[7] NYISO, June 8, 2017 Meeting with NY-BEST.
[8] Calculated from Table 4-8 in NYISO 2016 Reliability Needs Assessment.

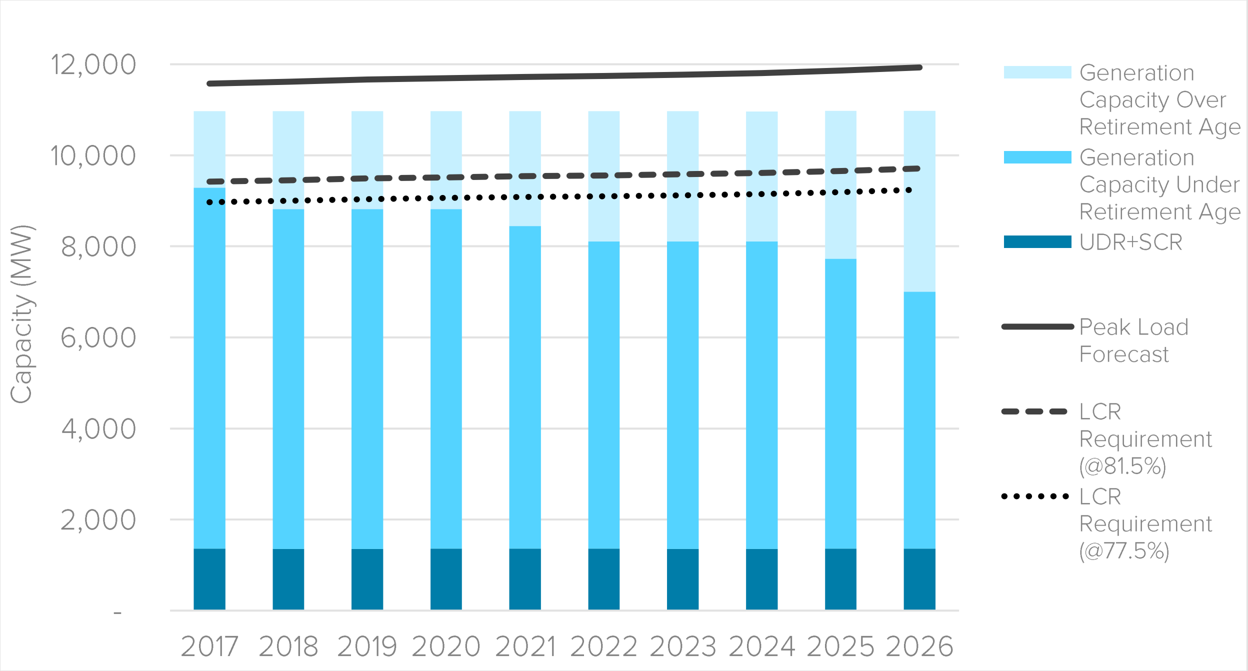

Figure 4. Existing Local Capacity (including UDR+SCR), Load Forecast, and Local Capacity Requirement (LCR) for Zone J (NYC). (Source: NYISO 2017 Load & Capacity Data aka "Gold Book").

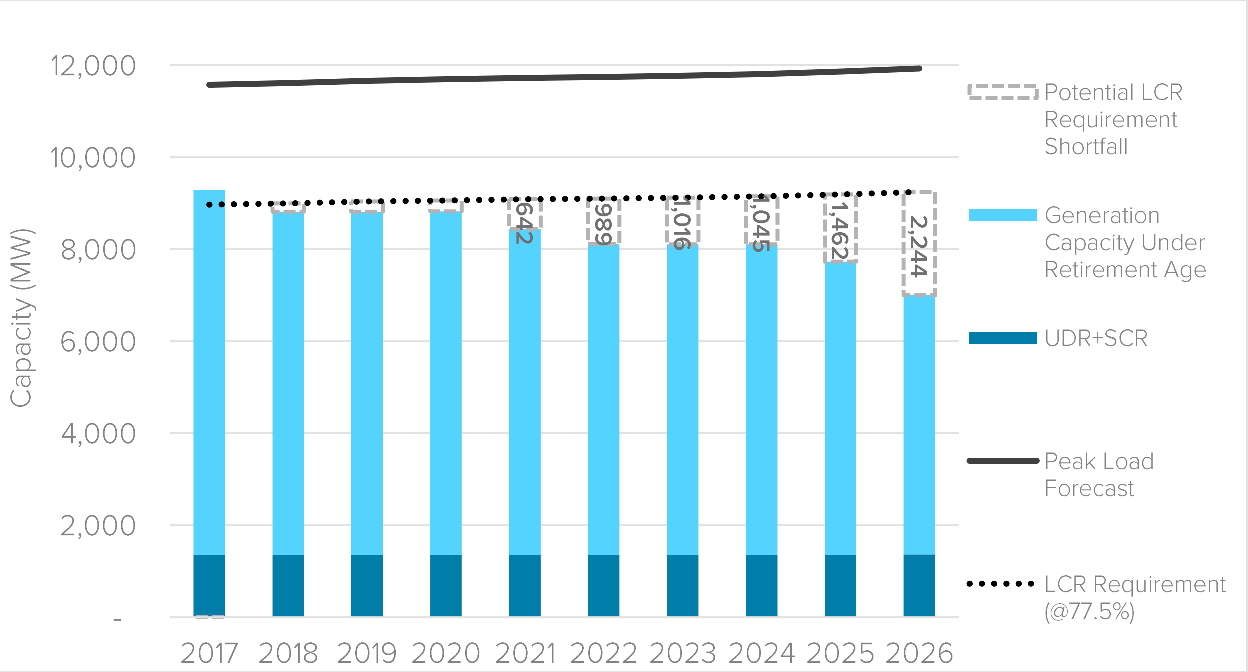

Figure 5. Potential capacity shortfall for Zone J (NYC) if generation past retirement age were removed. (Source: NYISO 2017 Load & Capacity Data aka "Gold Book").

There are several projects currently under development in the NYISO interconnection queue that might be able to help meet this capacity shortfall if they are placed into service on time. However, several of the proposed projects have not advanced to the stage of conducting a facilities study – a crucial step for determining the viability of a project. We identified about 456 MW of projects that have advanced to the stage of conducting a facilities study and could be online by 2021 (see Table 2). Even if all of these projects were completed on time, they would be insufficient to close the gap of approximately 642 MW mentioned above. Moreover, the proposed projects all rely on fossil fuels as their energy source and would ultimately detract from achieving the state's clean energy goals.

Table 2. Generation Projects in the NYISO Interconnection Queue for Zone J. (Source: NYISO, June 2017 http://www.nyiso.com/public/webdocs/markets_operations/services/planning/Documents_and_Resources/Interconnection_Studies/NYISO_Interconnection_Queue/NYISO%20Interconnection%20Queue.xls)

Project Name	Energy Source	Capacity (MW)	Proposed COD	Facilities Study in Progress?
Berrians East Repower	Fossil	102	2018	Yes
Bayonne Energy Center II	Fossil	120	2018	Yes
Linden Cogen Uprate	Fossil	234	2020	Yes
Subtotal	***Fossil***	***456***	**--**	***Yes***
Luyster Creek	Fossil	401	2017	No
South Pier Improvement	Fossil	91	2018	No
Champlain Hudson	Hydro	1000	2021	No
Hudson Transmission NY-PJM	Unknown	675	2021	No
Empire State Connector	Renewable/ Hydro/Nuclear	1000	2022	No
Liberty Generation	Fossil	1000	2019	No
NYC Energy	Fossil	80	2017	No
Astoria Generating Unit 4	Fossil	385	2018	No

1.4 Key Takeaways

- A significant amount of older generation capacity within New York City (Zone J) is at risk of retiring soon.
- Within 5 years, 2,860 MW of old steam and combustion turbines in Zone J will be past their normal retirement age, representing 30% of New York City's current generation fleet.
- To ensure grid reliability, approximately 77.5-81.5% of New York City's generation capacity must come from local resources.
- If these older units were to retire, New York City may have insufficient generation capacity to meet NYISO reliability requirements.
- While there are several proposed generators in the NYISO interconnection queue that could help meet this need, all of these have limitations.
- Only 456 MW of projects in the queue have advanced to the Facilities Study stage, which would be insufficient to meet a potential 642 MW shortfall as early as 2021.[9]
- Nearly all the proposed new projects in the queue would rely on fossil energy and would detract from the state's clean energy goals.

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[9] Based on NYISO forecast of Zone J load including impacts of energy efficiency and distributed generation.

Section 2 – Air Quality Impacts from Older Peaking Units

2.1 Impacts of Air Pollution from NYC Power Plants

Exposure to ground-level ozone pollution and fine particulate matter (PM 2.5) pollution are major health risks for New York City residents. According to the NYC Department of Health and Mental Hygiene,[10] exposure to ozone above background levels causes New Yorkers to suffer annually from:

- >400 premature deaths,
- 850 hospitalizations for asthma and
- 4,500 emergency department visits for asthma

Meanwhile, ozone-related hospital admission rates are 2x higher for children and 4x for adults in high poverty neighborhoods (see Figure 6).

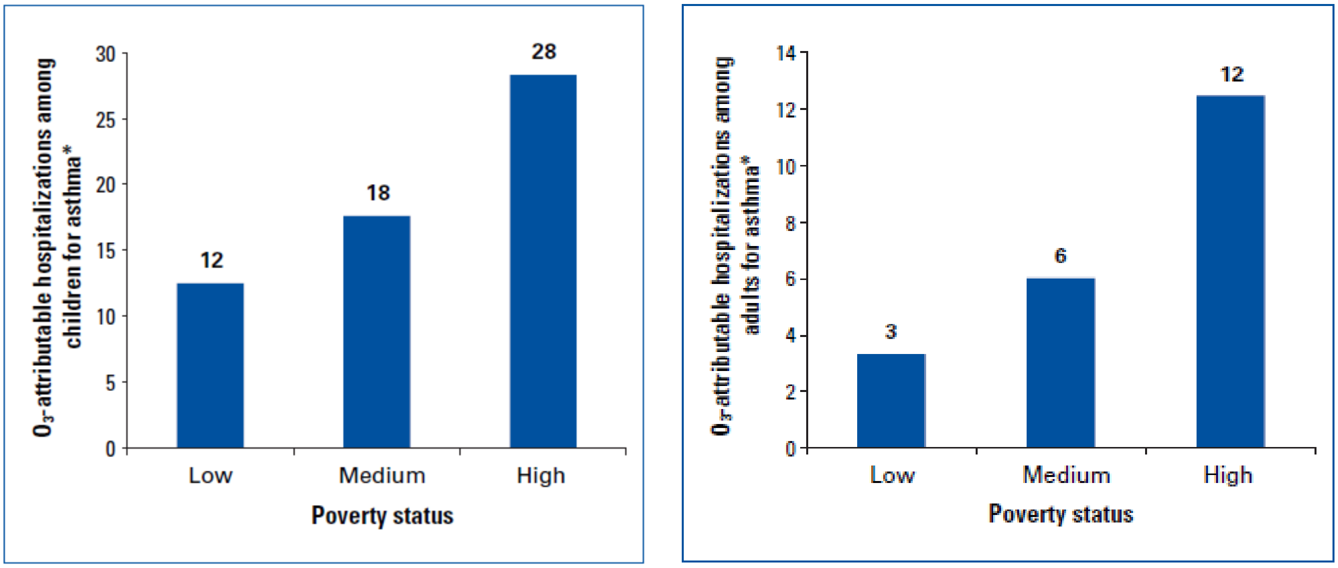

Figure 6. Hospitalization rates from ozone pollution disproportionately affect high poverty neighborhoods in New York City. (Source: NYC Dept. of Health and Mental Hygiene: Air Pollution and the Health of New Yorkers, https://www1.nyc.gov/assets/doh/downloads/pdf/eode/eode-air-quality-impact.pdf)

While New York City has made significant progress in addressing several types of air pollution over recent years, it has struggled to significantly reduce levels of ozone and PM 2.5. In fact, New York City and the surrounding areas are currently in non-attainment for federal ozone standards. In 2015, the U.S. Environmental Protection Agency established a maximum 8-hour average ozone concentration standard of 70 ppb. Figure 7 indicates the

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[10] Source: NYC Dept. of Health and Mental Hygiene: Air Pollution and the Health of New Yorkers https://www1.nyc.gov/assets/doh/downloads/pdf/eode/eode-air-quality-impact.pdf

regions where the state is in non-attainment with this standard. As of September 1, 2017, the NYC metro area already exceeded this standard on 14 occasions in the year.[11]

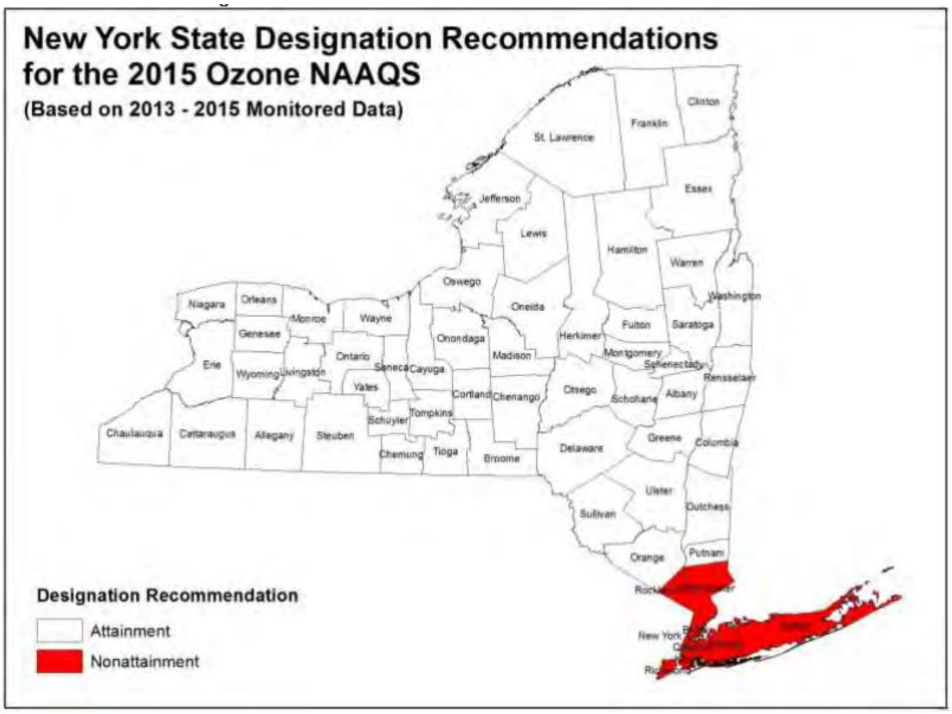

Figure 7. Source: New York State Designation Recommendations for the 2015 Ozone National Ambient Air Quality Standards, 2015. Source: NY DEC.

Ozone pollution is formed by emissions from a variety of sources including NOx emissions from power plants. In addition to contributing to ozone NOx and SOx emissions also serve as a precursor for PM 2.5 pollution. Recent analysis by NY DEC shows that NOx emissions from old combustion turbine power plants have contributed significantly to NOx emissions on high ozone days. DEC modeling showed that older peaking units may be contributing up to ~5 ppb towards the 8-hour daily max for ozone concentration of 70 ppb.[12] In fact, some facilities may even have the potential to exceed the 1-hour maximum of 100 ppb. NOx emissions from old CTs appear to be especially acute on high ozone days, as shown in DEC's recent analysis in Figure 8

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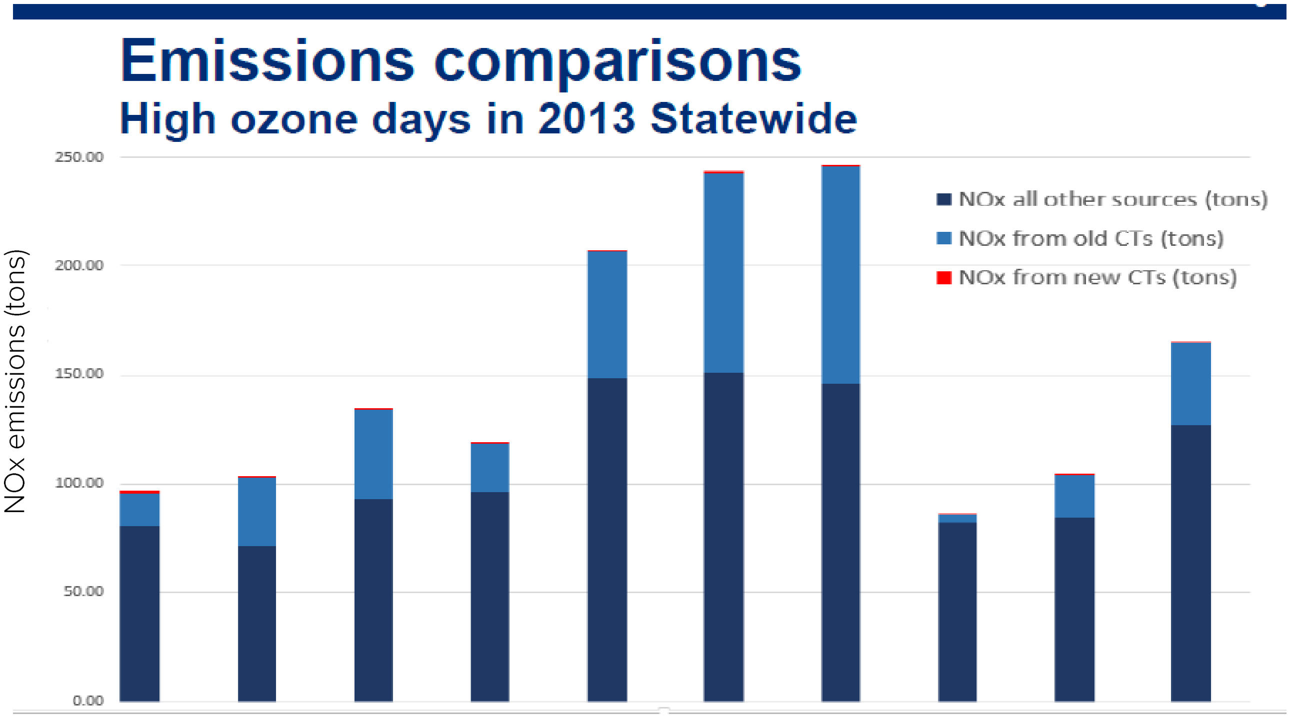
[11] NY DEC, Eight Hour Ozone Averages Greater than 0.070 ppm for NYC Metro Area during 2017, http://www.dec.ny.gov/chemical/38377.html

[12] NY DEC Stakeholder Meeting, January 20, 2017, slide 4.



Emissions comparisons

High ozone days in 2013 Statewide

Figure 8. NY DEC analysis of NOx emissions sources in the New York metro area on high ozone days in 2013. (Source: NY DEC Stakeholder Meeting, January 20, 2017, slide 8.)

Reducing NOx pollution from these facilities could help reduce harmful ozone pollution and yield a significant improvement to public health. According to the NYC Department of Health,[13] reducing ozone levels by just 10% could prevent:

- 80 premature deaths (annually)
- 180 hospital admissions (annually)
- 950 emergency department visits (annually)

In addition to the health impacts, emissions from local power plants are also harmful to New York's economy. We estimate that emissions form NYC plants cost at least $62 million annually based on the morbidity and mortality of NOx and SOx as precursors to PM 2.5 pollution (see Table 3).

Table 3. Economic Impacts of NYC Power Plant Emissions

Criteria Pollutant	Economic Value of Health Impacts ($/ton)[1]	NYC Plant Emissions, tons (2016)[2]	Annual Economic Impact ($)
NOx	$12,000	3,706	$44,472,000
SOx	$78,000	225	$17,550,000
Total			*$62,022,000*

[1]: US EPA Technical Support Document: Estimating the Benefit per Ton of Reducing PM2.5 Precursors from 17 Sectors
[2]: US EPA Air Markets Program Data, accessed June 2017, https://ampd.epa.gov/ampd/

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[13] NYC Dept. of Health and Mental Hygiene: Air Pollution and the Health of New Yorkers https://www1.nyc.gov/assets/doh/downloads/pdf/eode/eode-air-quality-impact.pdf

This estimate does not account for other potential damages such as additional health impacts, reduced visibility, degradation of materials, and other impacts that would further increase economic costs.

2.2 Identifying the Primary Emissions Contributors

Using EPA emissions monitoring data, we identified, the top 10 power plants in NYC that contribute to overall NOx emissions (Table 4). Additional characteristics of these plants are shown in Table 5. While this list includes several steam units with higher capacity factors (e.g. Ravenswood, Arthur Kill, and Astoria Generating Station), it also includes several combustion turbines with lower capacity factors (e.g. Narrows, and Astoria Gas Turbine Power). These CTs produce a disproportionate amount of NOx emissions given the fact that they run very infrequently. This is partly because many of these older plants do not have any form of NOx pollution controls installed. Plants without NOx controls installed were found to contribute 51% of NOx emissions from all plants in Zone J, despite only producing 4% of the power consumed by Zone J. Newer combined cycle plants (e.g. Astoria Energy I & II, and NYPA Astoria CC) also contribute to NOx emissions, but to a lesser degree even though they operate at higher capacity factors. Their lower overall contribution is partly due to higher efficiency and modern NOx controls installed.

Table 4. Top 10 polluting power plants in NYC ranked by total ozone season NOx emissions (average from 2011-2016). Source: US EPA Air Markets Program Data, accessed June 2017, https://ampd.epa.gov/ampd/

	Plant Name	NOx Controls?	Ozone Season NOx Emissions (tons)					
			2011	2012	2013	2014	2015	2016
1	Ravenswood	Yes	608	730	611	904	845	1,147
2	Arthur Kill	No	489	435	377	299	280	344
3	Astoria Generating Station	No	335	351	251	231	170	196
4	Narrows	No	250	292	335	43	210	199
5	Astoria Gas Turbine Power	No	187	215	167	62	92	119
6	East River	No	143	141	157	55	72	128
7	Gowanus	No	96	124	171	13	35	41
8	Astoria Energy I & II	Yes	64	79	72	64	72	69
9	59th Street	Yes	89	50	48	26	24	32
10	NYPA Astoria CC	Yes	25	26	32	28	30	36
	All Other Zone J Plants (9 total)		42	30	58	25	25	40
	Total		2,329	2,471	2,279	1,750	1,856	2,352

Table 5. Characteristics of highest NOx emitting plants in NYISO Zone J. Asterisk (*) indicates plants that are past normal retirement age. Source: NYISO 2017 Load & Capacity Data ("Gold Book")

	Plant Name	I/S Year	Steam Turbines	Combustion Turbines	Combined Cycle	Fuel Types
1	Ravenswood	1963*	1,706 MW (3 units)	273 MW (11 units)	--	#6 fuel oil, Nat. gas, Kerosene
2	Arthur Kill	1959*	844 MW (2 units)	12 MW (1 unit)	--	Nat. gas
3	Astoria Gen. Station	1954*	933 MW (3 units)	14 MW (1 unit)	--	Nat. gas, #6 fuel oil
4	Narrows	1972*	--	283 MW (16 units)	--	Kerosene, Nat. gas
5	Astoria GT Power	1970*	--	414 MW (12 units)	--	Kerosene, Nat. gas
6	East River	1951*	329 MW (2 units)	--	--	Nat. gas, #6 fuel oil
7	Gowanus	1971*	--	557 MW (32 units)	--	#2 fuel oil, Nat. gas
8	Astoria Energy I & II	2006		--	1126 MW (4 units)	Nat. gas, #2 fuel oil
9	59th Street	1969*	--	14 MW (1 unit)		Kerosene, Nat. gas
10	NYPA Astoria CC	2006	--	--	467 MW (2 Units)	Nat. gas, #2 fuel oil, kerosene

While Table 4 identifies the plants with the highest overall emission, Table 6 shows which plants have the highest emission rates (lbs/MMBtu). This helps to identify plants that may not operate frequently but have an outsized contribution towards NOx emissions when they are operating. Several plants rank highly on both tables, notably Astoria GT Power, Narrows, and Ravenswood, all of which include CTs that burn kerosene.

Table 6. Top 10 polluting power plants in NYC ranked by average ozone season NOx emissions rate (average from 2011-2016). Source: US EPA Air Markets Program Data, accessed June 2017, https://ampd.epa.gov/ampd/

	Plant Name	NOx Controls?	Ozone Season Avg. NOx Rate (lbs./MMBtu)					
			2011	**2012**	**2013**	**2014**	**2015**	**2016**
1	Hudson Avenue	No	0.50	0.50	0.56	0.56	0.56	1.03
2	Gowanus	No	0.58	0.76	0.53	0.53	0.53	0.53
3	Astoria GT Power	No	0.69	0.54	0.59	0.51	0.49	0.48
4	Narrows	No	0.39	0.45	0.45	0.45	0.45	0.33
5	Ravenswood	No	0.43	0.47	0.33	0.33	0.33	0.34
6	74th Street	No	0.40	0.41	0.33	0.25	0.26	0.25
7	59th Street	No	0.22	0.22	0.15	0.13	0.14	0.12
8	Astoria Gen. Station	No	0.10	0.13	0.19	0.19	0.18	0.16
9	Arthur Kill	No	0.20	0.14	0.14	0.13	0.13	0.15
10	East River	No	0.16	0.10	0.12	0.11	0.10	0.09

2.3 NOx Bubbles Generators

New York's Department of Environmental Conservation (DEC) established rules to limit NOx emissions rates from major sources including power plants (see Title 6 NYCRR Subpart 227-2). DEC allows compliance through several options including a "system averaging plan" whereby owners can average NOx rates for a portfolio of generators, each portfolio constituting a "NOx Bubble". There are three such NOx bubbles in New York City described below in Table 7. In theory, generation from the CTs with high NOx rates can be offset by generation from ST and CC plants w/ lower NOx rates to yield a portfolio average that meets compliance. The NYISO has developed special market dispatch rules to accommodate the specific needs of the NOx bubble generators. These rules allow the NOx Bubble generators to be committed even when it is not economic to do so as part of a special "Local Reliability Rule" exception.

Table 7. New York City "NOx Bubble" Generators

NOx Bubble	NYC Plants Included	Location
LS Power Bubble	• Ravenswood CC • Ravenswood CT	• Queens • Queens
NRG Bubble	• Arthur Kill ST • Astoria Gas Turbine Power CTs	• Staten Island • Queens
EasternGen Bubble	• Astoria Generating Station ST • Narrows CTs • Gowanus CTs	• Queens • Brooklyn • Brooklyn

However, according to NYISO's 2016 annual report, the NOx Bubble scheme may actually be leading to unintended consequences, increasing both NOx emissions and energy costs for NYC customers.[14] The following are excerpts from the NYISO 2016 report describing this phenomenon:

- "The commitment of steam turbines for NOx Bubble constraints rarely coincided with the operation of gas turbines." (p A-149) "These commitments generally do not reduce output from older gas turbines (as intended)." (p 87)
- "NOx bubble commitments actually *increased* overall NOx emissions in New York City because the commitment of steam turbine units typically crowds-out generation from new fuel-efficient generation with Selective Catalytic Reduction ("SCR") capability" (p 88)
- "The steam units emit approximately 13 times more NOx per MWh produced than the newer generators with emission-reduction equipment." (p 88)
- "These commitments also resulted in uplift that was socialized to other parties and distorted clearing prices from the commitment of out-of-market resources." (p 88)

2.4 Environmental Justice

In 2003, New York DEC established Commissioner Policy 29 (CP-29) to provide guidance on incorporating environmental justice concerns into New York State's environmental permitting review process. The policy establishes requirements for projects (including new electric generating facilities) in Potential Environmental Justice Areas with the potential for at least one significant adverse environmental impact. CP-29 defined Potential Environmental Justice Areas as 2000 U.S. Census block groups of 250 to 500 households each that had populations that met or exceeded at least one of the following statistical thresholds:

- At least 51.1% of the population in an urban area reported themselves to be members of minority groups; or
- At least 33.8% of the population in a rural area reported themselves to be members of minority groups; or
- At least 23.59% of the population in an urban or rural area had household incomes below the federal poverty level.

While the rules primarily apply to proposed new projects, there are several plants in New York City that are already in these Potential Environmental Justice Areas and may already be contributing to adverse environmental impacts. Table 8 below shows that most of the high NOx emitting plants described in Section 2.2 also reside in Potential Environmental Justice Areas.

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[14] NYISO 2016 State of the Market Report, http://www.nyiso.com/public/webdocs/markets_operations/documents/Studies_and_Reports/Reports/Market_Monitoring_Unit_Reports/2016/NYISO_2016_SOM_Report_5-10-2017.pdf

Table 8. High emitting plants in Potential Environmental Justice Areas

	Plant Name	Located in Potential Environmental Justice Area?
1	Ravenswood	Yes
2	Arthur Kill	No
3	Astoria Gen. Station	Yes
4	Narrows	Yes
5	Astoria GT Power	Yes
6	East River	Yes
7	Gowanus	Yes
8	Astoria Energy I & II	Yes
9	59th Street	Yes
10	NYPA Astoria CC	Yes

Figure 9 overlays the locations of all NYC power plants on the Potential Environmental Justice Area maps produced by the NY DEC Office of Environmental Justice.

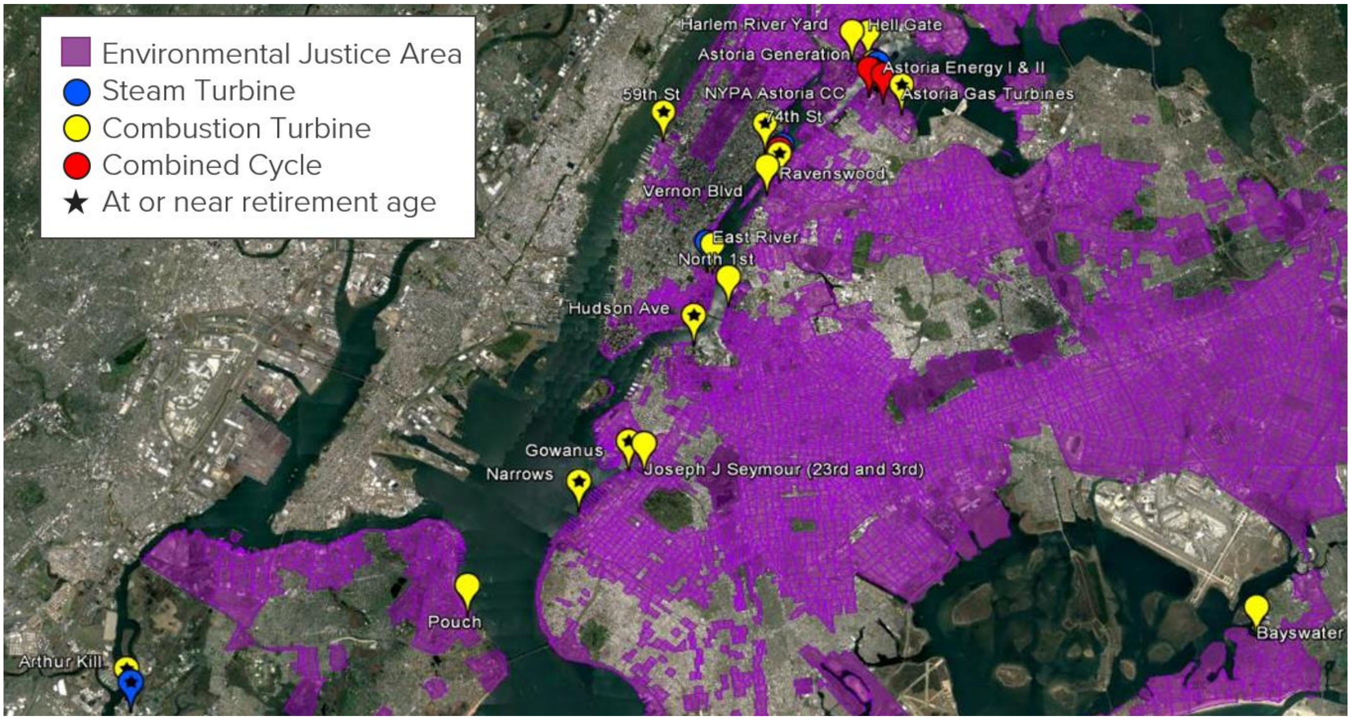

Figure 9. NYC Power Plants and Potential Environmental Justice Areas

2.5 Impact of Indian Point Closure

In addition to the local capacity requirement (LCR) for Zone J described in Section 1, NYISO also has established an LCR of 91% (or about ~14,500 MW) for Zones G through J, corresponding to New York City plus the Lower Hudson Valley. The 2,060 MW Indian Point nuclear plant, located in Zone H, comprises a significant fraction (~14%) of the local capacity in the G-J area. The plant also generates ~36% of the energy (MW) from all plants in the G-J area.

Recently, the plant owners announced that both generation units at Indian Point would retire soon (one unit would close in 2020 and the other would close in 2021). Absent new generation coming online beforehand, the closure of these units in the highly constrained G-J area will likely increase dependence on generation capacity in Zone J – where the bulk of remaining G-J capacity resides. This means that there could be an increase in the generation output and associated emissions from fossil plants. In fact, recent experience in ISO-NE further suggests this to be a likely outcome. The closure of the 600 MW Yankee nuclear plant led to a 12% increase in natural gas generation in 2015, as illustrated in Figure 10.

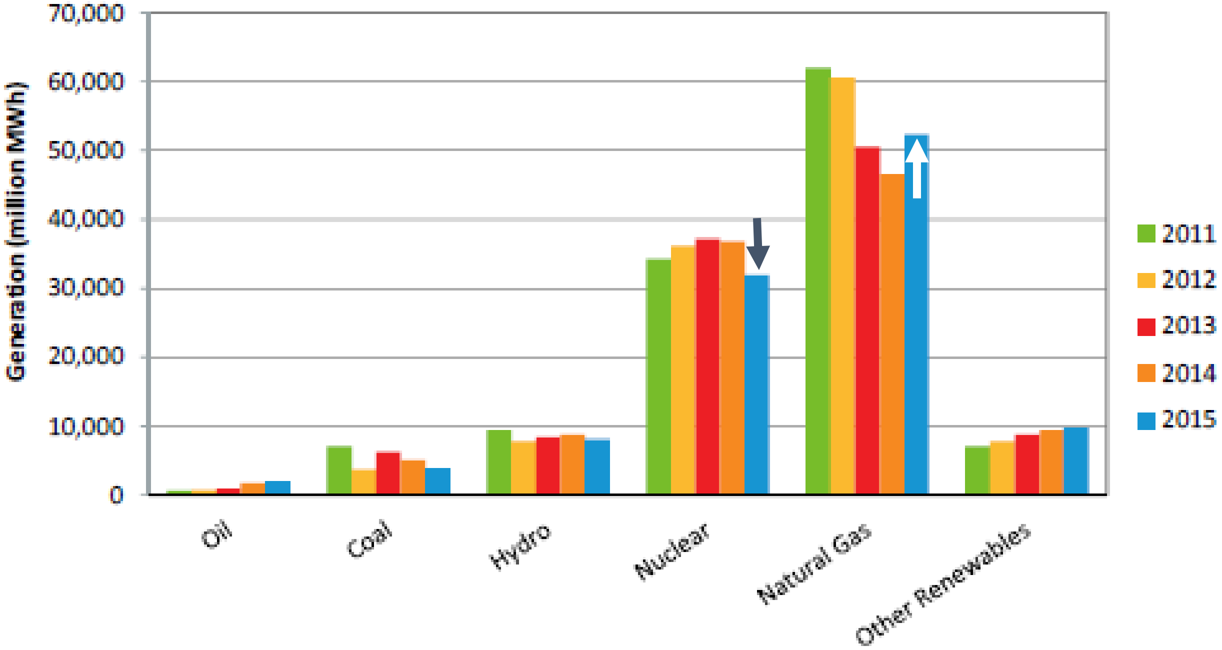

Figure 10. ISO New England Annual Generation by Fuel Type. Arrows indicate the reduction in nuclear and increase in natural gas associated with the Yankee plant closure. (Source: 2015 ISO New England Electric Generator Air Emissions Report)

Several combined cycle power plants are in advanced stages of development in the G-I areas that could serve as replacement power for Indian Point outside of Zone J. This includes the CPV and Cricket Valley projects. However, in the case of CPV, a new gas pipeline that was a key component of the project was recently rejected by NY DEC.[15] Without access to natural gas, the plant may need to rely on other more expensive fuel sources, thereby increasing the likelihood that Zone J resources would be operated more frequently once Indian Point closes.

2.6 Greenhouse Gases

In addition to criteria pollutants, power plants in New York City contribute to greenhouse gas emissions (GHGs). According to a recent GHG inventory conducted by the NYC Mayor's Office, electricity accounted for approximately 30% of the city's total GHG foot print (Figure 11).

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[15] http://www.timesunion.com/news/article/State-turns-down-gas-pipeline-request-12164835.php

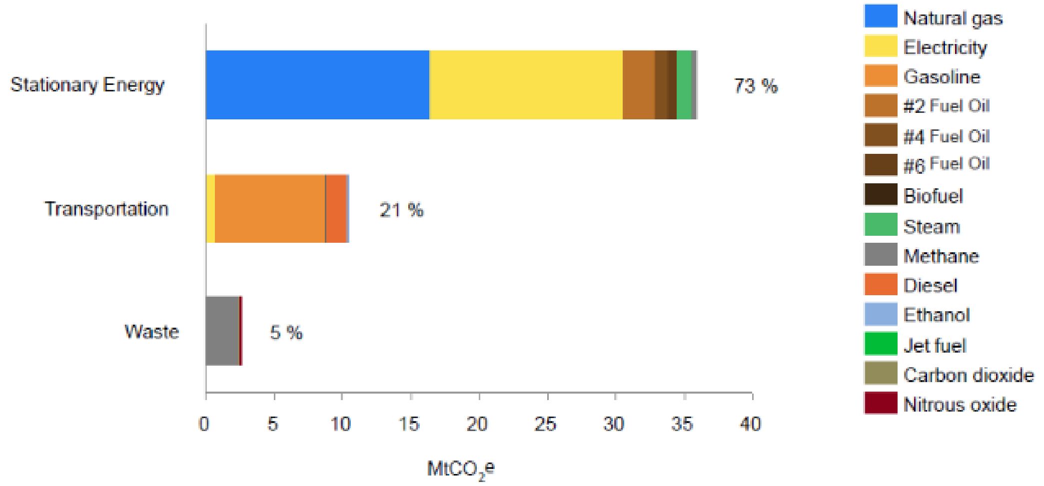

Figure 11. 2014 NYC Citywide GHG Emissions by Sector and Source (Source: NYC Mayor's Office)

New York City consumed approximately 53,653 GWh of electricity in 2016. Meanwhile, in-city power plants generated 27,223 GWh. Thus over 50% of New York City's electricity related GHG emissions likely resulted from fossil power plants located in the city. For New York to achieve its GHG goals, it will need to increase utilization of renewable energy in place of fossil fuels. This presents a challenge since most of the renewable resource potential in New York is in the upstate region. Delivering this energy to the downstate region – particularly during congested peak load hours may not always be feasible. However, solutions like energy storage could help to deliver renewable resources such as wind or hydro to New York at off-peak times when the transmission system is less congested, storing that energy for later use when it is needed.

In 2016, NYISO reported that natural gas combined cycle (NG-CC) resources and hydro resources were on the margin most frequently during 2016.[16] Thus, even if charging occurs when natural gas is the marginal resource, grid charged storage can be beneficial from a GHG emissions perspective. Newer combined cycle units are more efficient and have lower overall CO_2 emissions per MWh produced when compared to gas combustion turbines (NG-CT). Storage that is charged from NG-CC and displaces output from NG-CT will likely still reduce overall emissions, even after accounting for round-trip energy losses from charging and discharging. Figure 12 compares the emissions per unit of energy output for NG-CT resources and grid charged storage. Assuming grid charging occurs when the marginal resource is NG-CC 50% of the time and renewable resources (wind or hydro) during the other 50%, energy storage can significantly reduce CO_2 emissions from NG-CT units. We estimate that this reduction could range from 77% from older CT units to 62% from newer CT units. Storage could also reduce the number of starts and periods when thermal units are at operating below their peak efficiencies. Our analysis only looks

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[16] See NYISO 2016 State of Market Report, p A-12.

at marginal emissions rate and does not account for the additional emissions reductions storage enables by improving the efficiency of the rest of the fleet.[17]

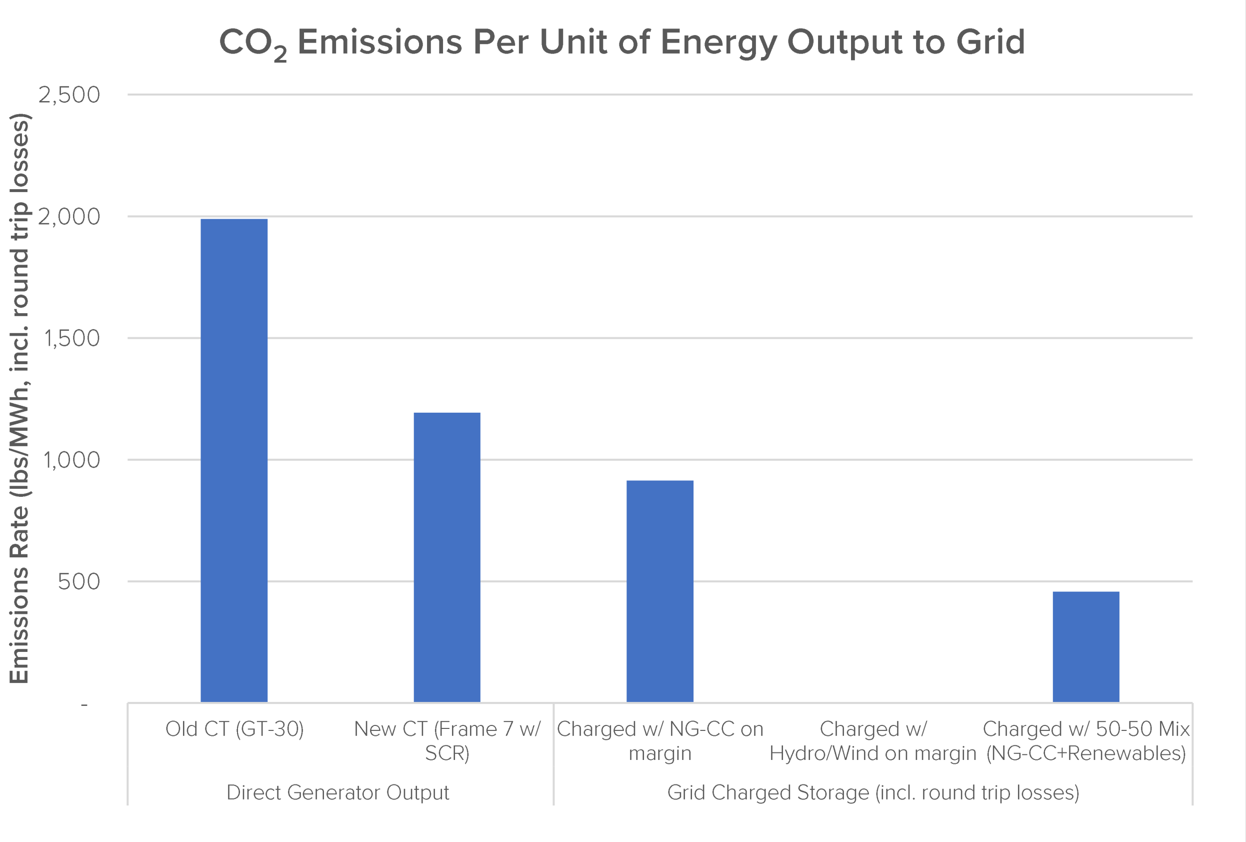

Figure 12. Comparison of CO_2 emissions from gas-fired combustion turbines and grid charged battery storage. For gas units, we assume heat rates consistent with NYISO's 2016 Net Revenue Analysis as follows: 17,000 Btu/kWh for Old CT, 10,193 Btu/kWh for a New CT, and 7,028 Btu/kWh for NG-CC (see NYISO 2016, State of Market Report, p A-174). For storage, we assume a round trip efficiency of 90%. Assumed carbon content of natural gas is 117 lbs CO_2/MMBtu.

2.7 Key Takeaways

- Air pollution, including ozone and PM 2.5, is a major public health problem for the New York metro area.
- Exposure to ozone above background levels causes New Yorkers to suffer annually from over 400 premature deaths, 850 hospitalizations for asthma and 4,500 emergency department visits for asthma.
- There are a small number of older peaking plants in New York City without NOx emissions controls that contribute significantly to ozone-forming NOx emissions in the region.
- Many of these plants run very infrequently, and typically on hot summer days that are likely to have higher ozone concentrations.

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[17] Storage can reduce fossil unit starts and shorten the periods in which they are operating below their maximum efficiency. Both of these cause actual system marginal emissions rates to be higher than estimated by using resource type of the marginal resource.

- On average, these few plants contribute 51% of the NOx emissions from in-city plants during ozone season, while generating only 4% of the power consumed.
- Many of these power plants also reside in Potential Environmental Justice Areas.
- Current strategies to control emissions from these plants (such as NOx Bubbles) have been ineffective and possibly counterproductive.
- The closure of Indian Point is likely to increase the utilization and emissions from fossil fuel plants – particularly those located in NYC (Zone J).

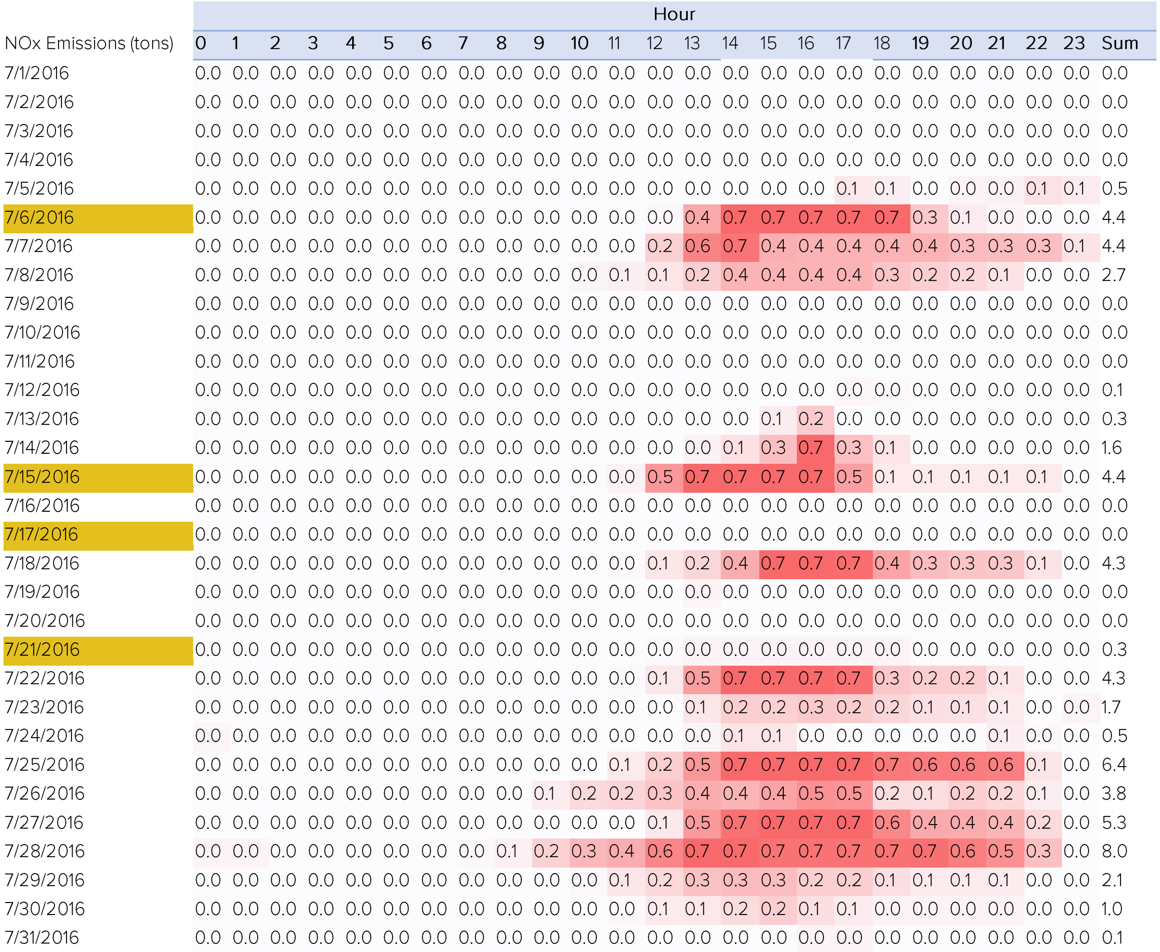
Section 3 – Potential Solutions through Energy Storage

While there is a compelling need for controlling NOx and SOx emissions from old peaker plants in NYC, there are relatively few options for doing so absent decommissioning or repowering the plants entirely. It appears likely that some of these plants may be decommissioned or repowered soon simply due to their advanced age. However, there is still a need for some form of local capacity to meet LCR requirements. New fossil generation with pollution controls is one potential option, however this has numerous drawbacks including onerous siting and permitting requirements, environmental justice concerns, fuel and pipeline constraints, and negative contribution to the state's clean energy and GHG goals. With these issues in mind, we explored a potential alternative solution whereby battery energy storage is used to both mitigate NOx emissions and provide local generation capacity during peak load hours.

3.1 Analysis of NOx emissions from NYC peaker plants

To better understand the potential for energy storage to serve as a local capacity and NOx mitigation solution, we examined the hourly dispatch and related NOx emissions from several NYC peaker plants during the summer of 2016. Figure 13 illustrates the hourly NOx emissions for each day in July at the Narrows Generating Station.

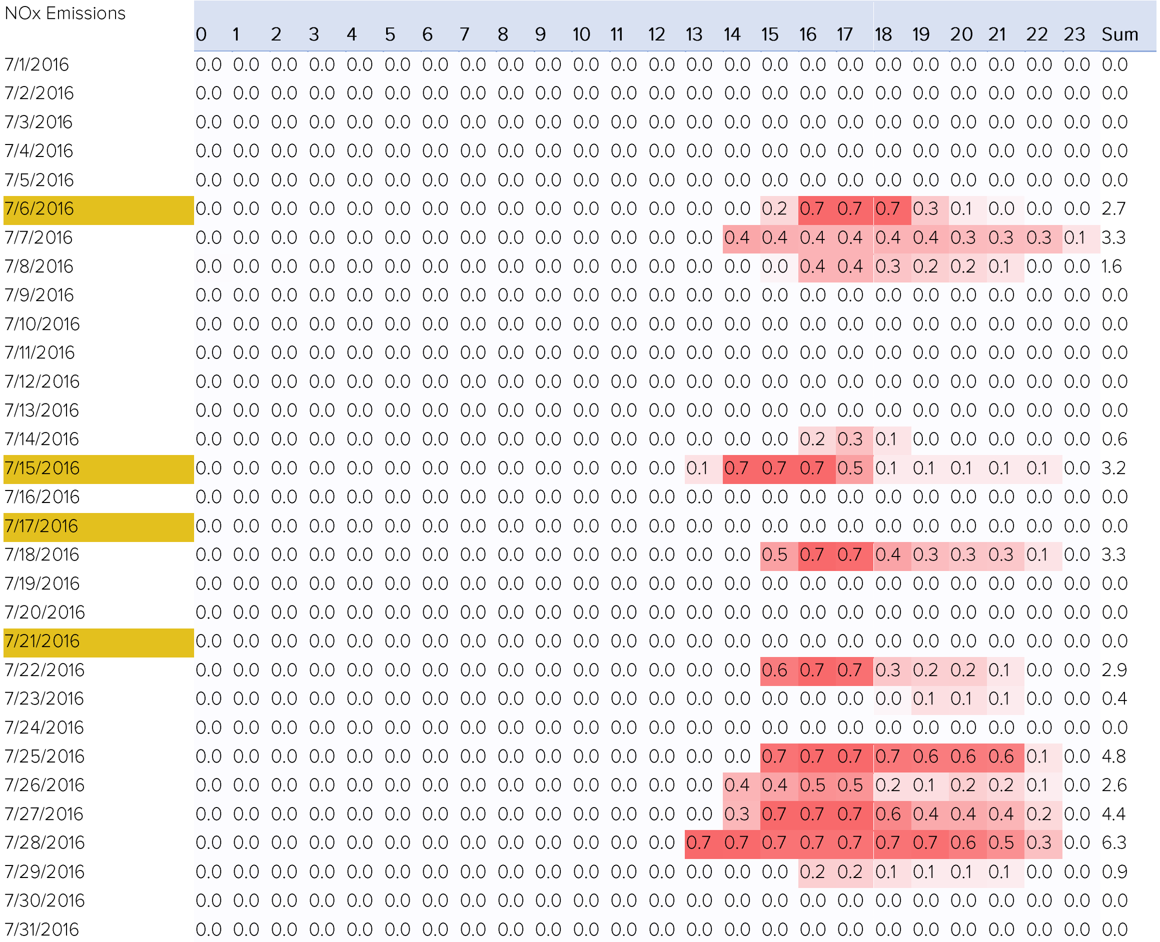
In July, this plant emitted 56 tons of NOx over the course of 21 days of operation. This accounts for 28% of the plant's ozone season total. Notably the plant ran at full capacity for only few hours on a small number of days. However, it did produce significant NOx emissions on several high ozone days (indicated in orange).



	Hour																								
NOx Emissions (tons)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Sum
7/1/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/2/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/3/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/4/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/5/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.5
7/6/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.7	0.7	0.7	0.7	0.7	0.3	0.1	0.0	0.0	0.0	4.4
7/7/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.6	0.7	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.1	4.4
7/8/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.4	0.4	0.4	0.4	0.3	0.2	0.2	0.1	0.0	0.0	2.7
7/9/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/10/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/11/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/12/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
7/13/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
7/14/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.7	0.3	0.1	0.0	0.0	0.0	0.0	0.0	1.6
7/15/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.7	0.7	0.7	0.7	0.5	0.1	0.1	0.1	0.1	0.1	0.0	4.4
7/16/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/17/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/18/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.7	0.7	0.7	0.4	0.3	0.3	0.3	0.1	0.0	4.3
7/19/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/20/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/21/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
7/22/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	0.7	0.7	0.7	0.7	0.3	0.2	0.2	0.1	0.0	0.0	4.3
7/23/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.3	0.2	0.2	0.1	0.1	0.1	0.0	0.0	1.7
7/24/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.5
7/25/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.7	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.1	0.0	6.4
7/26/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.3	0.4	0.4	0.4	0.5	0.5	0.2	0.1	0.2	0.2	0.1	0.0	3.8
7/27/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	0.7	0.7	0.7	0.7	0.6	0.4	0.4	0.4	0.2	0.0	5.3
7/28/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.4	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.5	0.3	0.0	8.0
7/29/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.0	0.0	2.1
7/30/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	1.0
7/31/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1

Figure 13. Actual hourly NOx emissions at Narrows Generating Station in July 2016. Orange highlights indicate high ozone days as reported by NY DEC. Data Source: US EPA Air Markets Program Data, accessed June 2017, https://ampd.epa.gov/ampd/

We then considered how the plant's generation and emissions output for the month might be altered with the addition of a hypothetical energy storage facility of the same power rating (MW). We considered 2-hrs, 4-hrs, and 8-hrs of energy storage at the rated capacity of the plant. For each day that the peaker plant operated, the energy storage facility was dispatched in lieu of generation from the plant, so long as there was additional energy remaining in the battery. In each case we considered the need for sufficient time to charge the storage facility at night. Figure 14 below and Figure 15 & Figure 16 on the following pages illustrate the potential impact of 2-hrs, 4-hrs, and 8-hrs respectively. As discussed further below and illustrated in Figure 17, the charging energy needed is unlikely to lead to any significant increase emissions that might offset these reductions.



NOx Emissions	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Sum
7/1/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/2/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/3/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/4/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/5/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/6/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.7	0.7	0.7	0.3	0.1	0.0	0.0	0.0	2.7
7/7/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.1	3.3
7/8/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.3	0.2	0.2	0.1	0.0	0.0	1.6
7/9/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/10/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/11/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/12/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/13/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/14/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.6
7/15/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.7	0.7	0.7	0.5	0.1	0.1	0.1	0.1	0.1	0.0	3.2
7/16/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/17/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/18/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.7	0.7	0.4	0.3	0.3	0.3	0.1	0.0	3.3
7/19/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/20/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/21/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/22/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.7	0.7	0.3	0.2	0.2	0.1	0.0	0.0	2.9
7/23/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.4
7/24/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/25/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.1	0.0	4.8
7/26/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.5	0.5	0.2	0.1	0.2	0.2	0.1	0.0	2.6
7/27/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	0.7	0.7	0.6	0.4	0.4	0.4	0.2	0.0	4.4
7/28/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.5	0.3	0.0	6.3
7/29/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.1	0.1	0.1	0.1	0.0	0.0	0.9
7/30/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/31/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

*Figure 14. Hypothetical NOx emissions at Narrows Generating Station in July 2016 with **2 hours** of energy storage.*

The hypothetical addition of 2 hours of energy storage reduced total July NOx emissions at Narrows Generation Station from 56 tons to 37 tons (34% reduction). Occurrences of NOx emissions were reduced from 21 days to 13 days.

NOx Emissions	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Sum
7/1/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/2/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/3/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/4/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/5/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/6/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.7	0.3	0.1	0.0	0.0	0.0	1.3
7/7/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4	0.4	0.3	0.3	0.3	0.1	2.0
7/8/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.2
7/9/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/10/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/11/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/12/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/13/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/14/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/15/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.1	0.1	0.1	0.1	0.1	0.0	1.4
7/16/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/17/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/18/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.3	0.3	0.3	0.1	0.0	1.9
7/19/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/20/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/21/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/22/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.3	0.2	0.2	0.1	0.0	0.0	1.4
7/23/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/24/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/25/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.7	0.7	0.6	0.6	0.6	0.1	0.0	3.9
7/26/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	0.2	0.1	0.2	0.2	0.1	0.0	1.4
7/27/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.7	0.6	0.4	0.4	0.4	0.2	0.0	3.0
7/28/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.7	0.7	0.7	0.7	0.6	0.5	0.3	0.0	4.9
7/29/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/30/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/31/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

*Figure 15. Hypothetical NOx emissions at Narrows Generating Station in July 2016 with **4 hours** of energy storage.*

The hypothetical addition of 4 hours of energy storage reduced total July NOx emissions at Narrows Generation Station from 56 tons to 21 tons (62% reduction). Occurrences of NOx emissions were reduced from 21 days to 10 days.

NOx Emissions	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Sum
7/1/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/2/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/3/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/4/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/5/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/6/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/7/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/8/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/9/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/10/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/11/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/12/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/13/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/14/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/15/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/16/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/17/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/18/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/19/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/20/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/21/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/22/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/23/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/24/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/25/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.6	0.1	0.0	1.0
7/26/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/27/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/28/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.7	0.7	0.7	0.6	0.5	0.3	0.0	4.0
7/29/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/30/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7/31/2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

*Figure 16. Hypothetical NOx emissions at Narrows Generating Station in July 2016 with **8 hours** of energy storage.*

The hypothetical addition of 8 hours of energy storage reduced total July NOx emissions at Narrows Generation Station from 56 tons to 5 tons (90% reduction). Occurrences of NOx emissions were reduced from 21 days to 2 days.

We also conducted a similar analysis for the Astoria Gas Turbine Power plant (the second highest non-steam plant in Zone J for NOx emissions in 2016) and found similar results:

- The hypothetical addition of 2 hours of energy storage reduced total July NOx emissions at Astoria GT Power from 71 tons to 44 tons (38% reduction). Occurrences of NOx emissions were reduced from 10 days to 6 days.
- The hypothetical addition of 4 hours of energy storage reduced total July NOx emissions at Astoria GT Power from 71 tons to 24 tons (66% reduction). Occurrences of NOx emissions were reduced from 10 days to 4 days.
- The hypothetical addition of 2 hours of energy storage reduced total July NOx emissions at Astoria GT Power from 71 tons to 6 tons (92% reduction). Occurrences of NOx emissions were reduced from 10 days to 2 days.

Charging energy storage from other generators at night is unlikely to substantially increase NOx emissions since marginal units during these periods are likely to be either zero-emissions resources (e.g. hydro, wind) or newer, more efficient combined cycle units with NOx controls. For example, Figure 17 illustrates the average NOx emission rate for several indicative generators in Zone J. On the left are two old CTs without NOx controls and on the right are two new CCs with NOx controls.

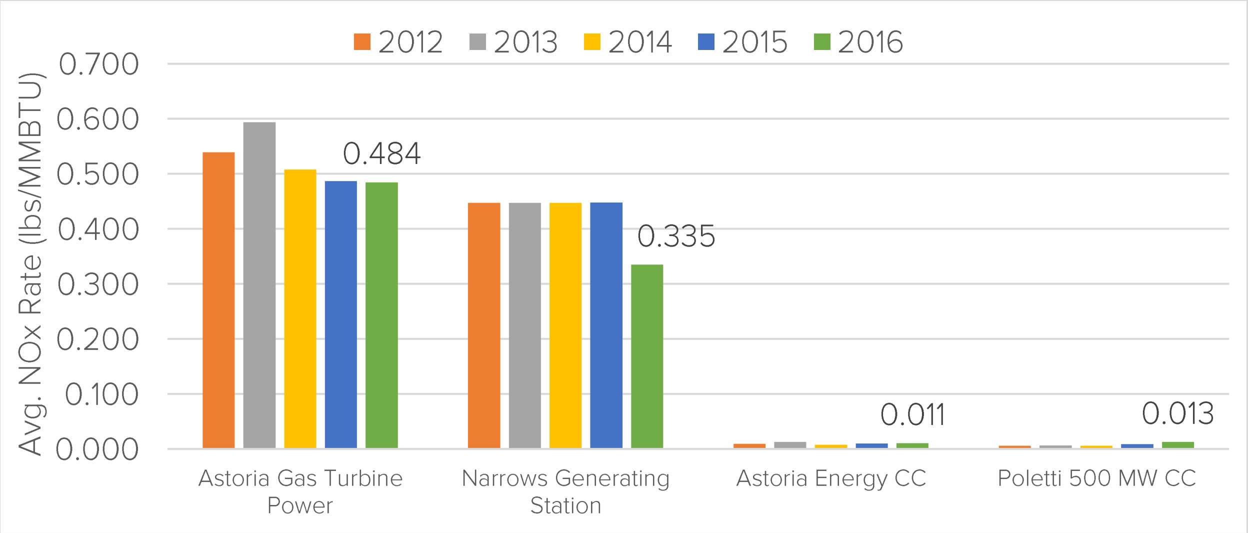


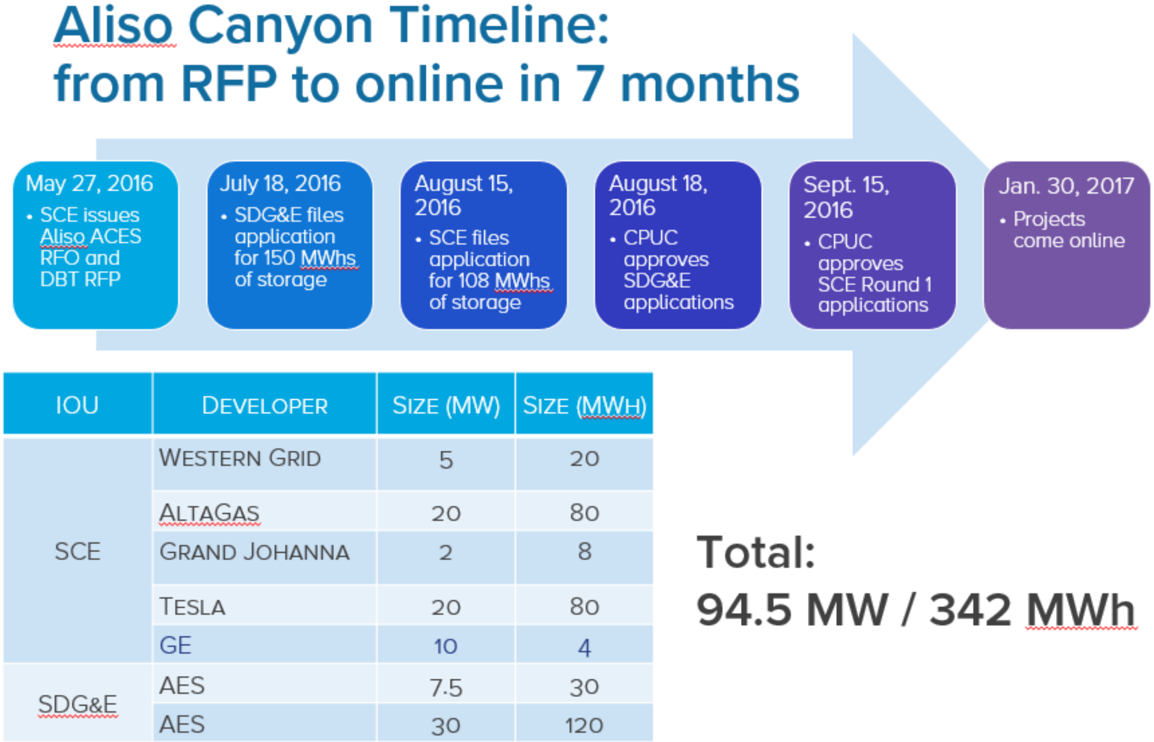
Figure 17. NOx Emissions Rate Comparison for Selected Zone J Plants
(Source: US EPA Air Markets Program Data, accessed June 2017, https://ampd.epa.gov/ampd/)

The CCs with NOx controls generate approximately 2-3% of the emissions per unit of energy versus the CTs. Thus, under a “worst case” scenario, the emissions reduction benefits from storage described earlier might be reduced by a corresponding 2-3% in some cases (e.g. 63-64% NOx reduction for a 4-hr duration battery versus 66%). However, as renewable energy penetration increases on the NYISO grid, it’s also increasingly likely that the marginal fuel type will be wind, in which case there would be no adjustment needed.

3.2. Development Timeline

A major advantage of battery energy storage technology is that it can be deployed relatively quickly compared to new generation resources. Conventional power plant project development faces numerous challenges in New York City. These include a complex environmental permitting process, high construction costs, minimal real estate available for new power plant construction, and local opposition. In contrast, energy storage does not have any emissions or water-use, has a small footprint, and operates with no noise. Energy storage projects can often be deployed on existing real estate and collocated with existing generator sites. These characteristics make their project development process easier and shorter compared to fossil powered peakers. Southern California faces many of the same project development challenges as New York City and the region’s recent experience with accelerated deployment of energy storage demonstrates these advantages.

As an example, Southern California faced a local reliability challenge in a highly populated part of Southern California due to an unexpected leak at the Aliso Canyon natural gas storage facility. In response, the CPUC worked with local utilities to conduct an emergency solicitation for energy storage projects. Several developers responded to this solicitation and were able to bring projects online in a matter of months. Figure 18 provides an illustration of the timeline for Aliso Canyon storage project solicitation.



Aliso Canyon Timeline: from RFP to online in 7 months

- May 27, 2016
  - SCE issues Aliso ACES RFO and DBT RFP
- July 18, 2016
  - SDG&E files application for 150 MWhs of storage
- August 15, 2016
  - SCE files application for 108 MWhs of storage
- August 18, 2016
  - CPUC approves SDG&E applications
- Sept. 15, 2016
  - CPUC approves SCE Round 1 applications
- Jan. 30, 2017
  - Projects come online

IOU	DEVELOPER	SIZE (MW)	SIZE (MWH)
SCE	WESTERN GRID	5	20
	ALTAGAS	20	80
	GRAND JOHANNA	2	8
	TESLA	20	80
	GE	10	4
SDG&E	AES	7.5	30
	AES	30	120

Total:
94.5 MW / 342 MWh

Figure 18. Summary of the Aliso Canyon energy storage project solicitation (graphic courtesy of the California Energy Storage Alliance)

3.3. Impacts of Solar PV on Net Load

In recent years, on days which peak load has occurred, Zone J has experienced extended periods of high load hours – particularly in the month of July. For example, on July 19, 2013 (Zone J's all-time peak), 12 hours were within the top 40 for the entire year. This phenomenon initially suggests that there is a need for capacity resources that can provided sustained output over a long duration (e.g. >4 hours). However, as New York's resource mix changes, the need for long-duration resources is also likely to change. This is particularly true due to anticipated additions of solar PV resources, which will have the effect of narrowing the peak net load period, and shifting it into the evening. To illustrate this, we evaluated the impact the likely addition of significant solar PV resources will have on net load for a similar peak load day.

According to a recent study by NREL, New York City has an estimated installed capacity potential of 8.6 GW for solar PV.[18] Additionally, the NY-Sun program established a statewide solar deployment goal of 3 GW. To date there has already been significant

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[18] NREL, Rooftop Solar Photovoltaic Technical Potential in the United States: A Detailed Assessment, January 2016

uptake as installations have increased 800% from 2011 to 2016. However, there are still over 900 MW of NY-Sun incentives available within ConEd's service territory.[19] New York City also has set an initial goal of achieving 1 GW of solar in the next several years.[20] Several city-led initiatives have also been established to promote solar installations including the following:

- *NYC Solar Partnership*: collaboration between New York City Mayor's Office of Sustainability and 40 partners to implement solar development in NYC
- *Solarize NYC*: provides resources to communities interested in solar including financial support, marketing materials, technical assistance, and connections to partners.
- *Shared Solar NYC*: platform to connect community shared solar developers to interested owners of potential host sites, including rooftops and open land.

Finally, the NYISO's 2016 Solar Integration Study forecasted that up to 1,063 MW of behind the meter solar alone could be installed by 2030 (this does not include any in-front-of-the-meter solar installations).[21]

Given the significant potential, substantial available incentives available, and supporting local programs, we believe it's reasonable to expect New York City to install 2 GW of solar PV over the next several years. We examined the hourly load in Zone J on the all-time peak day, July 19, 2013. We then estimated what the net load would look like with the addition of 2 GW of solar PV (see Figure 19).

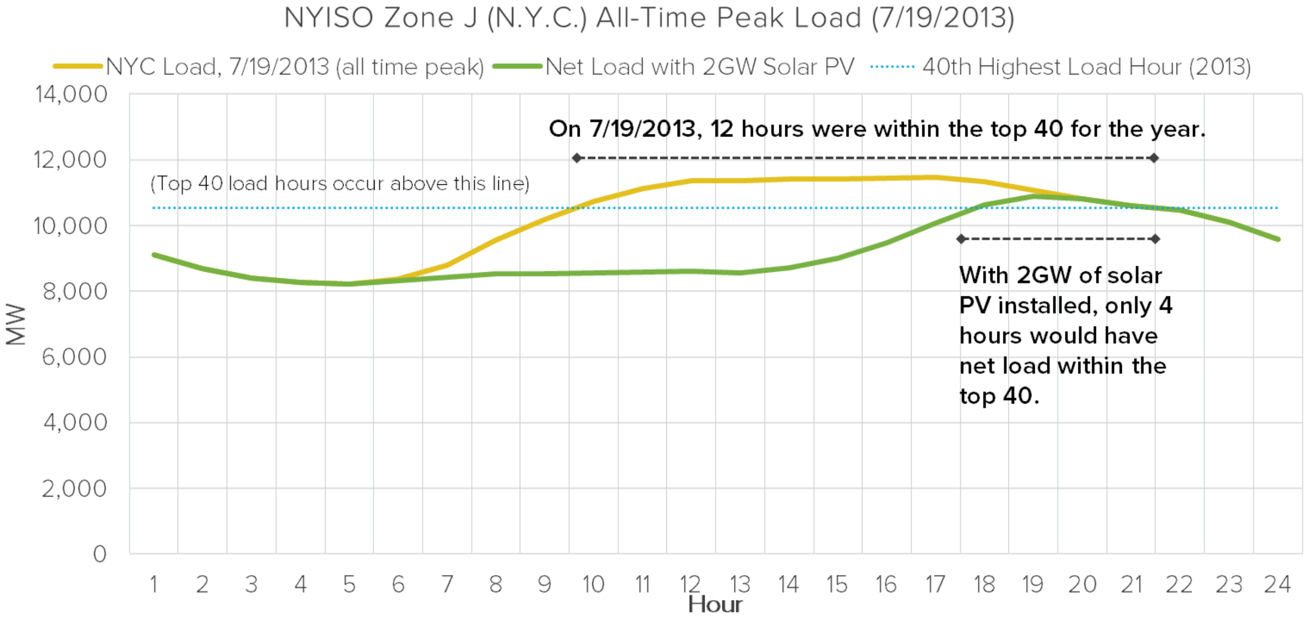

Figure 19. Impact of hypothetical addition of 2 GW of solar PV to hourly load on a peak day in New York City (note that this represents less than 25% of the technical potential identified by NREL).

To calculate the net load, we used historic solar radiation data from the National Solar Radiation Database (NSRDB) to model the production potential for 2 GW of solar PV in

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[19] https://www.nyserda.ny.gov/All-Programs/Programs/NY-Sun/Megawatt-Block-Dashboards
[20] http://www1.nyc.gov/office-of-the-mayor/news/767-16/climate-week-solar-power-nyc-nearly-quadrupled-since-mayor-de-blasio-took-office-and
[21] NYISO Solar Integration Study, June 2016.

NYC on July 19, 2013.[22] We then compared the number of hours with net load within the top 40 peak load hours before and after the addition of PV. The top 40 load hours corresponds to the baseline peak period established by NYISO to evaluate demand response (SCR) programs. As such, we believe the top 40 peak load hours is an appropriate basis of comparison in this case.

As illustrated in Figure 19, the addition of solar PV reduced the number net load hours that are within the top 40 from 12 hours to 4 hours. In conclusion, the addition of solar PV will have a significant impact on Zone J's load shape, and is likely to significantly narrow the peak load period. Thus, the need for sustained peak generation will be reduced.

3.4 Contribution of Storage to Grid Reliability

Grid operators must plan to ensure that there are sufficient resources on the system to meet strict resource adequacy criteria established by NERC. In general, the standard applied is a Loss of Load Expectation (LOLE) of one day in ten years. One commonly used metric for evaluating the contribution of individual resources towards meeting the LOLE criteria is known as Effective Load Carrying Capability (ELCC). While NYISO has yet to complete a comprehensive assessment of the reliability contribution of energy storage in terms of ELCC, several previous studies have been done in other regions. These studies have confirmed that energy storage can meaningfully contribute to system reliability. For example, IFC conducted an analysis in ERCOT showing that 4 hours of energy storage can provide nearly 100% capacity value (ELCC).

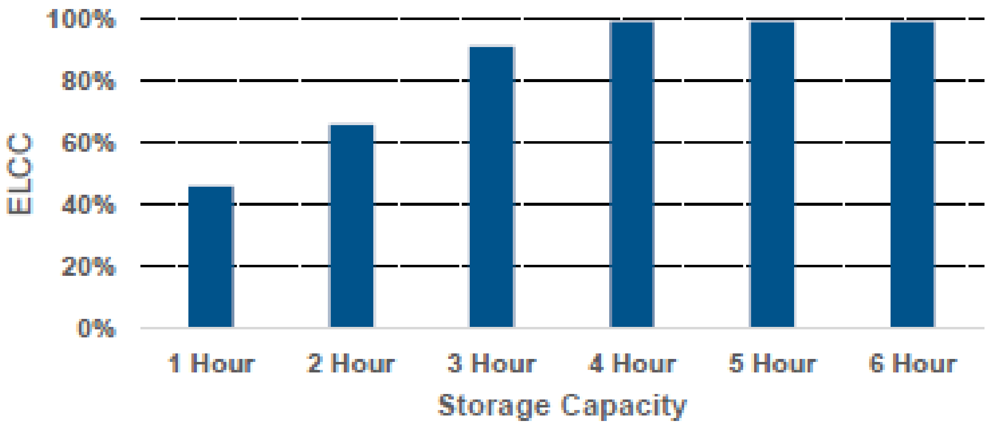

Figure 20. Capacity value of storage as a function of stored energy in ERCOT (Source: ICF, Unlocking the Hidden Capacity Value of Energy Storage, 2016 https://www.icf.com/-/media/files/icf/white-papers/2016/unlocking-the-hidden-capacity-2016.pdf)

Meanwhile, California has adopted a similar standard for determining the resource adequacy contribution of storage: "dispatchable energy storage receive Qualifying

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[22] Solar PV output modeled using historic solar radiation data for 7/19/2013 in NYC location from NREL NSRDB. Assumes fixed tilt installations.

Capacity in the same manner as other dispatchable resources, based on a four-hour Pmax, including testing and verification in CAISO operations”[23]

While an energy storage resource’s contribution to resource adequacy is limited by its duration, conventional resources also have limitations based on their availability as measured by the Equivalent Forced Outage Rate of demand (EFORd). According to NYISO, the average EFORd for old peaking units is 13%, meaning these units on average can qualify to provide only 87% of their capacity value.[24] This is roughly equivalent to the 3-hour duration storage system found in ERCOT which was found to have an ELCC value of ~90% (see Figure 20 above). For some units in NYISO, the EFORd reported was >50%,[25] roughly equivalent to a 1-2-hour duration storage system in ERCOT. While this comparison is instructive, we recognize that ERCOT’s system is very different than NYISO’s and a more robust Loss of Load Probability study is warranted to ascertain the true reliability contribution of storage for the NYISO system.

3.5 Key Takeaways

- Energy storage could reduce the need to dispatch old peaker plants as often on high ozone days.
- Deployment of storage in lieu of old peakers could be an effective strategy for controlling NOx emissions and ozone pollution that can be implemented relatively quickly.
- As solar PV penetration increases, NYC peak load hours will become narrower, requiring less need for long-duration generator output.
- Studies in multiple jurisdictions have demonstrated the ability of energy storage to contribute to resource adequacy and grid reliability.

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[23] CPUC, Qualifying Capacity and Effective Flexible Capacity Calculation Methodologies for Energy Storage and Supply-Side Demand Response Resources. R.11-10-023. http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=6553

[24] NYISO 2016 State of Market Report, p A-163.
[25] *Ibid.*

Section 4 – Economic Evaluation of Energy Storage as an Alternative to Gas Peakers

4.1. Existing Plant Utilization and Capacity Payments

Despite contributing significantly to NOx emissions, most of the plants described in Section 2 tend to run very infrequently relative to their capacity. As shown in Table 9, there are over 5,400 MW of older combustion turbine and steam turbine power plants in New York City with capacity factors less than 30%. Ten of these plants (>2,500 MW total) have capacity factors less than 10%. Generally, plants with low capacity factors are unable to remain economically viable with revenues from the energy and ancillary services markets alone. Additional support is needed to ensure sufficient capacity remains online to meet reliability needs (often referred to as the "missing money" problem). As such additional capacity payments are made to these resources to ensure that they are available to maintain reliability during future commitment periods. The NYISO administers a forward capacity market, awarding capacity payments to resources that clear its auctions. Ultimately, these capacity-related costs are passed along to end use customers as a component of the commodity or supply-related portion of their bills. In 2016, the average monthly NYISO ICAP market spot price for New York City was $8.66/kW-month. Based on this price, we estimate that that plants in Zone J with less than 30% capacity factor cost NYC electric customers an estimated $568M. Plants with capacity factors 10% or less accounted for an estimated $268M in 2016.

Table 9. High NOx-emitting Zone J plants ranked by capacity factor.

Plant	Unit Type[1]	Summer Capacity (MW)[2]	2016 Net Energy (GWh)[2]	Capacity Factor	Est. Capacity Market Awards in 2016 ($M)[3]
NYPA Astoria CC	CC	467	2,722	66.4%	$48.5
Astoria I & II	CC	1,126	6,261	34.0%	$117.0
East River	ST	329	760	26.3%	$34.2
Ravenswood	ST	1,706	3,675	24.5%	$177.4
Arthur Kill	ST	844	1,096	14.8%	$87.7
Astoria Gen. St.	ST	933	815	9.9%	$97.0
Narrows	CT	283	79	3.2%	$29.4
Astoria GTs	CT	414	48	1.3%	$43.0
Ravenswood	CT	273	20	0.8%	$28.4
Astoria Gen. St.	CT	14	1	0.7%	$1.5
Arthur Kill	CT	12	0	0.4%	$1.2
Gowanus	CT	557	17	0.3%	$57.9
Hudson Ave	CT	42	1	0.2%	$4.4
74th St	CT	40	1	0.1%	$4.1
59th St	CT	14	0	0.1%	$1.5
Total		**7,054**			**$733.1**

[1] CC = Combined Cycle, ST = Steam Turbine, CT = Combustion Turbine;
[2] Source: NYISO 2017 Load & Capacity Data ("Gold Book");
[3] Based on average monthly NYISO ICAP market spot price for New York City of $8.66/kW-month in 2016.

As described earlier in Section 2, several plants in the Zone J area participate in a special scheme to comply with NOx emissions rules, known as "NOx Bubbles." This scheme permits certain generation units to be committed to run in the NYISO market even when it is not economic to do so. Committing and dispatching generation units uneconomically leads to unnecessary "uplift" costs that are ultimately borne by electricity customers. Moreover, the scheme actually increases overall NOx pollution (the opposite of what's intended). NYISO analysis shows that uplift payments for New York City cost $34 million over the last two years, of which a significant portion is attributable to local reliability issues such as the NOx bubbles.[26]

In summary, both capacity payments and uplift payments represent a significant amount of funding (i.e. hundreds of millions of dollars annually) that is currently directed to support continued operation of old peaker plants in New York City. This is true even though most of these plants run very infrequently (i.e. less than 10% of the time in most cases). These payments ultimately end up being borne by New York City electric customers.

In theory, some of these costs could be redirected towards development of new capacity resources in Zone J, including energy storage facilities. The following sections compare some of the resource options to which these funds could be directed.

4.2. Cost Comparison for New Capacity Resources in Zone J

As old generation units in Zone J retire over the coming years, there will be a need to repower these units or replace them with new capacity resources to ensure sufficient local capacity to meet reliability needs. The NYISO's capacity market is designed to incentivize investment in an appropriate level of new capacity resources by setting capacity market prices through a demand curve that is in turn based upon the Net Cost of New Entry (Net CONE) of new generation units.

The Net CONE value established by the NYISO reflects the residual cost of a new capacity resource once market revenues (energy and ancillary services) are taken into account. The marginal capacity resource used in the most recent NYISO process is a Siemens SGT6-PAC5000F(5) SC Duel Fuel Combustion Turbine.[27]

NYISO recently published a Net CONE value for this resource as part of its Demand Curve Reset process and filed these values with FERC.[28] The values are computed using a

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[26] See NYISO 2016 State of Market Report, p A-152.

[27] NYISO Installed Capacity Demand Curves for Capability Year 2017/2018 and Annual Update Methodology and Inputs for Capability Years 2018/2019, 2019/2020, and 2020/2021.

[28] New York Independent System Operator, Inc., Docket No. ER17-386-000; Proposed ICAP Demand Curves for the 2017/2018 Capability Year and Parameters for Annual Updates for Capability Years 2018/2019, 2019/2020 and 2020/2021

Demand Curve Model developed for and published by the NYISO.[29] The NYISO did not consider energy storage resources in its Demand Curve Model or FERC filing.

Using the NYISO Demand Curve Model, we developed an estimate of the Net CONE value for both a traditional resource and a battery energy storage resource installed in Zone J. Key assumptions are provided below in Table 10. Both the energy storage and peaker Net CONE are based on a merchant cost of capital. If either asset has access to a long term PPA, its levelized fixed charge rate, and therefore annualized net CONE, would be substantially lower than the value estimated below.

Table 10. Cost comparison assumptions for both a new gas peaker and battery energy storage units.

Parameter	Peaker [1]	Energy Storage[2]
Location	Zone J – New York City	Zone J – New York City
Technology	SGT6-PAC5000F(5) SC	Li-ion Battery
Size	218 MW	218 MW, 4-hr
Service Life (Years)	20	20
Fuel Type	Duel Fuel	Grid Charge
Overnight Capital Costs ($/kW)	$1,314	$1,600
Fixed O&M + Site Lease ($/kW-yr)	$28.71	$26.00
Levelized Fixed Charge Rate (%)	13.12%	11.91%
Gross CONE ($/kW-yr)	$209	$226
Energy and Ancillary Service Revenues ($/kW-yr)[3]	$55	$70
Net CONE ($/kW-yr)	$154	$156

[1]: Assumptions equal to those used for NYISO Demand Curve Model unless otherwise noted; Includes NOx control (SCR) costs.
[2]: Reflects current forecast of cost of storage (storage costs may decline in coming years). Capital cost includes battery replacements. This is also reflective of costs at an existing site with sufficient interconnection capability (new site costs could be substantially higher). Lower levelized fixed charge rate for storage reflects difference in MACRS (7-yr versus 15-year schedule);
[3]: E&AS revenues escalated for 2017$. Peaker values based on NYISO E&AS model results. See Table 11 for E&AS revenues assumptions for storage.

For the energy storage resource, several additional assumptions are needed to account for how the resource would likely be dispatched and the energy and ancillary service benefits that could be derived to determine the Net CONE. We assume the storage unit would be dispatched during peak hours in both summer (June-Sept) and winter (Nov-Feb). This equates to 960 hours dispatched for peak needs in a year, requiring an additional 1,067 hours for charging (assuming additional time for trickle charging). After setting aside 250 hours for maintenance, the remaining time (6,483 hours) is available for the storage resource to provide ancillary services in the form of regulation service. For peak dispatch and charging, we examined the day ahead LBMP prices for Zone J in 2016 to determine the average peak and off-peak prices in each month. For ancillary services, we

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[29] NYISO Demand Curve Model, Sept 13, 2016
http://www.nyiso.com/public/webdocs/markets_operations/market_data/icap/Reference_Documents/2017-2021_Demand_Curve_Reset/Demand%20Curve%20Model%20-%202016_09_09%20_for%20posting.zip

conservatively assumed regulation service is provided at a price of $7/MW-hr.[30] This price is lower than the $8.34/MW-hr and $9.23/MW-hr prices NYISO had for regulation service in 2015 and 2016, respectively, and does not include mileage payments.[31] Key assumptions and levelized energy and ancillary service revenue are summarized in Table 11 below.

Table 11. Energy and Ancillary Service Revenue Assumptions for a Battery Energy Storage Resource

Category	Value	Unit
Average Peak LBMP (dispatch) (June-Sept 2016, hours 15-18; Nov-Feb, hours 16-19)	$47.67	$/MWh
Average Off-Peak LBMP (charging) (2016 hours 2-5, all months)	$20.97	$/MWh
Peak to Off-Peak Price Differential	$26.70	$/MWh
Average Ancillary Service Price – Regulation	$7.00	$/MW-hr
Hours Discharging for Peak	960	Hrs
Hours Charging for Peak Dispatch	1067	Hrs
Hours Dispatched for Ancillary Services[1]	6483	Hrs
Maintenance Time	250	Hrs
Annual Revenue – Energy	$23.40	$/kW-yr
Annual Revenue – Ancillary Services	$45.38	$/kW-yr

[1]: Storage unit was dispatched for ancillary services during all hours after accounting for time necessary for discharging during peak hours, charging time to meet peak hour needs, and time offline for maintenance. Actual ancillary service dispatch may vary and requires more detailed modeling that was beyond the scope of this analysis.

Using the assumptions described above, the net cost was calculated using the NYISO Demand Curve Model both a new gas peaker and a battery energy storage facility. The results for both are illustrated in Figure 21 below. As discussed in more detail later in this section, these estimates do not include system-level benefits which do not provide a revenue stream to the storage resource under the current NYISO market design.

We recognize that there is substantial uncertainty around assumptions for future regulation service prices. Given that regulation is a relatively small market in NYISO (~175-300 MW), any meaningful deployment of energy storage is likely to put downward pressure on these prices. We attempted to reflect this in our assumptions by reducing the regulation price from recent years. However, it is possible that prices would be pushed even lower under some scenarios. Under such circumstances, we note that energy storage can also provide other ancillary services such as spinning reserves, non-spinning reserves, and 30-min operating reserves. The market size for these services is substantially larger (e.g. 2,620 MW for 30-min operating reserves in NYCA in 2016) and could likely support greater deployment of storage, albeit at a lower price (e.g. $5-6/MW-hr). Under a scenario where

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[30] This reflects the fact that energy storage can provide regulation at a very low cost and is likely to exhibit some influence (reduction) on future regulation prices. Such a reduction has the potential to yield millions of dollars in benefits New York electricity customers.

[31] See Figure A-20 http://www.nyiso.com/public/webdocs/markets_operations/documents/Studies_and_Reports/Reports/Market_Monitoring_Unit_Reports/2016/NYISO_2016_SOM_Report_5-10-2017.pdf).

storage was primarily providing reserves, we estimate that that this could reduce the ancillary services revenue and increase the Net CONE by approximately $10/kW-yr (a 6% change). It is important to note that any reduction in future ancillary service prices that affects battery storage revenue will equally affect prices for new natural gas peakers too. While we did not assess the precise revenue impact, it could increase the Net CONE value for the peaker in a similar manner to storage (though to a lesser degree).

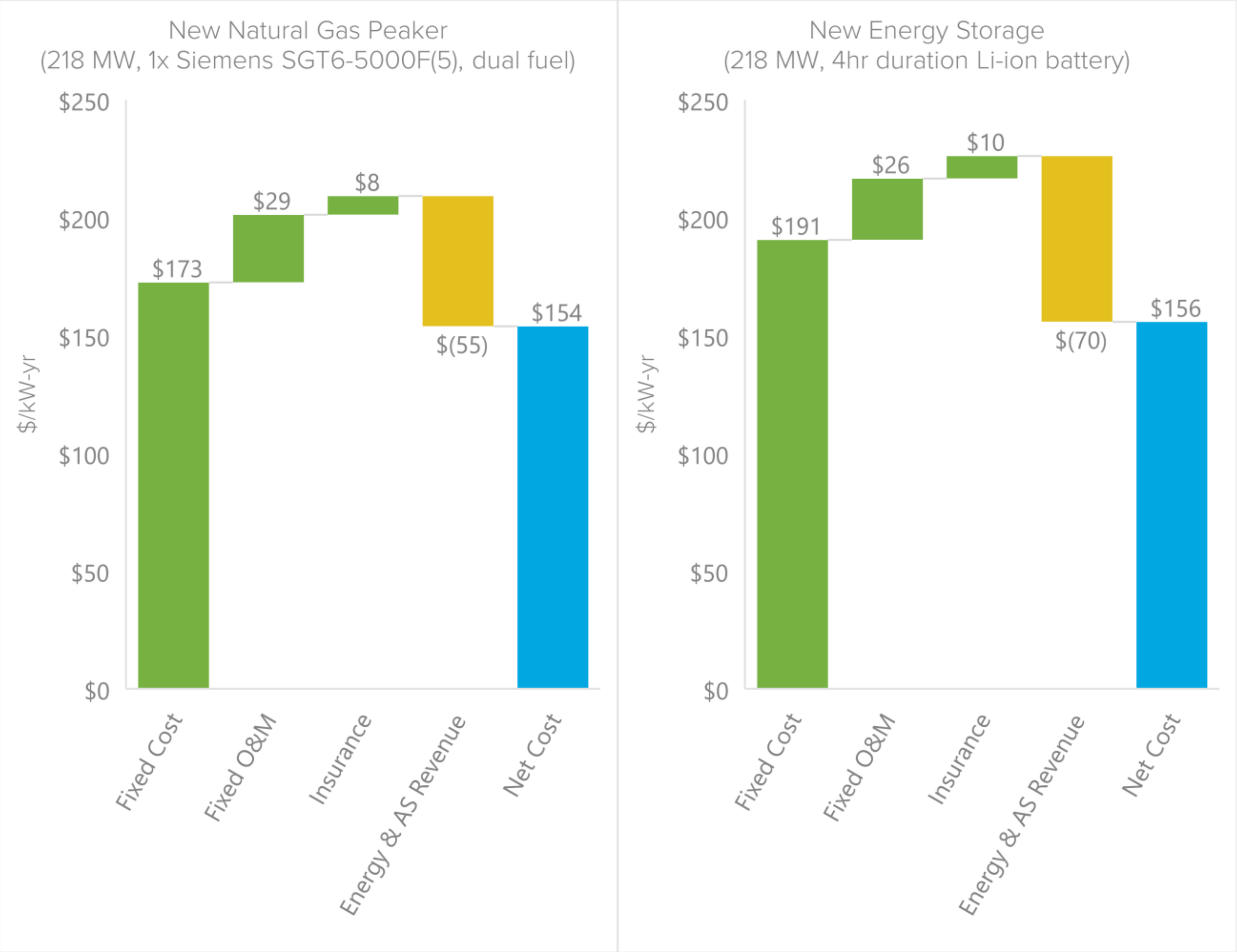

Figure 21. Net CONE comparison between a new natural gas peaker and a new battery energy storage unit. Reflects current forecast of cost of storage (storage costs may decline in coming years)

As shown in Figure 21, energy storage can be relatively cost-competitive versus a new gas peaker on a net cost basis (<5% difference in Net CONE). However, like many resources recently developed in New York, additional financial mechanisms are necessary to provide revenue certainty needed to secure project financing (see Section 4.3 for additional discussion).

Behind the meter (BTM) storage is also a viable option for contributing to replacement capacity in Zone J. However, different installation costs and revenue streams must be considered to estimated net costs. Generally, the installation costs will be higher on a per unit basis for smaller sized systems. However, BTM storage units can take advantage of additional revenue from retail demand charge reduction, local demand response programs payments (e.g. ConEd's CSRP program), and demand management program incentives. Accounting for these factors, we estimate an equivalent Net CONE value for BTM storage of approximately $159/kW-yr (see Appendix B: Behind the Meter (BTM) Storage Assumptions for more details on BTM storage assumptions).

If all the capacity market revenues for the least-used, older plants in Zone J were redirected, we estimate that it would be sufficient to attract investment in 1,724 MW of energy storage (4-hour duration). This is based on an estimated $156/kW-yr Net CONE for an energy storage resource and an estimated $268M annually in capacity revenue for older Zone J plants with <10% capacity factor. Setting aside just 5% of this revenue incrementally each year for storage may be sufficient to attract over 450 MW of new storage investment within 5 years.[32] At this rate, New York City could partially or completely phase out 7 of the 10 least-utilized, highest NOx-emitting plants by 2025, with very little impact (<1%) in total costs to customers, while continuing to meet NYISO's local reliability requirement.

In addition to energy market revenues there are also potential infrastructure cost savings by repowering peaker plants with energy storage. The need for new supply-side generation resources to replace aging peaker plants may require costly major transmission and distribution upgrades. Storage could be deployed at or near existing peaker plant sites and take advantage of existing distribution infrastructure. Making efficient use of existing grid assets by placing storage in these high value locations is aligned with NY's REV policy framework and will save electricity customers from needing to make expensive investments in the grid. This also helps provide a glide path option for existing generators to transition their plants from old fossil units to cleaner distributed energy resource technologies.

Replacing peaker plants with storage also has the potential provide substantial system benefits which could result in millions of dollars in annual savings to New York City customers. These benefits include avoided unit starts/stops, lower emissions, reduced fuel volatility, and less frequent out-of-merit dispatch. Quantifying these system level benefits was outside the scope of this study, as they are not compensated under NYISO's current market design. However, other studies have attempted to estimate these savings, as shown in Figure 22.

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[32] 5% of 1,724 MW is ~90 MW. An incremental 90 MW each year over five years amounts to 450 MW.

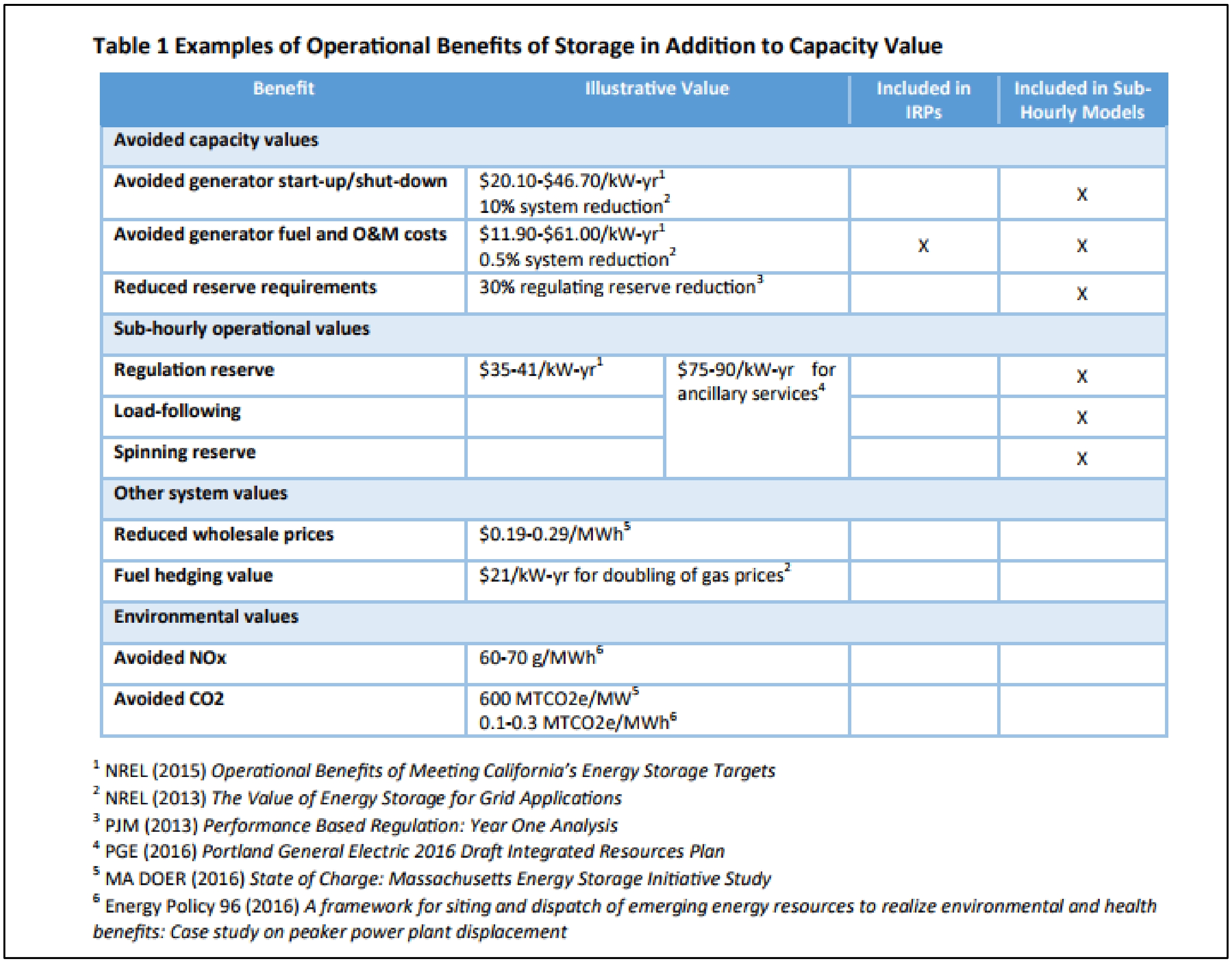

Table 1 Examples of Operational Benefits of Storage in Addition to Capacity Value

Benefit	Illustrative Value		Included in IRPs	Included in Sub-Hourly Models
Avoided capacity values				
Avoided generator start-up/shut-down	$20.10-$46.70/kW-yr[1] 10% system reduction[2]			X
Avoided generator fuel and O&M costs	$11.90-$61.00/kW-yr[1] 0.5% system reduction[2]		X	X
Reduced reserve requirements	30% regulating reserve reduction[3]			X
Sub-hourly operational values				
Regulation reserve	$35-41/kW-yr[1]	$75-90/kW-yr for ancillary services[4]		X
Load-following				X
Spinning reserve				X
Other system values				
Reduced wholesale prices	$0.19-0.29/MWh[5]			
Fuel hedging value	$21/kW-yr for doubling of gas prices[2]			
Environmental values				
Avoided NOx	60-70 g/MWh[6]			
Avoided CO2	600 MTCO2e/MW[5] 0.1-0.3 MTCO2e/MWh[6]			

[1] NREL (2015) *Operational Benefits of Meeting California's Energy Storage Targets*

[2] NREL (2013) *The Value of Energy Storage for Grid Applications*

[3] PJM (2013) *Performance Based Regulation: Year One Analysis*

[4] PGE (2016) *Portland General Electric 2016 Draft Integrated Resources Plan*

[5] MA DOER (2016) *State of Charge: Massachusetts Energy Storage Initiative Study*

[6] Energy Policy 96 (2016) *A framework for siting and dispatch of emerging energy resources to realize environmental and health benefits: Case study on peaker power plant displacement*

Figure 22. Examples of potential operational system benefits of energy storage as estimated by the Energy Storage Association. Source: http://energystorage.org/system/files/attachments/irp_primer_002_0.pdf

Figure 23 below illustrates a hypothetical net cost comparison with potential system benefits included. While energy storage could achieve several of the benefits outlined in Figure 22 simultaneously, for this comparison we estimated the storage resource would only realize $20/kW-yr in avoided generator start-up/shut-down costs, consistent with lower end of the range provided in Figure 22. Since system benefits are not compensated under current NYISO market design and would not accrue to the energy storage resource directly, but would instead accrue to all retail customers. This could amount to millions of dollars in potential benefits to New York City customers.[33]

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[33] For example, generators participating in NYISO markets are provided a guarantee that their startup costs will be recovered if they are committed in the day ahead market. If the generator does not recover its costs through real time dispatch, this often leads to additional "uplift costs" that are ultimately charged to load serving entities. In 2016, New York City paid $12 M in uplift costs from guarantee payments. Since storage has very low startup costs it can be dispatched without contributing to need for uplift costs.

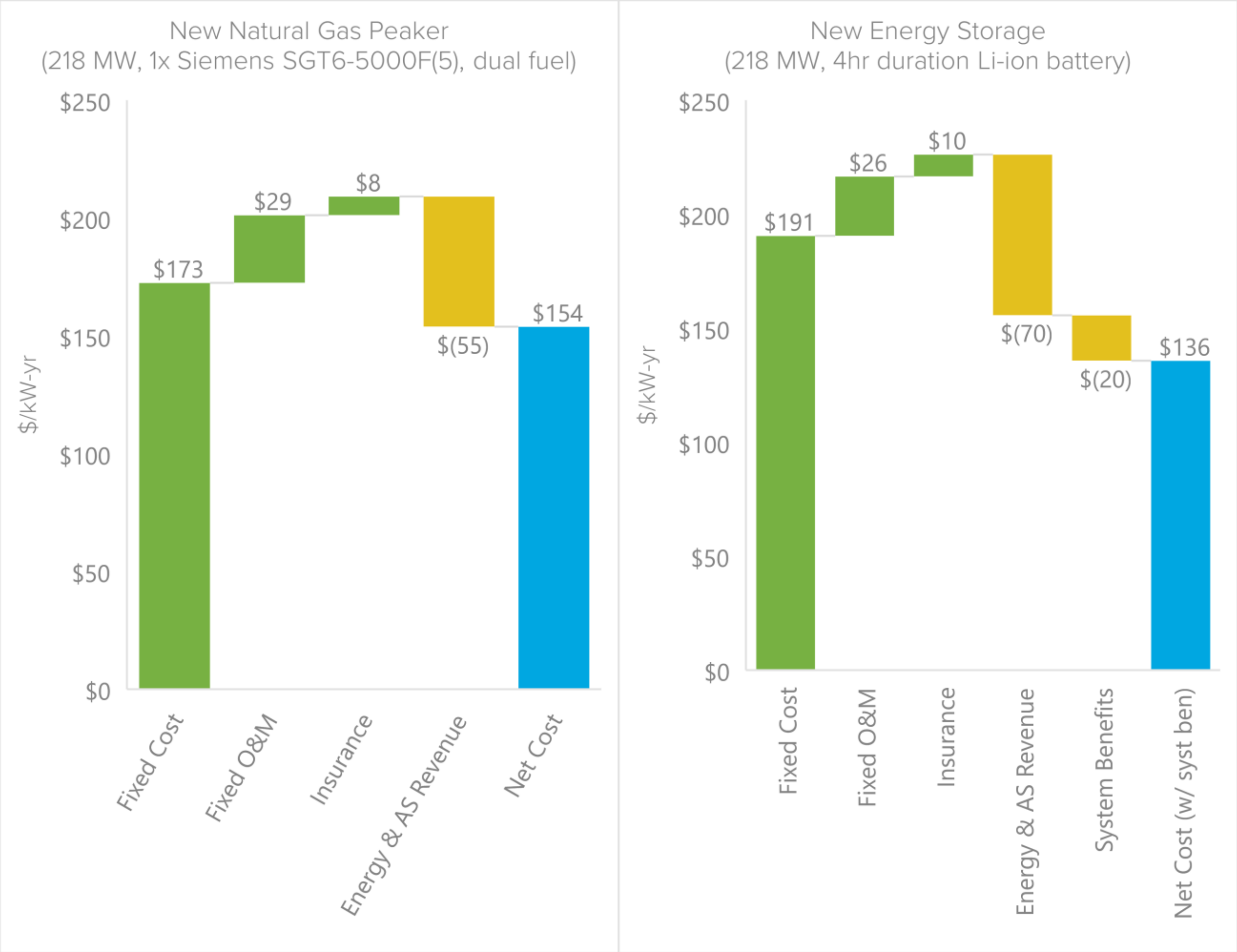

Figure 23. Net CONE comparison between a new natural gas peaker and a new battery energy storage unit, including system benefits. Reflects current forecast of cost of storage (storage costs may decline in coming years). System benefits (e.g. avoided startup costs) are not compensated under current NYISO market design but would accrue to all customers.

4.3 Providing Sufficient Revenue Certainty to Finance Energy Storage Projects

Historically generators in New York City have relied on out of market payments and bilateral agreements to ensure reliability is maintained. Recent examples of these bilateral agreements are the long-term contracts the New York Power Authority signed with Astoria Energy II and the Hudson Transmission Project to ensure that these new resources were built.[34] These bilateral agreements ensure that developers can secure financing for new projects, which is critical to their development since the cost of building new facilities in New York City is so expensive.

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[34] http://www.analysisgroup.com/uploadedfiles/content/insights/publishing/nyiso_capacity_market_evaluation_of_options.pdf

Long-term contracts have been critical to recent development of traditional generation assets elsewhere in the state such as the following projects:

- Caithness Long Island (natural gas combined cycle), a 20-year PPA with LIPA[35]
- Pinelawn Power Plant (natural gas combined cycle), a 20-year PPA with LIPA[36]
- Neptune Transmission Line, a 20-year PPA with LIPA[37]

Long-term power purchase agreements have also been critical to developing and financing many modern clean energy technologies. For example, the Solar Energy Industries Association states that solar "PPAs typically range from 10 to 25 years."[38] Similarly, Windustry indicates that "The stated term of most PPAs is 20 years, although a term ranging anywhere from 15 to 25 years is not unusual."[39] New York and many other states already use long-term contracts procure other advanced energy technologies such as wind and solar.[40]

Similarly, long-term revenue certainty is key to the successful deployment of energy storage projects that are deployed as an alternative to peakers, particularly in New York City where development costs are high. A payment stream that is predictable or known in advance (i.e. beyond 6 months) is an essential element for financing new storage projects. A 2016 report by Sandia National Labs "Energy Storage Financing: A Roadmap for Accelerating Market Growth" further supports this notion, stating the following:

- "There are two primary contract types that will be important to the energy storage market: the power purchase agreement (PPA), and the energy savings performance contract (ESPC)."
- "The contract terms may last anywhere from 5 to 20 years"

The report points to several recent examples of successful energy storage solicitations which have largely relied upon long-term contracting opportunities.

Given the fact that long-term revenue certainty is needed, there remains the question of how this could be implemented in the case of New York and what mechanism might be able to effectively procure storage to replace old peaking plants. While there are many potential options, we describe two options below. Either, or both, of these could be implemented relatively quickly and would complement New York's existing market structures.

Option 1: Set-Aside or Target for Local Capacity Resources

One option for ensuring sufficient clean energy resources for meeting local capacity needs would be through a small capacity set aside or target implemented in conjunction

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[35] http://www.caithnesslongisland.com/wp-content/uploads/2012/12/Press-release-October-1.pdf

[36] http://www.lipower.org/pdfs/company/investor/2005annual.pdf

[37] http://starwoodenergygroup.com/wp-content/uploads/2014/06/6_NeptuneAnnouncement.pdf

[38] http://www.seia.org/research-resources/solar-power-purchase-agreements

[39] http://www.windustry.org/community_wind_toolbox_13_power_purchase_agreement

[40] For example, NYSERDA's CES Phase 1 Implementation Plan stipulates a maximum contract duration of either 20 years or a facilities useful life, which generally ranges from 10-20 years. Source: http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId={6E36562D-8AE9-4E0B-AA35-4160F0E1F7AA}

with New York's existing capacity market. Under this option, a new rule would be applied requiring that a certain portion of an LSE's local capacity obligation be met with flexible capacity resources, such as energy storage. We recognize that there are many potential mechanisms for accomplishing this and the exact details should be developed through a stakeholder process. Some possible additional implementation steps could include the following:

- LSE's would identify the MW amount of generation below a 10% capacity factor that was used to meet their local capacity obligations in the previous year.
- Each year, the LSE would be required to procure a MW amount of storage equal to 5% of this amount in the following year.
- Procurement of flexible local capacity resources could be conducted directly by LSEs or through NYSERDA with contract lengths ranging from a 10- to 20-year period.
- To the extent that procured storage resources provide capacity value, they would contribute to the LCR or ICAP requirement and would be required to participate in the NYISO ICAP market process.
- Long-term contracts would guarantee revenue sufficiency for any portion not recovered from NYISO energy and capacity markets.
- Reverse auctions have served as a successful mechanism for competitive procurement of long-term fixed contracts for renewables and could also be used to procure storage New York.
- Setting the initial flexible resource target for local capacity may require a new statute, PSC rulemaking, or local law. Alternatively, NYSERDA could explore options for implementation under the existing Clean Energy Standard.

Option 2: VDER Tariff Modifications

Another mechanism for providing revenue certainty for storage projects would be to adapt the forthcoming Value of Distributed Energy Resources (VDER) tariff to fit this purpose. As part of the Reforming the Energy Vision (REV) effort, the New York Public Service Commission (PSC) has engaged in a process to establish tariffs for each utility to compensate distributed resources for the value they provide to the grid. The Phase 1 VDER tariffs are set to be implemented in late 2017. The Phase 1 tariffs would establish compensation rates for energy exported to the grid from distributed resources. This is intended to reflect various values such as energy, capacity, distribution deferral, and environmental benefits (i.e. the "value stack"). For dispatchable resources such as energy storage, this compensation also depends upon performance during certain critical times. For example, distribution value is based on output during the top 10 hours of the year, while capacity value is based on output during the top 1 hour of the year. For some components of the value stack, compensation is defined for a fixed period (e.g. 10-years for the local system relief value, "LSRV"). However, for other elements, compensation is much less certain (e.g. monthly spot prices for capacity value). In particular, the installed capacity ("ICAP") value for DERs under the proposed methodology is very uncertain and unlikely to be financeable, even though capacity is precisely the value that needs to be addressed in response to NYC's aging generation fleet. Applying a 10-year fixed period for ICAP (similar to LSRV) could ensure revenue certainty necessary to attract storage projects as capacity resources in Zone J. As a safeguard, this provision could be limited to a MW amount equal to an established set-aside for storage as described in Option 1.

In addition to enhancements to capacity value for storage DERs, enhancements could also be made to the "E" value to reflect the beneficial impact of reducing NOx, SOx, and GHG emissions from peaker plants. In the VDER construct "E" is used to represent environmental values such as reduced GHG emissions. Generally, storage has not been considered to provide environmental benefits in the same way as renewable energy resources since it does not reduce overall energy consumption. However, as we have demonstrated in this study, it can have a positive impact on criteria pollutants and GHGs and should be compensated accordingly.

Additionally, beyond VDER itself, the full suite of applicable tariffs must be considered to ensure sufficient storage development. The applicable tariffs must work together to make sure that projects are financeable and can support sufficient development of storage in the right locations. However, VDER as currently designed, may not fully facilitate deployment of storage – particularly in-front-of-the-meter (IFM) storage. An additional tariff is necessary for IFM storage to interconnect and to account for energy consumption from grid charging. Until very recently, no tariff options were in place or even proposed to allow this. However, in July 2017, ConEd proposed tariff revisions that could enable IFM storage but requires modification both in the economics and sizing requirements (to enable projects interconnected above 27kV).[41] A tariff similar to what ConEd has proposed for IFM storage can and should work in concert with the VDER tariff values (as modified above) to provide revenue certainty for IFM storage systems. Additionally, it is important that the rate for charging distributed energy storage projects is fair and not unduly burdensome. Tariffs that charge energy rates substantially more than wholesale rates, or have other features such as non-coincident demand charges may not be viable for IFM energy storage projects. We acknowledge that the PSC Staff is actively engaging these issues in the VDER proceeding and encourage continued dialogue with industry stakeholders on solutions for addressing New York's aging generation fleet through storage.

4.4 Key Takeaways

- New York City electricity customers currently pay over $268 M annually in capacity payments to support old peaker plants that run less than 10% of the time.
- Energy storage is cost-competitive with new natural gas peakers in NYC and could be an economically viable option based market revenues for new capacity over the next few years,
- Energy storage can provide system level benefits that are not compensated under NYISO's current market design. Accounting for these system-wide benefits could make storage less expensive than new natural gas peakers.

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[41] See Case No. 17-E-0458

- Like many other energy resources recently developed in New York (e.g. renewables, natural gas), long-term certainty is needed to make storage projects financeable.
- A relatively small capacity market set-aside could provide the stopgap financial support necessary to allow energy storage to effectively compete in replacing these old peakers.
- Adapting the proposed VDER tariff to provide revenue certainty may also be an effective option for deploying storage, especially for distributed storage resources.
- We estimate that a 5% annual incremental set-aside in New York City (Zone J) could help attract investment in over 450 MW of new energy storage resources over the next 5 years with very little impact (<1%) in total cost to customers.
- This will put New York on a path to transitioning away from old peaker plants that contribute significantly to NOx emissions, worsening the city's ozone pollution.
- Deployment of storage could also yield millions of dollars in customer bill savings through reduced energy and ancillary service costs and from potential system benefits.

Conclusions and Recommendations

General Conclusions

New York City's aging generation fleet faces challenges over the next few years. Existing generation units are critical for meeting local reliability needs, but face pressures due to their advanced age and significant contribution to air quality problems. Within 5 years, 2,860 MW of old steam and combustion turbines in Zone J will be past their normal retirement age, representing 30% of New York City's current generation fleet. Additionally, there are a small number of older peaking plants in New York City without NOx controls that contribute significantly to ozone-forming NOx emissions in the region. Ozone is a major public health problem for the New York metro area, causing New Yorkers to suffer annually from over 400 premature deaths, 850 hospitalizations for asthma and 4,500 emergency department visits for asthma.

However, the deployment of battery energy storage facilities in lieu of old peakers could be an effective strategy for controlling NOx emissions and ozone pollution. Our analysis shows that deploying 4-hours of energy storage at or near the top two NOx-emitting power plants may be sufficient to reduce emissions from those facilities by 62-66%. As solar PV is deployed this strategy could be increasingly effective for meeting reliability needs since peak net load periods will become narrower.

Meanwhile, energy storage is increasingly cost-competitive with new natural gas peakers in NYC and is an economically viable option for either supplementing or replacing aging plants over the next few years, even before accounting for the system level benefits storage provides. Similar to other new resources developed in New York City, a structure providing revenue certainty is needed to help make storage projects financeable and indirectly compensate storage resources for the system-wide benefits they provide.

Potential Pathways for New York City's Generation Fleet

Based on the analysis in this study, we can envision several potential scenarios that could unfold over the coming years for New York City's generation fleet. Of the scenarios outlined above, we believe that "Status Quo" is relatively unlikely given potential technical challenges and policy preferences at the state and local level. Of the remaining two scenarios, the final one (Proactive Procurement) is clearly the preferable option. We recommend that state and local authorities take appropriate steps to ensure this outcome. We have provided some suggested recommendations in the subsequent section.

- Status Quo: Under this scenario, New York City's aging generation fleet continues to operate indefinitely. Older generators encounter no technical barriers to continued operation beyond the age any other generators of their kind in the country. No additional steps are taken to address emissions from local generators and their health impacts perpetuate. Capacity market revenues support continued operation of older generators and eventually attract investments in new natural gas power plants in the city. New York City stalls in meeting its clean energy goals due to continued investment in fossil fuel resources.

- Capacity Crisis: Several older generators in New York City soon retire due to a combination of new environmental rules and technical challenges due to age. This leads to a local capacity shortfall that is exacerbated by the retirement of Indian Point. Prospective new generation and transmission projects are unable to be completed on time due to unanticipated cost overruns, local opposition, and NY DEC rejection of new pipeline projects. Energy efficiency and distributed generation efforts are ramped up, but still insufficient to meet local capacity requirements. Emergency steps must be taken to secure New York City's grid reliability, but few new generation options are available.
- Proactive Procurement for Reliability and Environmental Benefits: New York seeks proactive steps to simultaneously 1) address the environmental damages from old generators and 2) stave off local reliability issues should any of these generators be forced to retire. A policy is adopted to procure cleaner, flexible capacity resources. Energy storage is found to be an important component of implementing a new clean local generation portfolio. This results in meaningful deployment of energy storage resources which simultaneously serve to reduce local criteria pollutants, advance the City's GHG goals, contribute to local grid reliability.

Recommendations for action:

- *Establish a flexible capacity target for local resources* – A relatively small flexible capacity set aside or target for local capacity resources could provide the stopgap financial support necessary to allow energy storage to effectively replace or supplement old peaking units. We estimate that an incremental annual 5% set-aside in New York City (Zone J) capacity market could help attract investment in over 450 MW of new energy storage resources over the next 5 years with very little impact (<1%) in total cost to customers.
- *Establish a fair and effective VDER tariff for storage* —a near-term modification to the proposed VDER tariff could create certainty around a long-term revenue stream for energy storage. Tariff development should explore local environmental values and accommodate a variety of system sizes and configurations.
- *Complete the state's "storage roadmap" study* – Through NYSERDA, New York has begun to embark on a storage roadmap study that will help identify need and potential benefits of storage for the state. We recommend the timely completion of this study and that it include some focus on the role of storage for meeting New York City's local capacity needs.
- *Conduct a Loss of Load Expectation (LOLE) study for storage* – Similar to what ERCOT has done, we recommend that NYISO conduct a technical study on the ability of energy storage of various durations to contribute to its resource adequacy criteria (i.e. Loss of Load Expectation), particularly for projects located in the New York City local capacity area.

- *Explore procurement options under the Clean Energy Standard* – Given the ability for energy storage to aid renewable energy integration (e.g. reduced curtailment) and contribute to underlying goals of reduced greenhouse gas and criteria pollutants, it may warrant special consideration under the Clean Energy Standard. NYSERDA should consider ways to leverage its procurement process to include potential storage resources.

STRATEGEN
CONSULTING

Appendix A: Overview of Strategen

Strategen Consulting is a strategic consulting firm that has been exclusively focused on clean energy technologies for more than a decade including distributed energy resources, renewable energy, energy storage, and grid modernization. Founded by Janice Lin in 2005, we are a minority and women-owned business headquartered in California. Strategen's clients include city, state, and national government agencies, as well as utilities and private companies – all of whom are interested in advancing smart, creative, and sustainable clean energy policies and technologies.

Strategen Consulting brings the insight and hands-on experience required to make intelligent decisions about energy policy. We offer objective economic analysis, a deep understanding of DER technology and policy. Strategen has extensive experience in evaluating costs and benefits of emerging energy technologies and policies. We work closely with our clients to design and help implement successful strategies built on objective and quantitatively sound analysis. What sets Strategen apart from other consulting firms is our ability to deliver unique insights and guidance by integrating our knowledge of emerging energy technologies, markets, regulations and policies.

Appendix B: Behind the Meter (BTM) Storage Assumptions

Table 12. BTM Storage Parameters Used for NYISO Demand Curve Model.

Parameter	BTM Energy Storage
Location	Zone J – New York City
Technology	Li-ion Battery
Avg. System Size	200 kW, 4-hr
Service Life (Years)	20
Fuel Type	Grid Charge
Overnight Capital Costs ($/kW) [1]	$2,900
Fixed O&M + Site Lease ($/kW-yr)	$26.00
Levelized Fixed Charge Rate (%)	11.91%
Gross CONE ($/kW-yr), reflects DMP incentive value	$264
Demand Charge Savings and DR Program (ConEd) Revenues ($/kW-yr)[2]	$126
Net CONE ($/kW-yr)	$159

[1]: Includes 10-year battery replacement costs.
[2]: Demand charge savings and DR program revenues were entered into the NYISO DCM in lieu of Energy and Ancillary Service revenues.

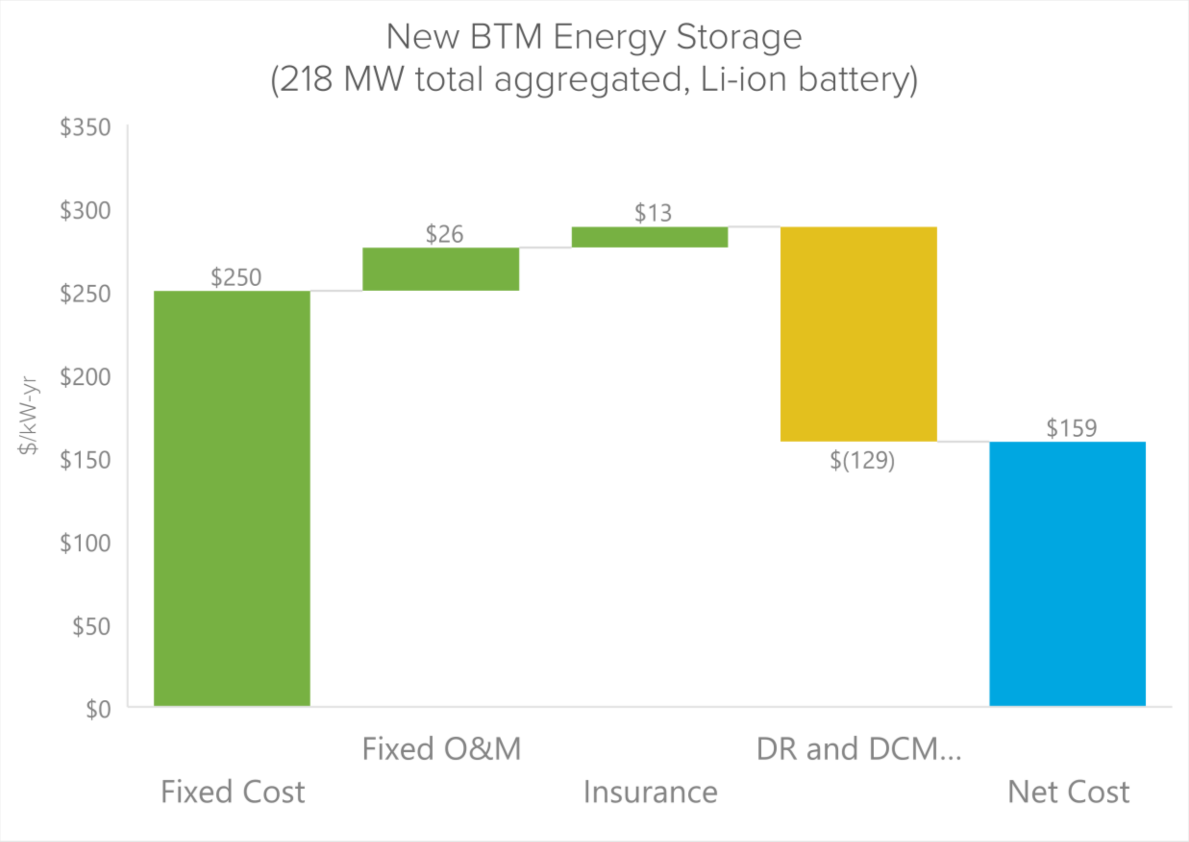

Figure 24. Net Cost estimate for a portfolio of BTM energy storage projects totaling 218 MW (equal to marginal gas peaker used in NYISO ICAP market).

Table 13. Additional assumptions used for calculation of Demand Charge and DR Program Revenues.

Category	Value
Average System Size (kW)	200
Project Cost ($/kW)	$2,900
Total Project Cost ($)	$580,000
Average On-Peak Demand Reduction for DMP	200
Demand Management Program Incentive - 2019 ($/kW)	$800
DMP Incentive (capped at 50% of project cost)	$160,000
Average On-Peak Demand Reduction for DCM	120
Demand Charge ($/kW) - monthly	$18.36
Annual Demand Charge Savings ($)	$2,203
Demand Response Program Revenue ($/100kW)	$12,000
Demand Response Program Revenue ($)	$24,000
Retail Rate for Charging/Discharging ($/kWh)	$0.061
Round Trip Efficiency	85%
Charging Losses	$976
Annual DR and DCM Revenue ($/kW-yr)	$126