Before the Before the State of New York Senate-Assembly
Environmental Conservation Committee

Testimony in Support of the Climate and Community Protection Act, S. 2992

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Senator Kaminsky, and Members of the Committee:

My name is Armond Cohen, and I am Executive Director of the Clean Air Task Force (CATF), a nonprofit environmental organization that, during our 23 years of existence, has been dedicated to advancing public policies that reduce or eliminate harmful air pollution and climate-warming emissions from the world's energy system.[1] We have worked with environmental groups and governments in nearly all states, including New York, to advance state policies that can also be models for national policy. I appreciate the opportunity to submit this written testimony today, which I am not delivering in person due to predicted hazardous driving conditions today between Boston, where I live, and Albany.

CATF strongly supports S. 2992 and its stated goal of zero carbon emissions in New York State by 2050 – as an important step for New York and as a potential national model. It has become abundantly clear that a zero emissions goal is the appropriate one. Because of the levels of carbon dioxide already in the atmosphere, the additional amounts that emitted in coming decades even if we begin a rapid decline in our emissions rate, and the century-scale natural decay rate of carbon dioxide, the only way to limit global warming is to reach net zero emissions of greenhouse gases in the coming decades. Indeed, as the recent report of the Intergovernmental Panel on Climate Change demonstrates, we will not just need to drop emissions to zero around mid-century; we will likely eventually need ***negative*** emissions technologies to ***remove*** carbon from the atmosphere.[2]

In this testimony, I will focus on the need to keep open technological options to achieve zero carbon emissions especially in the power sector – a sector which is key to deep emissions reductions in transport and industry via electrification.

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[1] More information on CATF can be found at www.catf.us.

[2] IPCC, 2018. *Special Report: Global Warming of 1.5 °C.* "Chapter 00: Summary for Policymakers." Intergovernmental Panel on Climate Change. https://www.ipcc.ch/sr15/chapter/summary-for-policy-makers/

We have an abundance of potential technology options available now and likely to be available in the future to meet the goal of zero carbon emissions on the New York State power grid. Solar and wind energy costs have come down substantially in recent years. Energy storage which can balance variability of solar and wind has also dropped in price. New York is also blessed with hydroelectric resources within the state and from our neighbor Canada. Technologies are in place today, and more are coming forward, which can utilize natural gas for power generation without carbon dioxide emissions to the atmosphere, utilizing carbon capture and sequestration.[3] In addition, we have both existing nuclear energy plants, which today provide most of New York's carbon free electricity, and the potential for future nuclear plants which may be less expensive and even safer than today's technology.[4] There may be the opportunity for advanced geothermal power using injection of water into deep hot rock formations, which could provide on-demand steam to generate electricity.[5]

If we keep all of our options and work to make them even more viable, we stand a good chance of meeting a mid-century zero carbon target. Nations and regions such as Sweden, France, Ontario, and Brazil have already achieved very low electricity carbon emission rates through use of some of these technologies, chiefly hydroelectric, wind and nuclear energy.

Here I want to focus specifically on the importance of keeping the door open for "firm" zero carbon energy sources to play a significant role in the Empire State's electric system as part of the design of S. 2992. Firm sources are those that are available on demand and are not dependent on weather. Firm low-carbon resources include, today, fossil fuels with carbon capture and storage, nuclear energy, and to a somewhat lesser extent, hydroelectric power.[6] In the future, they could include advanced geothermal and

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[3] See R. Service, "Goodbye smokestacks: startup invents zero emissions fossil power," *Science,* May 24, 2017, https://www.sciencemag.org/news/2017/05/goodbye-smokestacks-startup-invents-zero-emission-fossil-fuel-power

[4] See Clean Air Task Force, "Advanced Nuclear Energy: Need, Characteristics, Projected Costs, and Opportunities" (April 2018), https://www.catf.us/resource/ane-need-characteristics-project-costs/

[5] See https://www.energy.gov/eere/geothermal/how-enhanced-geothermal-system-works and https://www.hotrockhero.org

[6] Hydroelectric power output can vary with climate conditions, and dispatch can be constrained in some cases by environmental considerations that affect reservoir management. It should be noted that there are unsettled issues around greenhouse gas emissions from large hydroelectric reservoirs, even in

perhaps advanced cellulosic biofuels or combustion of zero-carbon fuels such as hydrogen or ammonia derived from electrolysis from zero carbon energy, steam reforming of natural gas combined with carbon capture, or nuclear energy.[7]

It may be technically possible, as some have argued,[8] to run New York's electric grid entirely or almost entirely, on wind and solar energy. However, the evidence suggests this would be a highly risky path to mandate today. First is the issue of cost. A recent review of 40 studies concluded that combining wind and sun with firm energy, rather than relying exclusively or overwhelmingly on wind and sun, would substantially reduce the cost of deeply reducing carbon emissions in the electricity sector.[9] A more recent detailed analysis of the role of firm energy in a Northeast US system found a dramatic cost difference between electric systems driven by wind and sun, and systems with substantial amounts of firm zero carbon energy in the mix.[10] Other non-cost risks attach to a wind- and sun-dominated strategy, which I will address later. I will focus first on the cost issue, using New York and California data to illustrate.

It is commonplace to say that "the wind doesn't always blow and the sun doesn't always shine." But this statement does not capture the real challenge of a wind- and sun-dominated electric system. Wind and sun don't just vary on ***daily*** cycles; they vary substantially over ***weekly*** and ***monthly*** periods.

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northern latitudes. See, e,g, Scherer, Laura, and Stephan Pfister. "Hydropower's biogenic carbon footprint." *PloS one* 11.9 (2016): e0161947.

[7] See Clean Air Task Force, "Fuels Without Carbon: Prospects and the Pathway Forward for Zero-Carbon Hydrogen and Ammonia Fuels" (December 2018) https://www.catf.us/resource/fuels-without-carbon/

[8] Jacobson, Mark Z., et al. "100% clean and renewable wind, water, and sunlight (WWS) all-sector energy roadmaps for the 50 United States." *Energy & Environmental Science* 8.7 (2015): 2093-2117.

[9] Jenkins, Jesse D., Max Luke, and Samuel Thernstrom. "Getting to Zero Carbon Emissions in the Electric Power Sector." *Joule* 2.12 (2018): 2498-2510. (Link here)

[10] Sepulveda, Nestor A., et al. "The role of firm low-carbon electricity resources in deep decarbonization of power generation." *Joule* 2.11 (2018): 2403-2420. ("Across all cases, the least-cost strategy to decarbonize electricity includes one or more firm low-carbon resources. Without these resources, electricity costs rise rapidly as $CO_2$ limits approach zero. Batteries and demand flexibility do not substitute for firm resources. Improving the capabilities and spurring adoption of firm low-carbon technologies are key research and policy goals.") (Link here).

This seasonal effect can be seen in New York for wind in Figures 1-3 below, illustrating smoothed, daily-average production[11] for onshore wind, offshore wind, and a 50/50 blend of the two[12]:

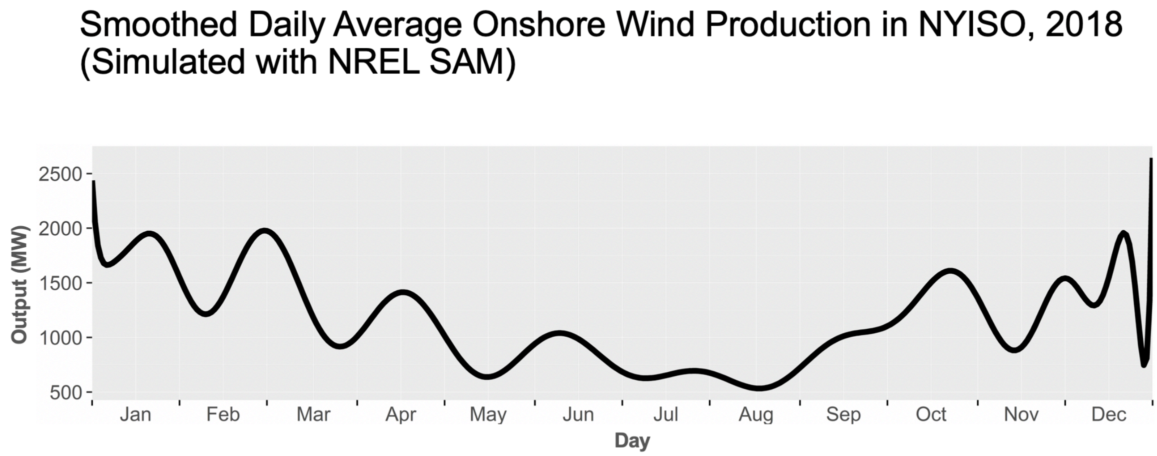



Figure 1

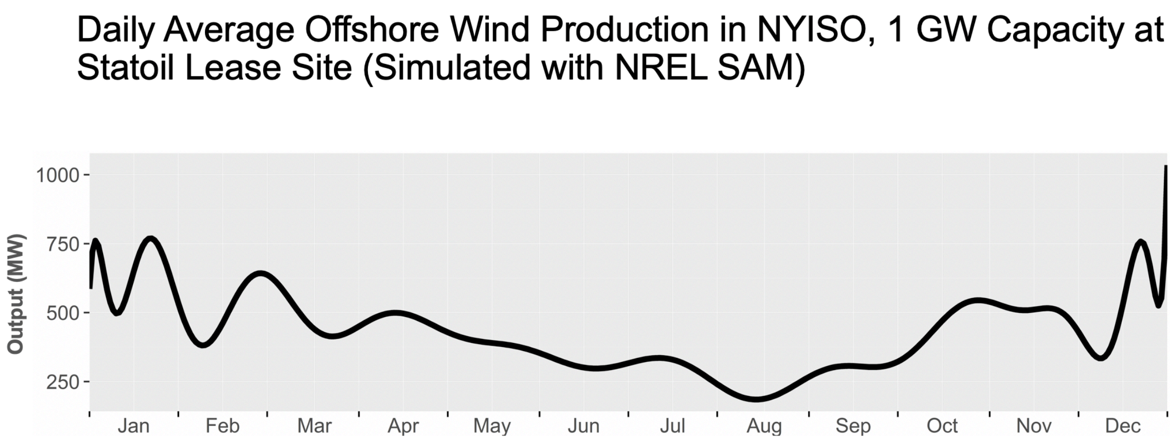



Figure 2

[11] This daily average smoothing conceals more significant variability *within* the day.

[12] A methodological note on NYISO figures, which were developed by Max Luke of NERA Economic Consulting, is found in Appendix 1.

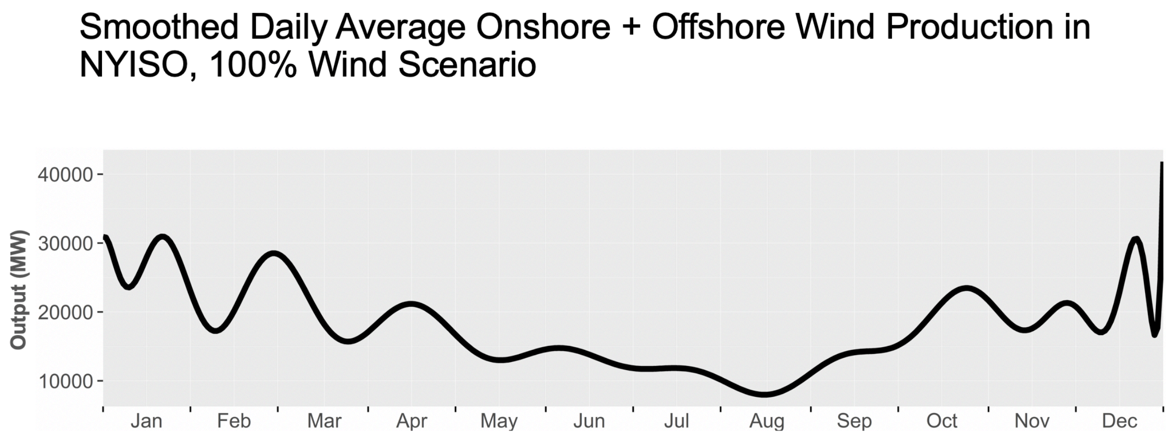



Figure 3

Daily average solar production in New York also exhibits a wide seasonal variation pattern, as can be seen in Figure 4 below:

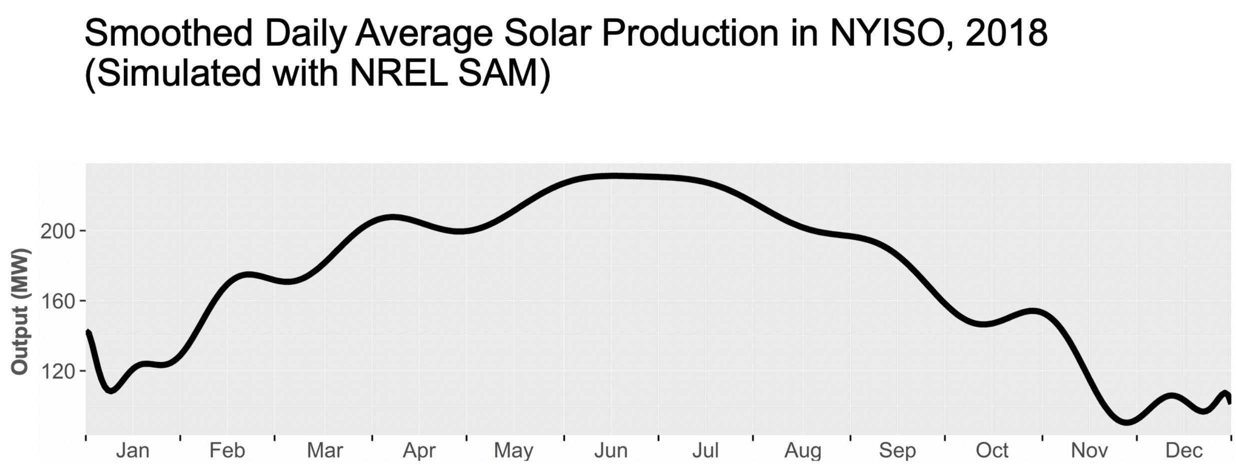
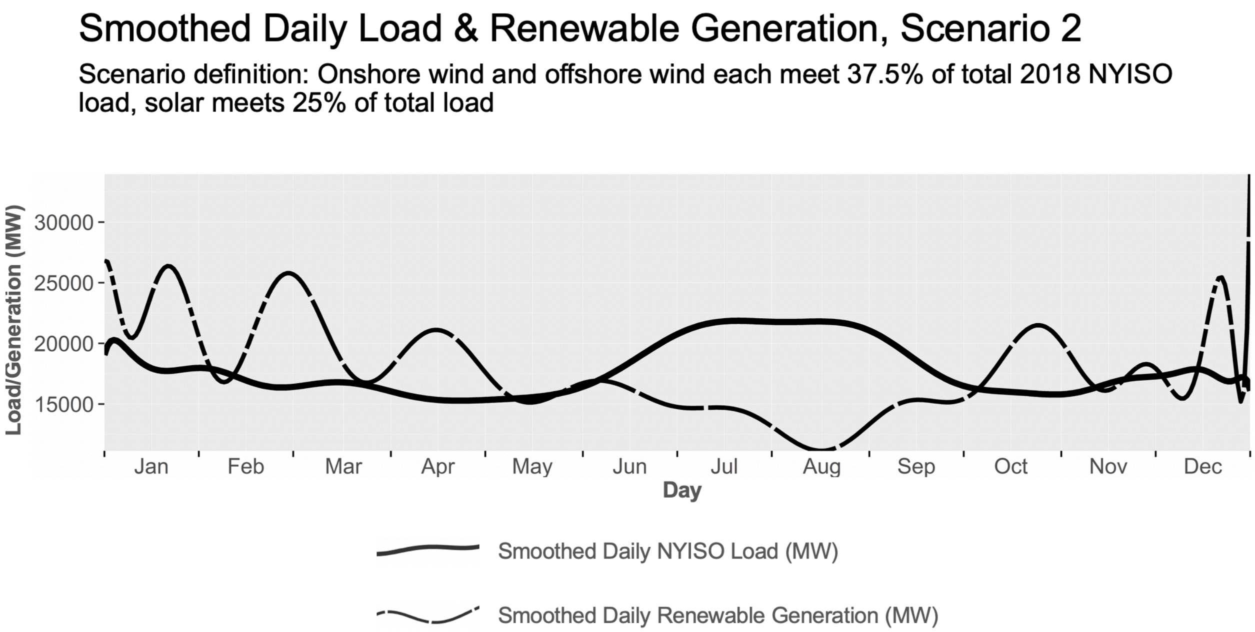



Figure 4

What happens when we combine wind and solar output to equal 100% of New York electric demand on an annual basis, and contrast it to actual demand in each day, week and month? Assuming that we have a 75% wind/25% sun system, we get a pattern like Figure 5 below:




As you can see, there are multiple weeks of average surplus above demand outside the summer months but a substantial three month deficit from June through September. Increasing the proportion of sun to 50% of New York demand does not substantially alleviate the seasonal deficit problem, as can be seen in Figure 6 below:

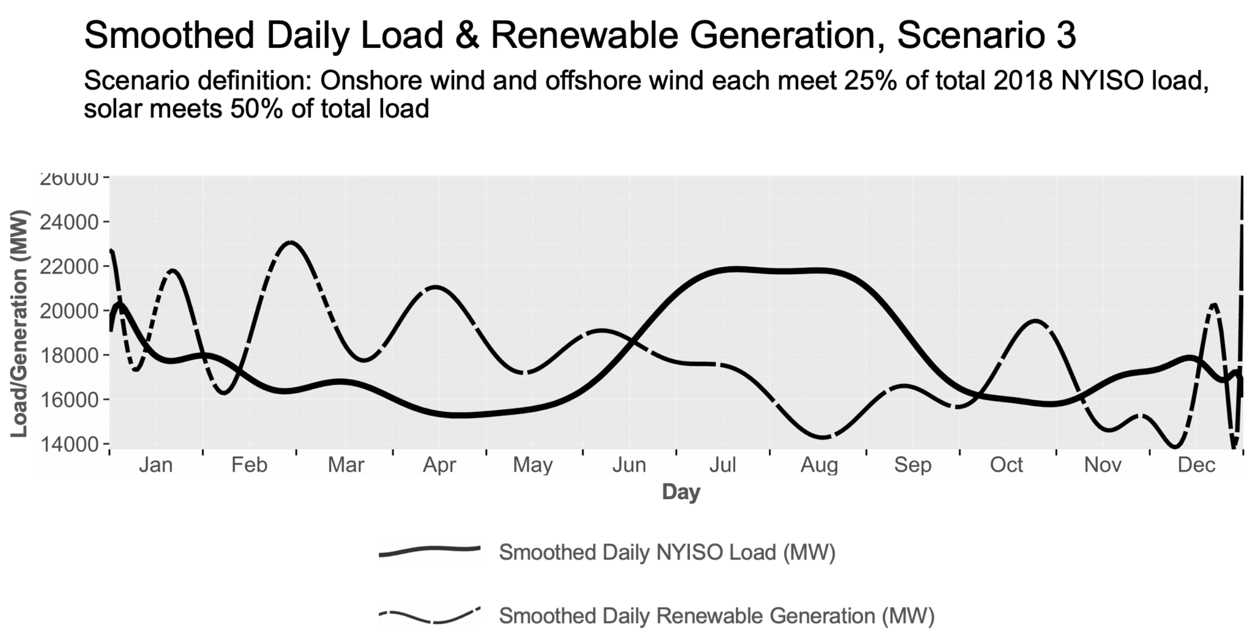



Figure 6

The consequence of this seasonal variation is that, even when New York procures enough wind and solar output to meet total electricity demand on an annual basis, ***roughly 25% of hours of the year cannot be served by wind and sun.*** This is shown in the “heat map” below, Figure 7, in which yellow, orange and red hours are unserved by variable wind and sun:

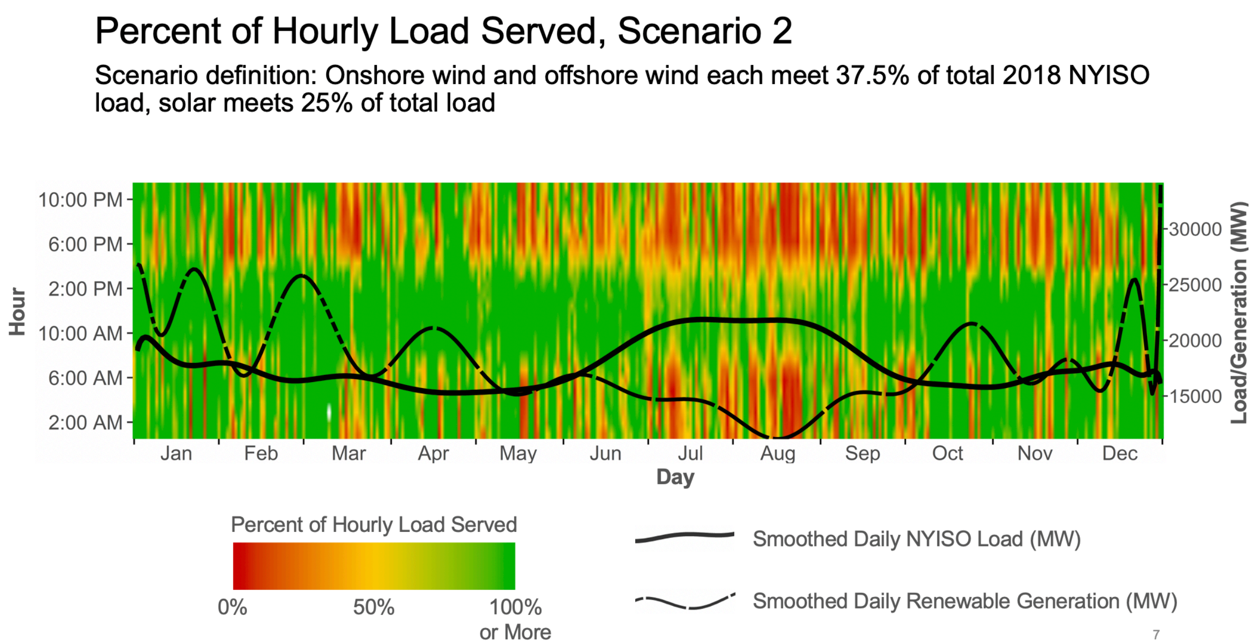



Figure 7

In theory, we could use energy storage to harvest surpluses and use them in deficit periods. But this is where cost comes in. The sheer amount of storage that must be built to capture maximum surplus, and then used at a fraction of its capacity, becomes cost prohibitive, even at very low storage costs.

In Figure 8, we see that the accumulated surplus during the year equals 31,681,809 MWh, or roughly 20% of the state’s annual electric usage:

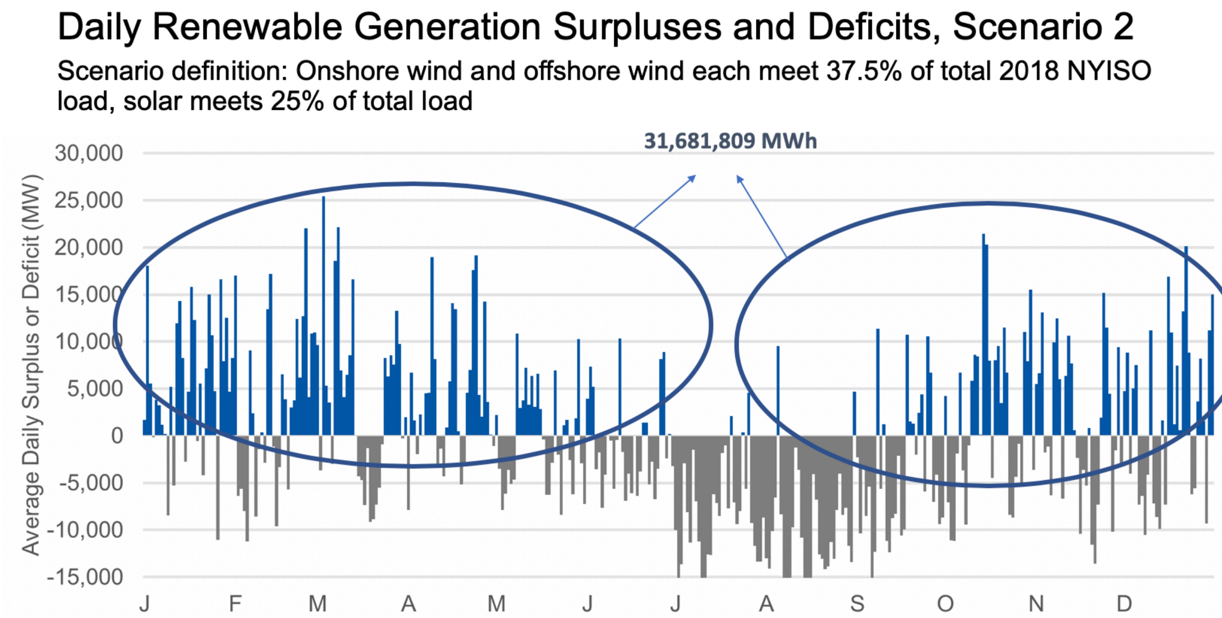



Figure 8

Storing that energy will first of all incur a very large capital expense. The US Department of Energy estimates the current cost of grid scale energy storage to be just under $500/kwh of capacity.[13] Let's assume we drop that cost by 80% to $100/kwh. The total cost of such a battery storage system would be ***$3.16 trillion, or more than one hundred times New York's total annual electric bill.***

But that in some way understates the problem, because this storage capacity would be used at a very low rate – about 1% of capacity in an average year. That is because only a small amount of the storage capacity would be used regularly to balance daily variations in solar and wind output. Most of the storage capacity would need to be built to store peak seasonal surplus and thus only cycle seasonally. That means large capacity divided by little use, resulting in very large per unit costs for stored energy.

An analysis of a similar surplus and deficit problem in California, depicted in Figure 9 below, shows that the escalating costs of storage per unit output required, as wind and sun percentages become higher, drive very large system cost increases of roughly

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[13] US EIA, "U.S. Battery Storage Market Trends "(May 2018) https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage.pdf

tenfold as wind and sun go from 50% of total supply to 80%, and roughly thirty-fold as wind and sun provide all system energy. In the California analysis, these costs translate into a cost per ton of CO2 reduction of $3,300 at 80% wind and sun, and $16,000 at 100% wind and sun.

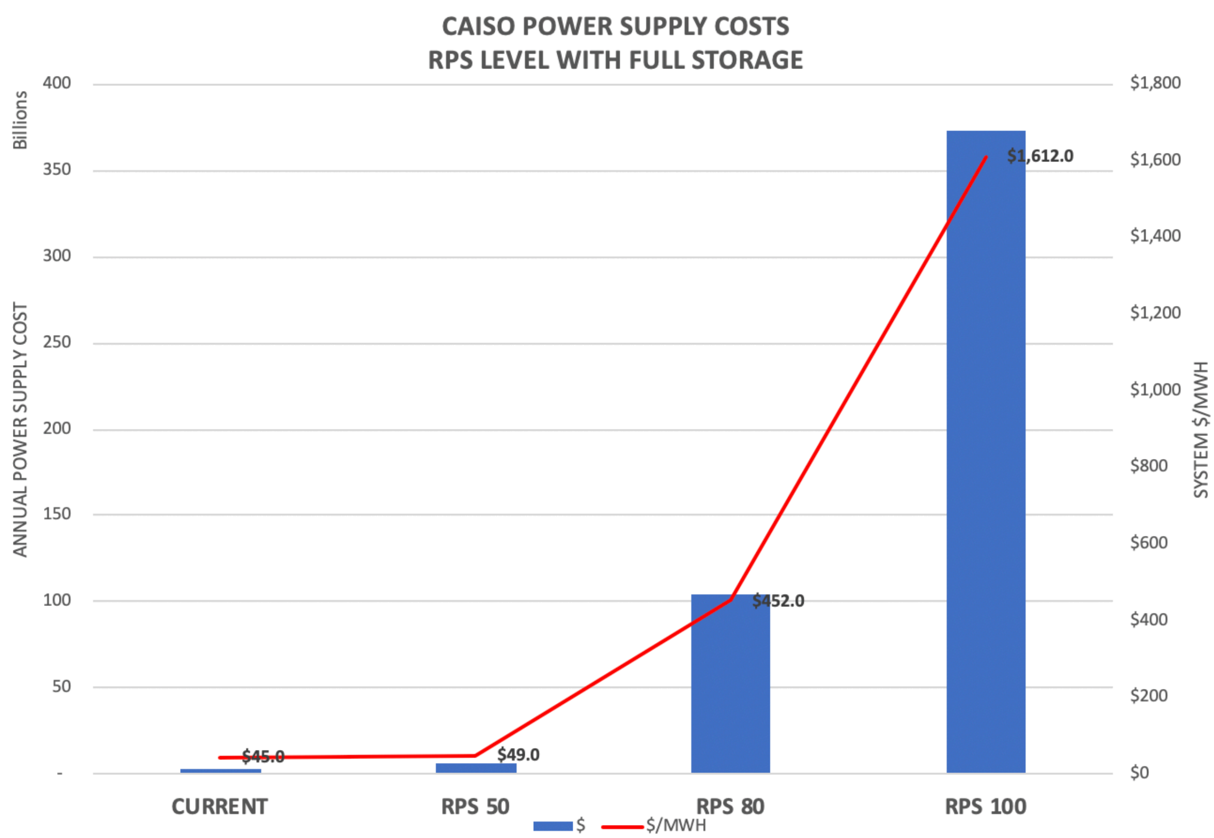
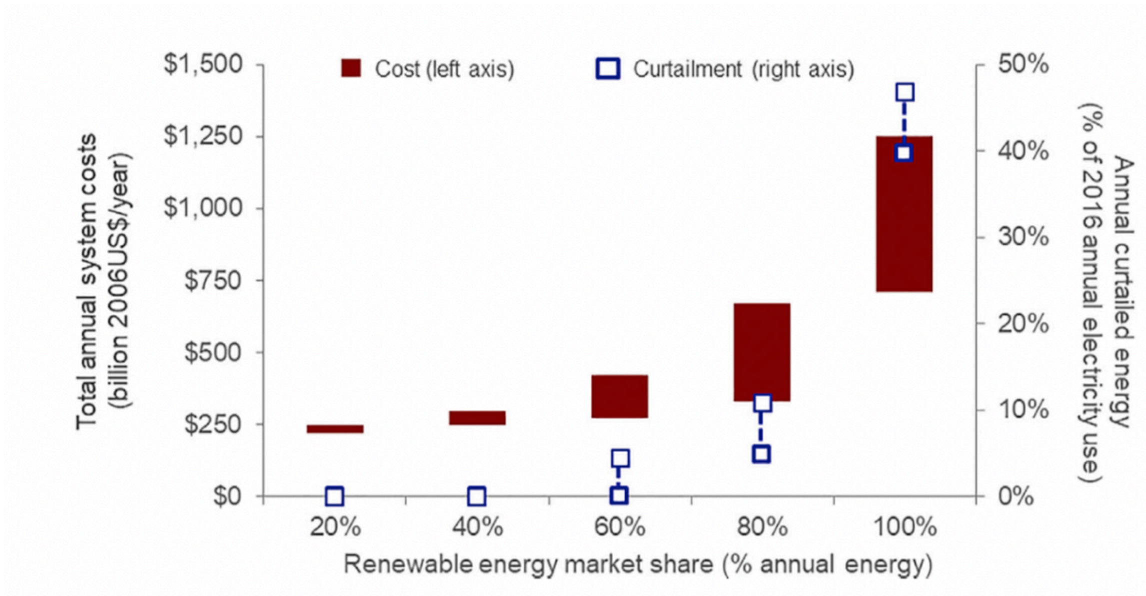



Figure 9. Source: Clean Air Task Force calculated from CAISO data

A similar cost escalation pattern has been seen in national studies, such as a recent one conducted by National Renewable Energy Laboratory analyst Bethany Frew, which assumed a transcontinental electric grid and optimal demand response mechanisms (see Figure 10 below):




Jenkins et al., Getting to Zero Carbon Emissions in the Electric Power Sector, Joule (2018), https://doi.org/ 10.1016/j.joule.2018.11.013, adapted from Frew, Bethany A., Jacobson, M. et al. "Flexibility mechanisms and pathways to a highly renewable US electricity future." *Energy* 101 (2016): 65-78.

Figure 10

None of this is to gainsay a substantial role – likely greater than 50% – for wind and solar energy in cost-effectively achieving the electric system portion of the S. 2992 challenge. And it is always possible that technological breakthroughs could occur that would make it possible to increase the percentage of economically affordable wind and solar to very high levels.[14] But at this stage CATF believes it would be bad public policy to ***assume*** such breakthroughs will occur in time to make a difference.

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[14] It is sometimes argued that "demand response," that is, the ability to curtail customer load, will alleviate the surplus and deficit problems outlined in this testimony. And, today, NYISO reports that it has in place 1,237 MW of load reduction capacity — representing 4.2% of the 2017 summer peak demand. See NYISO, Power Trends 2018, p. 19 https://www.nyiso.com/documents/20142/2223020/2018-Power-Trends.pdf/4cd3a2a6-838a-bb54-f631-8982a7bdfa7a But these agreements are generally understood to require interruptions for a few hours a few times a year. By contrast, as Figure 4 demonstrates, 100% wind and solar scenarios produce power deficits equal to as much as 36% of peak demand ***over weeks and months***. It is not likely that New York businesses, industries and consumers would effectively agree to seasonal curtailments, or that this would be good for the New York economy if they did.

It also may be argued that interconnection of New York to other control areas will alleviate the surplus and deficit problem. While greater interconnections can help at the margins, we must assume that other regions will be pursuing similar levels of decarbonization and are likely to adopt similar levels of variable energy. And wind and solar tends to be highly correlated on a daily and weekly across the nation. As a

The unavoidable fact is that there are real risks with all single technological pathways to zero carbon.  Nuclear energy, while comprising the vast majority of the nation's zero carbon energy today, has recently experienced cost overruns in the building of new first of a kind U.S. plants, and continues to face public concern around waste disposal and safety. The use of natural gas with carbon capture and storage to generate power, although based on well-demonstrated technologies, will likely face challenges from those opposed to the use of any fossil fuels as a matter of principle. And a large build-out of wind and solar energy capacity, along the substantial increase in transmission capacity that would be necessary to serve a wind- and sun-dominated system, may well face substantial and well organized opposition which has already emerged around relatively small scale proposals.[15] Hard trade-offs may be required.

No one knows yet what an economically and practically feasible zero carbon grid in 2050 will look like in New York State. S. 2992 wisely leaves this decision to a multi-agency process informed by expert input, iterated over time, and evolving markets and technology. CATF urges you to follow the example of California and Massachusetts[16] and continue to allow many paths to remain open to offer the greatest chance of success towards the ultimate goal of a zero carbon electric system.

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result, even with seamless national interconnection, as is assumed in the study referenced in Figure 10, substantial surplus and deficit problems are experienced at very high levels of wind and solar, with the resulting cost impacts shown in the figure.

[15] See. e,g. https://www.cbsnews.com/news/new-york-wind-turbines-face-uphill-battle/ and https://friendsofmainesmountains.org/?category=Anti-Wind+Groups

[16] See CA S.B. 100 (mandates a zero carbon grid by 2045 in California, with a 60% renewable energy share), https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB100; and Massachusetts Clean Energy Standard, requiring 80% of power generation to be carbon free, with legislature subsequently requiring 60% to be supplied by renewable energy, see https://acadiacenter.org/wp-content/uploads/2018/08/Acadia-Center-Summary-of-2018-Clean-Energy-Legislation-in-MA.pdf

## Appendix 1: Methodology for NYISO Figures in Testimony

Prepared by Max Luke, NERA Economic Consulting, for the Clean Air Task Force

We obtained hourly electrical load data for the New York Independent System Operator (NYISO) region for the year 2018, from the NYISO webite.[17] We simulated hourly electricity generation data for wind (onshore and offshore) and solar photovoltaic units using National Renewable Energy Laboratory (NREL) System Advisor Model (SAM)[18] in the following manner:

- For onshore wind, we simulated five wind farms in geographically diverse counties that span the state (Chautauqua, Delaware, Lewis, Tompkins, and Wyoming). The capacities of the wind farms sum to the actual capacity of existing and in-progress wind projects in New York (about 3,538 MW[19]).
- For offshore wind, we simulated a single wind farm in the Equinor Lease Area 20 miles south of Long Island (east of the Rockaways), in which Equinor plans to build an offshore wind farm.[20] We simulated a wind farm with a capacity of 1 GW, an upper estimate of the capacity of the wind farm that could be built there.
- For solar photovoltaic, we simulated eight solar arrays in geographically diverse counties that have higher-than-average per-capita installed capacities of solar (Dutchess, Franklin, Jefferson, Onondaga, Orange, Suffolk, Westchester, and Wyoming). The capacities of the solar arrays sum to the actual capacity of existing and in-progress solar projects in New York (about 1,160 MW[21]).

We loaded the hourly data into R programming language. We developed three hypothetical scenarios where renewable energy meets 100 percent of NYISO's total annual 2018 load. Our scenarios are:

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[17] https://www.nyiso.com/custom-reports
[18] https://sam.nrel.gov/
[19] https://data.ny.gov/Energy-Environment/Wind-Energy-Projects-Beginning-2004/jmxa-iz8m
[20] https://www.equinor.com/en/what-we-do/empirewind.html
[21] https://data.ny.gov/Energy-Environment/Solar-Electric-Programs-Reported-by-NYSERDA-Beginn/3x8r-34rs

1. Wind only: onshore wind and offshore wind each meet 50% of total 2018 NYISO load
2. Mixed renewable, wind heavy: onshore wind and offshore wind each meet 37.5% of total 2018 NYISO load, solar meets 25% of total load
3. Mixed renewable, solar heavy: onshore wind and offshore wind each meet 25% of total 2018 NYISO load, solar meets 50% of total load

In each scenario, we scale renewable energy generation so total annual renewable energy generation exactly meets total annual NYISO load. Hourly wind and solar generation scale in proportion to their hourly output in 2018. For example, if in a given scenario wind meets a total demand of 10 MWh in two hours, and its actual generation in PNM during those two hours were 1 MWh and 3 MWh, its generation in the two scenario hours are 2.5 MWh and 7.5 MWh. In other words, for each scenario and each hour *h*, renewable energy output equals actual output of the renewable resource in hour *h*, times the ratio of the total annual demand and total annual actual renewable energy output.

We use R programming language, and a related programming package "ggplot2," to create heat maps that show the percent of NYISO load met by renewable resources in each hour of every day of 2018, in each 100 percent renewable energy scenario. We also use R and ggplot2 to plot time series' of daily average NYISO loads and renewable energy output in each 100 percent renewable energy scenario. Additionally, we use R and ggplot2 to plot time series' of smoothed daily average PNM loads and renewable energy output in each 100 percent renewable energy scenario. We smooth daily average time series' with least squares smoothing (i.e., fitting polynomials to daily average time series'). Smoothed time series' conceal more drastic variation in daily and hourly time series'. Finally, we plot daily average energy surpluses and deficits in each scenario.