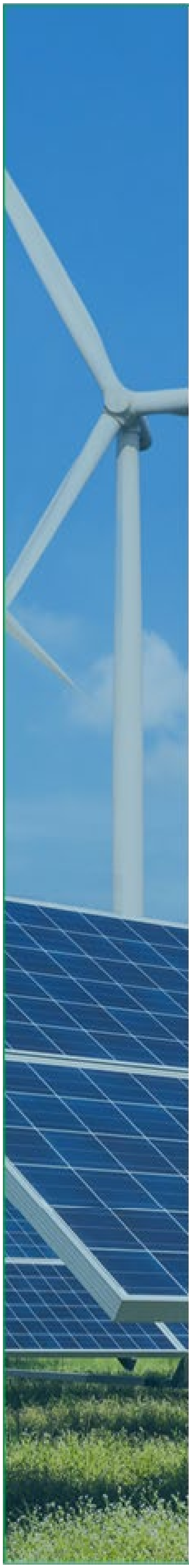


New York ISO
Independent System Operator

Appendix F: Dispatchable Emission-Free Resources

2023-2042 System & Resource Outlook

A Report from the New York Independent System Operator

July 22, 2024

Appendix F: Dispatchable Emission-Free Resources

Overview

Numerous studies have shown that a system comprised of intermittent renewable energy resources and short-duration storage (*i.e.* 4 and 8-hour capacity duration) that cycle daily can economically meet demand in most hours across a year. However, due to the seasonal mismatch in electricity demand and weather dependent production from wind and solar resources, there remains a significant amount of energy that must be shifted from the low net load intervals of the spring and fall seasons to the peak load times during the summer and winter months, as discussed in Appendix E: Renewable Profiles and Variability. Advances in technological, economic, and modeling approaches are needed to better quantify and characterize the seasonal energy gap that remains to be served after the coordinated economic dispatch of renewables and storage resources. The NYISO seeks to improve the representation of this fleet segment in each of its successive study, while understanding that characterization of emerging technology implementation pathways can introduce its own uncertainty into the model. The NYISO continues to recognize that there is a need for supply beyond renewables and storage resources that can provide dependability supply during the summer and winter peak periods and when the output of renewable resources is low.

In 2020, the NYISO introduced the concept of dispatchable emission-free resources (DEFRs) in the second phase of the NYISO Climate Impact Study.[1] That study showed an initial long-term need of 32 GW of DEFRs to serve unmet winter load under electrification scenarios due to the mismatch in renewable generation output and expected demand. In that study, the DEFRs served the role of an energy adequate resource that provides important essential reliability characteristics, such as dispatchability and ramping capability, allowing it to fill in for times when renewable energy output is below demand.

In general, the class of resources termed DEFRs currently does not exist as a single specific commercially viable technology option today. Several options are in various phases of research and development in an effort to become a viable, scalable resource in the electricity market. Various technologies have been highlighted as potential DEFR options. Some of the potential DEFR options have similar reliability attributes to retiring fossil-fuel generators but have the added benefit of being able to perform these various services without creating emissions. The Outlook has incorporated the DEFR concept into its evaluation of the Policy Case for further consideration.

[1] https://www.nyiso.com/documents/20142/16884550/NYISO-Climate-Impact-Study-Phase-2-Report.pdf

Technologies

While DEFRs represent a broad range of potential options for future supply resources, two technology pathways being discussed as potential options for commercialization are: 1) utilization of low- or zero-carbon intensity hydrogen (typically generated by electrolysis derived from renewable generation) in new or retrofit combustion turbine or fuel cell applications or 2) advanced small modular nuclear reactors, which are currently seeking approval from the relevant regulatory bodies to design and operate these resources. Currently, both technologies have shown limited commercial viability on the proof of concept. Even assuming that they are commercially viable, there remains significant work in the implementation and logistics that must be overcome to economically justify transitioning the dispatchable fleet to some combination of new technologies in the next 15 years. Long-duration energy storage could potentially serve in the role of the modeled DEFRs in the Outlook. In many respects, long-duration energy storage closely mimics various hydrogen production and conversion pathways. Long-duration energy storage adds to load in many hours, similar to electrolysis production of hydrogen. However, a notable difference is that electrolysis production of hydrogen has a lower round-trip efficiency when injecting energy into the system compared to other long duration energy storage technologies under development.

In the 2023-2032 Comprehensive Reliability Plan,[2] the NYISO looked at a range of potential DEFR technologies and shared preliminary observations on the possibility that these resources could contribute to the essential services or attributes necessary to maintain reliable operations throughout the grid's transition. Understanding that many aspects of these technologies are currently unknown and their capabilities and characteristics could change as more experience is gained, there is no standout leader among the options. Rather, it seems more likely that a combination of resources and approaches will be needed to serve the role of the DEFR fleet. In recognition of this uncertainty, the NYISO has again, in this Outlook, modeled several generic DEFRs to represent the range of potential capital and operating costs. In particular, the Low Capital/High Operating cost (LcHo) and High Capital/Low Operating cost (HcLo) DEFRs modeled in this Outlook are informed primarily by hydrogen and nuclear technologies, respectively.

Hydrogen, while the most abundant element in the universe, is also one of the most difficult substances to work with, including, among other things, for the production of energy. Hydrogen serves as an energy storage medium via the additional energy available when the diatomic gas' bonds are broken during combustion or electrochemical conversion. Hydrogen gas (H_2) is produced

[2] https://www.nyiso.com/documents/20142/2248481/2023-2032-Comprehensive-Reliability-Plan.pdf

by splitting water using zero-emissions electricity generation through electrolysis. The H_2 product must then be transported and stored until its eventual use. However, due to the conversion losses in the "round trip" from MWh to H_2 and back to MWh, the round-trip efficiency of this pathway is below 33% (and even more likely below 25%). Therefore, to get one MWh out of hydrogen, an additional 2 to 3 MWh would be lost.[3]

Despite its lower round-trip efficiency, one potential application for hydrogen is to reduce emissions in hard-to-electrify end-use applications, such as long-haul trucking, maritime transport, and aviation. Based on its availability for these end-use applications, hydrogen may have the potential to serve a limited role in the power sector as well. Regardless of the ultimate end use of the hydrogen, be it for power generation or in other sectors, the transport and storage of hydrogen also represent significant logistical challenges to the implementation of these technology options.

Multiple designs for small modular reactors (SMRs) are currently in development. Some are improved designs based on the standard technology used in operational large-scale, base-load nuclear power plants, which have been proven to be safe and effective. Others are based on alternative approaches, such as molten salt reactors. Some designs are built to slowly fluctuate generation throughout the day by adjusting control rods and, therefore, are advantageous for smoothing the net load. For instance, the ability to fluctuate the output helps to counteract the mid-day reduction in net load with high penetration of solar resources or helps to serve load during longer duration low wind events. Other designs allow the generation to follow minute-to-minute dispatch signals by either dumping a portion of steam to the condenser and bypassing the turbine or by using a dispatchable, behind-the-meter load to adjust the power sent to the grid.

Capital & Operating Costs

Assumptions on capital and operating costs for the DEFR fleet were required for the models in this Outlook to optimize candidate resource buildout and dispatch. With potential DEFR technologies still in development, the NYISO does not have any historical cost data to reference. For this reason, the NYISO examined an array of studies and created cost assumptions based on the aggregate findings from these studies. The NYISO used the EIA 2023 Annual Energy Outlook,[4] NYSERDA's Integration Analysis,[5] the 2021-2025 Demand Curve Reset,[6] the Grid in Evolution

[3] https://www.esig.energy/how-feasible-is-green-hydrogen-some-back-of-the-envelope-calculations/

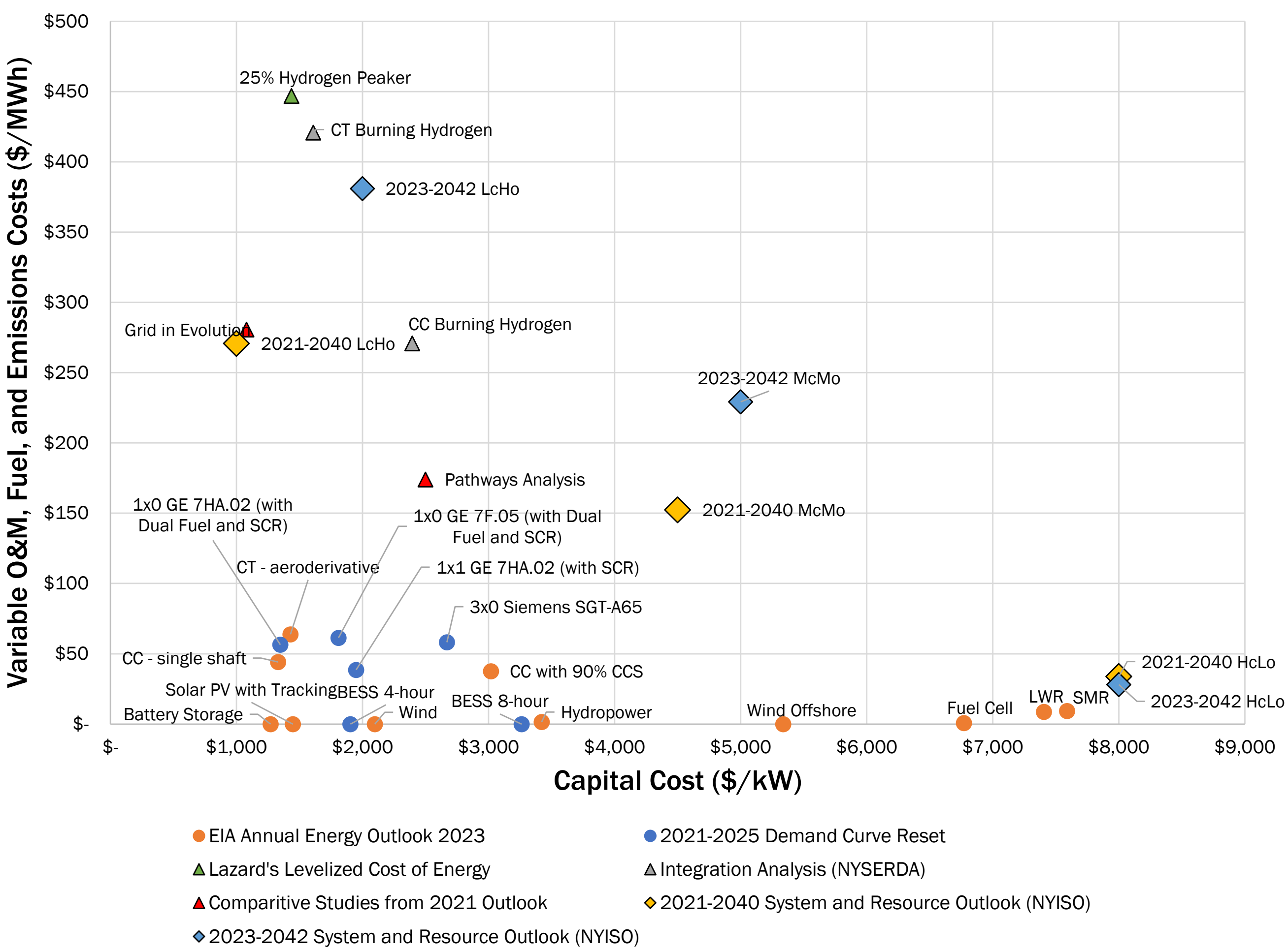
[4] EIA Annual Energy Outlook 2023

[5] Integration Analysis

[6] NYISO's 2021-2025 Demand Curve Reset

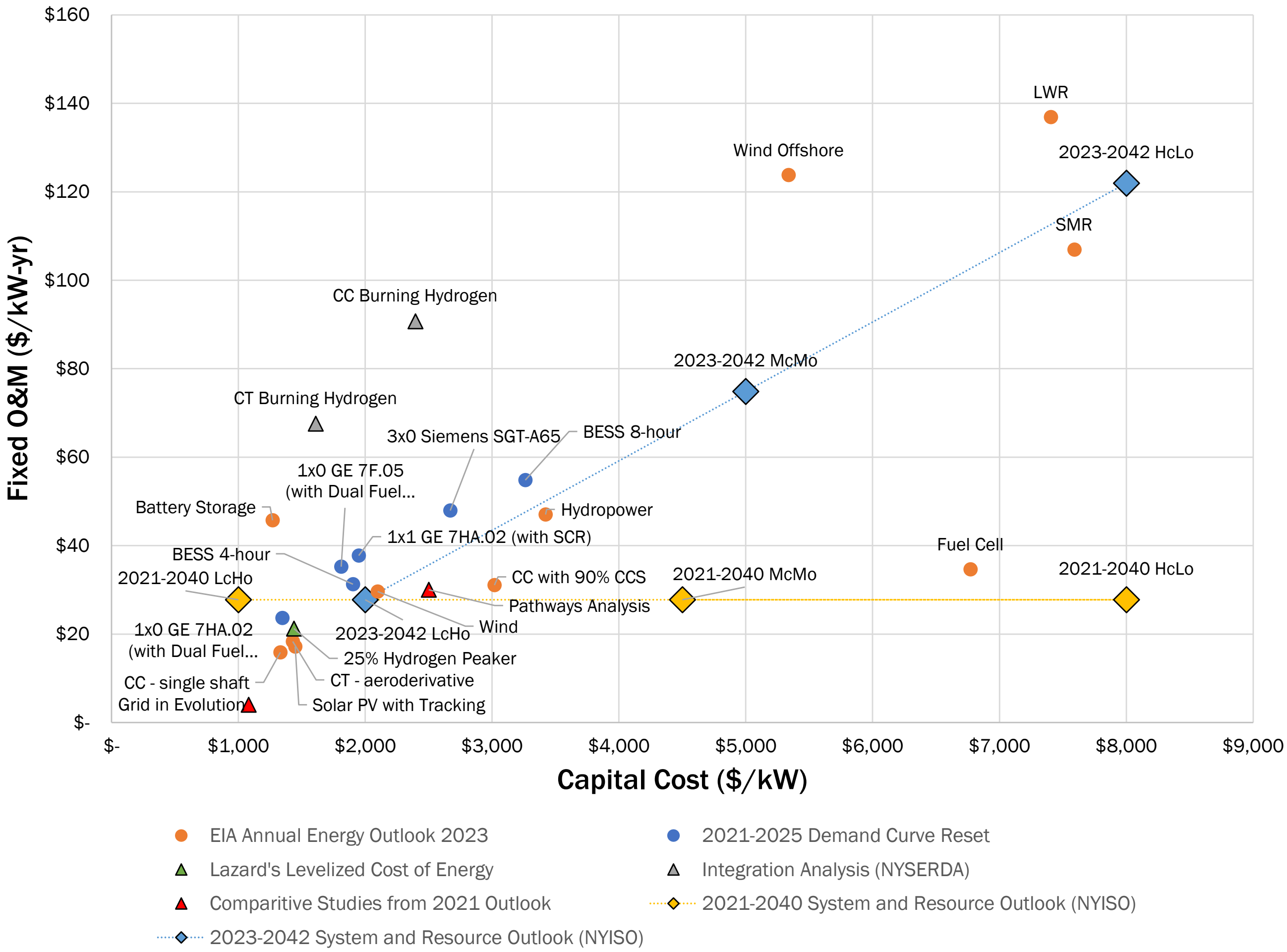
Study,[7] the Pathways Analysis,[8] and Lazard's Levelized Cost of Energy[9] to inform its assumptions for this Outlook. The two figures below compare the costs of various technologies based on the aforementioned studies. In addition, for comparison, the values used in the 2021-2040 Outlook are also presented.

Figure F-1: Generator Capital Cost vs. Variable Operating & Maintenance, Fuel, and Emissions Costs



7 New York's Evolution to a Zero Emission Power System
8 Pathways to Deep Decarbonization in New York State
9 Lazard's Levelized Cost of Energy

Figure F-2: Generator Capital Cost vs Fixed Operating & Maintenance Costs



The base cost assumptions used in the Outlook are shown in Figure F-3 below with resources in Zones G-K applying cost multipliers to model the increased expense of building and operating in the downstate regions as compared to upstate regions. Figure F-4 shows the zonal cost multipliers assumed in this Outlook.

Figure F-3: Summary of Candidate DEFR Resource Costs

Candidate DEFR Generator	Capital Cost ($/kW)	Variable Operating & Maintenance Cost ($/MWh)	Fixed Operating & Maintenance Cost ($/kW-yr)
Low Capital High Operating (LcHo)	2,000	16	28
Medium Capital Medium Operating (McMo)	5,000	9	75
High Capital Low Operating (HcLo)	8,000	2	122

Figure F-4: Zonal Cost Multipliers for DEFR Resource Costs

Zone	A	B	C	D	E	F	G	H	I	J	K
Cost Multiplier	100%	100%	100%	100%	100%	100%	114%	114%	114%	139%	130%

DEFR Cost Considerations

It is important to note that since DEFRs are a developing technology, the first units built will likely be more expensive compared to similar DEFRs built thereafter. For instance, a first-of-a-kind DEFR must incur design costs, validate construction approaches, and establish the required supply chain for fabrication that would not have to be incurred in subsequent deployments. This Outlook's assumed capital costs are intended to represent costs for repeated deployments of a technology (Nth-of-a-kind costs), and first-of-a-kind costs are not explicitly included as assumed cost components in this study. As a result, the costs for DEFRs in this Outlook are likely to be below the actual costs of the first DEFRs built on the system. SMRs are also a developing technology and therefore, have varying approaches to their design. Some designs employ cost-mitigation strategies. Unlike most large-scale nuclear units, which have many "one-off" features that are specific to each plant, SMRs have the potential of reducing cost through the development and use of uniform designs. Uniformity of SMR design may also improve manufacturing efficiency by constructing the units and parts at a factory and then shipping them for onsite assembly.

These strategies assist with capital costs, but SMR capital costs are still expected to be high in comparison to other technologies. Like large-scale nuclear power plants, SMRs can mitigate the risk of high capital costs with lower operating costs and operating with high utilization rates. In other words, it is optimal for an SMR to consistently operate at 100% power to take advantage of its low operating cost. This has the potential to conflict with the notion of DEFRs being used for their ability to dispatch up and down based on variability in the load. The disconnect between a DEFR's purpose and an SMR can be bridged by pairing the reactor with a behind-the-meter, dispatchable load. The SMR can remain at 100% power, while the behind-the-meter load dispatches up or down to effectively fluctuate the injection onto the grid, as needed.

Hydrogen-burning combustion turbines or combined cycle units have effective cost mitigation strategies as well. To minimize hydrogen transport costs, the electrolyzer can be sited at the same facility as the resource. This eliminates the need for using an expensive hydrogen pipeline to import the hydrogen from elsewhere in state or even out of state. Additionally, as fossil fuel burning combustion turbines and combined cycle units retire, their assets can be repurposed and retrofit to burn hydrogen as a fuel instead. This has the potential to be less expensive than building a brandnew resource since many elements of the combustion turbine or combined cycle power plants can be reused with limited modification.

Operating Parameters

The NYISO assumed a heat rate of 10,447 Btu/kWh for High Capital/Low Operating cost DEFRs, which is similar to the heat rate of a large-scale nuclear power plant. The NYISO also assumed a heat rate of 9,124 Btu/kWh for LcHo DEFRs, which is similar to the heat rate of a new combustion turbine. The NYISO applied a heat rate of 9,786 Btu/kWh for Medium Capital/Medium Operating cost DEFRs, which is the average of the assumed HcLo and LcHo DEFR values.

Since future DEFR technologies are currently in development, there is the potential that different designs are built that result in differing operational characteristics or features. For instance, some SMR designs have the capability to dispatch up and down as load varies minute-to-minute by redirecting steam from the turbine to the condenser or to another industrial process, such as hydrogen production or district heating. This method enables quicker ramp rates and, therefore, is useful for tracking minute-to-minute fluctuations in net load or variable wind turbine output. Conversely, appropriately designed SMRs could employ the method of daily control rod manipulation to adapt to predictable diurnal profiles in net load and solar generation. Other SMRs, which are not dispatchable themselves, can be tied to a co-located dispatchable battery that can offset the amount of energy injected onto the system.

Another interesting potential operational feature of certain SMR designs is the ability to refuel while remaining online. Traditional nuclear technology employed in the United States requires the unit to go offline for a refueling outage every 18-24 months depending on the reactor type. In recent history, these refueling outage durations have lasted about a month. The capability to remain online during refueling increases the number of days the power plant is available to support the grid.