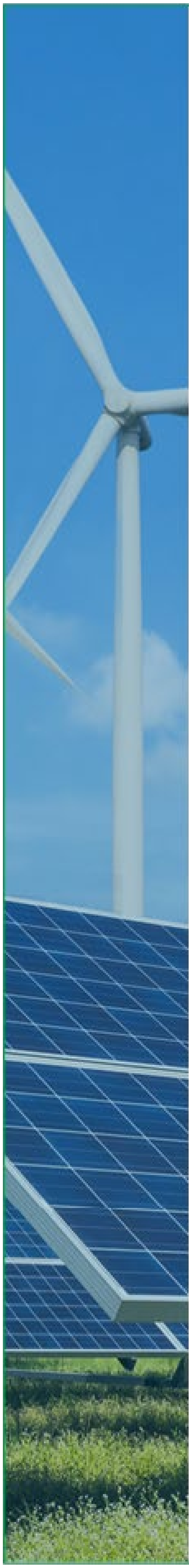


New York ISO
Independent System Operator

Appendix []: Dispatchable Emission Free Resources

2023-2042 System & Resource Outlook

A Report from the New York Independent System Operator

DRAFT for May 14 2024, ESPWG

Appendix []: Dispatchable Emission Free Resources (DEFRs)

Overview

Numerous studies have shown that a system comprised of intermittent renewable energy generators and short-duration storage (*i.e.* 4—8 hour capacity) 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 generators, 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. 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 representation of this fleet segment in each study performed understanding that characterization of non-extant technology implementation pathways can introduce its own uncertainty into the model.

The NYISO introduced the concept of Dispatchable Emission Free Resources (DEFRs) in 2020 in the second phase of the NYISO Climate Study.[1] That study showed an initial 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 general, the class of resources termed DEFRs currently does not exist as a single specific commercially viable technology option today and may be in various phases of traversing the path from research and development to becoming a viable, scalable market resource. Various technologies have been highlighted as potential DEFR options. Such DEFR options have similar reliability attributes to the retiring fossil fuel-fired generator fleet but have the added benefit of being able to perform these various services without creating emissions.

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 generators). Currently, both technologies have shown limited commercial viability of the proof of concept. Even assuming that they are

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

commercially viable, there remains significant work in 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 the role of the modeled DEFRs in the Outlook. In many respects, long-duration energy storage closely mimics hydrogen facilities because hydrogen units add to load in many hours due to electrolysis production of hydrogen but then has a lower round-trip efficiency when injecting energy into the system.

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 transition. Understanding that many aspects of these technologies are unknown and their capabilities and characteristics could change as more experience is gained, there is no standout leader in the group. Rather, it seems more likely that a combination of resources and approaches will be needed to serve the role of the DEFR fleet.

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's bonds are broken during combustion or electrochemical conversion. Produced by splitting water using zero-emissions electricity generation through electrolysis, the hydrogen gas (H_2) must be transported and stored until its eventual use. However, consideration of conversion losses in the round trip from MWh to H_2 and back to MWh bound the round-trip efficiency of this pathway below 33% and place it more likely below 25%. Therefore, to get one MWh out of this process an additional 2 to 3 MWh will be lost during the process.[3] 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 be a potential option in the power sector as well.

Multiple designs for small modular reactors are currently in development. Some are improved designs based on the standard technology used in operational large scale 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

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

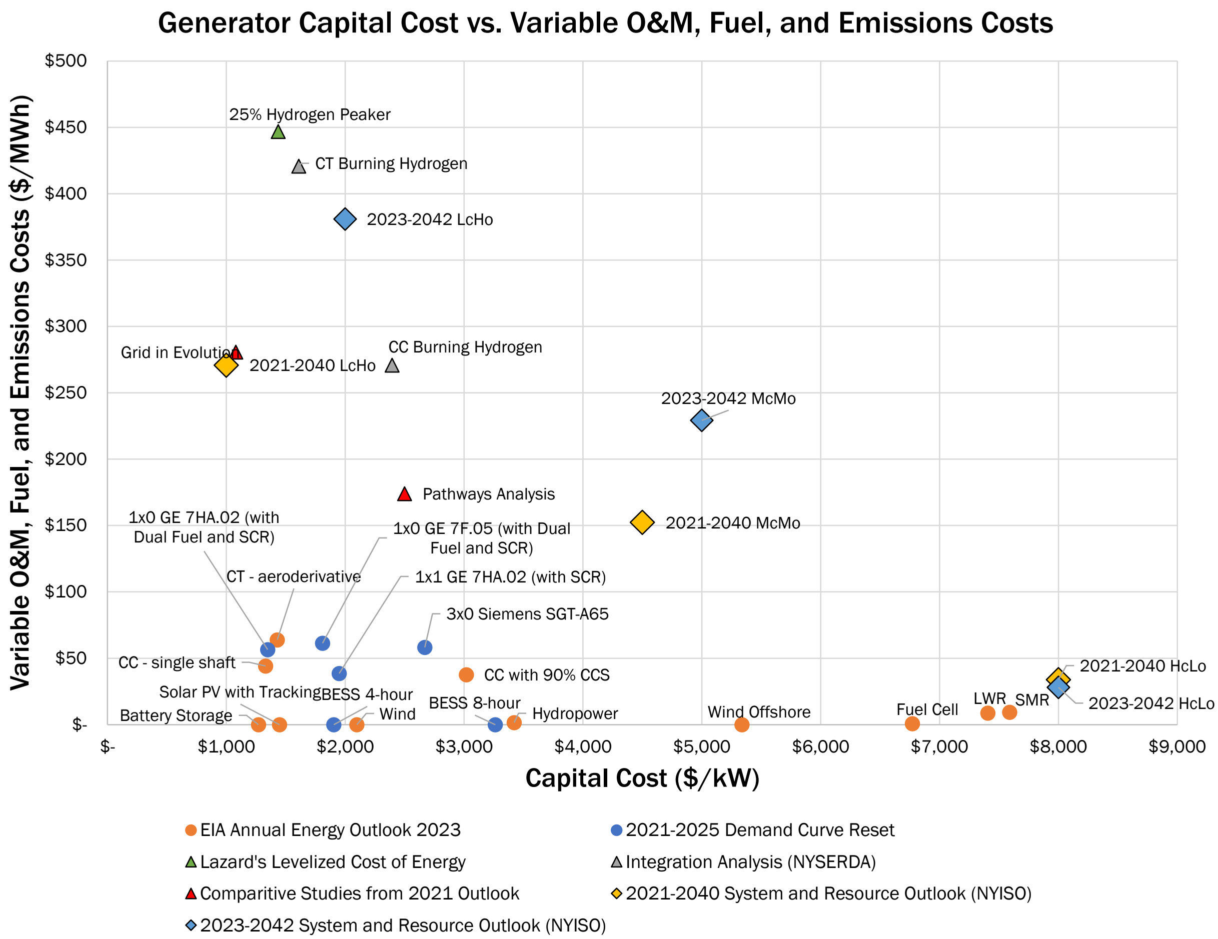
[3] How Feasible Is Green Hydrogen? Some Back-of-the-Envelope Calculations - ESIG

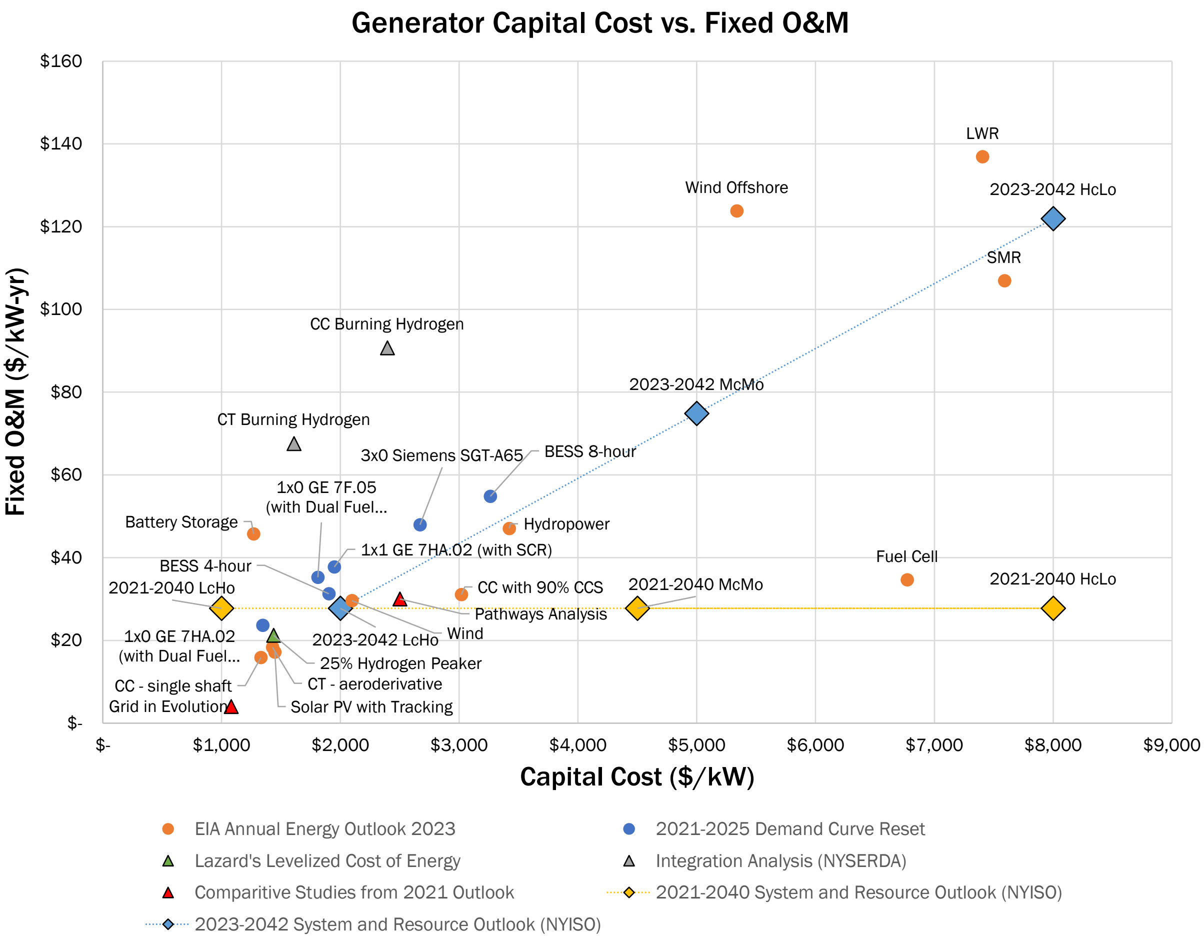
adjusting control rods and, therefore, are advantageous for smoothing the net load. For instance, the ability to fluctuate the output helps to counteract the duck curve with high penetration solar or helps to serve load during longer duration low wind events. Other designs allow the generation to follow 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 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 Study,[7] the Pathways Analysis,[8] and Lazard's Levelized Cost of Energy.[9] The two figures below compare the costs of various technologies based on the aforementioned studies.

4 EIA Annual Energy Outlook 2023
5 Integration Analysis
6 NYISO's 2021-2025 Demand Curve Reset
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


Generator Capital Cost vs. Variable O&M, Fuel, and Emissions Costs
Variable O&M, Fuel, and Emissions Costs ($/MWh)
Capital Cost ($/kW)
$500
$450
$400
$350
$300
$250
$200
$150
$100
$50
$-
$1,000
$2,000
$3,000
$4,000
$5,000
$6,000
$7,000
$8,000
$9,000
25% Hydrogen Peaker
CT Burning Hydrogen
2023-2042 LcHo
Grid in Evolution
2021-2040 LcHo
CC Burning Hydrogen
2023-2042 McMo
Pathways Analysis
1x0 GE 7HA.02 (with Dual Fuel and SCR)
1x0 GE 7F.05 (with Dual Fuel and SCR)
2021-2040 McMo
CT - aeroderivative
1x1 GE 7HA.02 (with SCR)
3x0 Siemens SGT-A65
CC - single shaft
CC with 90% CCS
2021-2040 HcLo
Solar PV with Tracking
BESS 4-hour
BESS 8-hour
Battery Storage
Wind
Hydropower
Wind Offshore
Fuel Cell
LWR
SMR
2023-2042 HcLo
EIA Annual Energy Outlook 2023
2021-2025 Demand Curve Reset
Lazard's Levelized Cost of Energy
Integration Analysis (NYSERDA)
Comparitive Studies from 2021 Outlook
2021-2040 System and Resource Outlook (NYISO)
2023-2042 System and Resource Outlook (NYISO)



The base cost assumptions used in the Outlook are shown in the figure 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.

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

Operating Parameters

Given the hourly resolution of both the capacity expansion and production cost models, neither model captures sub-hourly ramping characteristics of DEFRs. The NYISO used a flat heat rate of 10,447 Btu/kWh for High Capital Low Operating DEFRs, which is similar to the heat rate of a large-scale nuclear power plant. A flat a heat rate of 9,124 Btu/kWh was used for Low Capital High

Operating 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 DEFRs, which is the average of the assumed High Capital Low Operating and Low Capital High Operating values.

Operational Analysis

[This section will be filled out in future versions of this draft.]