POWER ADVISORY

Net Zero Reliability Initiative Report

Prepared for Pollution Probe

April 24, 2024

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Contents

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Purpose and Scope

- The bulk electricity system requires reliability services to maintain acceptable voltages and to achieve supply/demand balance amid system disturbances and uncertainty
  - Non-emitting resources can provide the full range of required reliability services, but they will need to be procured and operated in new ways to create a reliable net zero electricity system
  - In this report, the most common types of non-emitting resources are assessed for technical feasibility to provide each essential reliability service
  - Recommendations are presented to maximize the participation of non-emitting resources in electricity markets and procurements
- This report is not intended to address the use of non-emitting resources to defer or avoid distribution and transmission infrastructure (i.e. non-wires solutions)
  - Further actions would be needed, in addition to the recommendations presented here, to fully enable distributed energy resources to provide non-wires services and essential reliability services

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Part 1: Meeting Power System Needs

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Overview: Meeting Power System Needs

- Achieving a net zero electricity system in Ontario will require greater use of non-emitting generation, greater use of electricity storage and demand-side flexibility, and ultimately a suitable replacement for gas-fired generation
    - Techniques for planning and operating electricity systems need to evolve as new resource types (especially wind, solar, storage, and flexible demand) reach higher shares of the overall system
    - The IESO's 2022 Pathways to Decarbonization report contemplated a non-emitting resource mix, but noted that additional analysis is needed to fully understand the reliability and operability services required
- To minimize the cost of a non-emitting resource mix, the IESO's planning, procurement, and operations systems should:
    - Define appropriate products and choose the appropriate mechanisms to acquire them
    - Enable participation from all resource types technically capable of providing each product
    - Accurately assess needs and resource capabilities for each product

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Defining Essential Reliability Services and Resource Characteristics

- Reactive support and voltage control
- Black start
- Inertia and primary frequency response
- Regulation
- Operating reserve
- Ramping, flexibility, and quick start
- Capacity, duration and energy assurance

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Types of Reliability Services

- The supply and demand of active power is balanced over multiple timescales; different products and capabilities are needed to mitigate different forms of risk

Inertia and Frequency Response	Regulation	Operating Reserve, Ramping, Flexibility	Duration and Energy Assurance
Instant to less than one second	Seconds	Ten minutes to hours	Hours and days

- Reactive power is a separate product that must be managed across the transmission system
- Black start is needed only to respond to blackouts
- Some services are defined as products in the IESO-Administered Markets. Others are not formally defined

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Reactive Support and Voltage Control

- Definition
  - Reactive support is the ability of a resource to adjust the reactive power it supplies or draws from the system as needed
  - Reactive support is necessary to maintain appropriate voltage levels across the transmission system
- Acquisition
  - Reactive power can be provided by generators or by devices like static VAR compensated that are installed by the transmitter
  - Generators are required to provide a certain amount of reactive support as a condition of interconnection; this is primarily based on operating power factor ranges set out in the final System Impact Assessment (SIA) for a facility
  - In many cases, specialized devices such as static VAR compensators, reactors, and capacitors are installed to provide reactive support in areas of the transmission system with voltage stability concerns (e.g., locations with long transmission lines or limited generation resources)
  - In addition to reactive support requirements, the IESO acquires specific reactive support through bilateral contracts
  - Approximately $20 million per year of reactive support costs are recovered in the electricity market through uplift, while costs for transmitter-owned equipment is recovered through rates
- Needs
  - A shift to inverter-based resources (i.e., wind, solar, and battery storage) will require a re-assessment of reactive power needs and system capabilities; reactive support needs are determined using very complex engineering studies

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Black Start

- Definition
  - Black start is provided by resources which can start without an external power source to contribute to system restoration following a blackout
  - Resources providing black start are required to undergo regular testing and to participate in training activities (e.g., system restoration drills)
- Acquisition
  - The IESO acquires black start services from 4 generation facilities through bilateral agreements
  - Approximately $2 million per year of black start costs are recovered through uplift
- Needs
  - System restoration needs are set out in Northeast Power Coordinating Council (NPCC) Regional Reliability Reference Directory #8
  - IESO determines black start needs; the full set of black start resources much be strategically located across the province to establish a “Basic Minimum Power System” following a blackout
  - Some customers or distributors may value resources with black start capability for resilience (e.g. behind-the-meter resources acting as backup power and/or microgrids which can island during outages)

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Inertia and Primary Frequency Response

- Definition
  - Inertia is the kinetic energy stored in large rotating masses, such as those in synchronous generators. Immediately after a grid disturbance, inertia in devices that are synchronized to the system responds and resists the change in frequency due to the spinning mass accelerating from the reduction in system load
  - Primary frequency response also resists changes in frequency, but over a period typically less than a second.[1] Frequency response is provided by resources with control systems that detect local frequency and adjust power output to maintain the desired frequency
- Acquisition
  - Inertia and primary frequency response is provided automatically by synchronous generators (e.g., gas, hydro, nuclear); some inverter-based resources (wind, most storage) can be designed to provide synthetic inertia and frequency response, but this has not been fully demonstrated or enabled in Ontario
  - Neither service is specifically procured or priced in Ontario
- Needs
  - Retirement of synchronous generation could reduce the amount of inertia and frequency response on the system, particularly if this generation is replaced by inverter-based resources that are not configured to provide these services
  - However, studies conducted by system operators in the Eastern Interconnect generally do not find inertia or frequency response deficiencies, even in forward-looking low-emissions scenarios; this is primarily because of fast-frequency response capabilities of inverters to provide synthetic inertia

1. Alberta Electricity System Operator is developing a Fast Frequency Response Services procurement which requires response within 0.2 to 0.3 seconds.

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Regulation

- Definition
  - Regulation is the ability of resources to fine-tune their output on second-to-second basis. It helps to manage forecast errors and fluctuations in supply and demand within the 5-minute intervals that most resources are dispatched on. Regulation also helps to restore frequency after a system event following the inertial and primary frequency response
  - Some system operators define separate “up” and “down” regulation products, describing whether power output or consumption is increased or decreased. The IESO requires regulation providers to offer both directions
- Acquisition
  - The IESO currently acquires regulation through bilateral contracts, many of which are extensions of contracts awarded after previous competitive procurements
  - Approximately $50 million per year of regulation costs are recovered through uplift
- Needs
  - Regulation needs are determined by load profiles and forecast uncertainty. Higher shares of wind and solar on the system, addition of certain quickly-fluctuating industrial loads, or greater demand forecast uncertainty could all lead to higher regulation needs
  - IESO assessed regulation needs in the 2024 Annual Planning Outlook, forecasting regulation needs increasing 40% in 2026 and doubling by 2030
  - Many jurisdictions have open markets for regulation, but the IESO does not; this is a barrier to the development of new regulation resources

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Operating Reserve

- Definition
  - Operating reserve (OR) ensures there are adequate dispatchable resources available to replace lost capacity during a system outage (i.e. return the system supply/demand balance after an unexpected generation or transmission asset outage)
  - Operating reserve is provided when a supplier increases power output or a load decreases power consumption to respond to an imbalance. There are three OR products based on the allowable response time to provide the capacity: 10-minute spinning, 10-minute non-spinning and 30-minute response, and the capacity procured must be sustained for at least one hour
- Acquisition
  - OR is scheduled in the real-time market
  - Approximately $60 million per year of OR costs are recovered through uplift
- Needs
  - Total OR requirements are 1.5 times Ontario's single largest continency, which is most often a forced outage of an 878 MW Darlington nuclear unit
  - OR requirements are formally specified by NPCC Directory #5, which sets out required quantities of each OR product

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Ramping, Flexibility, and Quick Start

- Definition
  - There are several other products and attributes which deal with how quickly dispatchable resources can adjust their output over periods from 10 minutes to a few hours
  - Some markets define a ramping product, which ensures resources are scheduled in real-time that can adjust their output at a certain rate sufficient to handle forecasted needs, accounting for forecast uncertainty. Ramping products could in principle be defined over any length of time (e.g., 600 MW within 2 hours) and are sometimes divided into separate "up" and "down" products
  - Flexibility describes a more general capability to respond to changing conditions over longer timescales than OR. It could also mean responding quickly to a disturbance and sustaining that response for many consecutive hours (e.g., longer than 4 hours)
  - Resources with quick start capability can meet their dispatch within 5 minutes from an idle state. Gas-fired generators require a startup process which may take several hours; they are considered non-quick start
- Acquisition
  - Ramping, flexibility, and quick-start capability are not specifically procured by the IESO
  - Ontario has few simple cycle gas turbines with quick start capability; the IESO has procedures to raise the OR requirement or manually commit gas generation to provide flexibility or "spare energy"
- Needs
  - Ramping and flexibility needs are not specified by the IESO
  - With electrification-driven demand growth and increasing use of wind and solar generation, OR, ramping, and flexibility needs are expected to increase

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Capacity, Duration, and Energy Assurance

- Definitions:
  - Capacity can refer to the rated output of a power plant.
  - In the context of reliability services, Unforced Capacity (UCAP) is a fungible product defined for each resource describing its contribution to meeting resource adequacy needs. UCAP may consider rated output under various weather conditions, outage rates, historical performance, and other factors through a process called capacity accreditation
  - Duration is the length of time a resource such as a storage or hydroelectric facility can continuously provide capacity
  - Fuel and energy assurance describe how well the system can manage disruption to fuel supply (e.g. natural gas) and longer-term uncertainty in the output of weather-sensitive resources like wind, solar and hydroelectric facilities. For example, the risk of prolonged drought conditions on hydroelectric generation in Northern Ontario or the risk from multiple days of low wind output could be framed as an energy assurance need
- Acquisition
  - Capacity is acquired through the IESO's capacity auctions, IESO procurements, and bilateral contracts
  - A four-hour duration requirement is expressed in the accreditation methodology and testing requirements of the Capacity Auction and in the eligibility requirements of the IESO's E-LT1 and LT1 procurements
  - Fuel and energy assurance is not specifically acquired, but it may be considered when setting resource-specific procurement targets such as the non-storage targets in E-LT1 and LT1 procurements. IESO is also procuring bulk non-emitting energy through the LT2 procurement.

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Capacity, Duration, and Energy Assurance

- Needs:
  - Capacity and energy adequacy needs are forecasted in the IESO's Annual Planning Outlook
  - Duration and energy assurance needs are not specifically defined, nor are they fully captured in capacity and energy adequacy assessments
- Capacity need assessments are evolving to account for new technologies, emissions reduction, and emerging risks
  - Wind, solar, and storage resources have all required new methods for capacity accreditation
  - In a non-emitting resource mix, duration and energy assurance requirements become more important considerations
  - The impact of climate change on weather patterns will impact UCAP of existing resources in ways that may challenge existing resource adequacy capabilities; increasing temperatures may reduce the capability of thermal resources, and changing weather patterns can impact hydroelectric availability
  - There is increasing recognition of correlated outage risk in gas-fired generation, which may result from vulnerability to extreme weather events or the risk of interruption in natural gas supply

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Non-Emitting Resource Types

- Nuclear
- Hydroelectric
- Intermittent (Wind and Solar)
- Storage
- Demand Response
- Dispatchable Emissions-Free Resources

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Capabilities of Non-Emitting Resource Types

- Each resource type (wind, storage, nuclear, etc.) has varying capabilities to provide each reliability service
- Low-variable-cost options like solar, wind, and conventional nuclear are expected to form the bulk of non-emitting energy supply
  - However, when these resources reach a high share of the energy mix, there are periods where their energy production does not align with needs and excess energy must be curtailed
  - These resources can provide some reliability services, but they are generally unable to provide regulation and multi-hour flexibility
    - Wind and solar is limited by energy availability, while traditional nuclear technology cannot be ramped up and down as flexibly as a natural gas peaking plant
- Other options, like storage, hydroelectric, and demand flexibility can be used to provide services that wind, solar, and traditional nuclear are ill-suited for
  - The contribution of these resources may be limited by technical potential
  - These resources provide limited duration and energy assurance
- There are few non-emitting options to meet remaining reliability needs
  - Research is ongoing to improve the technical and economic feasibility of dispatchable emissions-free resources (DEFRs) like hydrogen for seasonal storage and highly-flexible next generation nuclear

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Nuclear

- Cost Structure:
  - High capital cost
  - Moderate fixed operating cost
  - Very low variable cost
  - Long lifespan (60-80 years)
- Technical Potential: Limited mainly by siting
- Main Challenges:
  - Limited modularity; typically built onsite in units of 300 to 800 MW with frequent design changes, leading to difficulty achieving cost reductions through "learning by doing"
  - High cost and long lead time, with significant cost and schedule risk
  - Limited operational flexibility
  - Cost structure encourages maximizing capacity factor, but curtailment may be needed

Reliability Service	Nuclear
Inertia and Frequency Response	Yes[1]
Regulation	No
Reactive Support and Voltage Control	Yes
Quick Start	No
OR and Flexibility	No[2]
Duration and Energy Assurance	Yes

1. Inflexible nuclear can provide inertia but not primary frequency response

2. Reactor physics puts operational limits on nuclear flexibility. Some modern nuclear designs claim to have higher flexibility than conventional nuclear.

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Wind and Solar

- Cost Structure:
  - Moderate capital cost
  - Low fixed operating cost
  - Effectively zero variable cost
  - Moderate lifespan (20 to 30 years)
- Technical Potential: Effectively unlimited
- Main Challenges:
  - Siting
    - Wind: not accepted in many populated areas; developing remote areas requires substantial transmission investment
    - Solar: land use is a concern, urban/rooftop solar mitigates this
  - Output and flexibility is limited by fuel availability
  - Cost structure encourages maximizing capacity factor, but curtailment may be needed

Reliability Service	Wind & Solar
Inertia and Frequency Response	Yes[1]
Regulation	No[2]
Reactive Support and Voltage Control	Limited[3]
Quick Start	No
OR and Flexibility	No
Duration and Energy Assurance	No

1. Inverter-based generation can provide synthetic inertia
2. In markets with separate "up" and "down" regulation products, intermittent resources can provide "down" regulation by curtailing
3. Inverter-based resources like wind and solar can provide some reactive support, but systems with large shares of inverter-based resources can face reactive power deficiency.

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Hydroelectric

- Cost Structure:
  - High capital cost
  - Moderate fixed operating cost
  - Low variable cost
  - Long lifespan (100+ years)
- Technical Potential: 3,500 to 5,100 MW[1]
- Curtailment: Dependent on flexibility and must-run requirements
- Main Challenges:
  - Limited technical potential, mostly in remote areas requiring substantial transmission investment
  - Flexibility and energy assurance is dependent on water conditions

1. Ontario Power Generation "Made-in-Ontario northern hydroelectric opportunities" February 2023 https://www.opg.com/documents/made-in-ontario-northern-hydroelectric-opportunities-pdf/

Reliability Service	Hydroelectric
Inertia and Frequency Response	Yes
Regulation	Yes
Reactive Support and Voltage Control	Yes
Quick Start	Yes
OR and Flexibility	Yes[2]
Duration and Energy Assurance	Limited[3]

2. Hydro provides a significant share of Ontario's OR and flexibility, but OR capability can be limited by water conditions (e.g., during spring freshet)
3. Many hydro facilities in Ontario has limited capability to store energy. Most are constrained by water management rules which, among other things, restrict operating below some minimum flow level or limit how much a reservoir can be emptied. They cannot necessarily deliver their full output for many days consecutively and energy output can be limited.

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Storage (less than 12-hour duration)

- Cost Structure:
  - Moderate capital cost
  - Moderate fixed operating cost
  - Low variable cost
  - Lifespan depends on technology and utilization
- Technical Potential: Unlimited,[1] but intra-day storage can provide capacity for up to ~15% of peak demand before duration becomes a concern[2]
- Main Challenges:
  - Duration limitation restricts the ability to offer services in all hours; also requires energy to charge
  - To access storage reliability service capabilities, changes to system operator tools and analysis are required

1. Pumped storage and underground compressed air storage requires suitable geology
2. Power Advisory analysis https://www.energystoragecanada.org/es-net-zero

Reliability Service	Storage
Inertia and Frequency Response	Technology-dependent[3]
Regulation	Yes
Reactive Support and Voltage Control	Yes
Quick Start	Yes
OR and Flexibility	Yes
Duration and Energy Assurance	No

3. Resources like pumped hydro and flywheels provide physical inertia. Inverter-based resources with advanced control systems can provide frequency response but not physical inertia; system operators recognize this "synthetic inertia" capability, but it requires more research

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Reactive Power Compensation

- Reactive Power Compensation devices such as capacitor banks, synchronous condensers, static VAR compensators, and static synchronous compensators are installed by the transmitter to provide reactive power
- Short-duration storage devices (i.e. less than 30 minutes), such as flywheels, have also been used for reactive power needs
- Technical Potential: Unlimited
- Main Challenges:
  - Useful only for reactive support and inertia

Reliability Service	Reactive Power Compensation
Inertia and Frequency Response	Yes[1]
Regulation	No
Reactive Support and Voltage Control	Yes
Quick Start	n/a
OR and Flexibility	n/a
Duration and Energy Assurance	n/a

1. Only synchronous condensers provide physical inertia.

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Demand Response

- Cost Structure:
  - Low capital cost and fixed operating cost
  - Range of variable costs
    - Loads like electric vehicles (EVs) can shift charging times at effectively zero cost
- Duration limitations: Similar to storage, although there is no technical limit on the duration that load could be actively curtailed, there is an economic limit (i.e., it will need to consume at some point)
- Main Challenges:
  - Measuring "output" is not straightforward
  - For high-variable-cost demand response, resource testing can be a significant financial burden but is also critical to ensuring reliability/dependability
  - Conventional DR (e.g. at a factory) is often disruptive and best used only a few times per year

Reliability Service	Demand Response
Inertia and Frequency Response	Limited[1]
Regulation	Limited[1]
Reactive Support and Voltage Control	No
Quick Start	Limited[1]
OR and Flexibility	Yes
Duration and Energy Assurance	Limited[2]

1. Some loads can respond quickly to control signals and others require more time. The IESO currently accommodates these differences with the Dispatchable Load and HDR resource types.
2. It is unclear how many loads would be willing to curtail for multiple consecutive days. Long-duration demand response could be constructed by chaining together multiple short-duration products.

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Dispatchable Emissions Free Resources (DEFRs)

- Necessary to provide the combination of flexibility, duration, and energy assurance that cannot be provided by other non-emitting resource types
- Fixed cost structure for combustion turbines is similar for natural gas and zero-emissions fuels
- There is no technically and commercially viable fuel option:
  - Hydrogen and other synthetic fuels are costly and energy-intensive to produce; when a fuel like hydrogen is produced from electricity, it acts like long-duration storage
  - Point source carbon capture on gas-fired generation is experimental, costly and may limit flexibility
  - Technical potential of renewable natural gas and other biofuels is insufficient for Ontario's needs
  - Multi-day storage could meet some reliability needs that would otherwise be met by DEFRs, but no cost-effective option is currently available

Reliability Service	DEFR
Inertia and Frequency Response	Yes[1]
Regulation	Yes
Reactive Support and Voltage Control	Yes[1]
Quick Start	Yes
OR and Flexibility	Yes
Duration and Energy Assurance	Yes

1. Options involving a turbine would provide inertia. Options like hydrogen fuel cells would provide no inertia and limited reactive support.

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Summary

Reliability Service	Nuclear	Wind/Solar	Hydroelectric	Storage	Reactive Power Compensation	Demand Response	DEFR
Inertia and Frequency Response	Yes	Yes	Yes	Technology-dependent	Yes	Limited	Yes
Regulation	No	No	Yes	Yes	No	Limited	Yes
Reactive Support and Voltage Control	Yes	Yes	Yes	Yes	Yes	No	Yes
Quick Start	No	No	Yes	Yes	n/a	Limited	Yes
OR and Flexibility	No*	No	Yes	Yes	n/a	Yes	Yes
Duration and Energy Assurance	Yes	No	Limited	No	n/a	Limited	Yes
Capital Cost	High	Moderate	High	Moderate	n/a	Low	Moderate
Fixed Operating Cost	Moderate	Low	Moderate	Moderate	n/a	Low	Moderate
Variable Operating Cost	Low	Zero	Low	Low	n/a	High	High

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Options for Zero-Emissions Supply

- In non-emitting capacity expansion studies, solar and wind resources as well as other non-emitting resources such as hydro, storage, nuclear, and hydrogen play a part in forming a net-zero grid.
  - Expanding transmission and intertie capability between jurisdictions is also beneficial
- The operational characteristics and reliability attributes of inverter-based, intermittent technologies, are different than those of conventional generation. Integrating these technologies requires additional ancillary services to ensure reliability.
- The following literature review provides several case studies in the following jurisdictions:
  - NREL Examining Supply-Side Options to Achieve 100% Clean Electricity by 2035 – United States
  - NYISO 2023-2032 Comprehensive Reliability Plan and NYSERDA Integration Analysis – New York
  - ISO-NE Future Grid Reliability Study – New England

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NREL Examining Supply-Side Options to Achieve 100% Clean Electricity by 2035

- The NREL 100% Clean Electricity by 2035 Study evaluates a variety of scenarios for a 100% clean electricity system (defined as zero net greenhouse gas emissions) in 2035 that could put the United States on a path to economy wide net-zero emissions by 2050

- The study found that 90% clean grid can be achieved by relying primarily on new wind, solar, storage, transmission, and other technologies available today. However, the path from 90% to full decarbonization is less clear, as multiple technologies, such as hydrogen and other low carbon fuels, advanced nuclear, CCS, and direct air capture, can help full decarbonization but are not yet ready for cost-effective deployment at large scale. The main uncertainty in reaching 100% clean electricity is considering the need to meet peak demand periods or during periods of low wind and solar output.
    - For instance, widespread electrification shifts the peak from summer to winter and increases the peak substantially. Specifically, electric space heating raises evening winter peaks and reduces the ability of solar energy to meet demand peaks.

- Wind and solar provide 60 to 80% of the generation in the least-cost electricity mix in all the main scenarios. Nuclear production more than doubles in the Constrained scenario, reaching above 30% of the generation. The Constrained scenario emphasizes the potential challenges with siting, land use, and transmission expansion

- Other demand-side mechanisms can reduce the supply-side infrastructure needs in the scenarios, such as geothermal heat pumps.

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NYISO 2023-2032 Comprehensive Reliability Plan

- The NYISO Comprehensive Reliability Plan (CRP) discusses concerns that intermittent resources may not be available to provide the required reliability services
- NYISO has defined a new class of resources, Dispatchable Emission-Free Resources (DEFRs). DEFRs are a classification of emission-free resources that provide the reliability attributes of synchronous generation and can be dispatched to provide both energy and capacity over long durations.
- A singular DEFR will not be expected to provide the essential characteristics or reliability services as a fossil-based generation does. However, DEFRs in the aggregate will need to provide the reliability attributes.
- The CRP states that various market design enhancements are required to properly consider reliability attributes. In May 2023, the New York Public Service Commission (PSC) initiated a process to examine reliability needs of the 2040 zero-emissions electric grid and identify innovative solutions.
- NYISO has found that transmission will continue to play a key role in moving power from the renewable resources to the load centers. The PSC has established Public Policy Transmission Needs to allow NYISO to select major transmission projects that enable delivery of renewable energy and ensure reliability.

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NYSERDA Integration Analysis

- NYSERDA prepared an Integration Analysis ("IA") for economy-wide decarbonization pathways model that illustrated costs and benefits of various technology pathways that achieve compliance with the state emission limits.

- The IA model found that a substantial increase in the adoption of intermittent renewable resources will necessitate zero-emission dispatchable resources to balance growth in peak and annual loads. The model identifies the need for:
  - 13-15 GW of 4–8-hour battery storage by 2040
  - 18-20 GW of Zero Carbon Firm resources by 2040. These resources are modelled as either thermal units or fuel cells that operate on green hydrogen.

- The analysis applied a series of firm capacity sensitivities that illustrated how a variety of resources can contribute to meeting grid reliability, including renewable natural gas combustion, relicensing existing nuclear facilities, higher end-use load flexibility in buildings and transportation, a low-cost new nuclear option, and a 100-hour energy storage breakthrough.

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ISO-NE Future Grid Reliability Study

- ISO-NE's Future Grid Reliability Study (FGRS) evaluates how a 2040 grid could perform with the shift in both supply resources to variable energy resources and increased demand due to electrification of heating and transportation. The study finds that under the scenarios considered, ISO-NE will experience challenges in three categories: energy adequacy, resource and demand flexibility, and resource mix diversity.

- A significant result was that high penetration of renewables in Scenario 3 struggled to provide the operational flexibility needed to serve the future load.
    - Analysis of Scenario 3* (Deep Decarbonization) showed that the system would be pushed to its limits in two situations: the curtailment of energy from an oversupply of renewables could not be stored and low output of wind and solar resources causing reliability issues.
    - Scenario 3 results revealed that the system relied on stored energy in existing gas pipeline infrastructure, LNG storage, and assumed future storage of renewable energy in order to meet demand during peak winter heating conditions. This caused the system to be considered unreliable on multiple days.

*Scenario 3 assumptions were derived from the "All Options Pathway" of the Massachusetts 2050 Deep Decarbonization Roadmap Study and forecasted heavy renewable penetration and electrification loads.

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ISO-NE Future Grid Reliability Study

- The FGRS Ancillary Service Analysis explored how the resource mixes studied in the 2040 grid would be able to provide necessary amounts of regulation, reserves, and ramping
  - It found that increasing penetrations of variable resources will require additional flexibility from the remainder of the system. Additional regulation or more frequent dispatches will be needed to compensate for the rapid variability of renewable resources. In addition, a system with increased penetrations of wind and solar may also require more reserves due to short-term forecast error.
- Within the four main scenarios, the analysis modelled several reserve requirements: 10-minute spinning requirement (TMSR), total 10-minute requirement, and the total 30-minute requirement. The results found that increased amounts of variable energy resources (i.e., onshore/offshore wind and solar) led to an increased need for regulation and of reserves due to increased periods of reserve requirement violations.
  - Scenario 3 experienced reserve requirement violations for over 10% of the year with respect to the TMSR.
- The ancillary services analysis found that a core amount of dispatchable generation was still needed to provide ancillary services. ISO-NE may need to incentivize more flexibility from its ancillary services market through additional tools such as faster ramp rates, higher/lower max/min power ratings, and faster startup times.

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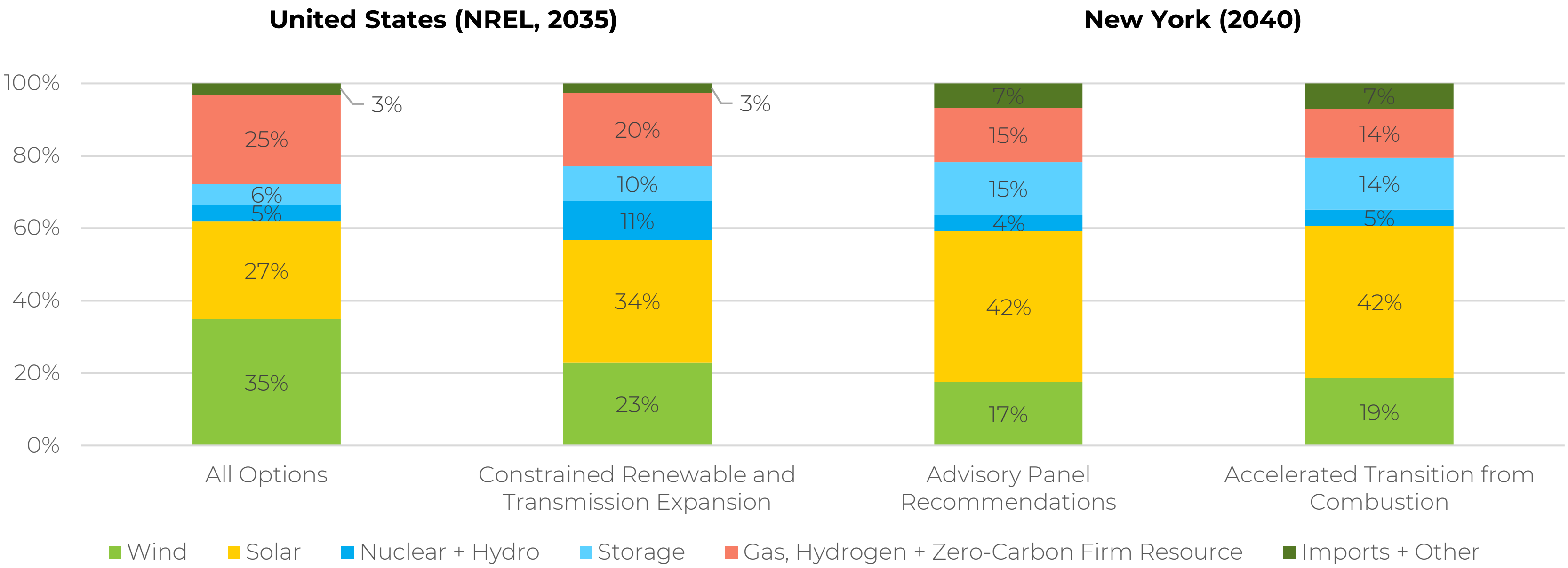
Anticipated Installed Capacity



NREL	New York
Other includes bioenergy paired with CCS and geothermal energy. All Options Scenario: includes the development and deployment of direct air capture (DAC) technology while other scenarios do not.	Other includes pumped storage and bioenergy.

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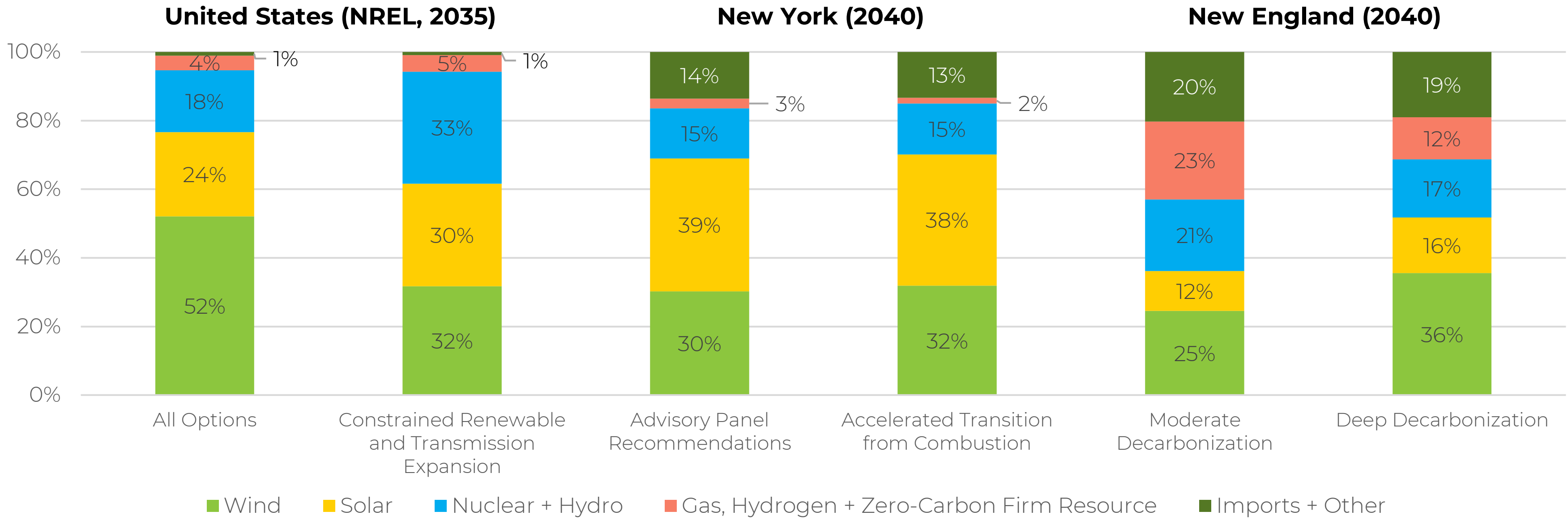
Anticipated Annual Energy Mix



United States (NREL)	New York	New England
Other includes bioenergy paired with CCS and geothermal energy. All Options Scenario: includes the development and deployment of direct air capture (DAC) technology while other scenarios do not.	Other includes pumped storage and bioenergy.	Other includes wood and landfill gas/refuse. Scenario 1 (Moderate Decarbonization) requires a significant amount of energy efficiency.

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Reliable Non-Emitting Resource Mix: Insights for Ontario

- Some findings from the studies reviewed in this section are also applicable to Ontario
  - A combination of wind, solar, and nuclear provides much of the additional clean energy needed; the optimal share is determined by cost assumptions, land use, amount of transmission expansion, and other factors
  - Intra-day storage has an important role but cannot meet all reliability needs
  - A dispatchable, flexible, and multi-day-duration resource option is needed which has a significant capacity share (potentially in the 20-25% range) but provides limited energy (potentially no more than 5% of the total)
- Ontario-specific factors to consider include:
  - Ontario's existing nuclear fleet and planned expansions, which will cement a substantial role for nuclear in the energy mix through 2050
  - Multiple interconnections to different markets in North America
  - Limited technical potential for new hydroelectric development
- The studies also noted:
  - Potential ancillary service shortfalls and/or the need to define new products
  - Opportunities for greater demand-side participation in balancing the grid

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Part 2: Barriers and Solutions

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Understanding Future Needs

- Based on previous IESO assessments and assessments in other North American markets:
  - Inertia and frequency response is not likely to be a concern in the Eastern Interconnect for some time, although enhanced monitoring is prudent
  - Increasing need for regulation capacity, doubling by 2030
  - There may be a need to increase OR requirements in order to integrate more wind and solar generation; these requirements may change in real-time
  - There is currently an unmet need for flexibility (or "spare energy") in IESO markets when few gas generators are online. The need is being managed by temporarily raising the OR requirement and with out-of-market gas commitments
  - In addition to the services discussed above (inertia, frequency response, and flexibility), retirement of gas-fired generation could lead to insufficient duration and energy assurance which intra-day storage resources cannot meet; the IESO has used this need to justify non-storage procurement targets and argue for relaxation of Clean Electricity Regulation requirements on gas-fired generation
- Market design and software implementation projects can take 5 or more years. To meet new kinds of needs using market mechanisms, they must be identified well before they emerge

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Data Sharing and Studies

- More information would help the market understand the timing, location, and magnitude of essential reliability service needs
- Data sharing also enables developers to focus their efforts prior to procurements and may increase their confidence in future market revenues
- Transparency is essential for market efficiency and enabling resources to participate effectively in the market
- Information generally includes:
  - Historical market data – long-term timeseries data on market demand, supply, bids, offers, etc. can help participants understand future opportunities
  - Planning information - while the Annual Planning Outlook's capacity and energy adequacy outlooks are valuable, these assessments could evolve to capture more granular and specific needs

Recommendation: Publish more historical market data, including lagged bids and offers and demand at each transformer station

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Data Sharing and Studies

- Greater clarity is needed on inertia and frequency response needs, including the potential needs in a scenario with significant nuclear and battery storage but little or no gas-fired generation

Recommendation: Continue to monitor inertia and frequency response needs, including assessment of low- or zero-emissions resource mixes

- Gas-fired generation currently provides the flexibility, fuel security, and multi-day duration capabilities that cannot be offered economically by current storage technology
  - However, these capabilities are not well-defined in planning assessments or studies
- New methods are needed for planning and operational studies to integrate higher levels of non-emitting resources and manage uncertainty

Recommendation: Formalize flexibility and multi-day energy assurance concepts in planning and operational assessments to define the specific reliability services that cannot be met by intra-day storage

Recommendation: Publish assessments of flexibility, ramping, duration, and energy assurance needs in a future system with a high share of intermittent resources

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Valuing Flexibility

- There is increasing recognition of a gap in the real-time ancillary services, which are currently focused on responses in one hour or less
    - Markets like CAISO face substantial multi-hour ramp requirements due to solar output profiles
    - Markets with significant wind output need to manage forecast uncertainty which could translate to many hours of energy shortfall compared to day-ahead expectations
- While multi-day duration is sometimes called for, some flexibility services could be provided by storage and duration-limited demand flexibility
- Like capacity, there may be cost savings from enabling flexible DERs to meet bulk system flexibility needs
    - Distributors can also use flexibility to optimize their systems (e.g. reducing losses)
    - New electrification-related loads (heat pumps, electric water heaters, and EVs) could offer significant real-time flexibility to the system

"Modeling and pricing the actual flexibility needed to operate the system instead of only the standard 10- and 30-minute reserve requirements is a critical first step in addressing [disorderly retirement of flexible resources]."

- PJM Report to FERC[1]

1. https://www.pjm.com/-/media/documents/ferc/filings/2022/20221018-ad21-10-000.ashx

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Valuing Flexibility

- Some of the flexibility need is driven by forecast error; forecasting in the day-ahead to real-time period will grow in importance as intermittent resource capacity increases

- The risk of forecast error may also become a more important contributor to OR needs than forced outages

Recommendation: Invest in improving day-ahead and real-time forecasts of wind, solar, and load

- Current OR products may not deliver sufficient flexibility (i.e. sustained, multi-hour response to a disturbance)
- One potential structure for a flexibility product could combine the response time of operating reserve (10 or 30 minutes) with a longer duration requirement (e.g. 4 to 8 hours)

Recommendation: Define and implement a new real-time flexibility product to address "spare energy" needs

Recommendation: Set OR and flexibility product requirements dynamically to account for real-time wind, solar, and load forecast uncertainty risk

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Hybrid Market Design for Zero Emissions

- Ontario's hybrid market combines:
  1. Efficient real-time operations, structured around market products
  2. Long-term contracts to reduce consumers' energy price risk and secure availability of services like capacity
- Day-ahead and real-time market solutions attempt to solve coordination problems like:
  - When it is worthwhile to bring gas generators online
  - How to optimally dispatch hydroelectric facilities with water limitations and complex interactions like cascade systems
  - How to ensure storage units have feasible and optimal schedules given state of charge limitations
  - How to best preserve OR and ramping capability for times when it may be needed
- Pricing real-time services appropriately can influence retirement decisions and – to the extent that future revenues can be confidently forecasted – investment decisions
- However, it has become clear that new resource development in Ontario requires a long-term revenue commitment in addition to expected market revenue
  - Procurements offering seasonal or multi-year commitments can be used to ensure the right capabilities are available
  - Risk allocation is a key consideration in the design of market mechanisms and procurement contracts; there is potential for customers and/or LDCs to contract directly with resources for the energy and other services they require

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Open, Technology-Neutral Forward Procurements

- As reliability needs evolve, simple pay-for-availability capacity contracts will no longer capture the range of services needed
  - The technology-specific targets used in the E-LT1 and LT1 procurements were an expedient solution for immediate capacity needs, but future procurements and capacity payment mechanisms can achieve greater technology-neutrality

- Improved capacity accreditation could enable more types of resources to compete on a level playing field
  - Capacity accreditation should be robust to changes in the timing, duration, and frequency of risks as supply and demand conditions evolve

Recommendation: Continuously refine capacity accreditation techniques with reference to best practices in U.S. markets, such as the use of marginal effective load carrying capability (ELCC) methodologies for intermittent resources and resources with duration limitations

- Future procurements may need to target specific capabilities and/or services, such as ramp rate, duration, and energy assurance

Recommendation: Consider acquiring non-emitting flexibility and/or energy assurance products through forward procurements to plan for gas retirement

- Regulation services have historically been procured bilaterally in Ontario, creating a significant barrier to new, potentially more cost-effective entrants

Recommendation: Acquire regulation services through open, technology-neutral mechanisms

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Enabling Resources

- New technologies may require new market mechanisms to be dispatched and procured effectively
  - The Market Renewal program has made significant design improvements to enable hydroelectric resources and gas turbines to participate in the electricity market efficiently
  - Similar design improvements are under development for storage and hybrid resources

Recommendation: Continue developing improved participation models for storage and hybrid resources

- Demand response (DR) products in the IESO-administered markets may also require enhancements, particularly as new, flexible electrification-related loads (EVs, electric water heaters, and heat pumps) become more common
  - The current baseline methodology (i.e. the yardstick that DR is measured against during an activation) has been criticized for undervaluing the contribution of weather-sensitive loads
  - A new approach to DR measurement may also be needed to ensure EV loads can be aggregated and dispatched for flexibility and capacity services

Recommendation: Revisit capacity accreditation and measurement methodologies for demand response (i.e. baseline methodologies) to enable demand flexibility from electric vehicles and weather-sensitive loads

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Transmission/Distribution Coordination

- The IESO is leading efforts to better integrate DERs into markets. Better understanding is needed of:
  - The technical requirements (visibility, telemetry, etc.) IESO would require to raise virtual DR caps and allow more ancillary services to be provided by DERs
  - The specific capabilities distributors must develop (e.g. forecasting, dispatch, etc.) to evolve into DSOs and make use of DERs for both local and bulk-system needs
  - How different forms of DERs (behind-the-meter storage, virtual power plants, etc.) can be integrated into the same DER framework
  - The potential benefits of allowing distributors to take more responsibility for securing reliability services
- There are currently zonal caps on the amount of virtual (i.e. distribution-connected) hourly demand response because it cannot be tied to a specific transmission station and IESO does not have real-time telemetry
  - Ratepayers could benefit if caps on virtual DR reflected technical capabilities of the demand resource

Recommendation: Enable distributed resources to provide all reliability services they can demonstrate they are technically capable of

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Transmission/Distribution Value Stacking

- Distribution-connected resources (i.e. DERs) can provide reliability services to both the host distributor and the bulk system ("revenue stacking")
  - For example, a storage or demand response on the distribution system could simultaneously defer new distribution wires investment and provide capacity and flexibility to the bulk power system
  - There are no clear rules for how resources can provide multiple services or how conflicts in the timing of needs might be handled (e.g. four-hour storage could not meet a distribution need occurring from 11am to 3pm and a bulk system need occurring between 3pm and 7pm)
    - The IESO Transmission Distribution Working Group (TDWG) is exploring this issue from an operations viewpoint, but there is no coordination on procurement among other needs to unlock DER value
- Value stacking has been difficult to implement in practice, particularly for capacity products where distributor needs are different from bulk system needs

Recommendation: Define rules for value-stacking and coordinating when a resource provides services to both the IESO and a distributor

Recommendation: Continue to experiment with innovative rate designs such as interruptible rates to provide more options for demand-side and behind-the-meter resources

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