Pathways to Decarbonization

Assumptions for Feedback – March 2, 2022

This document contains the preliminary assumptions related to the Pathways to Decarbonization study for stakeholder feedback. Assumptions include the categories below, and to ensure transparency, detailed financial and technical data is included for each resource, as well as the source of the data.

Policy	Demand	Resources
• Carbon price and policy • Clean fuel standard • Codes & standards	• Heating & cooling • Transportation • Industrial electrification • Conservation programs • DER potential	• Technical: energy, capacity, lead time and project life • Financial: capital, operating and fuel cost

The input received will inform the development of scenarios to achieve electricity system decarbonization in Ontario. Stakeholders are welcome to provide evidence-based feedback on the reasonableness of the assumptions, additional data sources, and information to address data/information gaps.

Please use the dedicated Stakeholder Engagement Feedback form to submit your comments and feedback is welcome until **March, 16, 2022**. You may attach research studies or other materials for consideration by the IESO to support your submission.

For questions and to submit your feedback please email engagement@ieso.ca

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	Moratorium	Pathways
Study Period	2024 - 2035	2024 - 2050
Objective and Further Opportunity	Replacement of 2021 Annual Planning Outlook proxy resources with incremental non-emitting resources based on availability, reliability and cost, with existing natural gas assumed to be available through the study period	Develop an expansion and replacement resource mix with incremental non-emitting resources based on availability, reliability and cost, with existing natural gas available if retrofitted with carbon capture and storage or to operate on low-carbon fuels
	Evaluate opportunity to replace 2021 Annual Planning Outlook existing natural gas with incremental non-emitting resources based on availability, reliability and cost	Evaluate policy opportunities to enable net zero emissions by 2050 or earlier timeframe
Policy	**Moratorium Modelling**	**Pathways Modelling**
Carbon Prices	• $50/tonne CO2e in 2022 • rising $15/tonne CO2e/year in 2023-2030 • $170/tonne CO2e in 2030-2035	• $50/tonne CO2e in 2022 • rising $15/tonne CO2e/year in 2023-2030 • $170/tonne CO2e in 2030 • rising $15/tonne CO2e/year in 2031-2050 • $470/tonne CO2e in 2050
Carbon Border Adjustment	No	Yes
Emissions Performance Standards (EPS) Natural Gas fired Electricity Generation Allowance Benchmark	• 370 tonne CO2e/GWh for 2024 - 2035	• 370 tonne CO2e/GWh until 2030 • tapering to 0 tonne CO2e/GWh by 2035
Offshore Wind	Not Considered	Part of Potential Resource Options
Carbon Capture, Utilization and Storage (CCUS)	Not Considered	Part of Potential Resource Options
Demand Scenario	**Moratorium Modelling**	**Pathways Modelling**
Demand Forecast	• 2021 Annual Planning Outlook Reference Scenario Demand Forecast	• Pathways Scenario demand forecast to be developed in 2022 Q1-Q2 ○ Consistent with societal decarbonization goals ○ Step changes in technology adoption curves based on known, flagged and potential policy ○ Primarily driven by widespread fuel switching ■ From fossil fueled equipment ■ To electric supplied equipment, high efficiency case if available
Conservation Programs	• Consistent with 2021 Annual Planning Outlook Reference Scenario Demand Forecast ○ Includes assumption of continued delivery of conservation programs through the end of the outlook period at budget and savings levels consistent with the current 2021-2024 CDM Framework • Incremental electricity conservation program savings potential exists up to the level of savings as identified in the 2019 IESO and Ontario Energy Board Integrated Ontario Electricity and Natural Gas Conservation Achievable Potential Study, maximum potential Scenario "B" ○ This incremental savings will be considered as an option that competes with other Potential Resource Options	• The level of Conservation Program savings included in the Pathways Scenario demand forecast will be consistent with the maximum potential scenario identified in the latest available electricity conservation and demand management acheivable potential study. The IESO is currently updating the 2019 study and will use new findings if available
Distributed Energy Resources (DERs)	• Consistent with 2021 Annual Planning Outlook Reference Scenario ○ Based on current identified levels of distributed energy resources, assumed to have continued availability post contract, through the end of the outlook period • Incremental distributed energy resources can potentially exist up to levels to be identified in the IESO 2022 Distributed Energy Resource Achievable Potential Study ○ This incremental energy resource potential will be considered as an option that competes with other Potential Resource Options	• Incremental distributed energy resources can potentially exist up to levels to be identified in the IESO's 2022 Distributed Energy Resource Achievable Potential Study ○ This incremental energy resource potential will be considered as an option that competes with other Potential Resource Options

IESO Pathways to Decarbonization Study
Demand Scenario Driver Assumptions

Sector	End Use / Sub-Sectors	Case	Assumption
Residential	Space Heating	New buildings, new equipment	• Expected regulation: space heating equipment in new construction of residential sector buildings to be zero emissions from 2030 ○ Substitution of natural gas, propane or heating oil fuelled space heating equipment to a mix of electric powered air source heat pumps, ground source heat pumps and resistive heating technology
		Existing buildings, replacement of expired equipment	• Expected regulation: 100% of sales of new space heating equipment for residential buildings to be zero emissions by 2035 ○ For replacement of installed equipment in existing buildings ○ Substitution of natural gas, propane or heating oil fuelled water heating equipment to a mix of electric powered heat pumps and resistive heating technology
	Water Heating	New buildings, new equipment	• Expected regulation: water heating equipment in new construction of residential sector buildings to be zero emissions from 2030 ○ Substitution of natural gas, propane or heating oil fuelled water heating equipment to a mix of electric powered heat pumps and resistive heating technology
		Existing buildings, replacement of expired equipment	• Expected regulation: 100% of sales of new water heating equipment for residential buildings to be zero emissions by 2035 ○ For replacement of installed equipment in existing buildings ○ Substitution of natural gas, propane or heating oil fuelled water heating equipment to a mix of electric powered heat pumps and resistive heating technology
	Clothes Drying	New buildings, new equipment	• Expected regulation: clothes drying equipment in new construction of residential sector buildings to be zero emissions from 2030 ○ Substitution of natural gas fuelled clothes drying equipment to electric powered resistive heating technology
		Existing buildings, replacement of expired equipment	• Expected regulation: 100% of sales of new clothes drying equipment for residential buildings to be zero emissions by 2035 ○ For replacement of installed equipment in existing buildings ○ Substitution of natural gas fuelled clothes drying equipment to electric powered resistive heating technology

Commercial	Space Heating	New buildings, new equipment	• Expected regulation: space heating equipment in new construction of commercial sector buildings to be zero emissions in 2030 and thereafter ○ Substitution of natural gas, propane or heating oil fuelled space heating equipment to a mix of electric powered air source heat pumps, ground source heat pumps and resistive heating technology
		Existing buildings, replacement of expired equipment	• Expected regulation: 100% of sales of new space heating equipment for commercial buildings to be zero emissions by 2035 ○ For replacement of installed equipment in existing buildings ○ Substitution of natural gas, propane or heating oil fuelled water heating equipment to a mix of electric powered heat pumps and resistive heating technology
	Water Heating	New buildings, new equipment	• Expected regulation: water heating equipment in new construction of commercial sector buildings to be zero emissions in 2030 and thereafter ○ Substitution of natural gas, propane or heating oil fuelled water heating equipment to a mix of electric powered heat pumps and resistive heating technology
		Existing buildings, replacement of expired equipment	• Expected regulation: 100% of sales of new water heating equipment for commercial buildings to be zero emissions by 2035 ○ For replacement of installed equipment in existing buildings ○ Substitution of natural gas, propane or heating oil fuelled water heating equipment to a mix of electric powered heat pumps and resistive heating technology

IESO Pathways to Decarbonization Study
Demand Scenario Driver Assumptions

Sector	End Use / Sub-Sectors	Case	Assumption
Industrial	Mining		• Continued sub-sector development, supported by Ontario Critical Minerals Strategy, to produce raw materials required to enable societal electrification infrastructure ○ Including continued development of Ontario Ring of Fire region mineral deposits and electrification of transportation infrastructure
	Other Manufacturing		• Continued fossil fuel to electricity substitution for industrial processes over the outlook period, similar to approach taken in previous IESO outlook demand forecast ○ For Pathways Scenario, beginning in year 6, an incremental 1% per year of existing fossil fuel consumption is converted to electricity over the outlook period ■ For example, based on 2019 Ontario Industrial fossil fuel energy consumption equating to approximately 90 TWh / year: □ by year 5, 2028: 0% fuel switching □ by year 6, 2029: 1% fuel switching of 2019 levels results in approximately +1 TWh/year; □ by year 10, 2033: 5% fuel switching of 2019 levels results in approximately +5 TWh/year; □ by year 20, 2043: 15% fuel switching of 2019 levels results in approximately +14 TWh/year; □ by year 27, 2050: 22% fuel switching of 2019 levels results in approximately +20 TWh/year;
Transportation	Light Duty Vehicles		• Light Duty Vehicles ○ Consistent with federal government policy targets: ■ Mandatory target of 100% of new sales of light-duty vehicles in 2035 and thereafter to be zero-emission (announced June 29, 2021) ■ Interim target of at least 50% of new sales of light-duty vehicles in 2030 and thereafter to be zero-emission (announced December 17, 2021)
	Heavy Duty Vehicles		• Heavy Duty Vehicles ○ Consideration of 100% of municipal transit commission buses to be electrified by 2040
	Rail Transit		• Steady expansion across the province over the outlook period
	Rail Shipping		• Emerging electrification over the 2030s, advancement in the 2040s

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Demand Scenario Driver Assumptions	NREL Resource Class	Capacity Factor (%)	Summer Capacity Value (UCAP%)	Winter Capacity Value (UCAP%)	CAPEX ($2021CAD/kW)	OM&A ($2021CAD/kw-yr)	Technology Readiness Level (TRL) - 2022	Construction Lead-Time (years)	Project Life (years)	Data Source
Onshore Wind	Class 1-8	35-52%	22-50%	42-62%	$1,109-1,486	$47-55	9	2-3	30	ATB
Offshore Wind	Class 5,8	45-54%	27-53%	45-62%	$2,942-4,273	$104-135	9			ATB+
Solar	Class 10	20-23%	34-41%	0.5-2%	$923-1,477	$21-27	9	1-3	20	ATB
Hydro	NA	27-67%	18-91%	25-91%	$5,989-10,694	$28-77	9	5-10	50-100	In House

Thermal	Outage Rate (EFORd %)	Summer Capacity Value (UCAP%)	Winter Capacity Value (UCAP%)	Start-Up Time (hrs)	Minimum Run Time (hrs)	Minimum Down-Time (hrs)	Minimum Loading Point (MW)	CAPEX ($2021CAD/kW) @ 1.25 USD/CAD	Variable OM&A ($/MWh)	Fixed OM&A ($2021CAD/kW-year) @1.25 USD/CAD	Fuel Cost ($/MWh)	Technology Readiness Level - 2022	Construction Lead-Time (years)	Project Life (years)	Data Source	Commercial Readiness - 2022	Earliest In-service Date
Large Nuclear	Avg of Current Fleet	93%	93%	Same as Current Fleet				$7,320-8,998	$2.50	$181	$0.85-0.91	9	12	30	ATB	1	2037
Small Modular Nuclear												6				1	2032
Retrofit - Renewable Natural Gas	All Performance Characteristics Will be the Same as the Underlying Unit Being Retrofitted										$88.19	9	Fuel Cost: https://www.cga.ca/wp-content/uploads/2020/08/RNG-Handbook-for-Municipalities-in-the-GTHA_2020-07-07.pdf			TBD	NA
Retrofit - Hydrogen SCGT	All Performance Characteristics Will be the Same as the Underlying Unit Being Retrofitted											8				1	~2030
Retrofit NG with CCS	All Performance Characteristics Will be the Same as the Underlying Unit Being Retrofitted							$533.03 - 2,169.18	$3.75 - 5.00	$36.25 - 47.50		8-9	ATB + NETL Retrofit Assumption: https://data.openei.org/submissions/4129			1-2	
Biomass												9				6	

Storage	Representative Technologies	Outage Rate (EFORd %)	CAPEX ($2021CAD/kW-installed)	Summer Capacity Value (UCAP%)	Winter Capacity Value (UCAP%)	Upper Limit on MW in Category (UCAP MW)	OM&A ($/kW-yr)	Roundtrip Efficiency (%)	Technology Readiness Level - 2022	Construction Lead-Time (years)	Project Life - (years) - Proposed - Number Cycles @ 80% Depth of Discharge	Data Source	Commercial Readiness - 2022	Earliest In-service Date
4 hour storage	Batteries: e.g. Li-ion, NaS	5%	$432-1,555	95%	95%	2000	$11.25-38.75	75-85%	9	1-3	Li-Ion - ~3,500 NaS - ~4,000	ATB	5-6	
8 hour storage	Li-ion, Flow Battery, CAES, Pumped Hydro	5%	$783-2,813	95%	95%	2000	$20-70	65-85%	8-9	1-6	Li-Ion - ~3,500 CAES - ~10,000 Flow - ~10,000	ATB	1-5	
12 hour storage	Flow Battery, CAES, Pumped Hydro	5%	$1,133-$4,073	95%	95%	1000	$23.75-86.25	65-85%	7-9	2-8	CAES - ~10,000 Flow - ~10,000	ATB	1-5	
24+ hour storage	Air-metal Battery, CAES	5%		95%	95%	1000			6-7	2-8	CAES - ~10,000		1	

Load Participation	Acceptable Number of Activations (#/yr)	Max Hours of Delivery per Activation (Hrs)	Summer Capacity Value (UCAP%)	Winter Capacity Value (UCAP%)	Annual Capacity Cost ($/MW-yr)	Activation Cost ($/MWh)	Technology Readiness Level - 2022	Construction Lead-Time (years)	Data Source
Hourly Demand Response (HDR)	3	4	60-75%	60-75%		250-500	9	N/A	IESO
5-min Dispatchable Load	NA								
5-min Dispatchable BTM Generation & Storage	NA								

Firm Imports	Maximum Capacity Being Considered (MW)	Summer Capacity Value (UCAP%)	Winter Capacity Value (UCAP%)	Annual Capacity Cost ($/MW-yr)	Energy Cost ($/MWh)	Technology Readiness Level - 2022	Construction Lead-Time (years)	Data Source
Quebec	3,300	100%	100%			9	Depends on Capacity Amount: related to Transmission build-out	IESO
Manitoba	500	100%	100%			9		IESO

Table	Column	Description
Renewables	**NREL Resource Class**	NREL's in-house classification of the strength of the underlying fuel availability (i.e. wind, solar irradiance etc.) - https://data.openei.org/submissions/4129
	Capacity Factor (%)	Capacity factor is the measure of how often a power plant runs for a specific period of time. It's expressed as a percentage and calculated by dividing the actual unit electricity output by the maximum possible output.
	Summer Capacity Value (UCAP%)	A measure of the total MW that can be relied upon to contribute towards Resource Adequacy during the Summer Delivery Period in % of ICAP MW
	Winter Capacity Value (UCAP%)	A measure of the total MW that can be relied upon to contribute towards Resource Adequacy during the Winter Delivery Period in % of ICAP MW
	CAPEX ($2021CAD/kW)	Estimate of capital expenditure required to build new MWs
	OM&A ($2021CAD/kw-yr)	The fixed annual Operations, Maintenance and Administration costs
	Technology Readiness Level (TRL) - 2022	See TRL-CRI Definitions Tab
	Construction Lead-Time (years)	Number of years required to build the new MWs
	Project Life (years)	Number of years the project is anticipated to be in service

Incremental Categories In Thermal	**Outage Rate (EFORd %)**	A measure of the probability that an electric power generating unit will not be available due to a forced outage or forced derating when there is a demand on the unit to generate
	Start-Up Time (hrs)	The amount of time required for the unit to reach its Minimum Loading Point (MLP)
	Minimum Run Time (hrs)	The minimum amount of time that the unit must remain at or above its MLP
	Minimum Down-Time (hrs)	The minimum amount of time between when the unit is shut-down and when it can be re-started
	Minimum Loading Point (MW)	The minimum generation output level that must be maintained while the unit is online
	Variable OM&A ($/MWh)	A measure of the variable operations, maintenance and administration costs
	Fixed OM&A ($/kw-year)	A measure of the fixed operations, maintenance and administration costs
	Fuel Cost ($/MWh)	The cost of the input fuel (e.g. Renewable Natural Gas, Uranium, Hydrogen)
	Commercial Readiness - 2022	See TRL-CRI Definitions Tab
	Earliest In-service Date	This is to capture that some resource types will not be mature enough for commercial operation until later in the study horizon

Table	Column	Description
Incremental Categories In Storage	**Representative Technologies**	This category provides example technologies that would be able to provide the storage durations defined. Pumped Hydro storage will be limited to the 3 facilities identified in the November 10, 2021 Minister's letter
	Upper Limit on MW in Category (UCAP MW)	This is the upper cap on total installation of each storage duration category. The concept is to try and capture the diminishing returns (or increasing reservoir size need) as more storage is adopted on the system
	Roundtrip Efficiency (%)	A measure of how much energy can be re-injected into the grid after it has been stored in the storage unit. A percentage of how much energy can be re-injected from total energy consumed to charge the unit
Incremental Categories In Load Participation	**Max Number of Activations (#/yr)**	A measure of how many times per year the DR unit can be called upon to deliver energy
	Max Hours of Delivery per Activation (Hrs)	A measure of the maximum number of hours that the DR unit can deliver energy per activation
	Annual Capacity Cost ($/MW-yr)	A measure of how much it is expected to cost to secure DR capacity
	Activation Cost ($/MWh)	A measure of how much it is expected to cost to activate a DR unit to deliver energy
Incremental Categories In Imports	**Maximum Capacity Being Considered (MW)**	This is the maximum amount of capacity that IESO anticipates could be made available from the neighbouring jurisdiction. The limits will be based on capacity and internal transmission limits identified in the neighbouring jurisdictions; Ontario transmission considerations will be incorporated into our capacity cost curves
	Energy Cost ($/MWh)	This is the expected average cost of the energy being delivered from the neighbouring jurisdiction

IESO Pathways to Decarbonization
Study TRL-CRI Definitions

Level	Technology Readiness Level
Level 1	Basic principles of concept are observed and reported
Level 2	Technology concept and/or application formulated
Level 3	Analytical and experimental critical function and/or proof of concept
Level 4	Component and/or validation in a laboratory environment
Level 5	Component and/or validation in a simulated environment
Level 6	System/subsystem model or prototype demonstration in a simulated environment
Level 7	Prototype ready for demonstration in an appropriate operational environment
Level 8	Actual technology completed and qualified through tests and demonstrations
Level 9	Actual technology proven through successful deployment in an operational setting

Australian Renewable Energy Agency, ARENA 2014 - Commercial Readiness Index for Renewable Energy Sectors

Source: https://arena.gov.au/assets/2014/02/Commercial-Readiness-Index.pdf

Status Summary Level	Commercial Readiness Index
6	**"Bankable" grade asset class** driven by same criteria as other mature energy technologies. Considered as a "Bankable" grade asset class with known standards and performance expectations. Market and technology risks not driving investment decisions. Proponent capability, pricing and other typical market forces driving uptake.
5	**Market competition driving widespread deployment** in context of long-term policy settings. Competition emerging across all areas of supply chain with commoditisation of key components and financial products occurring.
4	**Multiple commercial applications** becoming evident locally although still subsidised. Verifiable data on technical and financial performance in the public domain driving interest from variety of debt and equity sources however still requiring government support. Regulatory challenges being addressed in multiple jurisdictions.
3	**Commercial scale up** occurring driven by specific policy and emerging debt finance. Commercial proposition being driven by technology proponents and market segment participants – publically discoverable data driving emerging interest from finance and regulatory sectors.
2	**Commercial trial:** Small scale, first of a kind project funded by equity and government project support. Commercial proposition backed by evidence of verifiable data typically not in the public domain.
1	**Hypothetical commercial proposition:** Technically ready – commercially untested and unproven. Commercial proposition driven by technology advocates with little or no evidence of verifiable technical or financial data to substantiate claims

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