2022 Net-Zero Pathways Preliminary Results

March 28, 2022

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  1. Click “Raise Hand” and the host will be notified that you would like to ask a question. The host will unmute your microphone, you in turn will need to unmute your microphone and then you can ask your question. Your name will appear on the screen, but your camera will remain turned off.
  2. You can also ask questions by tapping the “Q&A” button and typing them in. You can up-vote questions that have been already asked.
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Welcome and introductions

- Kevin Dawson, Director, Forecasting & Analytics
- Dave Johnson, Manager, Forecasting & Market Simulation
- Jin Chen, Senior Market Simulation Analyst
- Chad Ayers, Senior Market Simulation Analyst
- Lars Renborg, Forecasting Analyst
- Adam Gaffney, Senior Forecasting Analyst
- Leo Tovar, Senior Market Simulation Analyst

Agenda

Time	Agenda Item	Presenter
10:00 - 10:05	Introductions and session objectives	Kevin Dawson
10:05 - 10:20	Purpose, Scope, and Stakeholder Feedback	Adam Gaffney
10:20 - 10:40	Load Forecast	Jin Chen & Leo Tovar
10:40 - 10:50	Open Q&A	
10:50 - 11:00	Generation Forecast: Assumptions	Adam Gaffney
11:00 – 11:20	Generation Forecast: Scenarios	Lars Renborg & Chad Ayers
11:20 – 11:30	Next Steps	Adam Gaffney
11:30 – 11:45	Open Q&A	
11:45 – 11:50	Session close-out	Kevin Dawson

Session purpose and objectives

- Purpose
  - The purpose of the virtual session is to engage stakeholders in a discussion of the AESO's draft preliminary modeling results around the net-zero emissions pathways, provide clarification and share next steps and timing
- Session objectives
  - Share our learnings from the initial round of net-zero emissions pathways stakeholder feedback
  - Present the preliminary net-zero emissions pathways modeling results
  - Provide clarification around current assumptions and framework
  - Seek another round of stakeholder written feedback before the AESO finalizes it's modeling and analysis

Registrants (as of March 21, 2022)

- Alberta Energy
- Alberta Energy Efficiency Alliance
- Alberta Ministry of Energy – Generation Transmission & Markets
- Alberta Newsprint Company
- Alberta Utilities Commission
- AltaLink Management Ltd.
- ATCO
- Battle River Power Coop
- BECL and Associates Ltd.
- Best Consulting Solutions Inc.
- Big Spruce Law
- BluEarth Renewables
- Boost Energy Ventures
- BRCC
- Bruce Power
- Burgess & Associates
- Calgary Climate Hub
- Calgary Economic Development
- Canadian Global Affairs Institute
- Canadian Nuclear Association
- CANDU Owners Group
- Canadian Renewable Energy Association (CanREA)
- Capital Power
- CAPP
- Carbon Assessors
- Cenovus Energy
- Chapman Ventures Inc.
- CIBC
- City of Edmonton
- City of Medicine Hat
- Computare
- Customized Energy Solutions
- DePal Consulting Ltd.
- Direct Energy
- Dunsky
- EDC Associates
- EDF Renewables
- Elemental Energy
- Enbridge
- Enel Green Power Canada & NA
- Energy Storage Canada
- Enfinite
- ENMAX Corporation, Energy & Power
- EPCOR Distribution & Transmission Inc.
- EQUS
- Evolugen
- Finning
- FortisAlberta, Inc.
- Futera Power
- Government of Alberta
- Greengate Corporation
- Heartland Generation Ltd
- Hill+Knowlton Strategies.
- Imperial Oil
- Independent Power Producers Society of Alberta (IPPSA)
- Industrial Power Consumers Association of Alberta (IPCAA)
- Jupiter Energy Advisors
- KAPA Emerging Solutions Inc.
- Kineticor
- KnightFork
- Lionstooth Energy Inc.
- Lorneville
- Market Surveillance Administrator (MSA)
- Maxim Power Corp
- METSCO
- Members of the public
- Municipal Climate Change Action Centre
- North American Environmental Markets Inc.
- NRG Curtailment Solutions
- ODoig Consulting Services In.
- Ontario Power Generation
- Pembina Pipeline Corp.
- Power Advisory
- Powerex
- Prairie Sky Strategy
- SaskPower
- Signalta Resources Limited
- SLR Consulting
- SMS Energy-Engineering Inc.
- Solas Energy Consulting
- Spartan Controls
- Suncor Energy Inc.
- TC Energy
- TD Securities
- The Conference Board of Canada
- TransAlta Corporation
- TransCanada Energy Ltd.
- University of Calgary
- Utilities Consumer Advocate (UCA)
- URICA Asset Optimization
- Voltus, Inc.
- WSP Canada

AESO Stakeholder Engagement Framework

Stakeholder participation

- The participation of everyone here is critical to the engagement process. To ensure everyone has the opportunity to participate, we ask you to:
  - Listen to understand others’ perspectives
  - Disagree respectfully
  - Balance airtime fairly
  - Keep an open mind

Net-Zero Emissions Pathways Analysis

Overall purpose of analysis

- The Net-Zero Pathways Analysis is a planning exercise, not a policy or market design recommendation document
  - The net-zero emissions pathways work is not intended to represent a specific policy or market design recommendation or reflect an expectation of, or full detailed analysis of, a particular government policy implementation
  - The analysis is intended to highlight the potential high-level reliability, cost and market implications of a range of plausible potential net-zero outcomes
- The AESO's Net-Zero Pathways Analysis presents preliminary impacts to Alberta's electricity system that may result from ambitious electrification and decarbonization policies
  - Although no distinct "Net-Zero" policy exists today, federally or provincially, such policy has been considered by politicians, academics, and industry leaders and presents an opportunity to analyze potential pathways
- Policies that target de-carbonization in different sectors (transportation, heating systems in buildings, and industrial processes) would lead to massive electrification
  - This would result in a significant increase in electric load and would change overall demand of the electric system
- Several generation technologies could contribute to a net-zero carbon emissions electricity sector in Alberta
  - Many are proven technologies, like hydro, wind, solar or nuclear fission while others are cutting-edge, like hydrogen-fired generation, combined cycle with carbon capture, fuel cells, or small modular nuclear reactors
  - Capital stock turnover and retrofit needs would be significant in net-zero scenarios
- The analysis will enable the AESO to better understand emerging technologies and changing electricity consumption patterns
- This is not a comprehensive or definitive pathway document – there are several alternative net-zero pathways that will not be included in this preliminary assessment
  - Further AESO analysis, including upcoming long-term outlook reports, will continue to refine the scope and breadth of net-zero analyses

Net-zero report scope

Included in June 2022 Report

> Electrification Scenario with Sensitivity Analysis
> Three Potential Supply Mix Futures (Not including 100% renewables)
> Resource Adequacy Assessment
> High-level Generation Cost Estimates
> Carbon Output (Less Oilsands)
> Transmission cost (Rough Estimate)
> High-level commentary on potential market and operational challenges

Not Included in June 2022 Report

> Recommendation to Policy Makers (ex. T-Reg, TIER)
> Market Enhancements
> Detailed Delivered Cost of Electricity
> Flexibility/Reliability Assessments
> Detailed Transmission Costs and Rate Impacts

Determine additional analysis required and expect to begin conducting analysis starting Q3 2022 and continue through 2023 LTO / 2024 LTP

Stakeholder engagement

- On December 16, 2021, the AESO launched stakeholder engagement regarding its intended Net-Zero Carbon Emissions Pathways analysis for the electricity sector
- By February 2022, the AESO had received responses from 47 stakeholders (600+ pages), representing electricity generators, consumers, academic organizations and other interested parties
- AESO will continue to work with stakeholders to understand their concern and perspective regarding generation and load evolution

AESO integration of stakeholder feedback

- Focus on costs resulting from the net-zero scenarios
- Define the parameters of the analysis:
  - No expected or modeled changes to the electricity market in Alberta
  - Clearly define regulatory assumptions regarding GHG benchmarks, legislation and carbon pricing

Macroeconomic and Load Modifications:

- Incorporate sensitivity analysis of oilsands production, energy efficiency, EV penetration, and heating system electrification to capture directionality and magnitude of different impacts

Generation Modifications:

- Removing the branding of “Economic Scenario” will enable an agnostic and unbiased approach to a broad range of potential future scenarios
- Drop 100% renewable + storage case – not viewed as viable by stakeholders
- Expand generation scenarios from two to three focusing on levels of renewables and energy storage penetration:
  1. Dispatchable generation, limited renewable growth (Dispatchable Dominant)
  2. High renewable growth with dispatchable generation (First-Mover Advantage)
  3. Very high renewable growth, limited dispatchable growth, backed by storage (Renewables and Storage Rush)
- Incorporate additional storage technologies into analysis (pumped hydro and compressed air)
- Incorporate simple-cycle hydrogen-fired generation options
- Revise nuclear and hydroelectric capital costs to align with recent builds

Preliminary Scenario Details: Load Forecast

Load forecast overview

The AESO's net-zero load forecast is composed of the following driving factors

Base Load

- Most recent economic outlook from CBoC – pandemic rebound, new normal
- No more greenfield oilsands projects
- Energy efficiency based on historical trend

Distributed Energy Resources (<5 MW)

- Higher total DER outlook than the 2021 LTO Clean-Tech scenario
- Solar DER will dominate the DER additions
- Gas DER muted by carbon policy and credits phasing out

Electric Vehicles (EV)

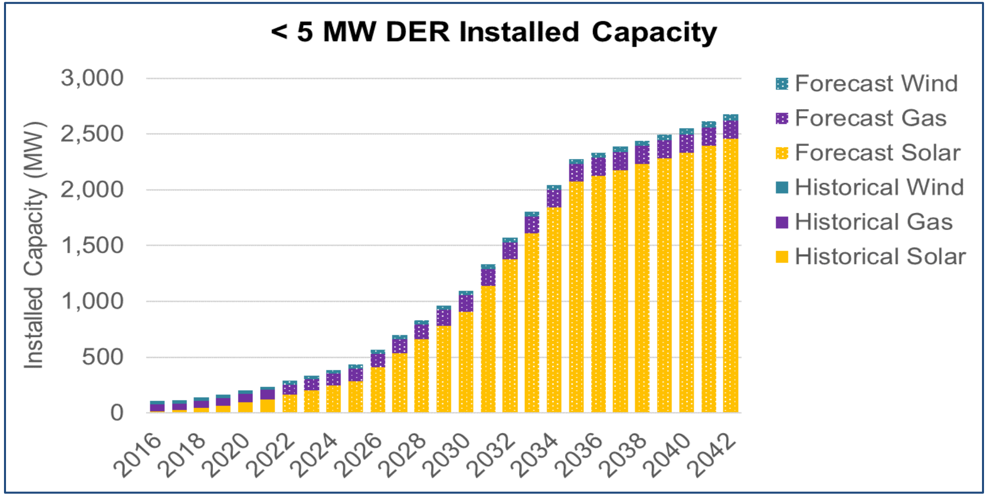
- Refined model to reflect more EV categories (light/medium/heavy duty, buses)
- Vehicle adoption based on policy drivers, not economics
- Improved EV charging profiles and charging needs

Hydrogen Load and Electrification of Buildings

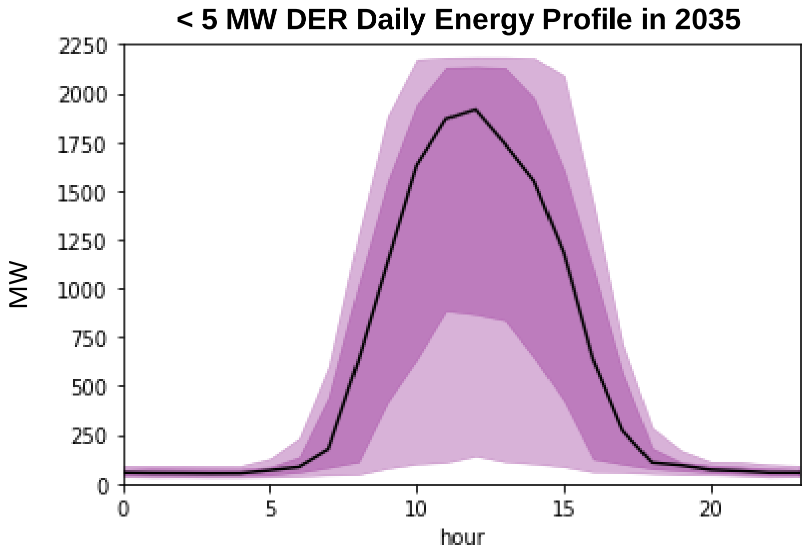
- Ramp up in hydrogen production in Alberta will increase industrial load in the province
- Electrification of space and water heating systems in buildings is expected to be modest in the lead up to 2035 due to lack of policy support

DER (< 5 MW) outlook

- Focus is on key technologies (natural gas, wind, and solar) that currently compose the majority of DERs
  - Each technology is modeled separately based on a combination of historical uptake, regulatory treatment, economic incentives and capital costs
- Solar DER is expected to have the highest adoption amongst the different technologies



- The dominance of solar means that the DER impact to overall load will be an energy profile that is mostly diurnal and intermittent



Notes: This chart illustrates multiple percentiles of daily energy profiles. The light-shaded areas represent 1-99 percentiles, dark-shaded areas represent > 25 and < 75 percentiles, and the black line represents the median.

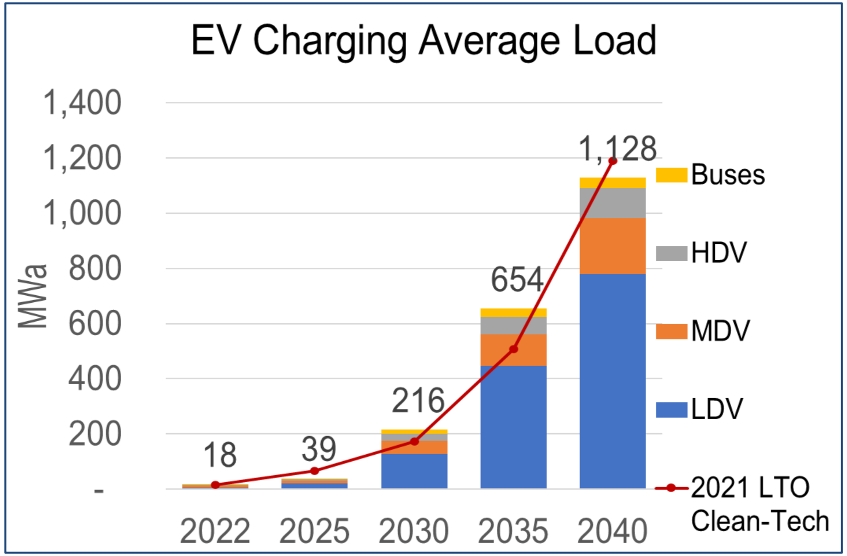
Electrification of the transportation sector

- Each vehicle segment is uniquely assessed

Vehicle	Adoption	Daily charge*	Profile
Light-duty	Federal targets 10% by 2025, 50% by 2030, 100% by 2035	Passenger car = 6 kWh; Truck = 8 kWh	Home and workplace / public charging
Medium-duty	30% of new urban delivery/ utility vehicles by 2040	70 kWh	Depot charging only (no public charging)
Heavy-duty	20% of new short-haul truck sales by 2040	350 kWh	Depot charging only (no public charging)
Buses	55-65% of new buses from 2030 onwards	110 kWh	Depot charging only (no on-route charging)

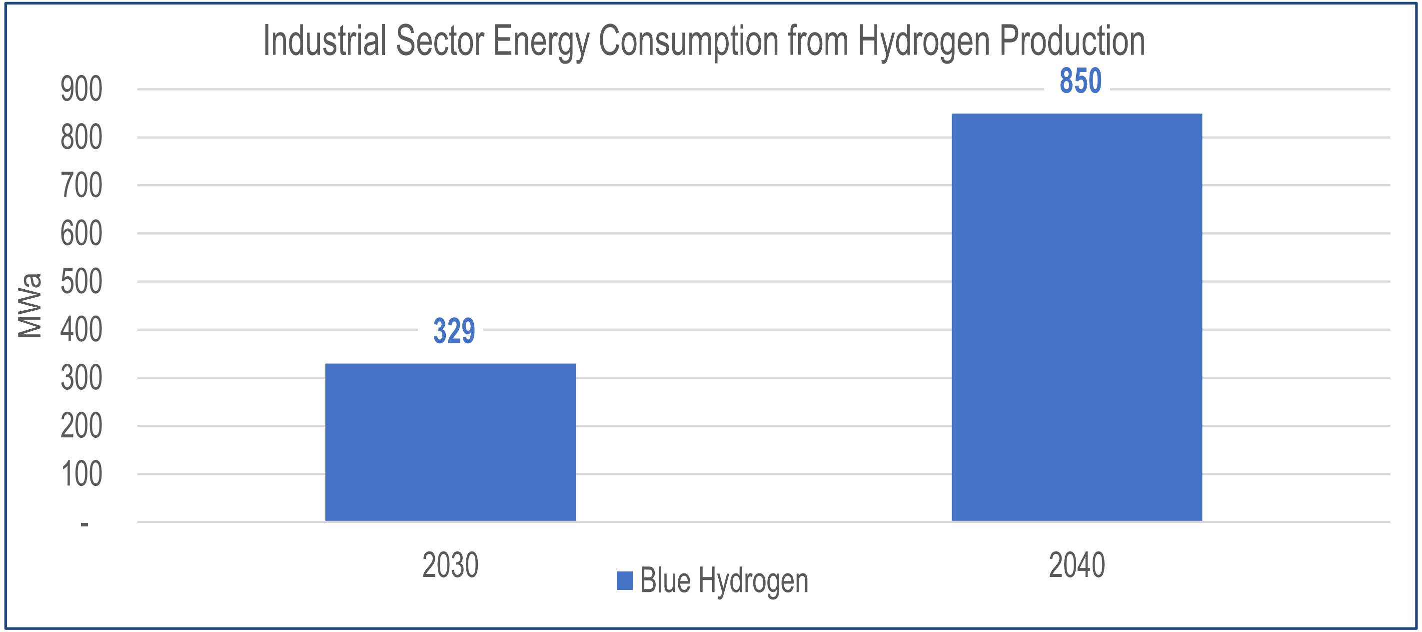
* Assumptions adapted by the AESO from a study developed by Dunsky Energy + Climate Advisors for use by EPCOR in assessing EVs in the utility's service territory

- 30% higher EV load compared to 2021 LTO Clean-Tech in 2035
  – EV load charging profiles can have a significant impact to overall load shape and system needs (see appendix)



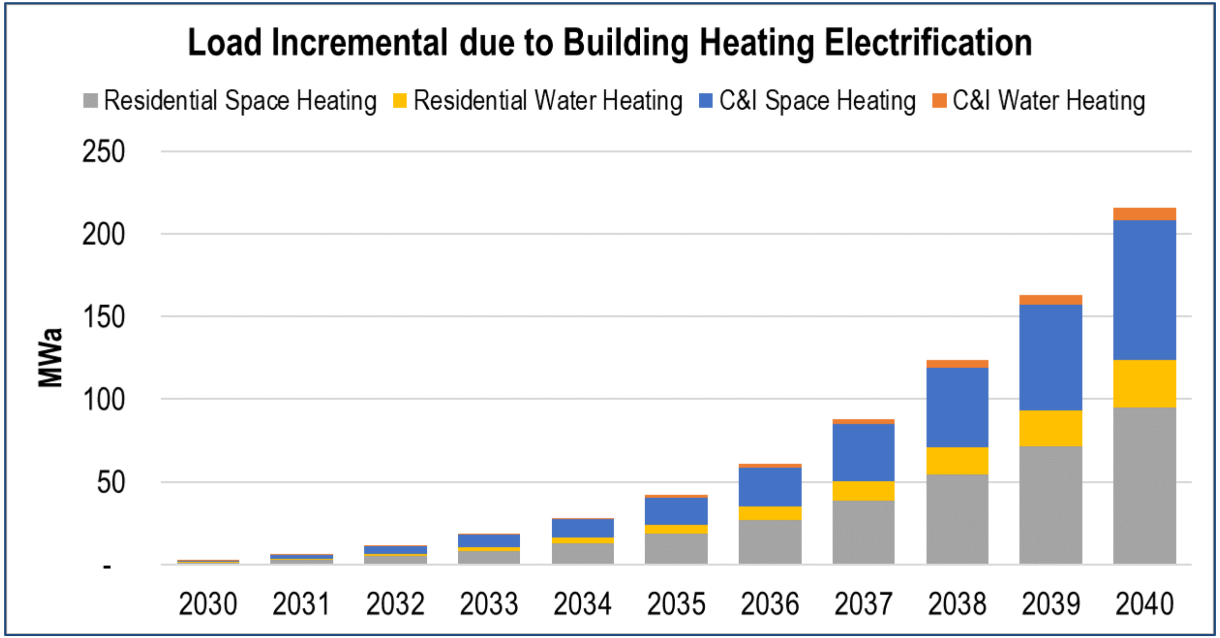
Industrial growth from hydrogen production

- Hydrogen production in Alberta is based on near-term capital projects and Canada Energy Regulator's 2021 Energy Future projections, and aligns with the Government of Alberta's hydrogen roadmap
  - Production is based on blue hydrogen technologies (SMR & ATR)



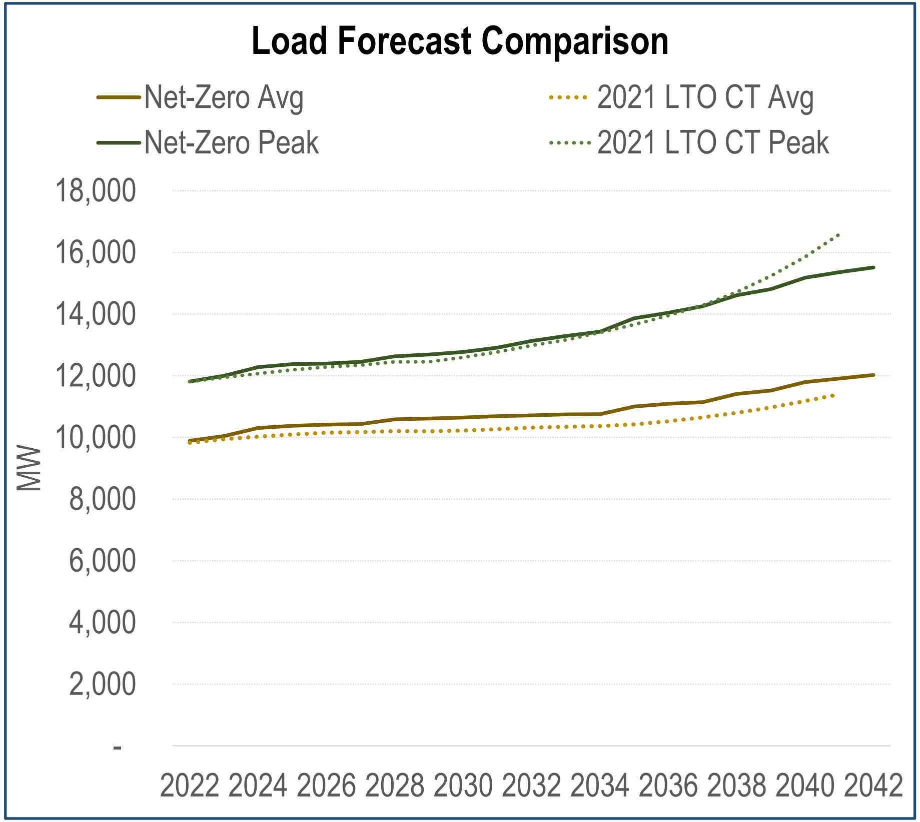
Electrification of heating systems in buildings

- Fuel-switching space and water heating systems from natural gas to electricity requires significant investment and policy coordination – neither of which are prominent in current net-zero commitments
- Modeling assumes uptake in electricity-based heating will be modest by 2035, accelerates beyond that



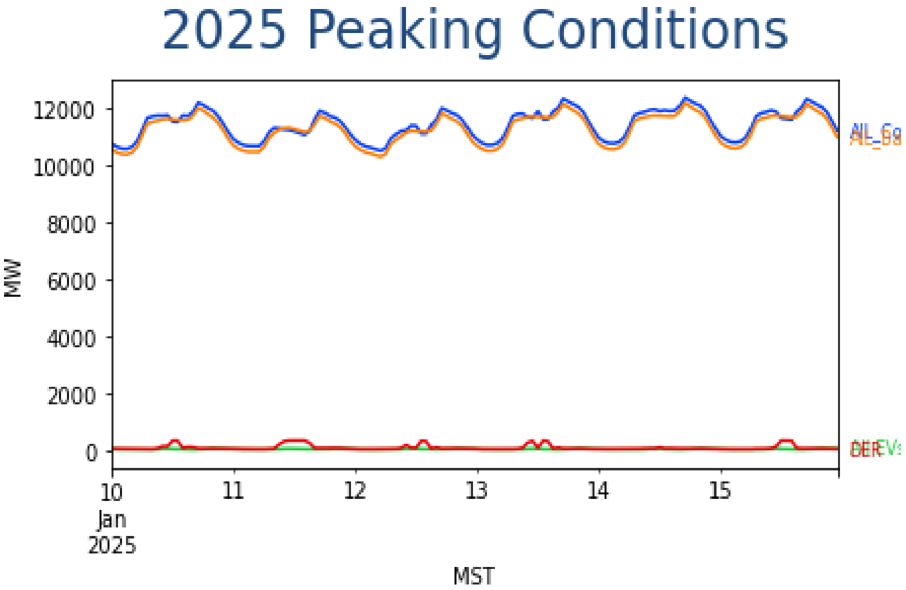
Aggregated impact to load growth

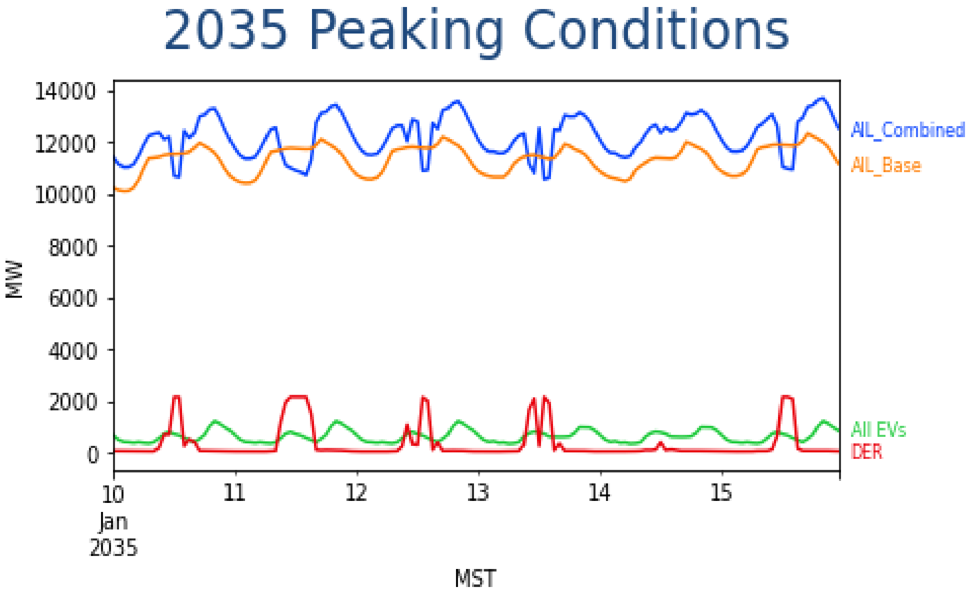
- Impact of electrification (due to the decarbonization efforts of other sectors and net-zero policies) will translate in an increase of overall load in Alberta
- Annual growth is forecast at 1.0%, while peak load growth is 1.4%
  - Average load is higher than 2021 LTO Clean-tech
  - Peak load is higher than 2021 LTO Clean-tech until late 2030s
- Peak load growth mostly driven by EV charging
  - Managed EV charging explains difference in peak growth in late 2030s compared to the 2021 LTO
  - DER impact is minimal (no solar during winter peaks)



Impact to peak demand

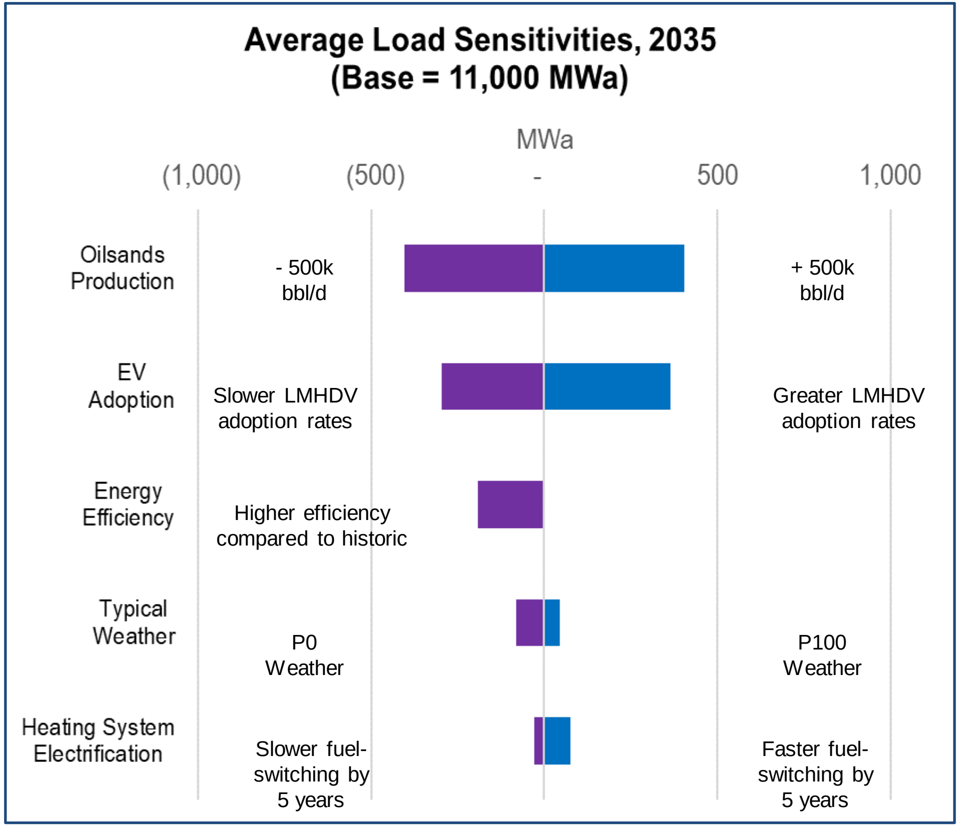
- Increased electrification and adoption of net-zero technologies will change daily energy profiles and affect typical peaking conditions
  - System flexibility (variability and ramping), transmission congestion assessments, grid planning, and real-time operation processes will need to be assessed under a new net-zero "normal"





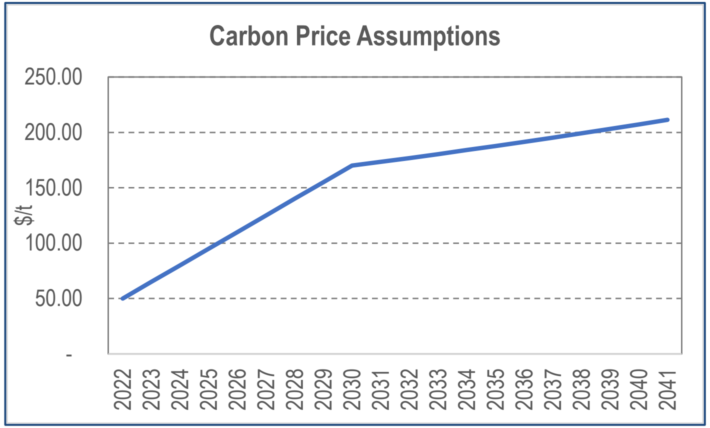
Sensitivity of load drivers and signposts

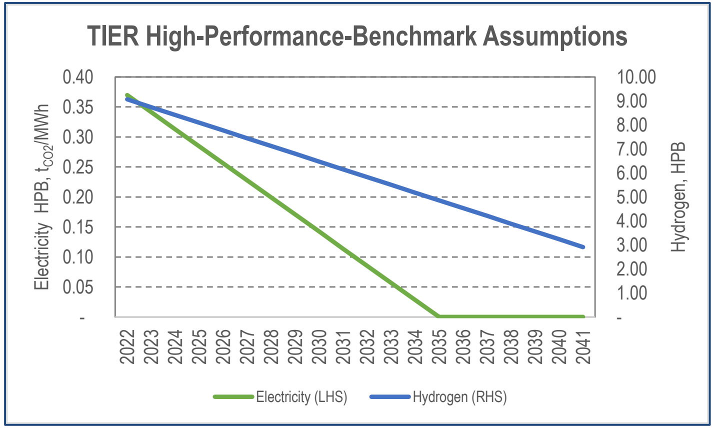
- Multiple factors can affect load growth pace and directionality
  - Isolating these impacts is critical for evaluating signposts relevant to further electrification and net-zero efforts
- Signposts include
  - Growth prospects of the energy sector in Alberta
  - Federal targets and subsidies incenting EV adoption, especially MHDVs
  - Technological and/or policy push towards more energy efficiency
  - Changes in “typical” weather conditions
  - Policy changes (e.g., building code) and subsidies to promote fuel-switching of space/water heating systems



Preliminary Net-Zero Generation Forecasting

Key regulatory assumptions





- Generation supply forecasts are predicated on certain policy assumptions that could incentivize net-zero enabling technologies:
  - Carbon prices are forecast to rise to $170/tonne by 2030, and then escalate at an inflationary rate
  - The forecast assumes the continuation of Alberta's *TIER Regulation,* with a modification of the "High-Performance Benchmark" for the electricity sector, declining to zero by 2035
    - The impact in the electricity sector is that there will be no allowance for emissions by 2035 (currently benchmarked against "best-in-class" combined cycle technology)
    - Carbon emissions will be fully exposed to the carbon price by 2035
    - Emissions Performance Credits generated by the electricity sector will decline in value until 2035 (based on the "high-performance benchmark" for electricity), at which point they will no longer generate value

Generation assumptions

- Hydrogen (H_2) fired generation assumptions
  - Earliest availability date: estimated at 2027
  - H_2 source : Steam Methane Reformer (SMR) or Autothermal Reformer (ATR)
    - Capital and operating costs associated with H2 production have been rolled into commodity price ($/kg)
    - CO_2 sequestration costs and estimated value of offset credits rolled into commodity price
- CC with CCUS modeling assumptions
  - Parasitic load: 7.4% of gross power output
  - Variable cost increases: approximately double
- Hydro assumptions
  - Build cycle (at least 10 years)
  - Capital cost updated to $14,545/kW (based on a $16B capital cost and 1,100 MW capacity)
- Nuclear
  - Build cycle (estimated to be at least 10 years)
- Wind / Solar modeling assumptions
  - Capital cost reductions expected for both technologies
- Storage cost assumptions
  - Battery storage costs are expected to decline
- Carbon & Emissions
  - $170/t by 2030 Federal policy assumed
  - Use of carbon offsets and credits allowed to achieve “Net-Zero” emissions
  - Cogeneration emissions will be dealt with in the sectors under which they report their emissions (not the electricity sector in many cases)

Preliminary Scenario Details: Generation

Scenario comparison

- Lending to the diversity of stakeholder feedback, the AESO has expanded its net-zero pathways to include quantitative analysis of three scenarios that could result from net-zero policies and different technologies:

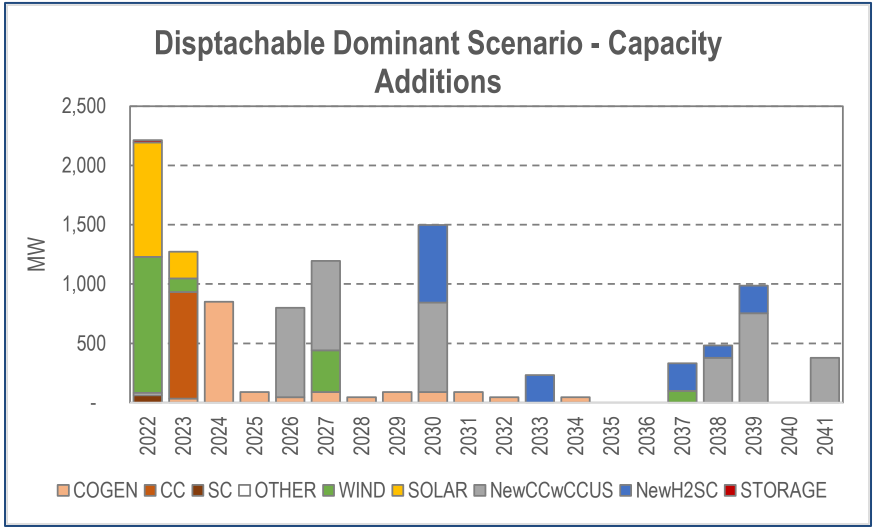
Dispatchable Dominant	First-Mover Advantage	Renewable & Storage Rush

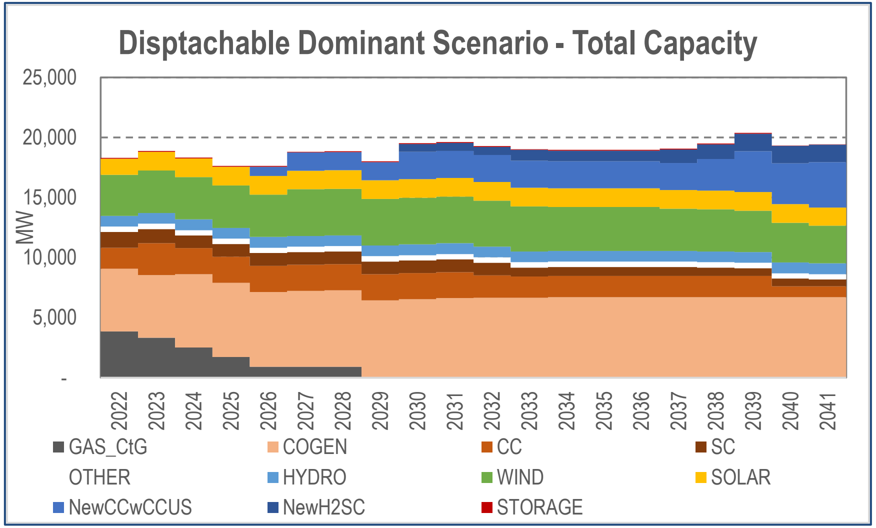
▪ Focuses on dispatchable low-emissions technologies with carbon-capture as major contributors to capacity development
  ▪ Hydrogen-fired generation and post-combustion carbon capture techniques are expected to dominate supply additions
	▪ Rapidly decreasing cost for wind and solar energy lead to increased penetration in Alberta's generation landscape
	  ▪ These technologies, readily available today, accelerate through the 2020's
	  ▪ Favored by corporate sustainability objectives, renewables continue to develop
	▪ Hydrogen simple-cycle generation fills some of the voids left by intermittent renewables
		▪ Significant development of wind and solar generation continues through the forecast horizon and dominates generation capacity additions
		▪ Diverse energy storage technologies provide the dispatchability requirements of the grid, as a result of significant cost declines
		▪ Thermal generation is limited to hydrogen peaking units

Dispatchable dominant scenario – Assumptions and signposts

- Combined-cycle with CCUS dominant through 2035 with hydrogen peaking units following post 2030
- Scenario presumes cost declines, enabled by government support for carbon capture technologies
  - Full CCUS capability for combined-cycle assets by 2026 (including storage hubs and transport)
  - Hydrogen pipeline infrastructure available post-2030

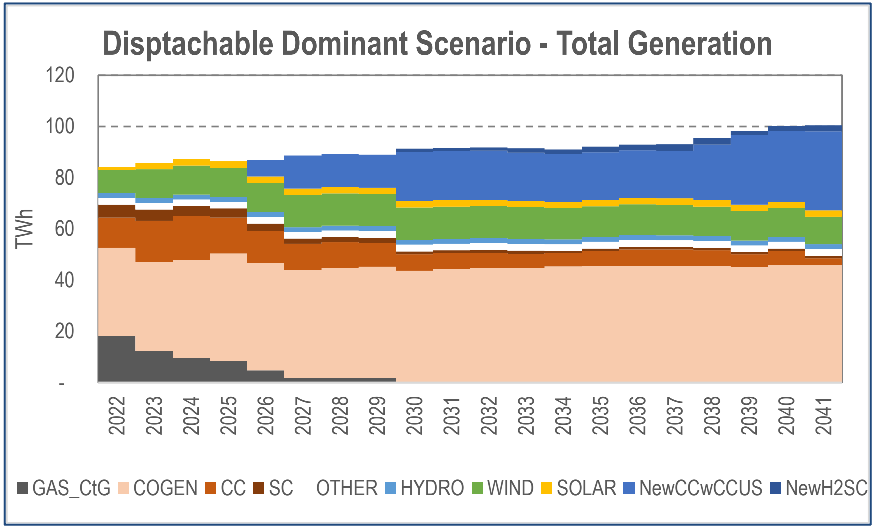
Dispatchable dominant scenario – Preliminary generation builds and capacity

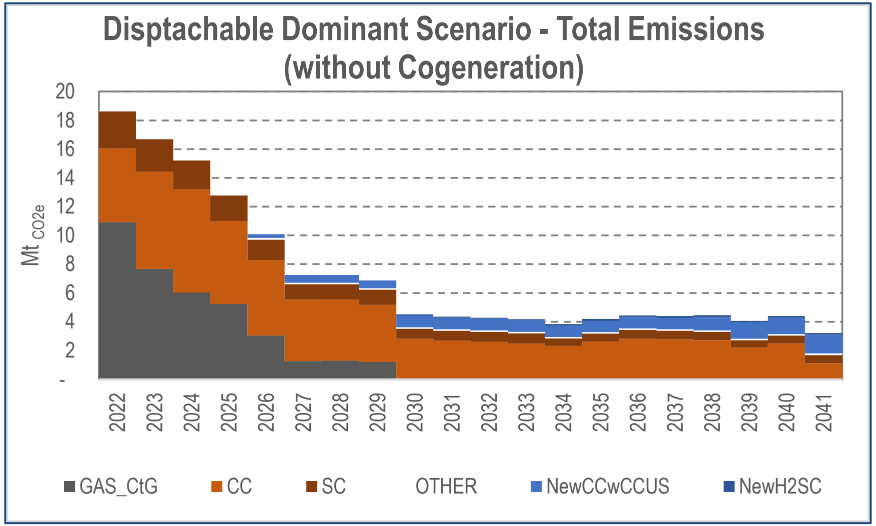




- A diverse suite of new technologies is added to Alberta's generation fleet, including:
  - 3,770 MW of combined cycle with CCUS
  - 1,456 MW of hydrogen-fired simple cycle generation
  - 1,515 MW of cogeneration
  - Limited amounts of wind (1,711 MW) and solar (1,190 MW) generation

Dispatchable dominant scenario – Preliminary total generation and emissions



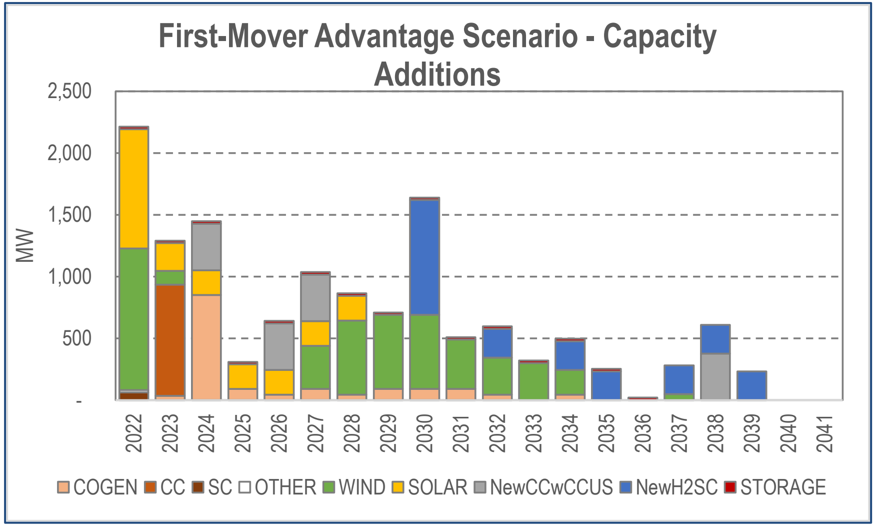


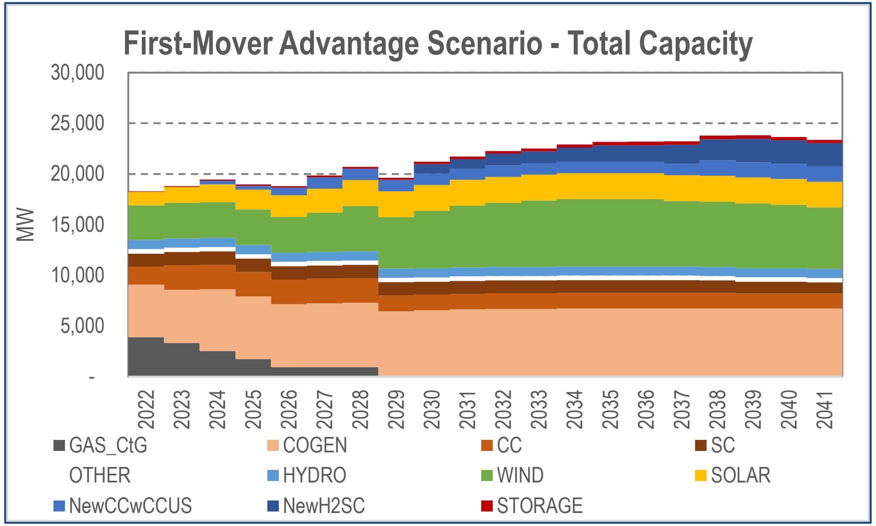
- Low emissions hydrogen-fired and CC with CCUS technologies produce a growing portion of net generation by 2035
- Emissions are estimated to be approximately 4 Mt from the electricity industry
  - This level of emissions would need to be mitigated using offsets and emissions performance credits
  - May also see retrofitting/replacing brownfield thermal assets

First-mover advantage scenario – Assumptions and signposts

- Renewable Corporate PPAs continue to add supply to Alberta's grid
- Renewable cost declines are anticipated to continue, supporting wind and solar economics
- Wind and solar additions continue in the 2020s and slow after 2035 due to the decreasing EPCs and offset value
- Combined-cycle generation with CCUS and required infrastructure is developed on a timely basis
- Hydrogen infrastructure in place for the start of the next decade

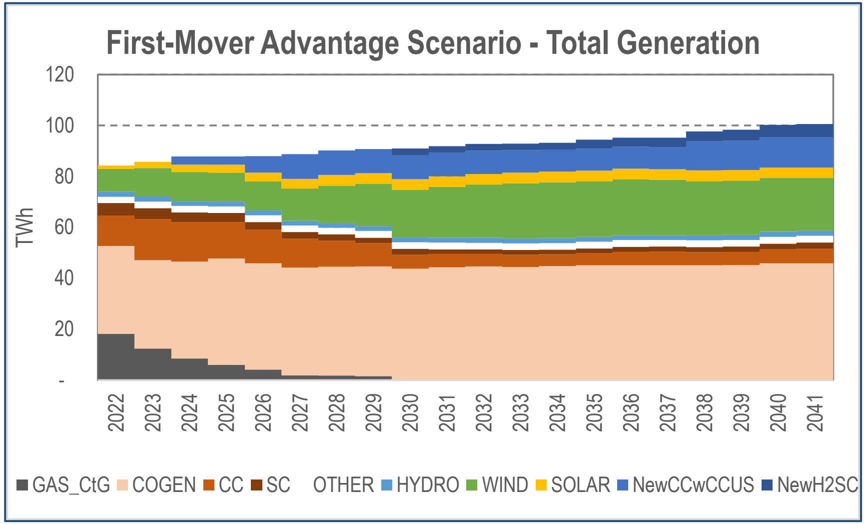
First-mover advantage scenario – Preliminary generation builds and capacity

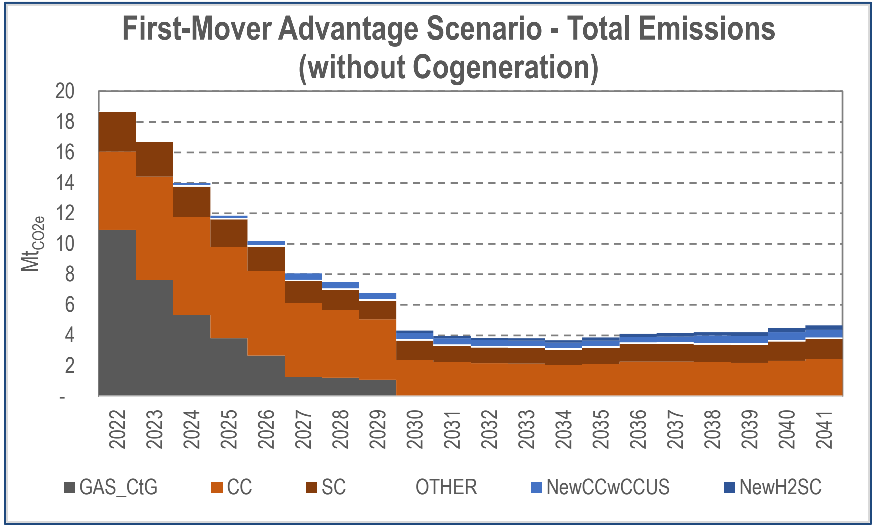




- Renewable growth is prominent in this scenario, with significant amounts of combined cycle with CCUS and Hydrogen-fired generation:
  - 1,508 MW of combined cycle with CCUS
  - 2,326 MW of hydrogen-fired simple cycle generation
  - 1,515 MW of cogeneration
  - 4,661 MW of new wind and 2,190 MW of new solar generation
  - 300 MW of battery energy storage

First-mover advantage scenario – Preliminary total generation and emissions



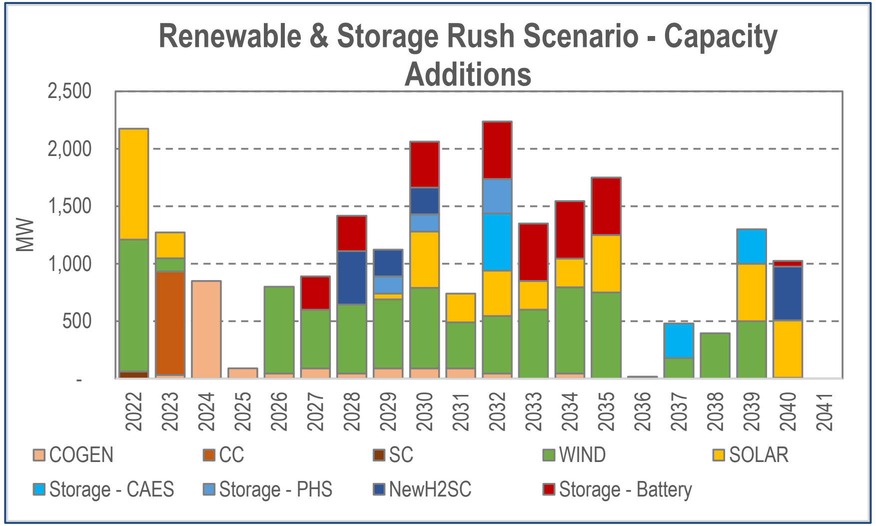


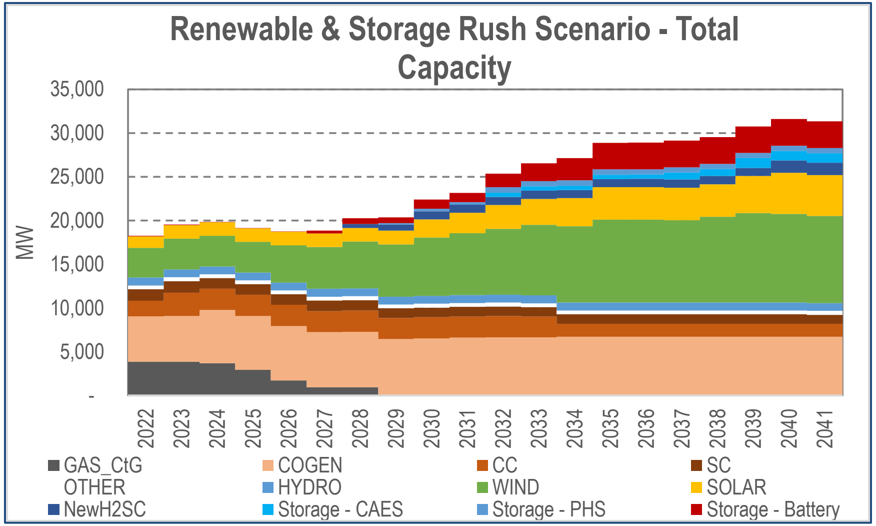
- Zero emissions renewables account for 32% of provincial generation by 2035 (30% by 2030)
- Low emissions hydrogen-fired and CC with CCUS technologies produce a growing portion of net generation by 2035
- Emissions are estimated to be under 4 Mt in 2035 from the electricity industry
  - Emissions are modestly lower than the Dispatchable Dominant scenario
  - Existing units may also retrofit/replacing brownfield thermal assets with low emission technology

Renewables and storage rush scenario – Assumptions and signposts

- Scenario assumes energy storage development from significant cost reductions, technology advances, or government support
  - 4-hour, 19-hour, and 60-hour energy storage technologies were assumed
- Limit capacity additions from new dispatchable resources
  - Combined-Cycle with CCUS and infrastructure does not advance
  - Limited hydrogen infrastructure in place before 2030

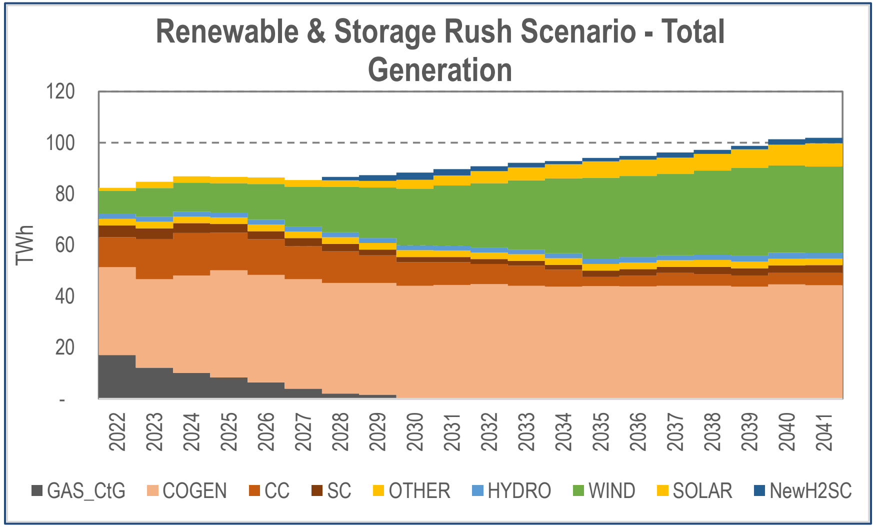
Renewables and storage rush scenario – Preliminary generation builds and capacity

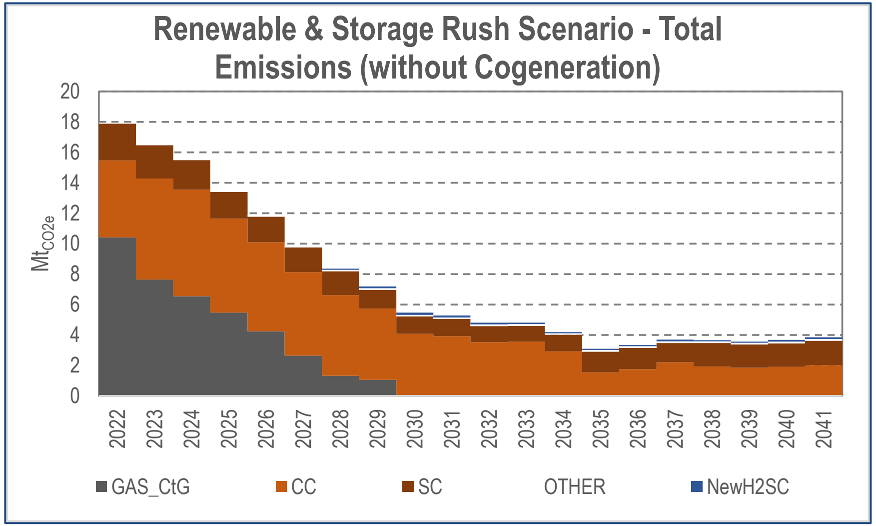




- Storage and renewable growth is very robust to 2041:
  - 1,515 MW of cogeneration
  - 8,527 MW of new wind and 4,376 MW of new solar generation
  - 4,745 MW of storage including 3,048 of battery energy storage, 1,096 MW of compressed air energy storage, and 600 MW of pumped hydro storage
  - Limited amounts of thermal capacity, 1,396 MW of hydrogen-fired simple cycle generation

Renewable and storage rush scenario – Preliminary total generation and emissions





- Zero emissions renewables account for 45% of provincial generation by 2035 (34% by 2030)
- Emissions are estimated to be approximately 2 Mt from the electricity industry
  - This level of emissions would need to be mitigated using offsets and emissions performance credits
  - May also see retrofitting/replacing brownfield thermal assets

Alternative net-zero pathways

- The AESO's initial Net-Zero Pathways quantitative analysis does not include alternative approaches that could achieve decarbonization policy objectives
  - Hydroelectric capacity additions could contribute significantly to decarbonization efforts
  - Nuclear generation could also reduce reliance on fossil-fuel generation sources
  - Interties with low-carbon jurisdictions may also enable decarbonization
- Many alternative net-zero technologies may require significant development timelines and regulatory processes
- Government support would likely be required to develop large hydroelectric generation, nuclear generation, or transmission interconnections with other jurisdictions

Total generation capacity and load comparison

Total Capacity (MW)	Dispatchable Scenario	First Mover Scenario	Renewables Storage Rush	2021 LTO Clean-Tech	2021 LTO Ref Case
Technology	2035	2035	2035	2035	2035
Greater than 5 MW generation (Transmission Connected)					
Wind	3,651	6,651	9,466	4,997	4,747
Solar	1,553	2,553	3,724	2,539	1,189
Storage - 4 hour duration	70	330	3,047	1,020	85
Storage - 60 hour duration			496	-	-
Storage - 19 hour duration			600	75	-
Combined Cycle - Hydrogen				-	-
Simple Cycle - Hydrogen	886	1,628	930	-	-
Combined cycle - CCUS	2,262	1,131	-	-	-
Combined Cycle	1,768	1,548	1,475	4,822	2,648
Simple Cycle	741	1,268	1,097	1,544	1,397
Coal to Gas - Steam Boiler	-	-	-	935	2,535
Cogeneration	6,712	6,712	6,712	6,669	6,669
Hydro	894	894	894	894	894
Other	443	443	443	483	423
Total	18,979	23,158	28,885	23,978	20,587
Less than 5 MW generation (Distribution Connected)					
Solar	2,074	2,074	2,074	1,780	638
Wind	45	45	45	52	44
Gas	158	158	158	174	138
Load Forecast (net of <5MW distribution connected generation)					
Peak AIL	13,863	13,863	13,863	13,660	12,666
Average AIL	11,000	11,000	11,000	10,421	10,560

Session Close-Out and Next Steps

Further analysis – Resource Adequacy Modeling

- The AESO will evaluate resource adequacy utilizing its electric system risk model and the associated risk of unserved energy
  - Evaluate all three scenarios for resource adequacy for 2030 and 2035 using RAM with specifications aligned with the net zero load and generation scenarios
  - Potential to evaluate additional scenarios to test standard results and risks
- The tool allows for fast simulation of thousands of iterations of unit performance to identify frequency and magnitude of firm load shed events and determine if the Long-Term Adequacy Threshold is met
- The RAM determines the tradeoff between capacity (MW) and reliability (EUE MWh) using a probabilistic approach that varies load and generation
  - Hourly chronological dispatch using a stochastic (Monte Carlo) simulation
  - Distribution for load/weather, load growth uncertainty, outages, intermittent renewable output, intertie, and emergency operating procedures

Further analysis – Cost estimation

- Review high-level estimates of the system integration and transmission costs of the generation fleet build scenarios
- Estimate the operating costs associated with electricity production
- Estimate the capital costs associated with new generation construction
- Review and revise generation asset level modeling and results
  - New generation plant-level economic analysis
  - Simulated unit operations
  - CTG retirement refinements
- Release Net-Zero Pathways Report in June 2022

Request for feedback

- We invite all interested stakeholders to provide their input on this session and the preliminary modeling results via the questions set out in the **Stakeholder Comment Matrix Net-Zero Preliminary Modeling Results on or before April 11, 2022.** The comment matrix is available on our website at www.aeso.ca
  - Path: Market > Net-Zero Emissions Pathways
- This comment matrix is intended as a follow-up and seeks any additional insights and comments that the AESO will consider prior to the completion of our analysis and final publication of a report by the end of June

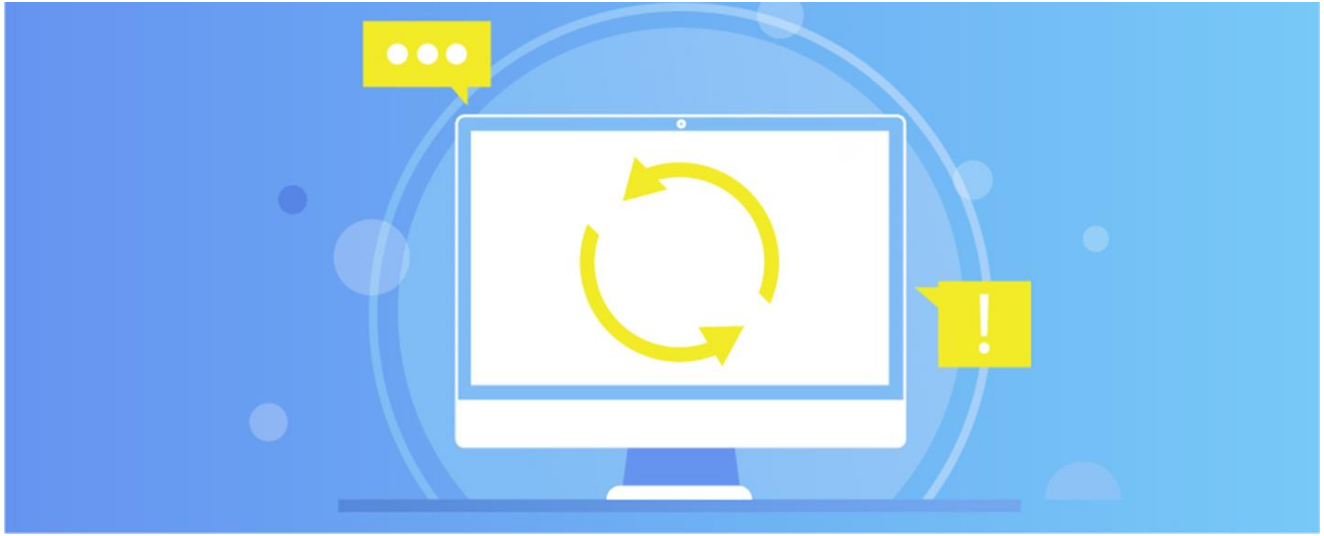
Next steps

- April 11, 2022 | Stakeholder feedback due
- April 13, 2022 | Stakeholder feedback received will be complied and posted
- Mid-May 2022 | Publish a summary directional update
- End of June 2022 | Publish Net-Zero Pathways Report

Session close-out

- We want to thank you for attending the Net-Zero Emissions Pathways Stakeholder Engagement Session and we would appreciate your feedback on the session
- Launch poll
  - The purpose of the session was clear
  - The information was presented in a clear manner
  - The presentation content was clear and informative
  - I found this session valuable

Contact the AESO



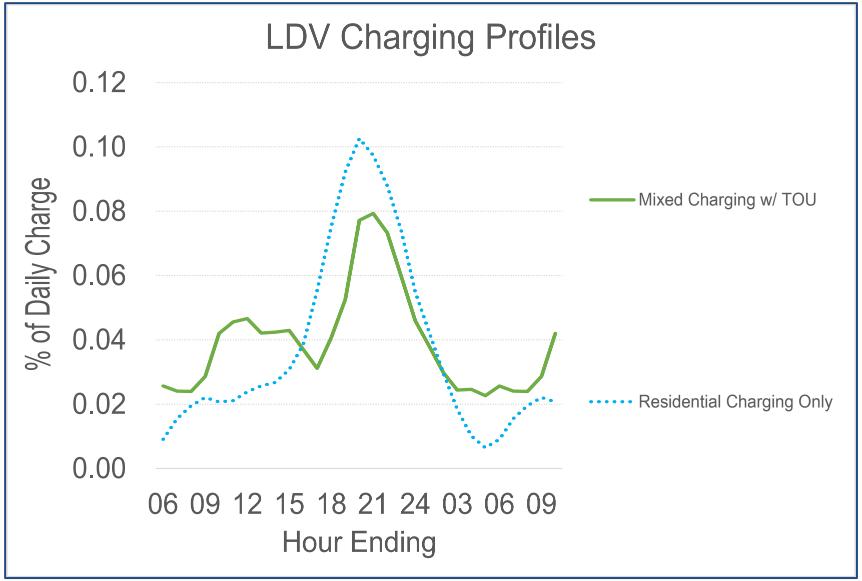
- *Twitter:* *@theAESO*
- ***Email:*** *forecast@aeso.ca*
- ***Website:*** *www.aeso.ca*
- Subscribe to our stakeholder newsletter

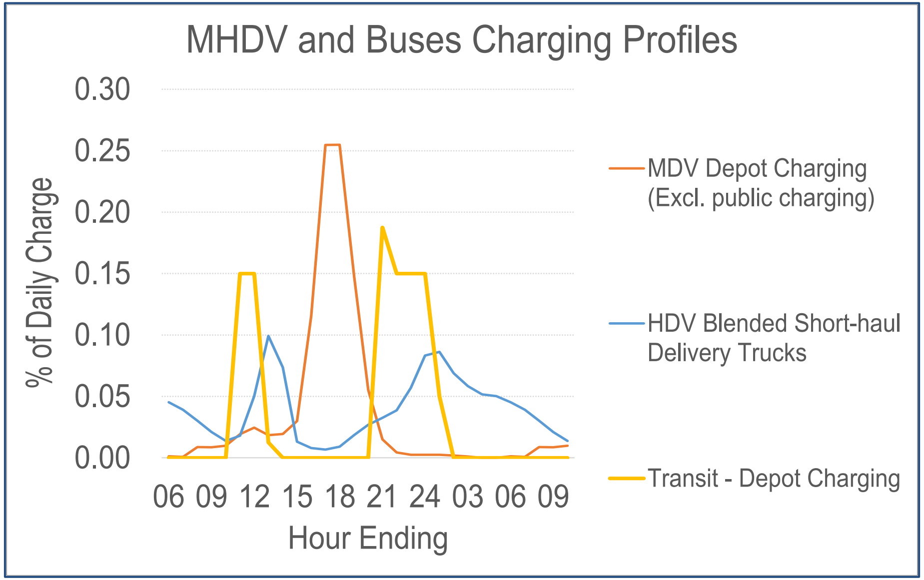
Thank you

Appendix

EV charging behaviour will depend on retail programs and technological advancements

- Unmanaged charging for LDVs is unlikely to continue going forward – managed charging reduces on-peak concentration
  - In recent years, ATCO began piloting an EV fast-charging service rate (Price Schedule D23) while ENMAX's Charge Up pilot program is testing different non-rate-based managed charging approaches
- MDHV and bus charging are limited to depot charging as plans for fast-charging public charging infrastructure remains unclear – depot charging translates into concentrated, high-intensity charging during off-duty hours





But charging profiles could go many ways…

- Each profile has its own set of considerations (economics, technology/grid readiness, reliability and accessibility)
- Value in providing sensitivity of different combination of profiles, provides a range of outcomes instead of deterministic approach

LDV
- Residential only vs workplace/residential vs some % of public charging
- 100% Unmanaged vs 100% Managed vs a blend

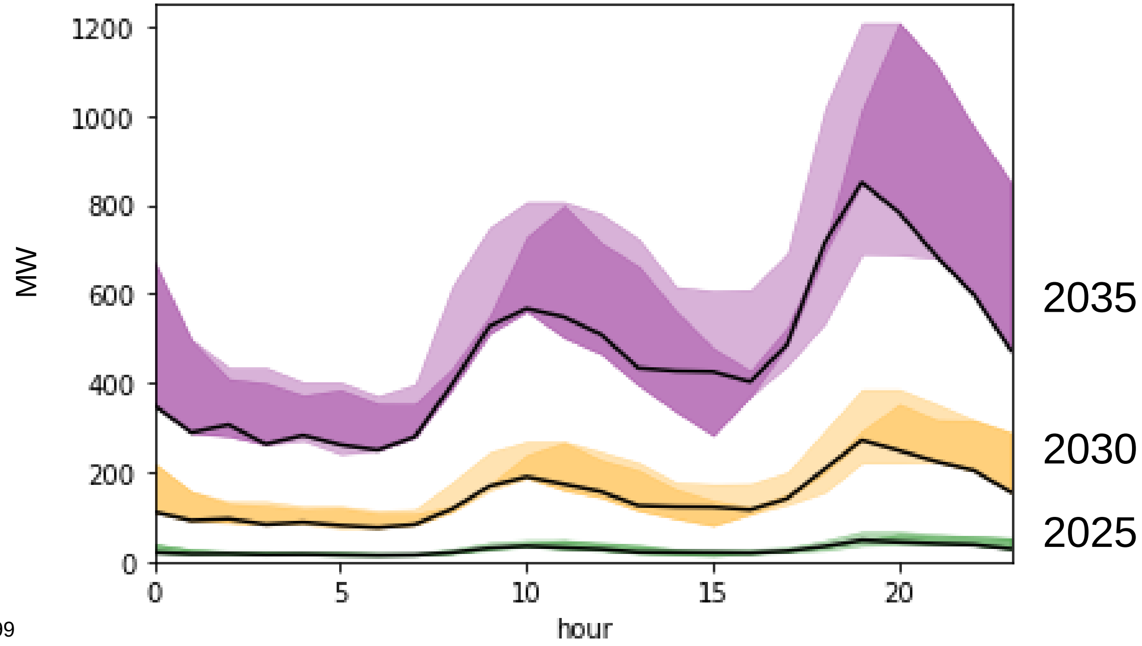
MDV
- Depot charging vs on-route/public charging

HDV
- Depot charging vs on-route
- Use-specific profiles (diurnal, nocturnal, weekday/end shifts)

Buses
- Depot-charging vs on-route

The daily impact gets gradually more impactful over time

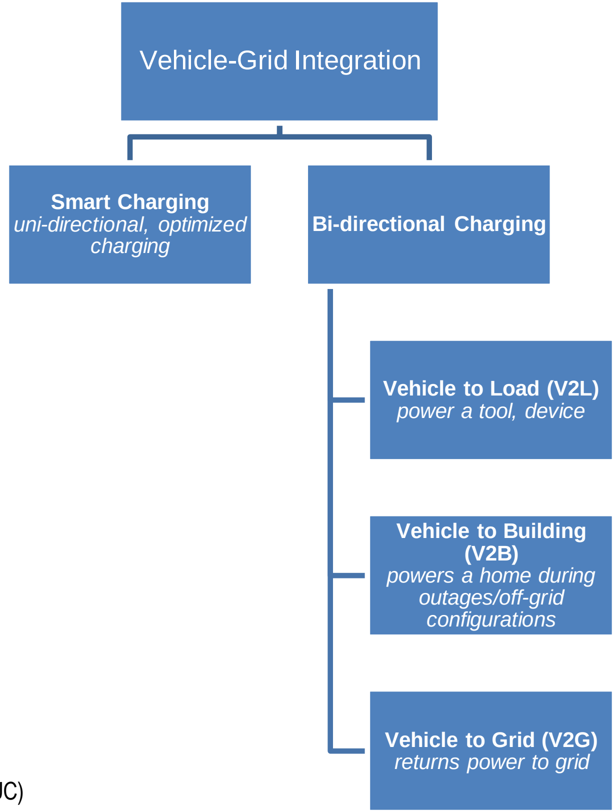
- EV charging load is limited until 2030; more pronounced by 2035 and beyond
- Range is driven by day-of-week and seasonal variations of the entire EV *fleet*



Note on reading this chart: this chart represents multiple percentiles within the range of load. The light-shaded areas = 1-99 percentiles, dark-shaded areas = 25-75 percentiles, black line = median.

Why isn't bi-directional charging in the model?

- Vehicle-grid integration could potentially turn EVs into distributed energy resources[1]
  - Benefits include opportunities to alleviate or manage peak load or congestion impacts, synchronize charging with renewables, enable energy arbitrage, defer grid investments, etc.
- Near-term widespread adoption of VGI technology is unlikely due to
  - Limited utility process/policies – limited residential time-of-use rates[2] or V2G charging processes
  - Technological limitations – limited vehicle selection that can perform bi-directional charging configurations (Ford's F-150 can do V2L/V2B at most)
  - Lack of industry standards – DC/AC bi-directional charger/inverters can be integrated into the vehicle or the station, each presenting its own set of interoperability and safety issues
- Due to these uncertainties, the AESO modelling assumes smart charging for certain segments but no bi-directional VGI



1 For more details, see https://www.dunsky.com/scaling-vehicle-to-grid-v2g-technology-benefits-and-considerations/
2 Only aware of ATCO's TOU pilot in Grande Prairie (Price Schedule D13 included in 2019 Dx Tariff Application and approved by AUC)

Generation technologies included

- The AESO has significantly expanded its "new resource" options within the Aurora forecasting software to focus on Net-Zero enabling technologies
- The following asset types and technological characteristics enhance net-zero modeling efforts:

Technology	Capacity, MW	Capital Cost, $/kW		Fixed O&M, $/kW-yr	Variable O&M, $/MWh
		2022	2030		
Solar PV – 2022; 2026	50	1,643	1,388	31.88	-
Wind – 2022, 2026	50	1,586	1,105	32.50	-
Nuclear Fission	2,156	7,612		153.27	2.99
Nuclear Fission SMR	600	7,801		119.70	3.78
Hydroelectric	100	14,545		37.62	-
Fuel Cell	10	8,442		38.78	0.74
Combined Cycle w CCUS	377	3,126		34.78	7.36
Hydrogen Fired Combined Cycle	418	1,667		49.71	2.49
Hydrogen Fired Simple Cycle – Frame	233	898		26.93	0.74
Hydrogen Fired Simple Cycle – Aeroderivative	105	1,159		52.83	4.24
Battery Energy Storage	10 (4 hour)	1,942	1,456	31.25	-
Compressed Air Energy Storage	100 (19 hour)	1,499		20.31	-
Pumped Hydro Energy Storage	150 (60 hour)	3,305		38.30	-

Storage performance assumptions

Characteristics	Lithium-Ion Battery Energy Storage	Pumped Hydro Energy Storage	Compressed Air Energy Storage
Storage Duration, hours	4 hr	19 hr	60 hr
Storage Capacity, MWh	10 MW	150 MW	100 MW
Round Trip Efficiency (RTE), %	88%	80%	52%

Acronyms

- ATR = Autothermal Reformer
- AS = Ancillary Services
- CBoC = Conference Board of Canada
- CC = Carbon Capture
- CCUS = Carbon Capture, Utilization and Storage
- DER = Distributed Energy Resource
- DFO = Distribution Facility Owner
- EPC = Emissions Performance Credits
- ES = Energy Storage
- EV = Electric Vehicle
- GHG = Green House Gas
- HDV = Heavy-Duty Vehicle
- LDV = Light-Duty Vehicle
- LTO = Long-term Outlook
- LTP = Long-term Transmission Plan
- MDV = Medium-Duty Vehicle
- MHDV = Medium and Heavy-Duty Vehicle
- OR = Operating Reserve
- PPA = Power Purchasing Agreement
- RAM = Resource Adequacy Modeling
- SMR = Steam Methane Reformer
- TIER = Technology Innovation and Emissions Reduction Regulation
- VGI = Vehicle grid integration