ALBERTA'S FUTURE ELECTRICITY GRID

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OUTLINE

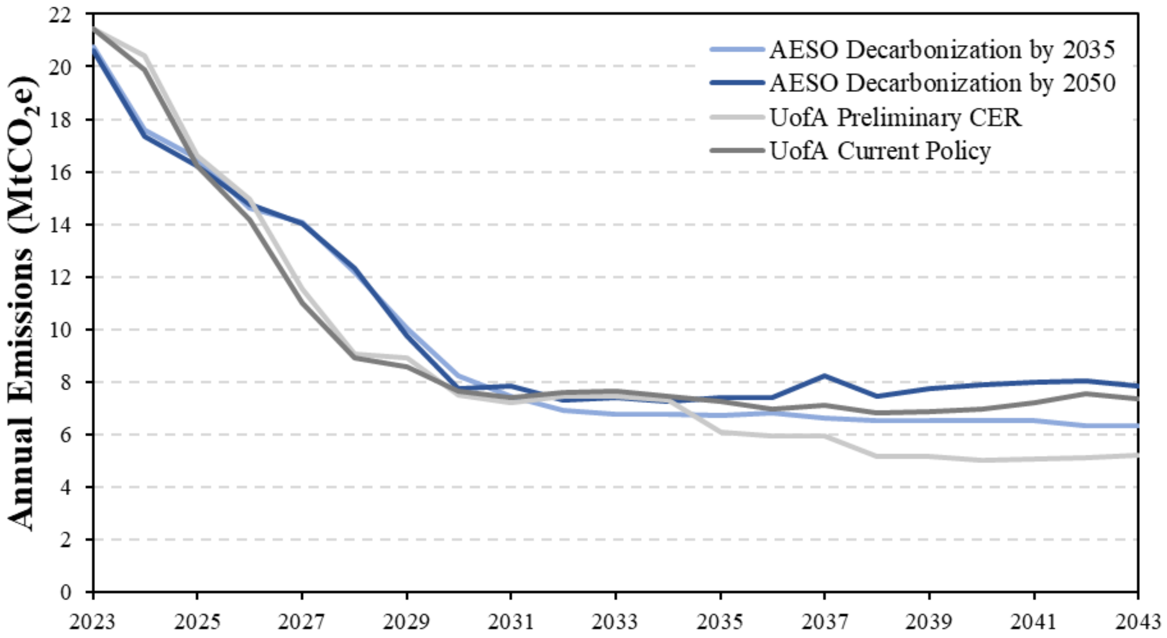
- INTRODUCTION
- CURRENT LANDSCAPE AND NET-ZERO ELECTRICITY
  THE UofA MODEL
  - ASSUMPTIONS AND METHODOLOGY
  - KEY FINDINGS
- CONCLUSION AND FUTURE WORK

PREVIEW

Review the current electricity landscape.

Explore what a transition to net-zero could look like in the electricity sector:

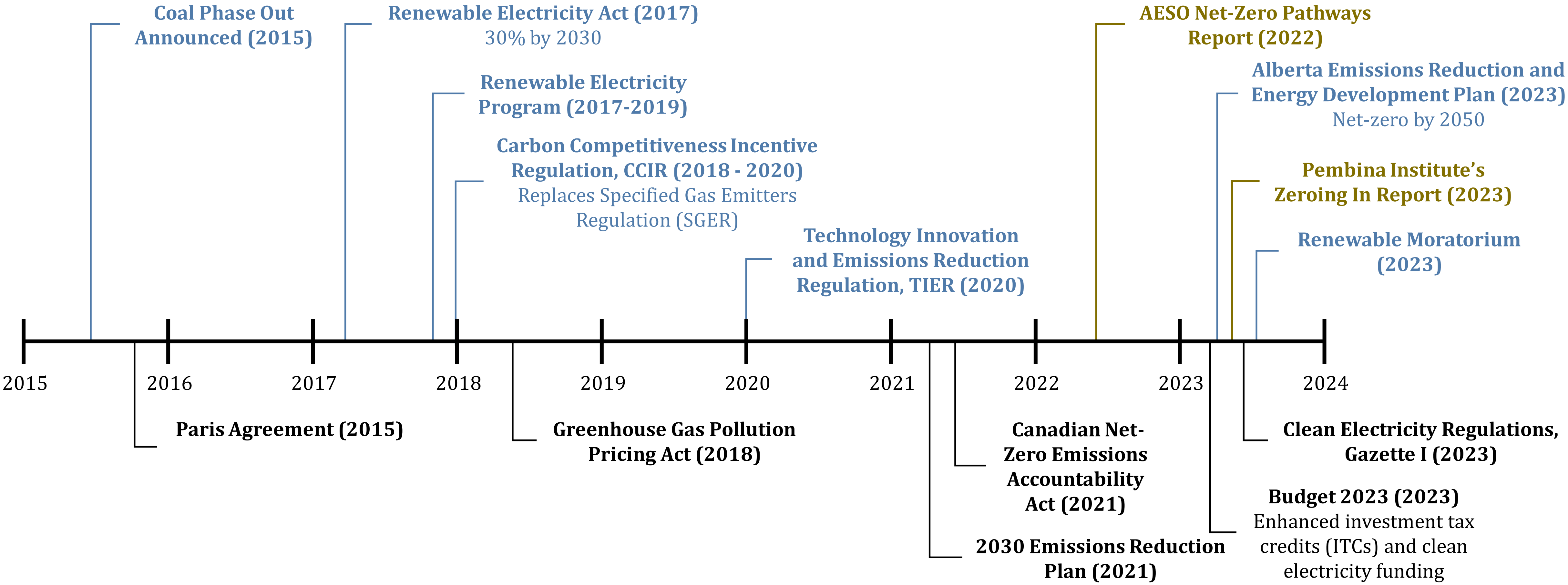
- Wind energy increases 3.5 – 4 times current capacity.
- Alberta as a net-energy exporter.
- Majority of decarbonization in the next 5 years.



Cogeneration emissions remains status quo

ALBERTA GRID MODELING

NET-ZERO MOMENTUM
A SUMMARIZED TIMELINE



AESO – Alberta Electric System Operator

CLEAN ELECTRICITY REGULATIONS (CER)

The draft CER[1] is meant to limit fossil fuel emissions in the electricity sector starting in 2035.

ELIGIBILITY

I. Large power plant
II. Burn fossil fuels
III. Electricity exporter

Large power plants: > 25 MW

ANNUAL COMPLIANCE

Achieve ~95% carbon capture

OR

Limit annual emissions

Exemptions granted during "emergency circumstances"

START DATE

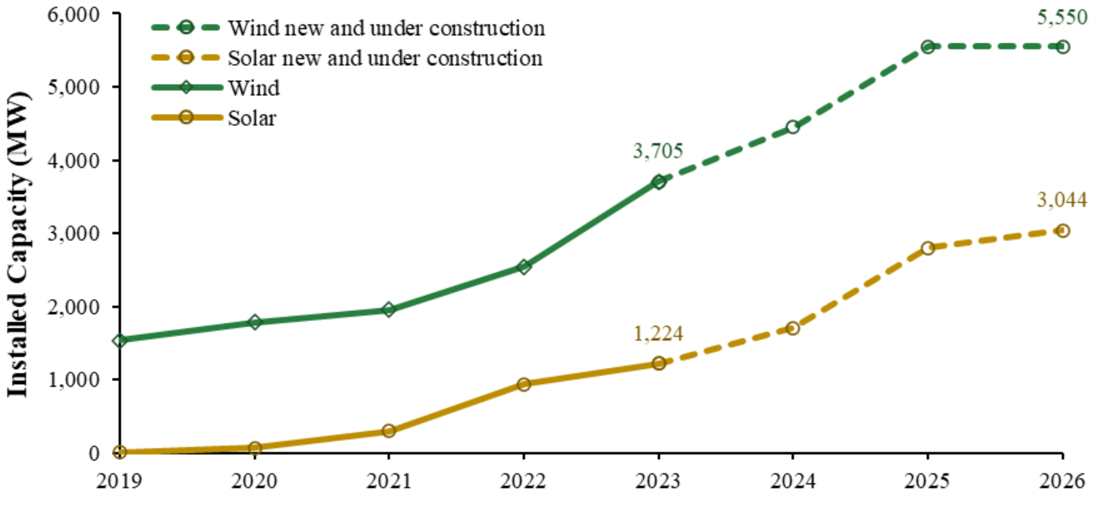
January 1, 2035

- If commissioned before 2025, eligible for a 20-year grandfathering period

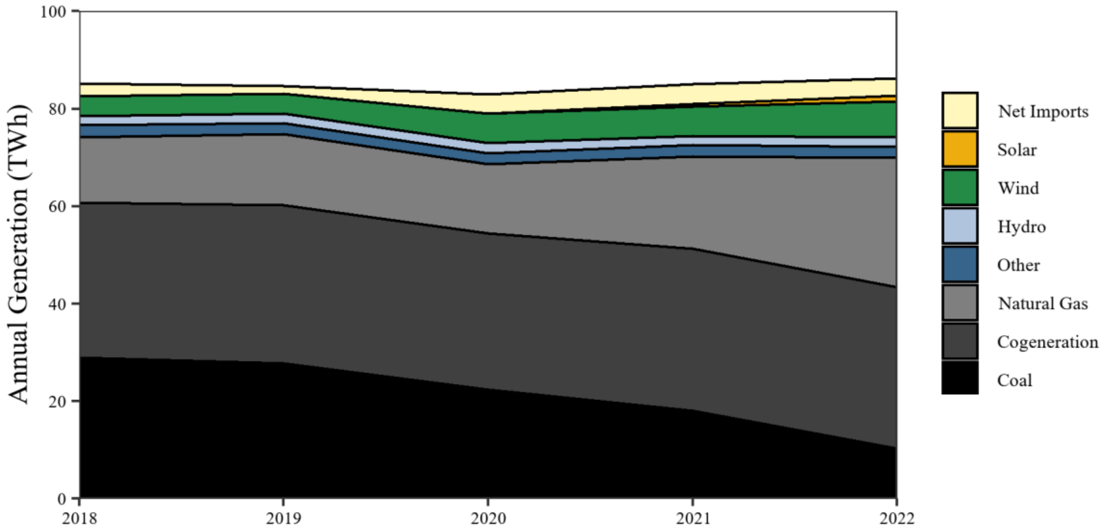
1 https://www.gazette.gc.ca/rp-pr/p1/2023/2023-08-19/html/reg1-eng.html

ALBERTA
ELECTRICITY SUPPLY

- Deregulated competitive wholesale market.
- Alberta has seen enormous renewable energy growth in past 5 years.
- Natural gas remains the dominant fuel source, with coal to be phased out by 2024.
  - 17% of net-to-grid generation and 31% of installed capacity in 2022[2].



Data from AESO Annual Market Statistics and AESO November 2023 LTA

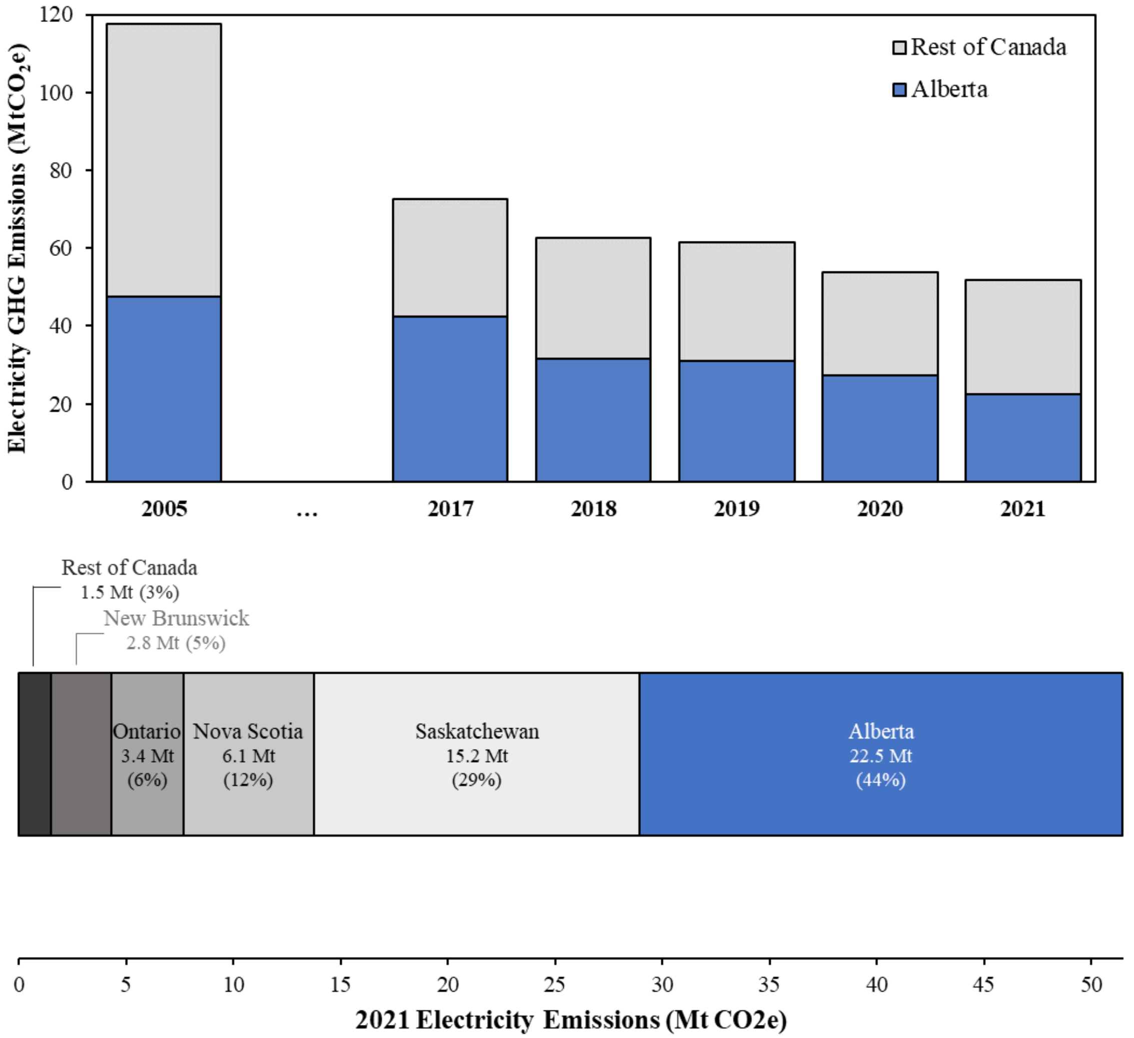


Data from NRGStream

2 https://www.aeso.ca/market/market-and-system-reporting/annual-market-statistic-reports/

ALBERTA
EMISSIONS

- Both Canada and Alberta have reduced emissions over 50% in the electricity sector since 2005[3].
- Canada already generates over 80% of its electricity from clean sources.
- Alberta is the largest contributor to Canada's electricity sector emissions.



Data from Environment and Climate Change Canada

3 https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/greenhouse-gas-emissions.html

NET-ZERO FACTORS

ALBERTA CONSIDERATIONS

Resource Mix

- Northern climate and temperature extremes
- Historical reliance on fossil fuels
- Lack of hydropower (unlike BC or PQ)

Technical

- Reliability
- Industrial load and cogeneration

Other

- Policy certainty
- Capital required

NET-ZERO STRATEGIES

Buildout

- Renewable and storage integration
    - Strong renewable potential
- Strengthen interties
- New technologies such as carbon capture and storage or small modular reactors (SMR)

Other

- Increase energy efficiency
- Grid modernization
- Flexible policy design

RECENT ALBERTA ELECTRIC SYSTEM OPERATOR (AESO) REPORTS

AESO's **Net-Zero Emission Pathways** (2022)[4]

- Forecast three net-zero 2035 scenarios .

AESO's **2024 LTO** (Preliminary Update)[5]

- Decarbonization by 2035 and decarbonization by 2050 scenarios.
- Compared with UofA scenarios.

4 https://www.aesoengage.aeso.ca/net-zero-emissions-pathways-report
5 https://www.aesoengage.aeso.ca/forecasting-insights

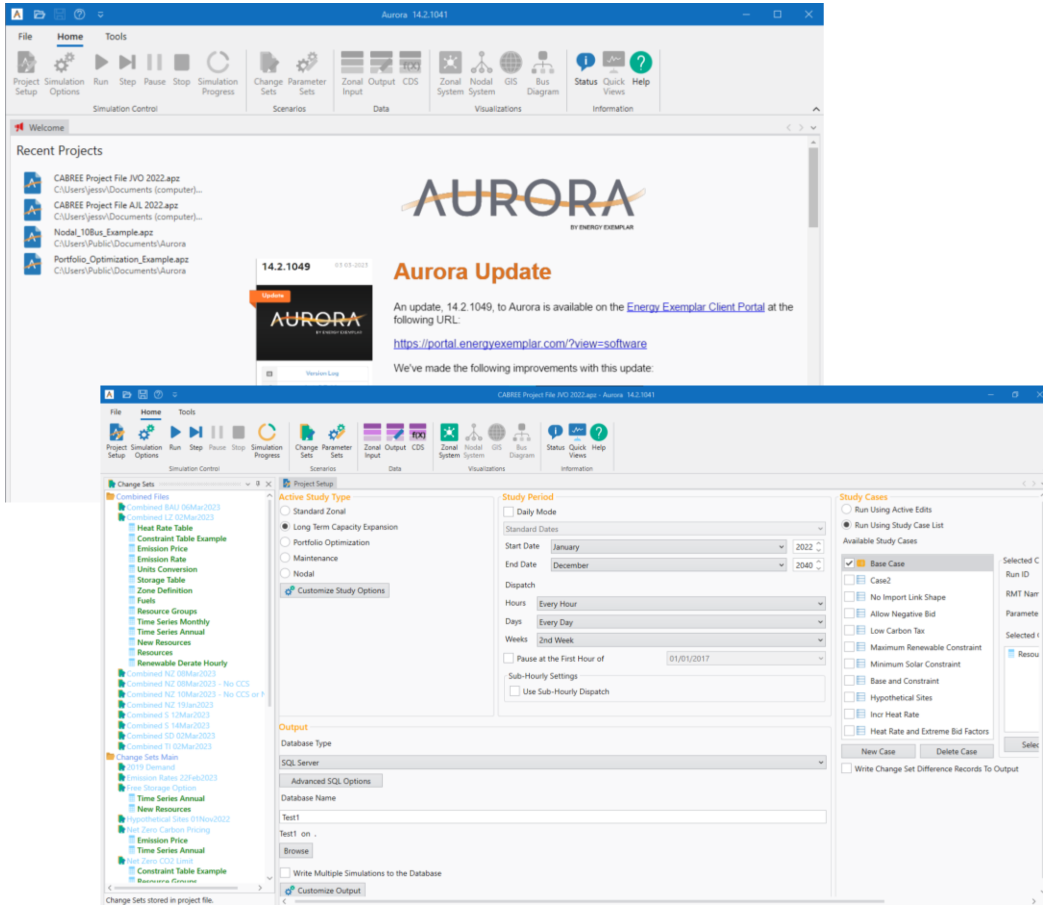
THE UALBERTA MODEL

AURORA

UofA model development started in 2017.

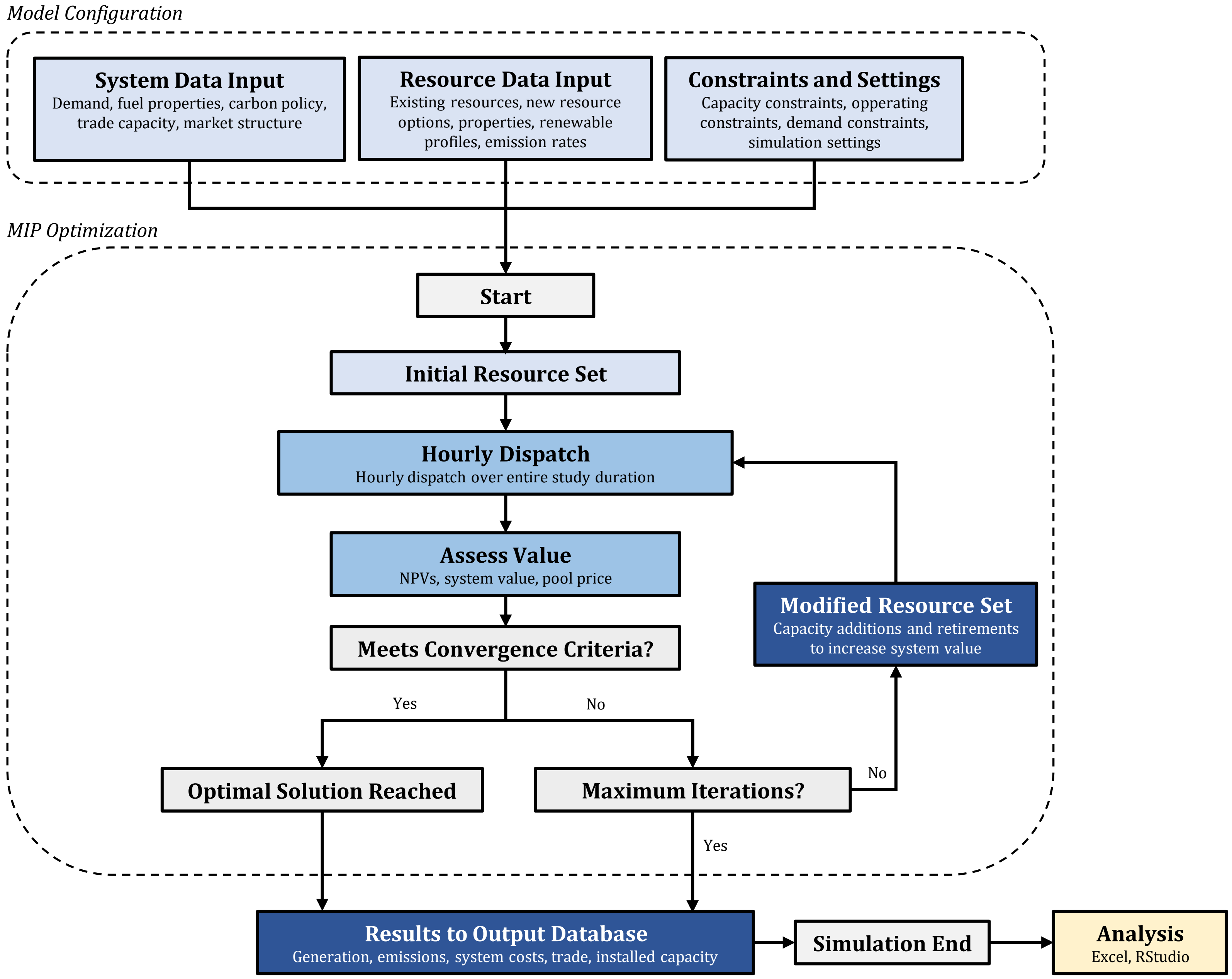
Market modelling software:

- Long term capacity expansions.
- **Inputs:** plant information, fuel prices, Alberta electricity demand, carbon pricing, and more.
- **Outputs:** capacity additions/retirements, system costs, wholesale electricity price, emissions, and more.



GUROBI OPTIMIZATION

WORKFLOW


Model Configuration
System Data Input
Demand, fuel properties, carbon policy, trade capacity, market structure
Resource Data Input
Existing resources, new resource options, properties, renewable profiles, emission rates
Constraints and Settings
Capacity constraints, opperating constraints, demand constraints, simulation settings
MIP Optimization
Start
Initial Resource Set
Hourly Dispatch
Hourly dispatch over entire study duration
Assess Value
NPVs, system value, pool price
Modified Resource Set
Capacity additions and retirements to increase system value
Meets Convergence Criteria?
Yes
No
Optimal Solution Reached
Maximum Iterations?
No
Yes
Results to Output Database
Generation, emissions, system costs, trade, installed capacity
Simulation End
Analysis
Excel, RStudio

CONSTRAINTS

Temporal resolution: Every hour, every day, one week per month

Timeline: 2023-2043 (20 years)

Annual retirement limit: 3500 MW

Objective function: Chronological, maximize the value of the system by comparing NPVs of new and existing resources

Solver: Gurobi

KEY ASSUMPTIONS/INPUTS

Emission Credits	Generated by clean technology based on offset EGDF (wind and solar) or TIER HPB. *Credit Value (\$/MWh) = Price (\$/tCO*$_2$*e) * Benchmark (tCO*$_2$*e/MWh)*
Carbon Price	Following federal (and provincial) schedule – static after 2030 @ $170/t
Intertie Capacity	BC + MT: 1100 MW, SK: 153 MW
Inter-Provincial Interties	Connecting markets are not modelled independently. Rather they are treated as Combined Cycle Natural Gas (CCNG) units being the marginal price cost to compete against. i.e. when AB market prices are below CCNG costs it is possible to export, when above CCNG, the system considers import.
Hydrogen Emissions	Assume zero emission.
Demand Curtailment	Aurora will prioritize meeting demand over system value, curtailment happens as a last resort.
Transmission Modelling	Alberta's electricity market places transmission costs on consumers not generators and are therefore transmission costs are not automatically accounted for in market optimization.
Average and Maximum AIL	Values taken from AESO's Net-Zero Emissions Pathways AIL forecast. These values account for load changes due to projected changes in electrification and Distributed Energy Resources (DERs).
Hourly Demand Shape	Based on Alberta Internal Load (AIL) values taken from 2022 AESO.
Federal Investment Tax Credits	Included based on Budget 2023.

RESOURCE GROUP ASSUMPTIONS

WIND & SOLAR

- Allocated carbon credits
- Availability based on historic weather patterns
- Bid at $0/MWh

FOSSIL FUELS

- Carbon tax applied
- Bidding based on historic behavior
- Combined cycle plants have carbon capture retrofit option

COGENERATION

- Excluded from emissions policy
- Not eligible for retirement
- “Must run” units
- Bidding based on historic behavior

STORAGE

- Price based dispatch
- Consider battery, compressed air, or pumped hydro

Large scale hydro and nuclear SMR were considered but not built in either scenario

NEW RESOURCE OPTIONS

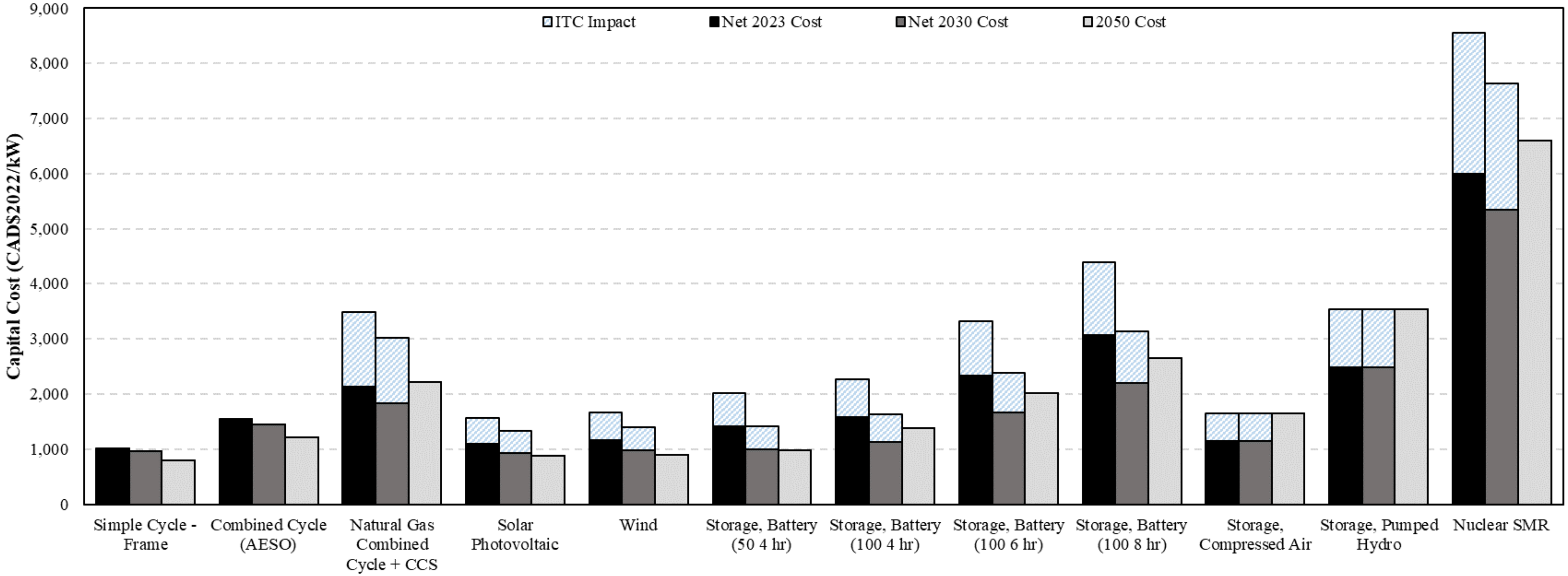
Plant Type	Fuel	Heat Rate [GJ/MWh]	Fixed O&M [$2022/kW-year]	Variable O&M [$ 2022/MWh]	Lifetime	First Eligible Year	Source
Hydroelectric	Water	NA	42.77	NA	100	2026	AESO
Combined Cycle	Hydrogen, Gas	6.79	20.20	3.65	25	2025	AESO
Simple Cycle - Aeroderivative	Hydrogen, Gas	9.68	23.35	6.73	25	2025	AESO
Simple Cycle - Frame	Hydrogen, Gas	10.45	10.03	6.45	25	2025	AESO
Natural Gas Combined Cycle + CCS	Nat Gas	7.52	39.53	18.28	25	2025	AESO
CCS Retrofit	Gas	7.52	39.53	18.28	25	2027	AESO
Nuclear SMR	Uranium	10.60	136.07	4.30	60	2030	AESO
Biomass (Other)	Biomass	14.24	138.00	10.00	45	2025	E3MC
Solar Photovoltaic	Sun	NA	32.42	NA	32	2025	CEC
Wind	Wind	NA	71.95	NA	30	2026	AESO

Plant Type	Storage Type	Efficiency [%]	Fixed O&M [$2022/kW-year]	Variable O&M [$ 2022/MWh]	Lifetime	First Eligible Year	Source
Storage, Battery (50 4 hr)	Lithium ion	88	57.28	NA	20	2025	AESO
Storage, Battery (100 6 hr)	Lithium ion	88	23.52	NA	12	2025	CEC
Storage, Battery (100 8 hr)	Lithium ion	88	23.52	NA	12	2025	CEC
Storage, Compressed Air	Compressed Air	52	21.76	NA	20	2025	CEC
Storage, Pumped Hydro	Pumped Water	80	38.05	NA	100	2026	AESO

Source Description:
AESO – AESO 2024 LTO Preliminary Results[6]
CEC – Clean Energy Canada A Renewables Powerhouse Report[7]
E3MC – Cost estimates published in Clean Electricity Regulations[8]

6 https://www.aesoengage.aeso.ca/forecasting-insights
7 https://cleanenergycanada.org/report/a-renewables-powerhouse/
8 Canada Gazette, Part 1, Volume 1, Number 1: Clean Electricity Regulations

NEW RESOURCE CAPITAL COSTS



Capital costs were reduced based on NRELs Annual Technology Baseline Cost and Performance Data for Electricity Generation[9] data.

9 https://catalog.data.gov/dataset/2023-annual-technology-baseline-atb-cost-and-performance-data-for-electricity-generation-t

SCENARIO ASSUMPTIONS

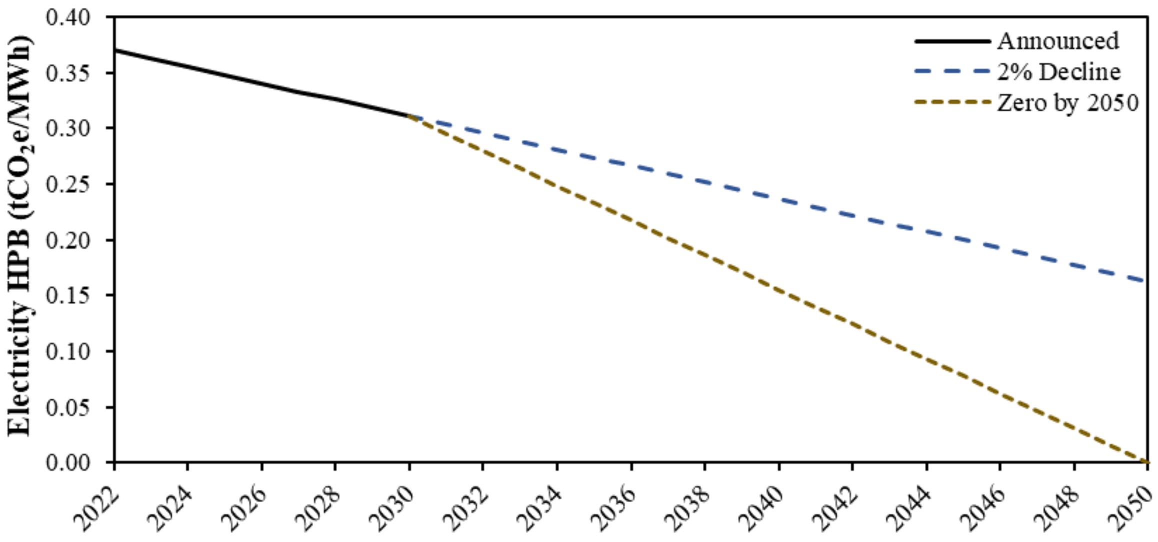
Current Policy Scenario

- Follows current carbon pricing trajectory.

Preliminary CER scenario

- Full carbon price exposure by 2050.
- Limit annual generation from unabated fossil fuels*.

	Current Policy	Preliminary CER
Exposure to carbon price	2% annual increase in exposure	Full exposure by 2050
Flexibility Constraint (CER)	No	Yes

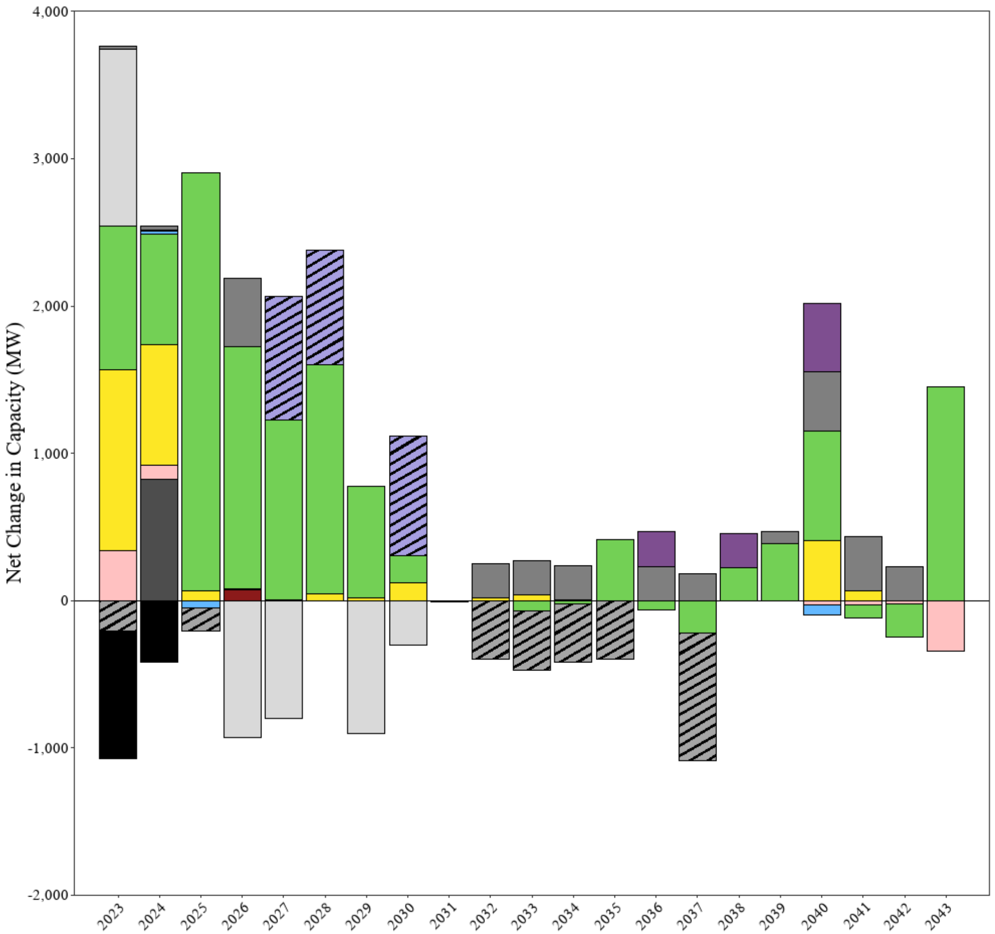


**Simplified application of CER. 450 hour operating limit represented by a 5% capacity factor constraint.*

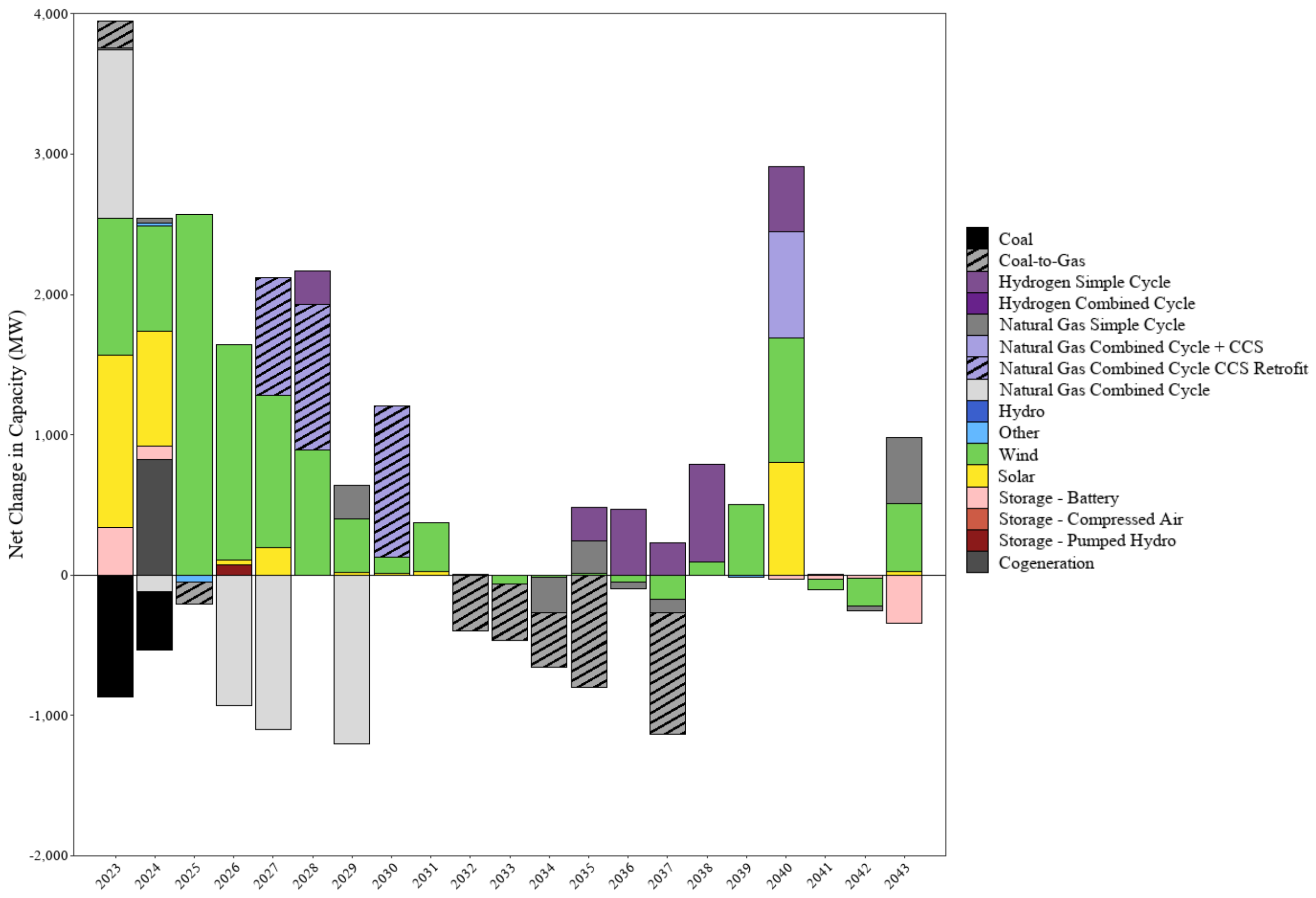
PRELIMINARY RESULTS

NET ANNUAL CAPACITY CHANGES

U of A



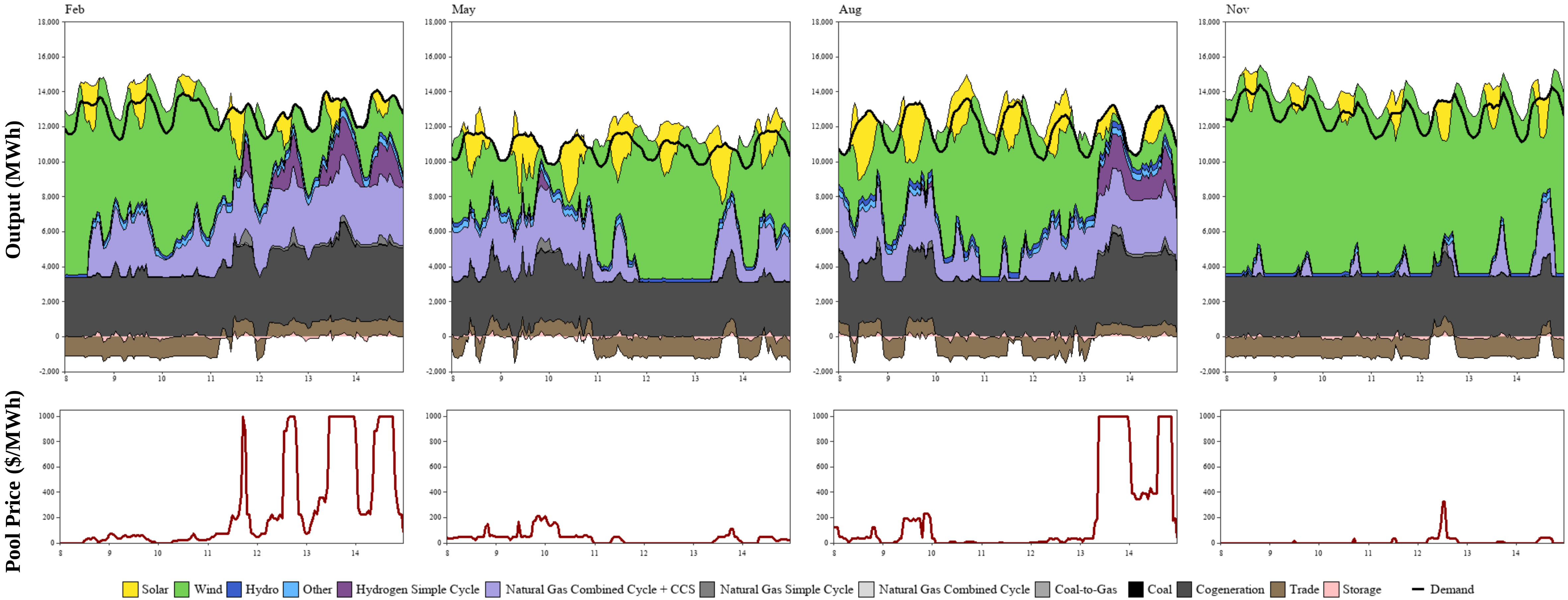
Current Policy



Preliminary CER

EXAMPLE WEEKS IN 2040

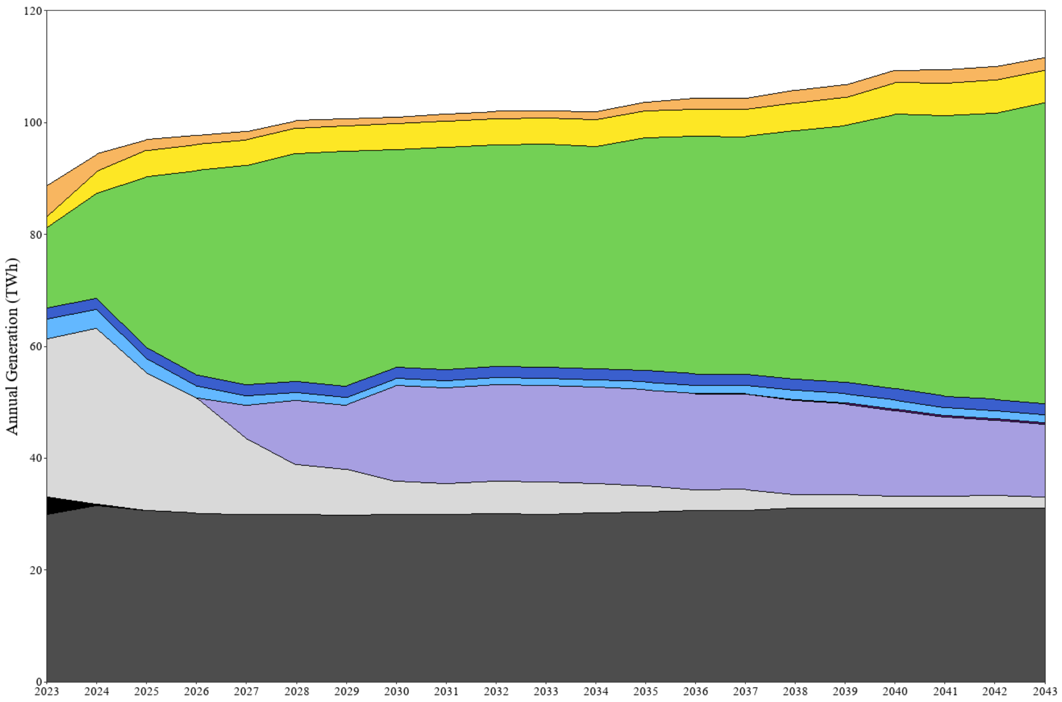
U of A



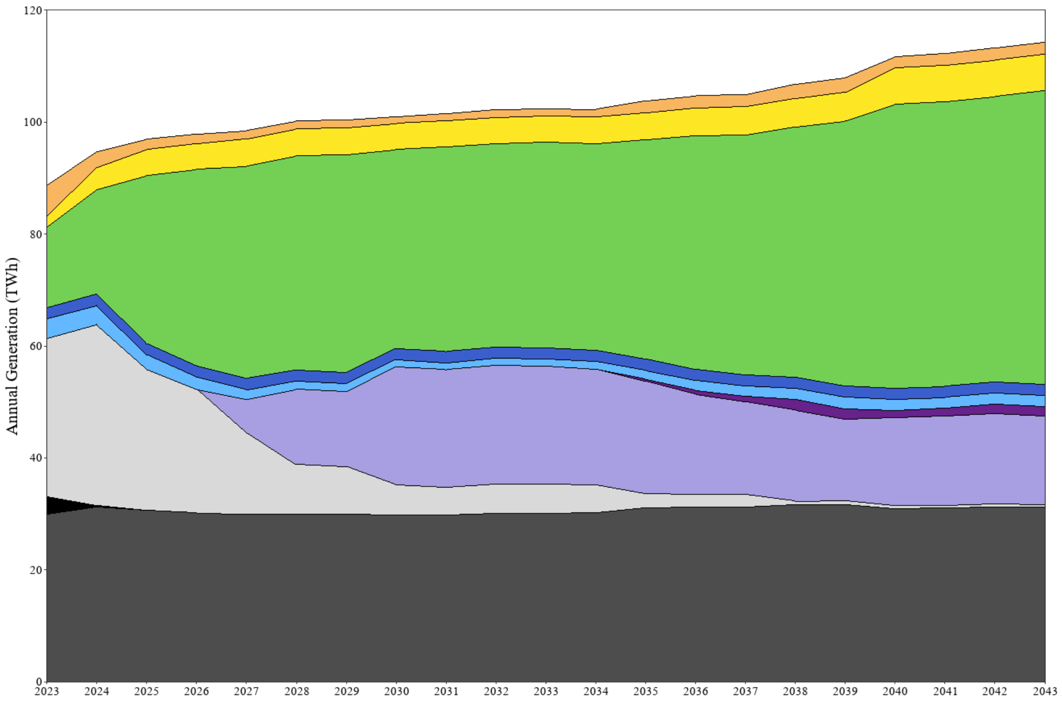
year: 2040 , Database: LZ2050_CF5_23Nov2023

ANNUAL GENERATION

UofA



Current Policy



Preliminary CER

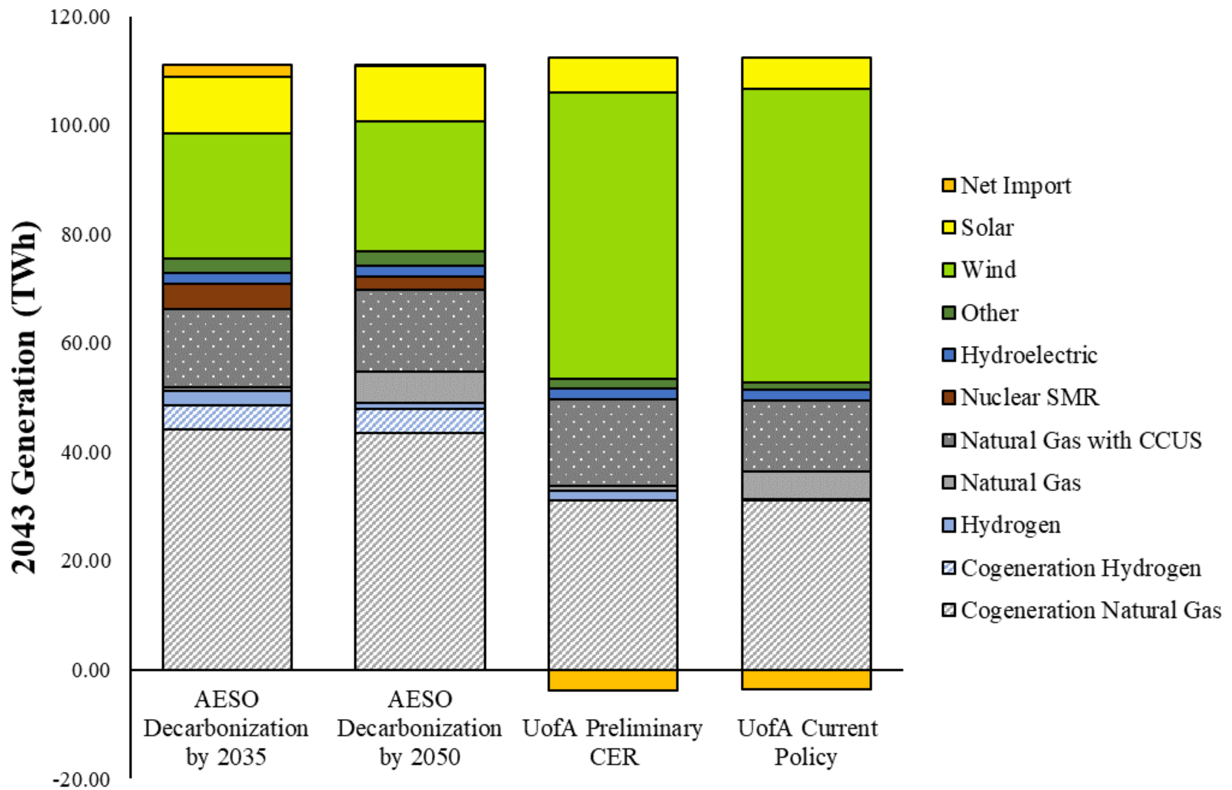
Import Solar Wind Hydro Other Hydrogen Natural Gas + CCS Natural Gas Coal Cogen

ALBERTA GRID MODELING

2043 GENERATION & NET IMPORTS

UofA Scenarios

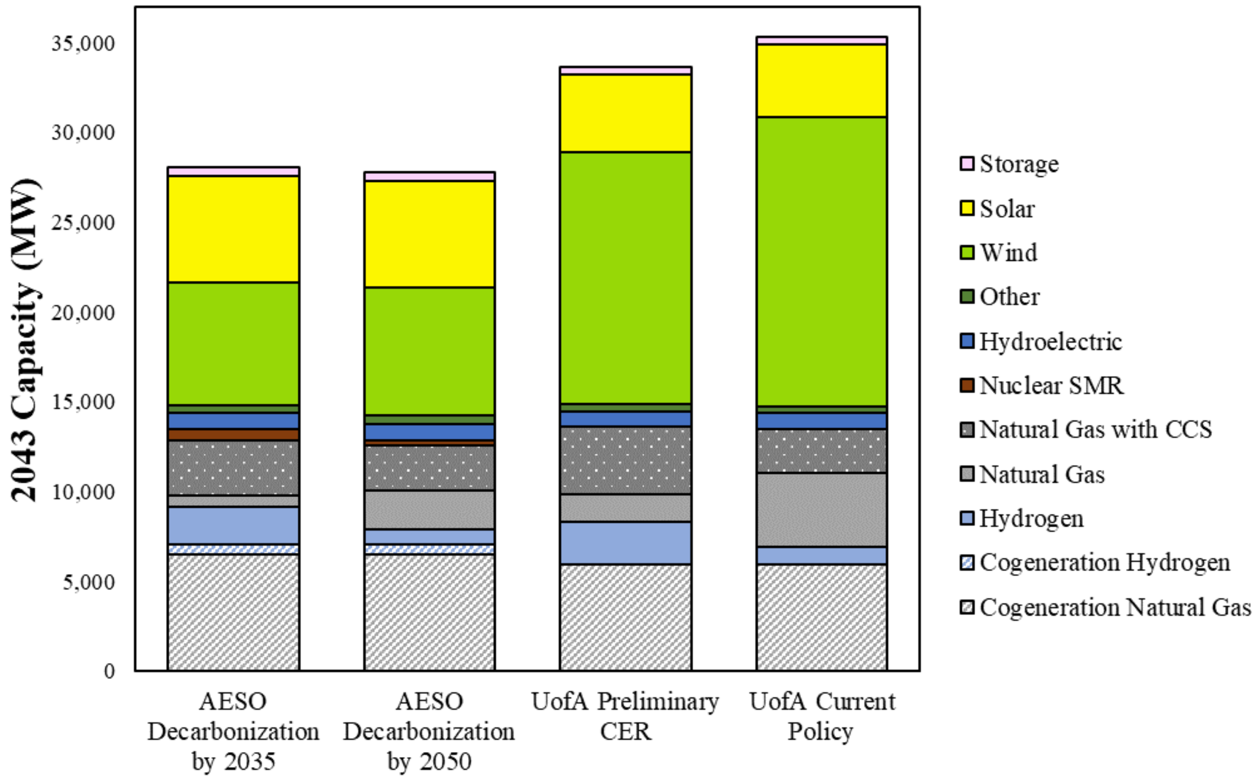
- Alberta is consistently a net exporter (AESO results similar in earlier years).
- Wind supplies nearly half of total generation.



CAPACITY

UofA Scenarios

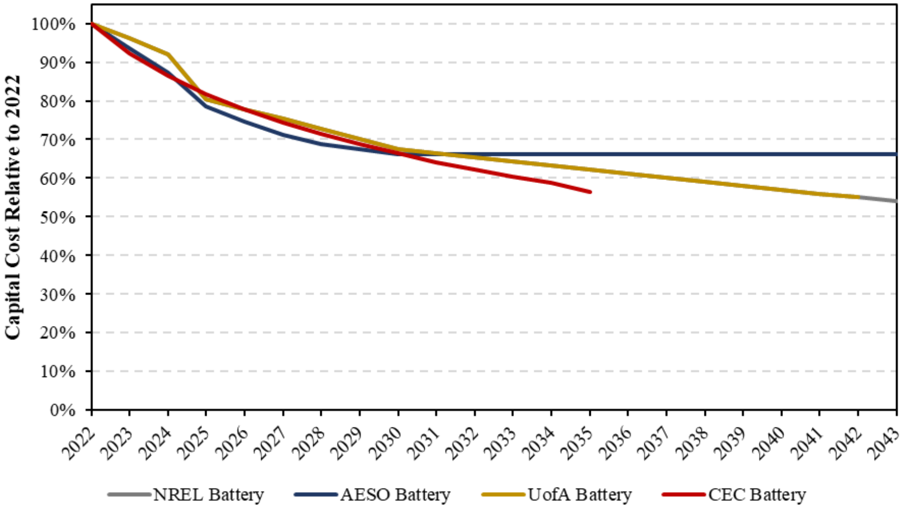
- Both UofA scenarios see significant wind additions.
- Current policy scenario includes more unabated natural gas.
- Preliminary CER scenario utilizes hydrogen to play peaking role.



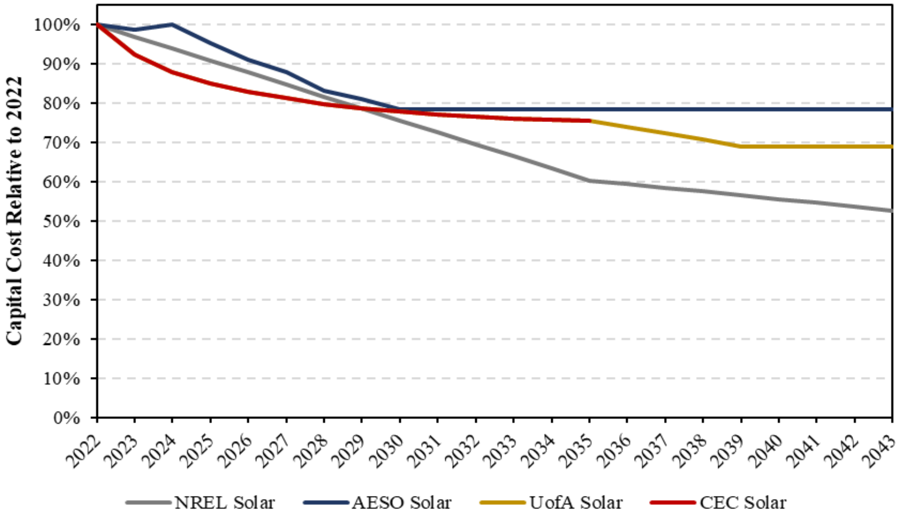
ALBERTA GRID MODELING

CAPITAL COST REDUCTIONS

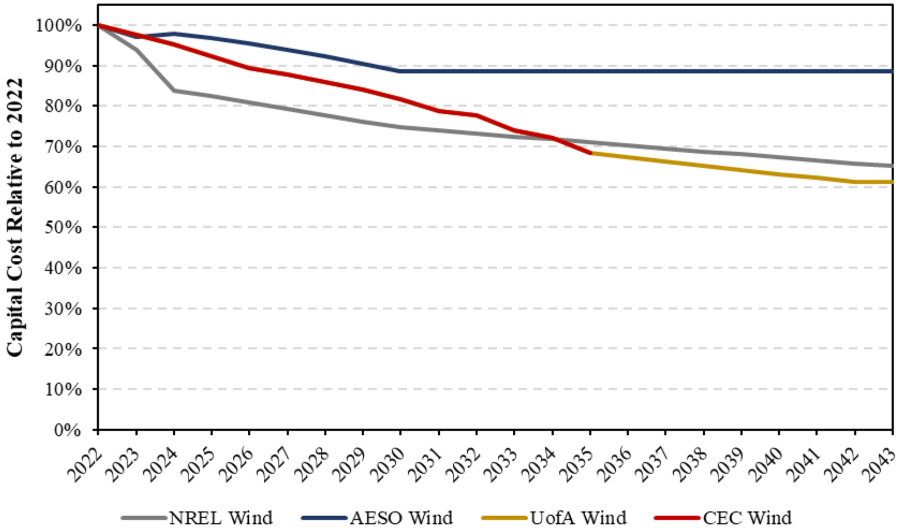
Battery Storage



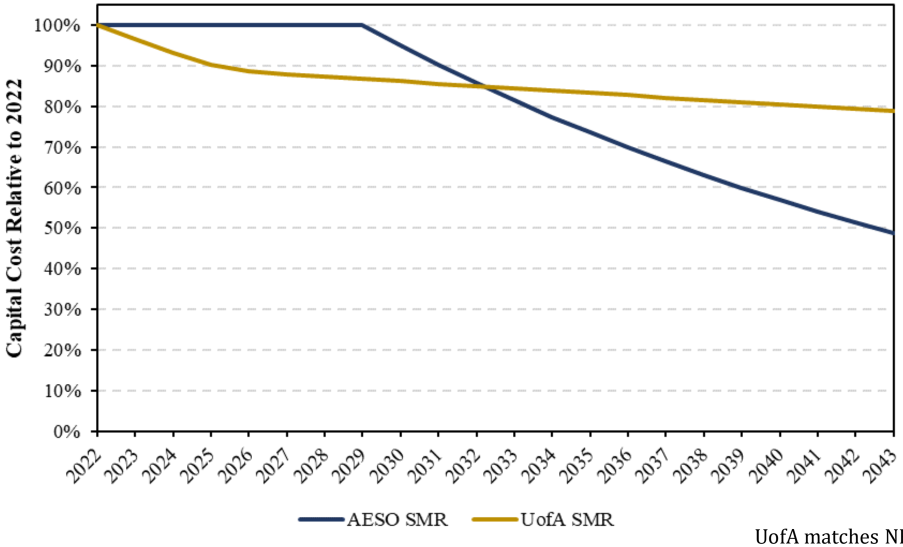
Solar



Wind



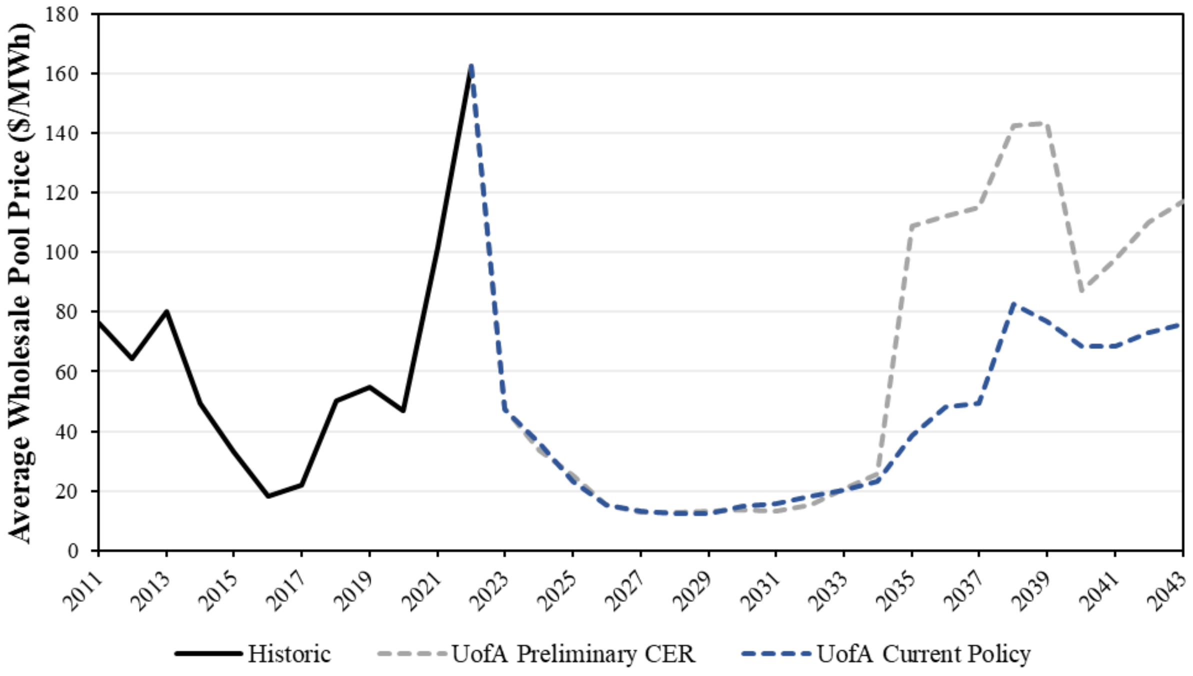
Nuclear SMR

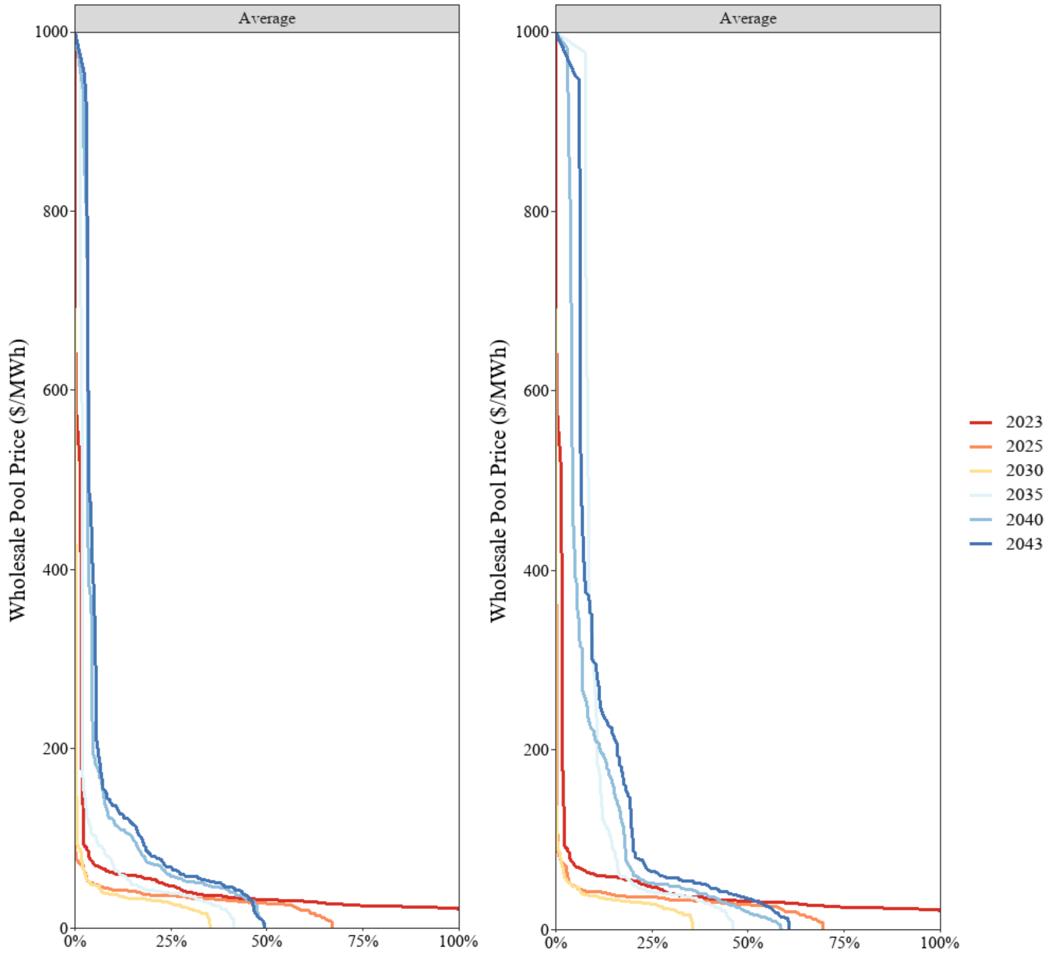


UofA matches NREL rates for Nuclear SMR

WHOLESALE POOL PRICE

UofA



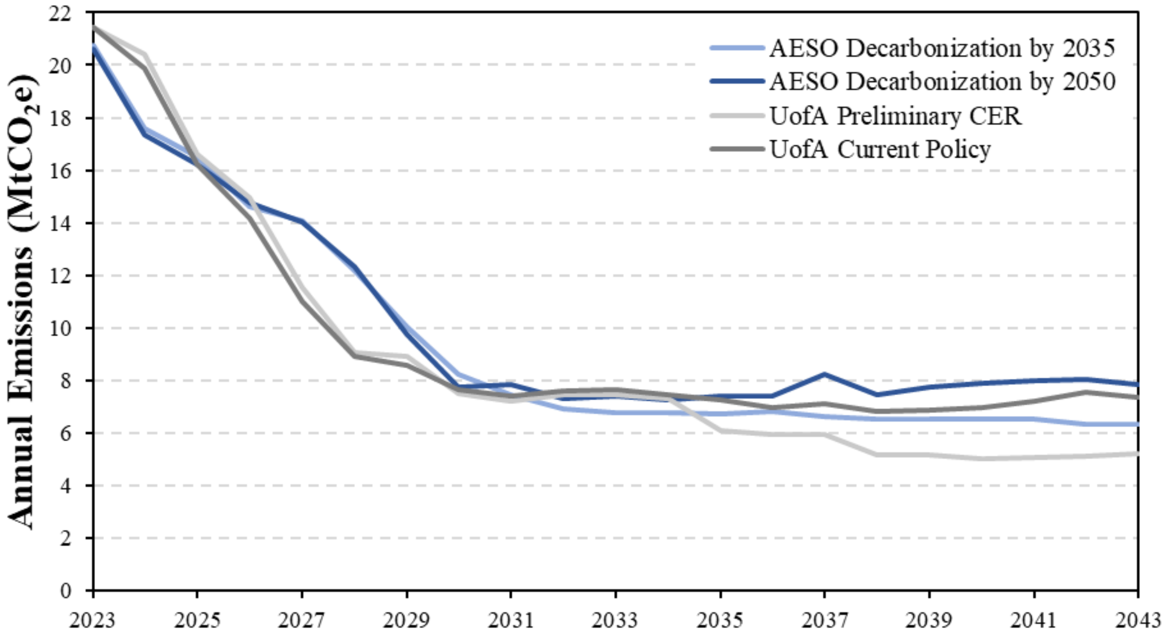


Current Policy *Preliminary CER*

EMISSIONS

Preliminary CER scenario emissions savings ~14 $MtCO_2e$ between 2023 and 2043 compared to Current Policy scenario.

- Near term emissions outcomes are similar in all cases.
- Corrected for 4 – 6 $MtCO_2e$ of additional cogeneration emissions annually.



Cogeneration emissions remains status quo

In each scenario, cogeneration output was multiplied by a factor of 0.13 tCO_2/MWh and added to reported emissions. This emissions intensity factor was calculated based on results from the AESO Net-Zero Pathways report and only accounts for cogeneration facilities which reported emissions under NAICS code 221112 in 2022.

CONCLUSIONS

I. **Near term results look similar in all cases.**
   - Major emissions reductions in next 5 years.
   - Remaining uncertainty around renewables policy and carbon capture technology.

II. **Alberta as a net energy exporter.**
   - Potential opportunities with neighboring regions.

III. **Continued renewable expansion backed up by limited dispatchable natural gas.**
   - Future work includes intertie expansion and improved storage modeling.

IV. **Rapid emission reductions by carbon pricing.**
   - Majority of the grid decarbonized by 2035, cogeneration emissions become majority.

THANK YOU

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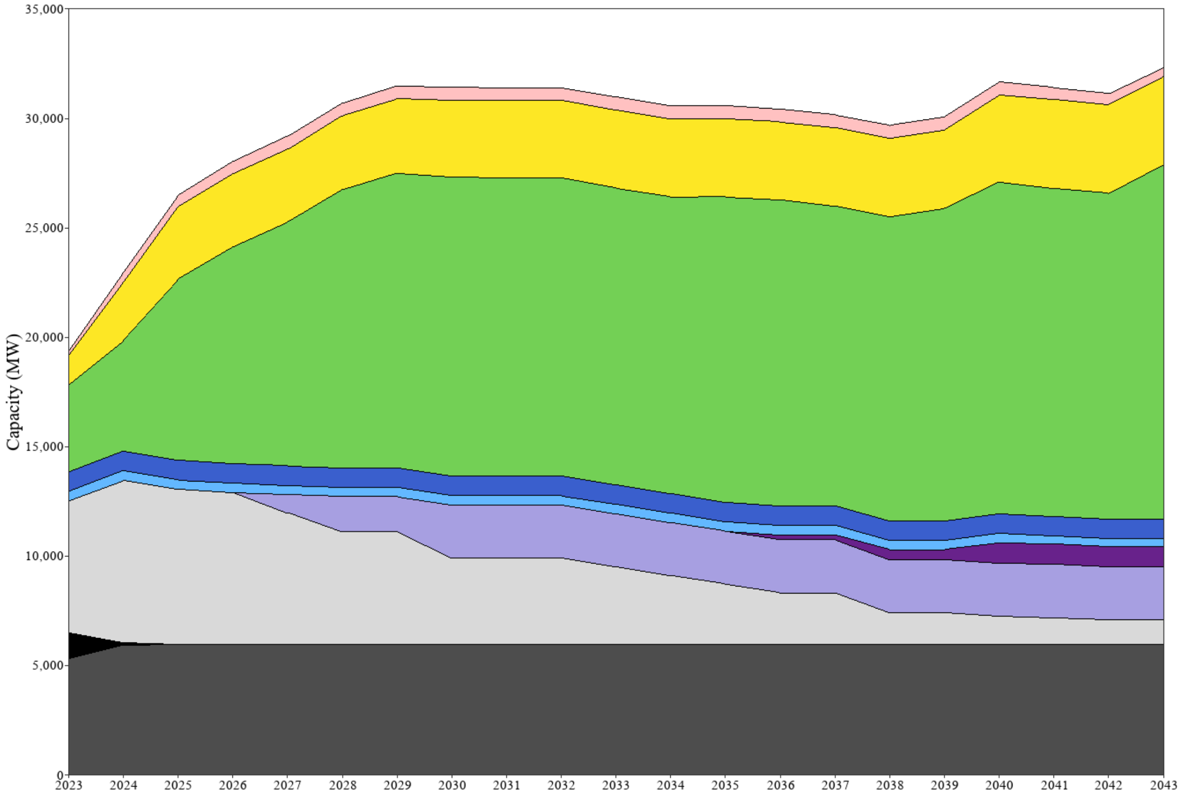
APPENDIX

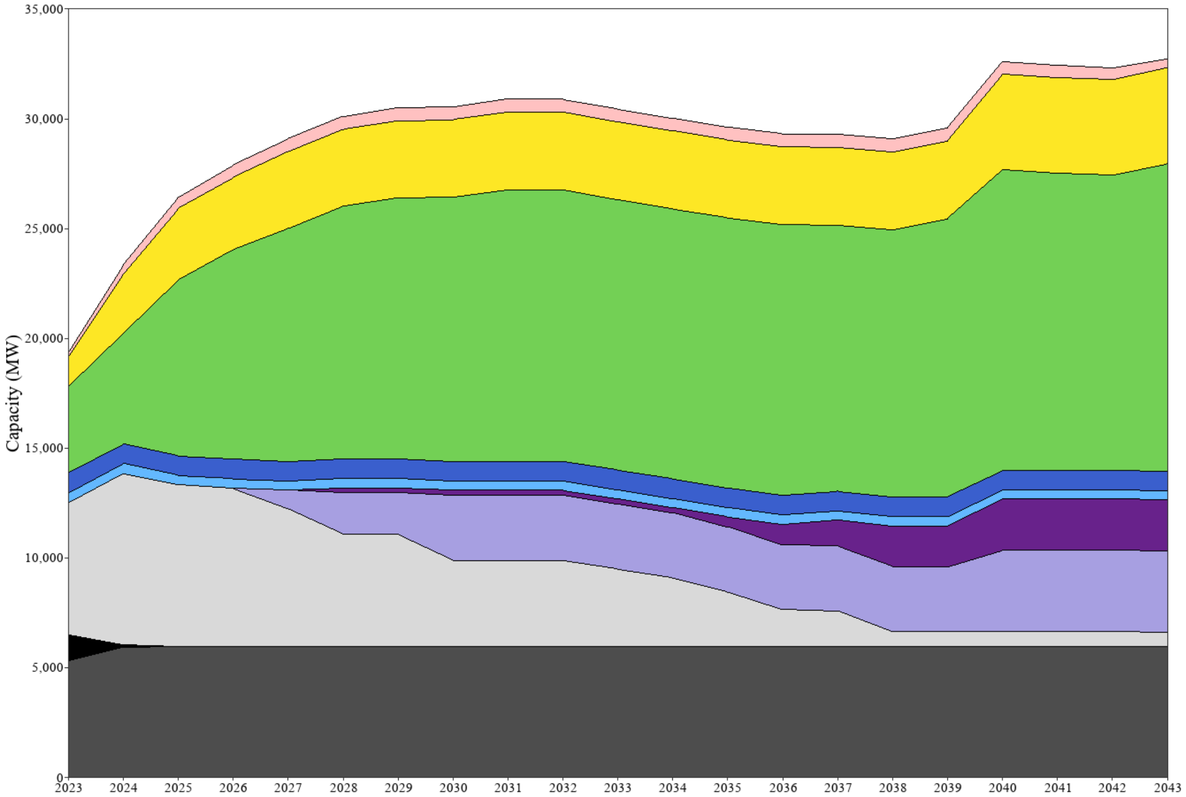
UNIVERSITY OF ALBERTA

ANNUAL CAPACITY

UofA



Current Policy

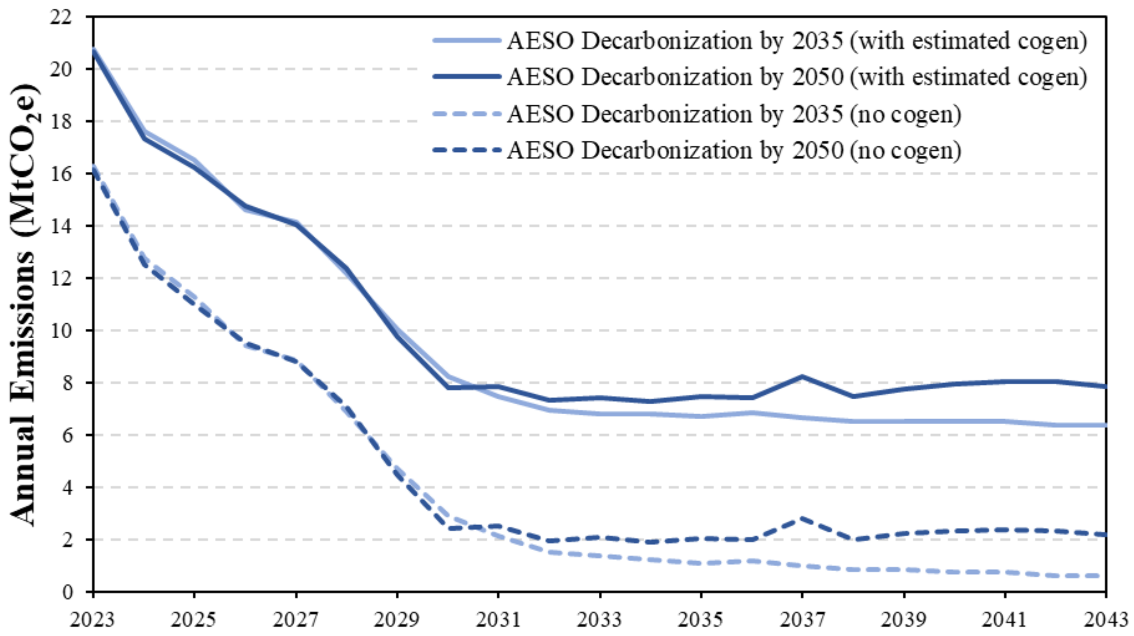


Preliminary CER

Storage Solar Wind Hydro Other Hydrogen Natural Gas + CCS Natural Gas Coal Cogen

COGENERATION EMISSIONS NOTES

- Uncertainty surrounding future cogeneration emission rates and reductions.
- AESO cogeneration emissions were estimated independently, they were not included in preliminary LTO results.
- Adjustments do not include all facilities, the total emissions from all cogeneration technology would be significantly higher.



In each decarbonization scenario, total cogeneration output was multiplied by a factor of 0.13 tCO_2/MWh and added to emissions from other technologies. This emissions intensity factor was estimated based on values obtained from a separate report, the AESO Net-Zero Pathways report. By dividing reported cogeneration emissions by the total generation an estimated emissions from cogeneration as a group could be found. Importantly, this is only representative of emissions from cogeneration facilities which reported emissions under NAICS code 221112 (fossil-fuel electric power generation) in 2022. Other cogeneration emissions would be reported in alternative sectors.

TIMELINE SOURCES

Coal Phase Out Announced (2015) - https://www.alberta.ca/climate-coal-electricity

Paris Agreement (2015) - https://unfccc.int/process-and-meetings/the-paris-agreement

Renewable Electricity Act (2017) - https://open.alberta.ca/publications/r16p5

Renewable Electricity Program (2017 – 2019) - https://www.aeso.ca/market/market-related-initiatives/renewable-electricity-program/

Carbon Competitiveness Incentive Regulation (2018 – 2020) - https://www.alberta.ca/carbon-competitiveness-incentive-regulation

Greenhouse Gas Pollution Pricing Act (2018) - https://laws-lois.justice.gc.ca/eng/acts/g-11.55/FullText.html

Technology Innovation and Emissions Reduction Regulation (2020) - https://www.alberta.ca/technology-innovation-and-emissions-reduction-regulation

2030 Emissions Reduction Plan (2021) - https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/emissions-reduction-2030/plan.html

Canadian Net-Zero Emissions Accountability Act (2021) - https://laws-lois.justice.gc.ca/eng/acts/c-19.3/FullText.html

AESO Net-Zero Pathways Report (2022) - https://www.aeso.ca/future-of-electricity/net-zero-emissions-pathways/

Budget 2023 - https://www.budget.canada.ca/2023/home-accueil-en.html

Alberta Emissions Reduction and Energy Development Plan (2023) - https://open.alberta.ca/publications/alberta-emissions-reduction-and-energy-development-plan

Pembina's Zeroing In Report (2023) - https://www.pembina.org/pub/zeroing-in

Clean Electricity Regulations, Gazette I (2023) - https://www.gazette.gc.ca/rp-pr/p1/2023/2023-08-19/html/reg1-eng.html

Renewable Moratorium (2023) - https://www.alberta.ca/article-renewables-review