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# ROLE OF HYDROGEN SUPPLY-SIDE PATHWAYS IN GHG MITIGATION IN CANADA

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Contribution to the Energy Modelling Initiative (EMI)

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A collaborative effort between ECCC, NRCan and Systematic Solutions, Inc (SSI)

Canada

# OVERVIEW

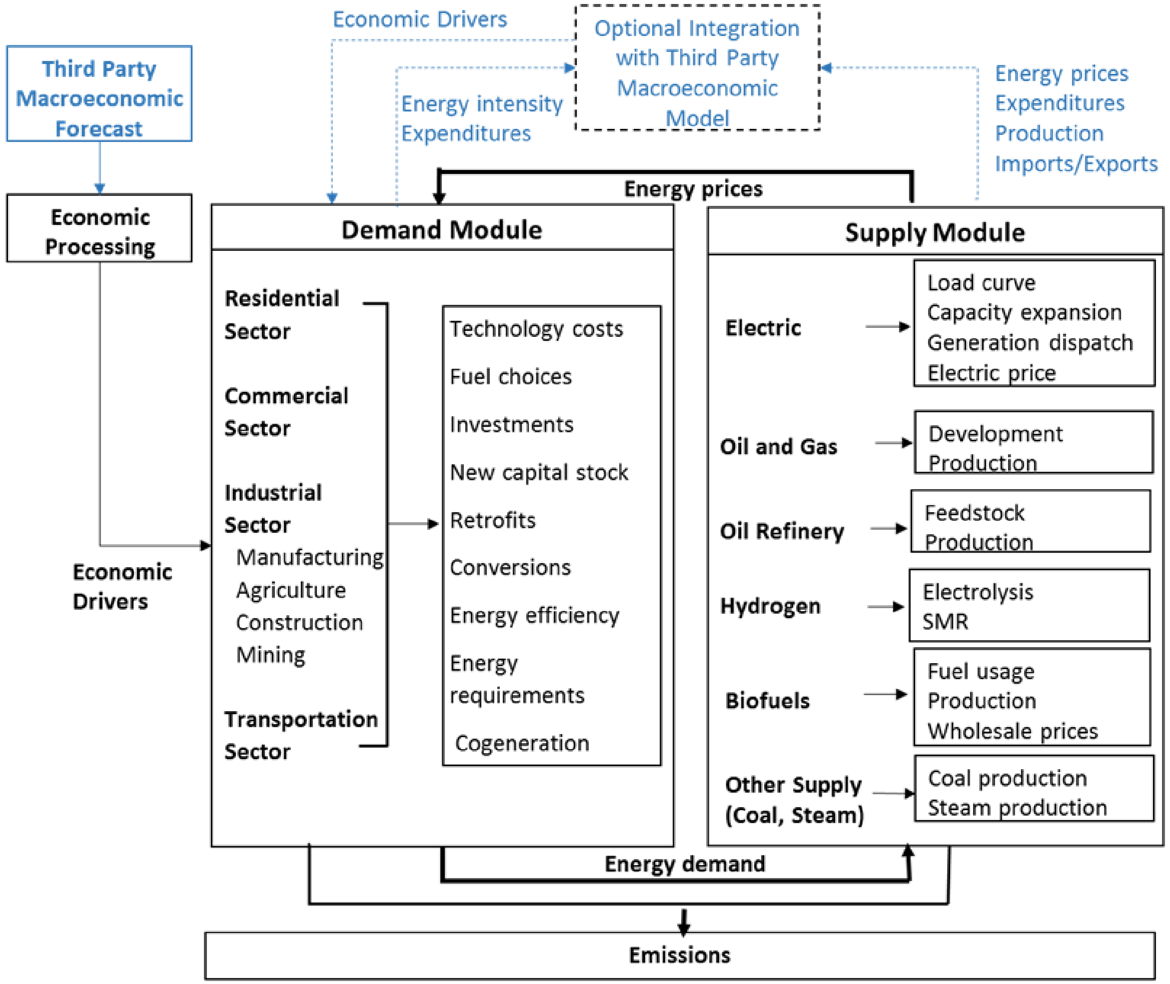
1. Motivation
2. Modeling Framework
3. Scenario Development and Assumptions
4. Modeling Results and Analysis
5. Conclusion

# MOTIVATION

- Government of Canada committed to achieve net-zero emissions by 2050
- Electrification ill-suited for decarbonisation in certain applications
  - High grade heat and feedstocks in industry
  - Heavy-duty freight
- Increased interest for $H_2$ as a non-emitting fuel in Canada and internationally
  - Hydrogen Strategy for Canada and several studies/reports across provinces
- Known $H_2$ production methods include steam reformation (SMR) and electrolysis
  - GHGs associated with production type vary
- <u>Study Objective:</u> Explore the impact of different illustrative hydrogen production pathways on GHG mitigation and electric capacity and generation out to 2050

# MODELING FRAMEWORK

# ENERGY 2020 MODEL STRUCTURE




- Energy 2020 (E2020) is a bottom-up end-use energy model
  - Partial equilibrium or system dynamics (SD) model that simulates behaviour
  - Does not fully equilibrate government budgets and the markets for employment and investment
- Can be integrated with a macroeconomic model to model economic impacts of policies
- The integrated Energy, Emissions and Economy Model for Canada (E3MC) modelling framework is used by ECCC to develop GHG and air pollutant projections for Canada

# ELECTRICITY SECTOR

**Structure of Electric Generating Units**

- Electricity sector has a unit-by-unit representation

- Twenty-four electric plant types (e.g. Solar PV, Onshore Wind, Oil/Gas Combined Cycle, Coal+CCS)

- Includes exogenous historical units and endogenously-built units to meet electricity demand during projection years.

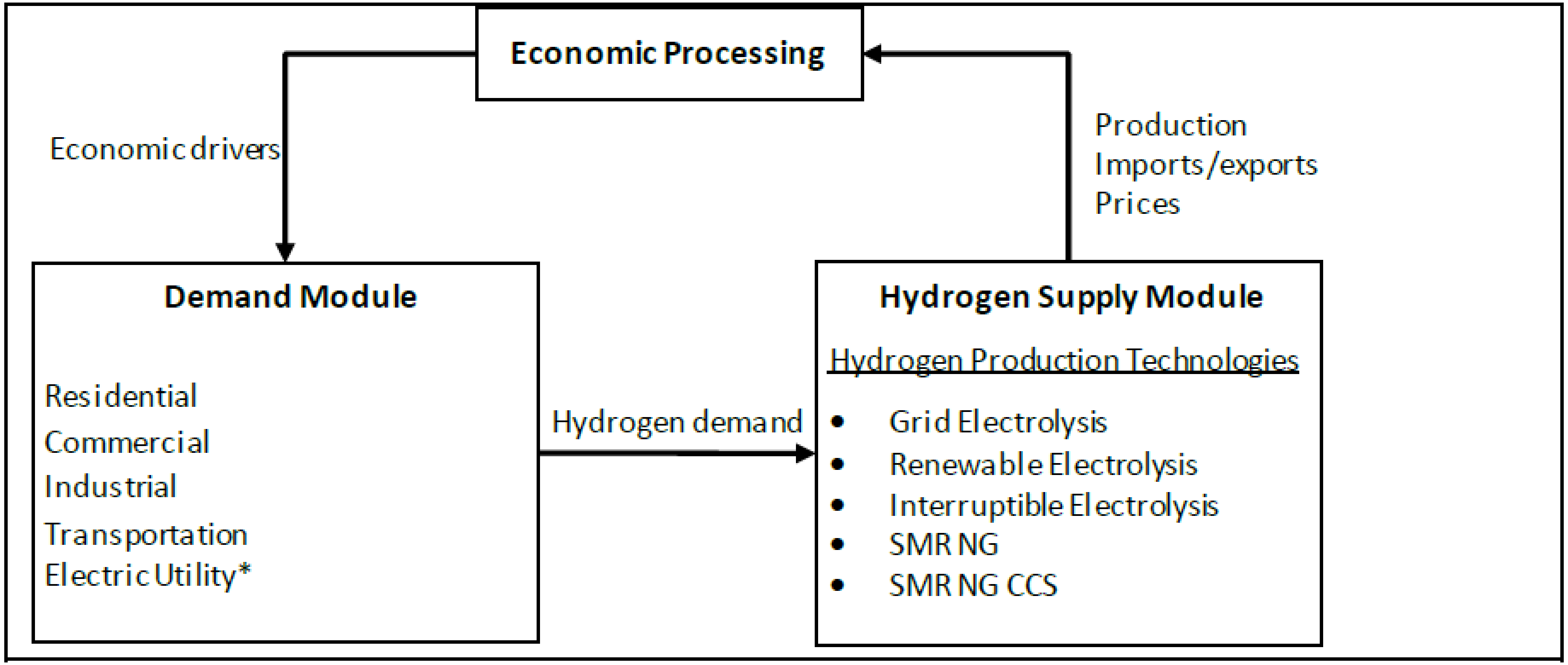
**Transmission & Dispatch**

- The transmission network consists of a set of nodes connected by transmission lines
  - Canada - 14 nodes, one for each province and territory plus Labrador

- Energy 2020 determines the amount of electricity needed at each node by minimizing the costs to meet demand from all sectors.

- Generating units are dispatched across six time periods (from low to peak load hours) in each of winter and summer seasons.

# HYDROGEN MODELING IN E2020




*Note: Electric utilities may consume $H_2$ in the natural gas fuel mix or pure $H_2$ in fuel cells. Only the former use of $H_2$ was modeled in this exercise.

# SCENARIO DEVELOPMENT AND ASSUMPTIONS

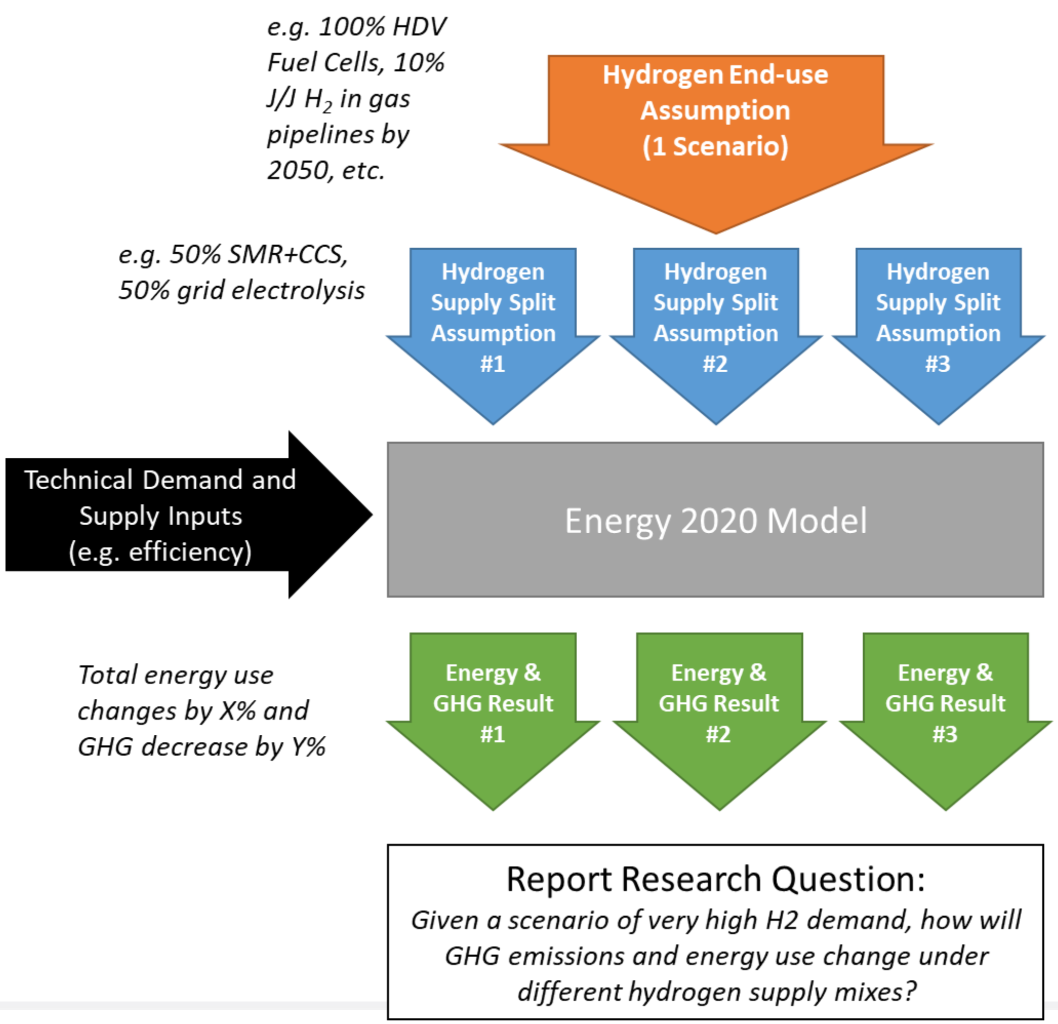
# DATA SOURCES

| Data | Source |
|---|---|
| **Energy & Emissions** | |
| End-use Energy | Statistics Canada, NRCan |
| GHGs & Air Pollutants | Canada's National Inventory Report |
| Agriculture Emissions | Agriculture & Agri-Food Canada (AAFC) |
| **Technology Parameters** | |
| End-use Device Efficiencies & Costs | Energy Information Agency (EIA) |
| Electricity Generation Efficiencies & Costs | National Renewable Laboratories (NREL) |
| $H_2$ Production, Transmission & Distribution | NREL, Bloomberg New Energy Finance (BNEF) |
| **Prices** | |
| Wholesale Oil & Natural Gas Prices Projections | Canadian Energy Regulator (CER) |
| **Drivers** | |
| GDP | Finance Canada |
| Population | Statistics Canada |
| Oil & Natural Gas Production Projections | Canadian Energy Regulator (CER) |

# REFERENCE SCENARIO

- Reference Case from *Canada's GHG and Air Pollutant Emissions Projections 2020*
- Includes all policies and measures funded, legislated and implemented by federal, provincial and territorial governments as of September 2020
- Canada’s strengthened climate plan measures not included (e.g. carbon price increase to $170/tonne $CO_2$-e by 2030, and the clean fuel standard)
- Did not apply the output-based pricing system (OBPS) to the $H_2$ production sector
  - Output-based allocations (OBAs) on net emissions (including non-combustion) for chemicals & fertilizers, oil sands upgraders and refineries did not account for $H_2$ production

# SCHEMATIC DIAGRAM OF HYDROGEN SCENARIOS



# HYDROGEN DEMAND & SUPPLY ASSUMPTIONS

| Demand Assumption | Units | 2025 | 2050 |
|---|---|---|---|
| % H2 in Natural Gas Distribution Pipelines | % (J/J) | 1% | 10% |
| % Industrial Heat from H2 Boilers | % (J/J) | 1% | 5% |
| % Coal/Coke feedstock replacement with H2 in Iron & Steel | % (J/J) | 5% | 100% |
| % Natural Gas feedstock replacement with H2 in Fertilizers, Refineries & Upgraders | % (J/J) | 5% | 100% |
| % Fuel Cell Market Share in Freight Heavy-Duty Trucks and Trains | % ($/$) | 2% | 100% |
| % H2 fuel mix in Heavy-Duty Diesel Trucks (Off-Road and On-Road) | % (J/J) | 2.5% | 5.0% |

**Portfolio Electricity Grid Capacity Expansion**

| Technology | Capacity Additions Ratio |
|---|---|
| Onshore Wind | 0.45 |
| Solar PV | 0.35 |
| Gas (OGCC, OGCT, Small OGCC) | 0.15 |
| Peak Hydro | 0.05 |

| | | Scenario | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Low Costs | | | Medium Costs | | | High Costs | | |
| H2 Production Method | H2 Production Subtype | BC/AB/SK | ON | Other PTs | BC/AB/SK | ON | Other PTs | BC/AB/SK | ON | Other PTs |
| Electrolysis | Grid | | | 100% | 50% | | 50% | 25% | 25% | 25% |
| Electrolysis | Renewable | | | | | 40% | 50% | 75% | 65% | 75% |
| Electrolysis | Interruptible* | | | | | 10% | | | 10% | |
| Natural Gas - CCS** | | 100% | 100% | | 50% | 50% | | | | |

# MODELING RESULTS AND ANALYSIS

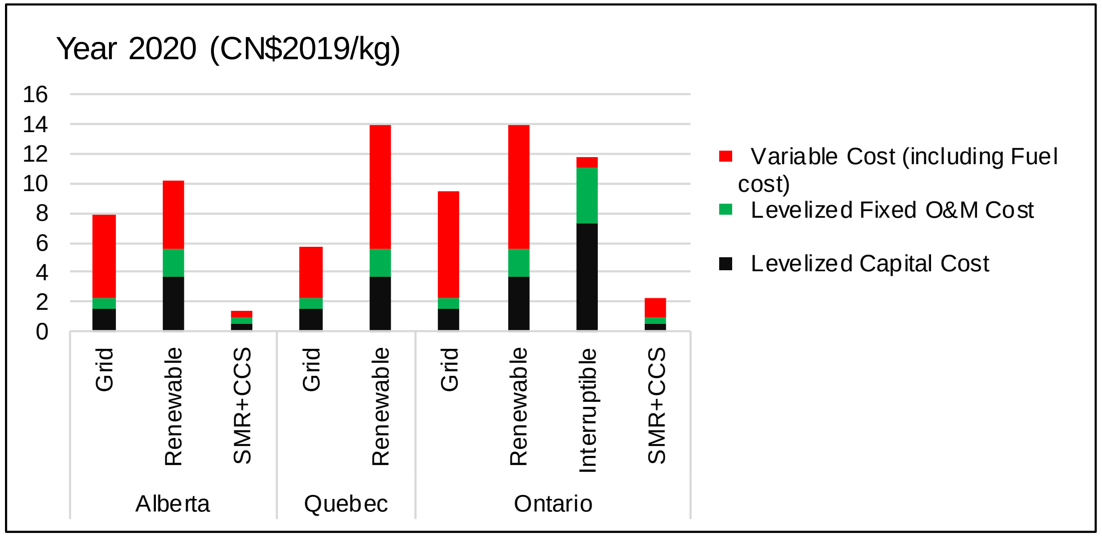
# ELECTRIC GENERATING COST VARIABLES

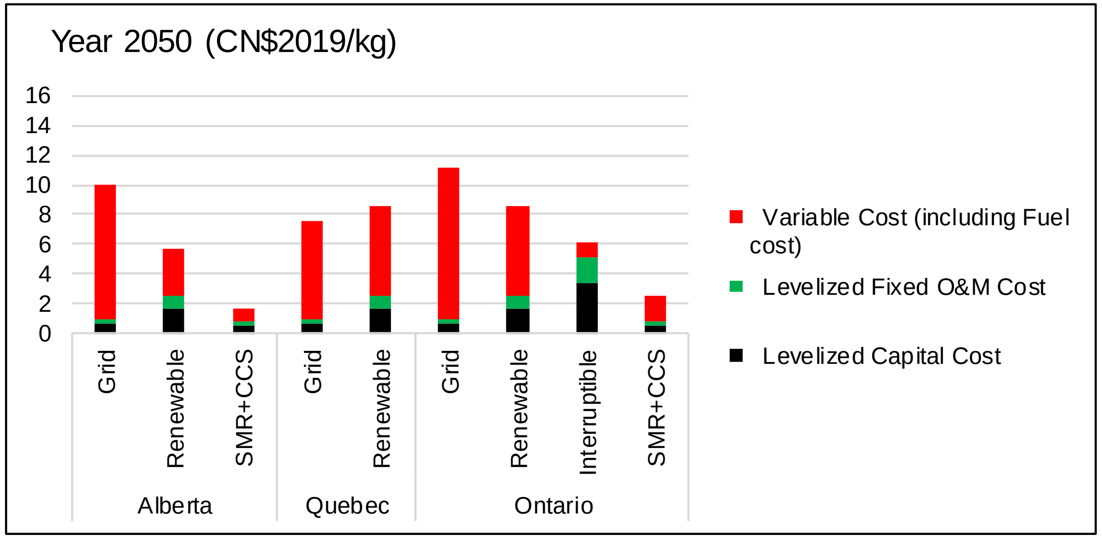
| Variable | 2025 | 2050 |
|---|---|---|
| ***Gas/Oil Combined Cycle*** | | |
| Marginal Cost of Energy (CN$2018/MWh) | 19 | 29 |
| Variable Cost (CN$2018/MWh) | 8 | 21 |
| Overnight Construction Cost (CN$2018/KW) | 1,110 | 808 |
| Plant Capacity Factor (MW/MW) | 0.95 | 0.95 |
| ***Onshore Wind*** | | |
| Marginal Cost of Energy (CN$2018/MWh) | 12 | 12 |
| Variable Cost (CN$2018/MWh) | (24) | (24) |
| Overnight Construction Cost (CN$2018/KW) | 1,458 | 1,440 |
| Plant Capacity Factor (MW/MW) | 0.40 | 0.40 |

Sample Alberta Medium Scenario base-load costs

- Wind has lowest MCE and variable cost
- VRE has lower availability
- MCE's increase over time

# $H_2$ PRODUCTION COSTS

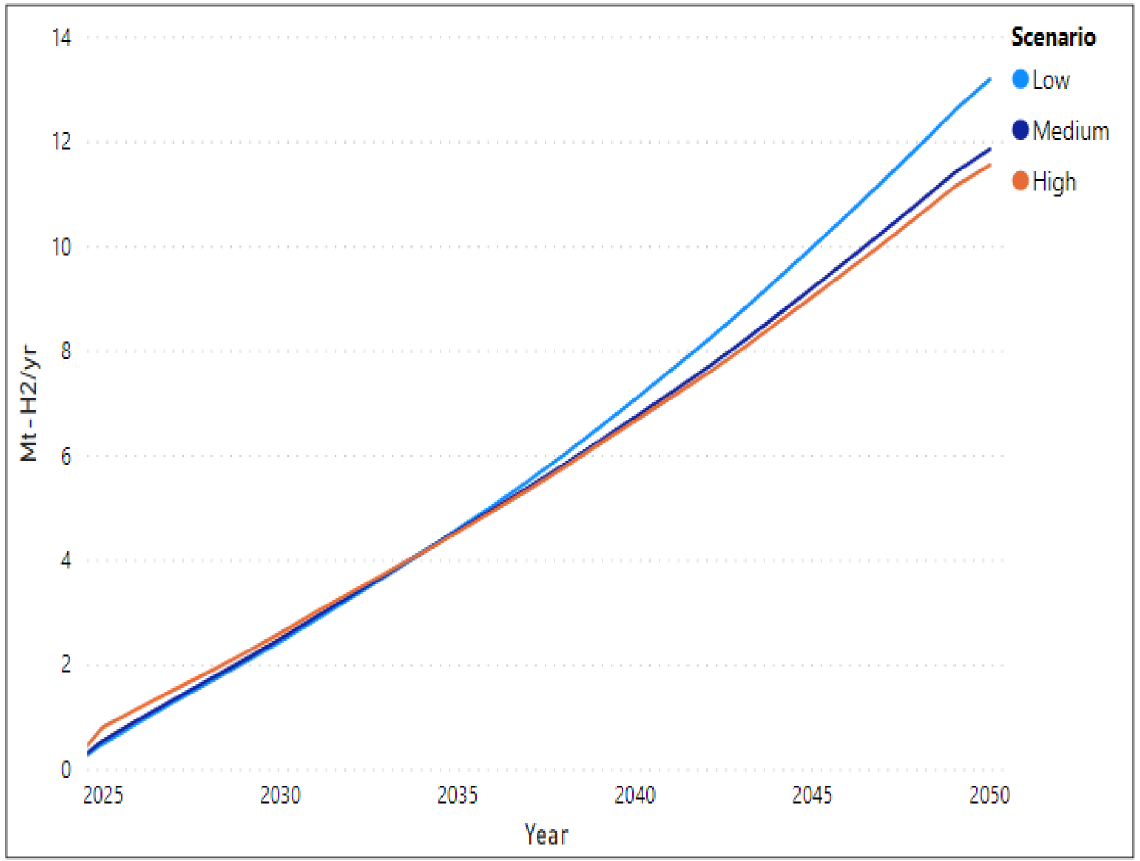


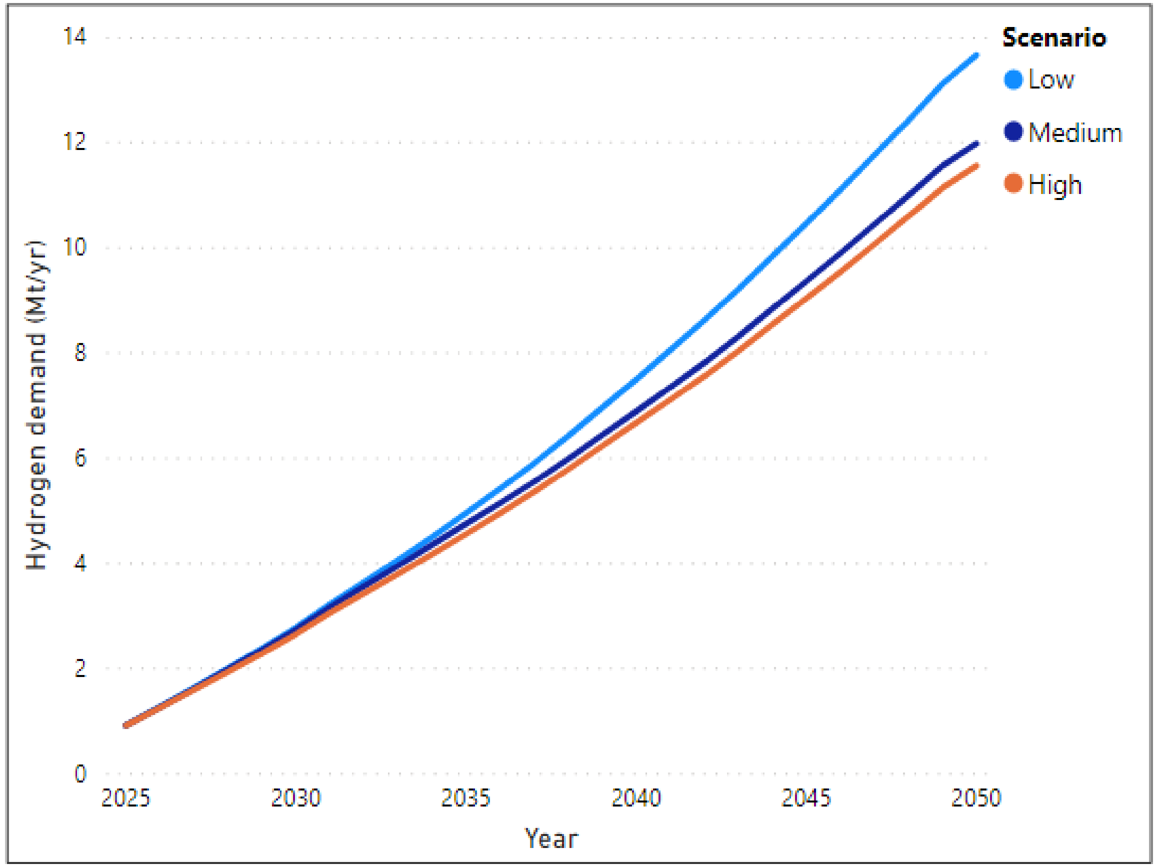

- SMR+CCS cheaper than electrolysis through all time periods
- Fuel cost is the biggest expense for grid-electrolysis based $H_2$
- SMR+CCS and grid-based electrolysis increased over time due to increased fuel costs
- Renewable and interruptible electrolysis decreased over time due to cheaper electrolyzer and VRE capital costs
- High levelized cost of capital for interruptible electrolysis due to low utilization rate

# HYDROGEN SUPPLY/DEMAND BY SCENARIO

## Hydrogen Production by Scenario

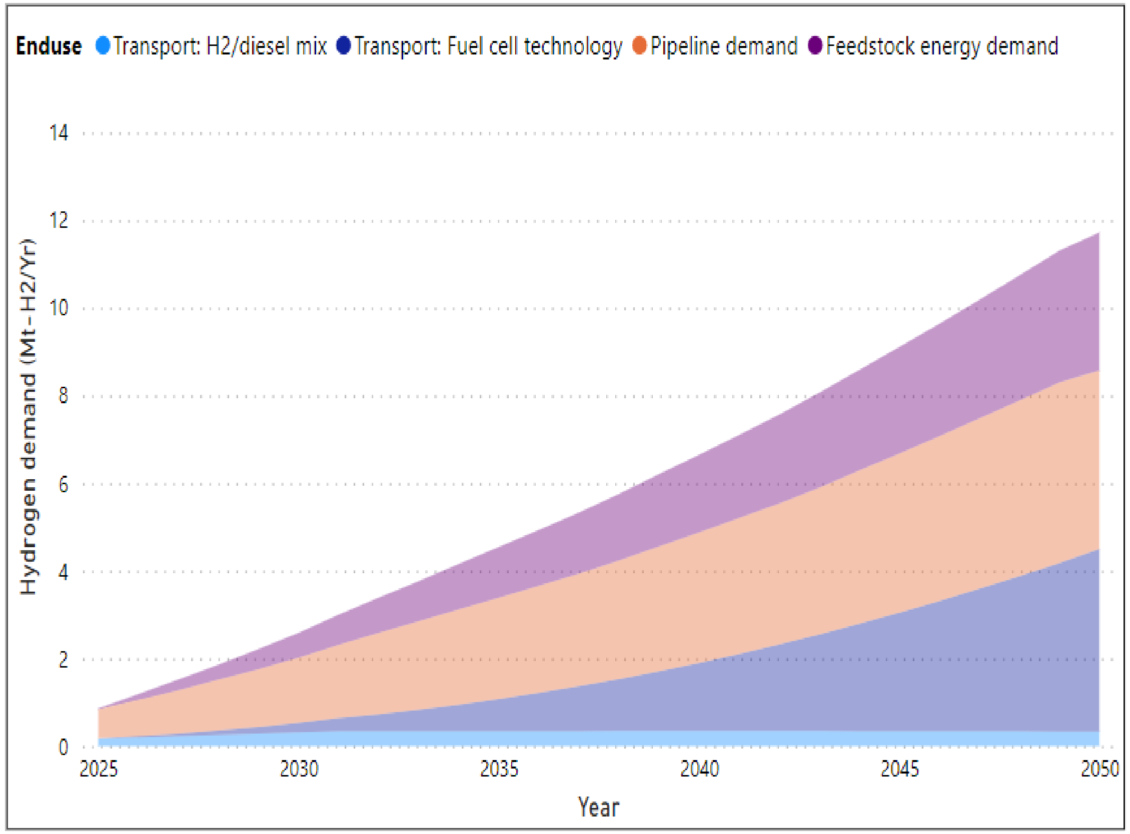



## Hydrogen Demand by Scenario

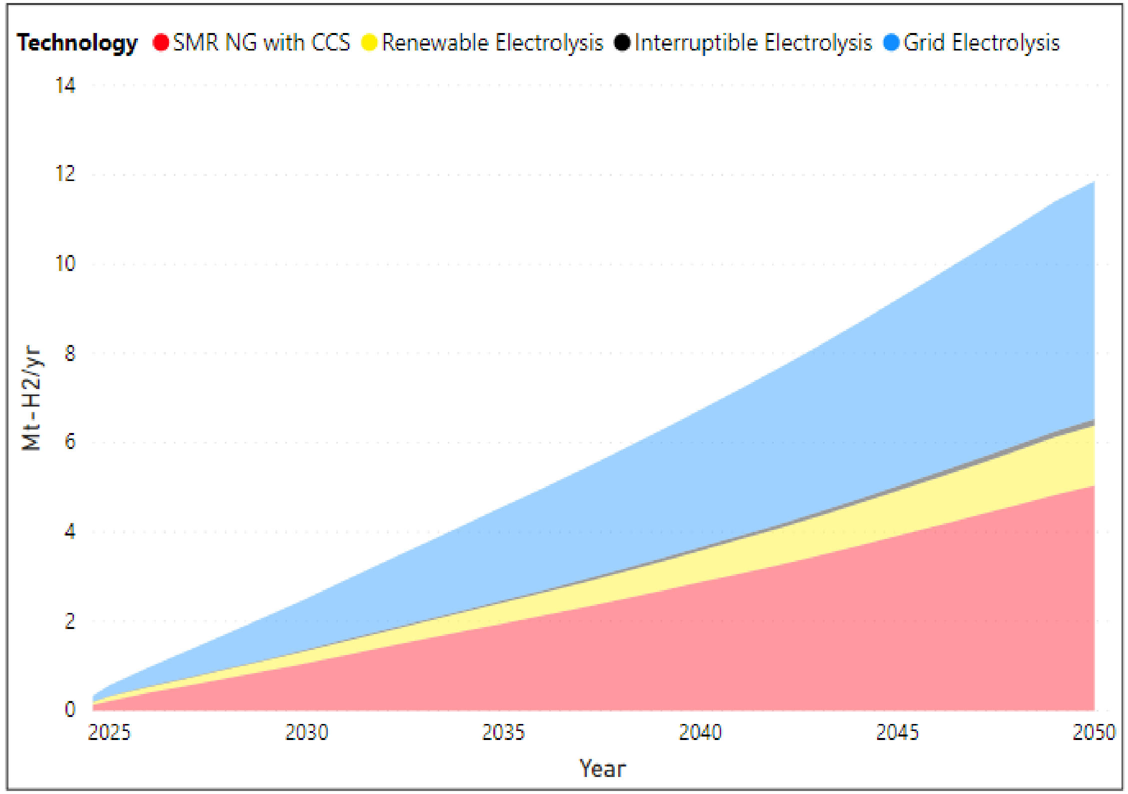


# MEDIUM SCENARIO OVERVIEW

Hydrogen Demand by Use for the Medium Scenario

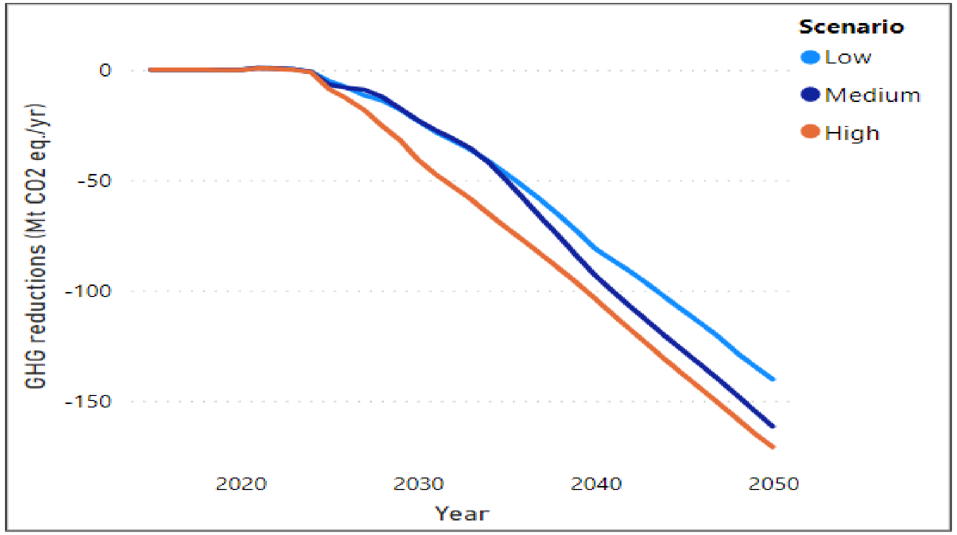



Hydrogen Production Pathways for the Medium Scenario



# GHG EMISSIONS IN CANADA

GHG Mitigation for Hydrogen Supply Production Scenarios




- Higher costs scenarios had more GHG reductions by 2050
- Prior to 2038, the medium scenario exhibited the lowest overall GHG reductions due to fossil fuel fired electricity generation in Alberta.

GHG Mitigation by Sector Compared to the Reference Scenario in 2050 (Mt CO2-e/yr)

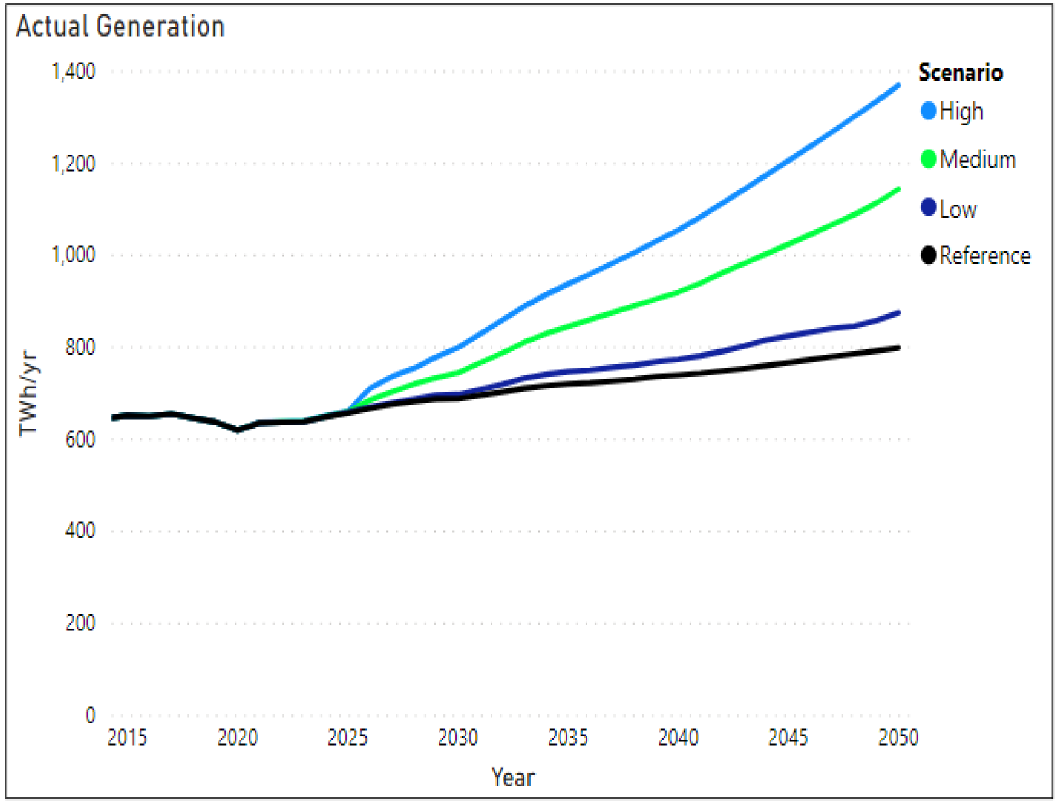
| | Low | | | Medium | | | High | | |
|---|---|---|---|---|---|---|---|---|---|
| Sectors | Fuel switching | Efficiency gains | Total | Fuel switching | Efficiency gains | Total | Fuel switching | Efficiency gains | Total |
| Agriculture | 0 | -1 | **-1** | 0 | -1 | **-1** | 0 | -1 | **-1** |
| Buildings | -5 | -2 | **-7** | -5 | -4 | **-9** | -5 | -5 | **-10** |
| Electricity and Steam | -1 | -14 | **-15** | -1 | -12 | **-13** | -1 | -13 | **-14** |
| Heavy Industry | -24 | -12 | **-36** | -23 | -16 | **-39** | -23 | -17 | **-40** |
| Oil and Gas | -22 | -31 | **-53** | -20 | -46 | **-66** | -19 | -51 | **-70** |
| Transportation | -27 | -1 | **-28** | -21 | -8 | **-29** | -20 | -9 | **-29** |
| Waste and Others | -2 | -3 | **-5** | -2 | -5 | **-7** | -2 | -6 | **-8** |
| Hydrogen Production | 5 | 0 | **5** | 2 | 0 | **2** | | | |
| **Total** | **-75** | **-65** | **-140** | **-69** | **-93** | **-162** | **-69** | **-103** | **-171** |

*Notes: 1) Totals may not add up due to rounding
2) Values reported under efficiency gains for Electricity & Steam refer to reductions associated with substitution of VRE for fossil-fuel generation

- Impacts from efficiency gains exceed those from fuel substitution for higher costs scenarios
- NG based hydrogen production generates emissions for the Low and Medium scenarios

# ELECTRIC CAPACITY AND GENERATION

Canada Electric Generation (Grid + Dedicated VRE) by Scenario

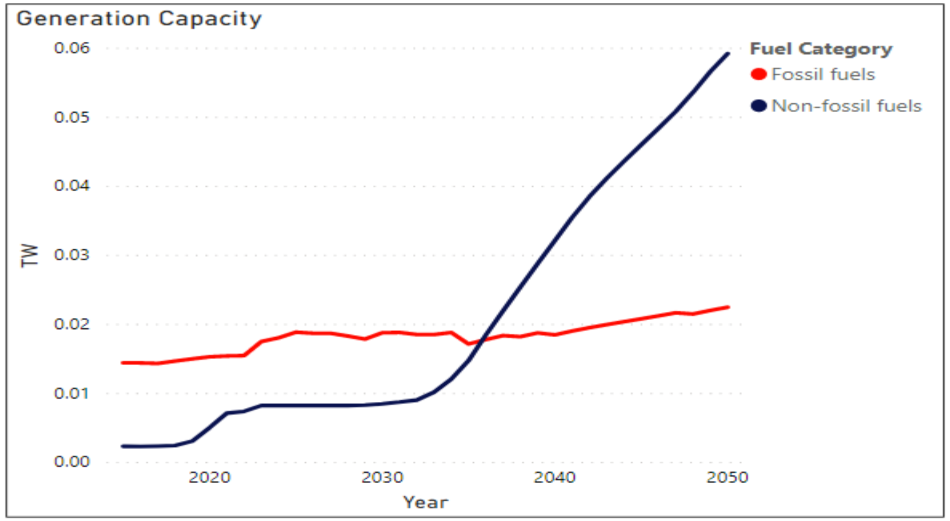


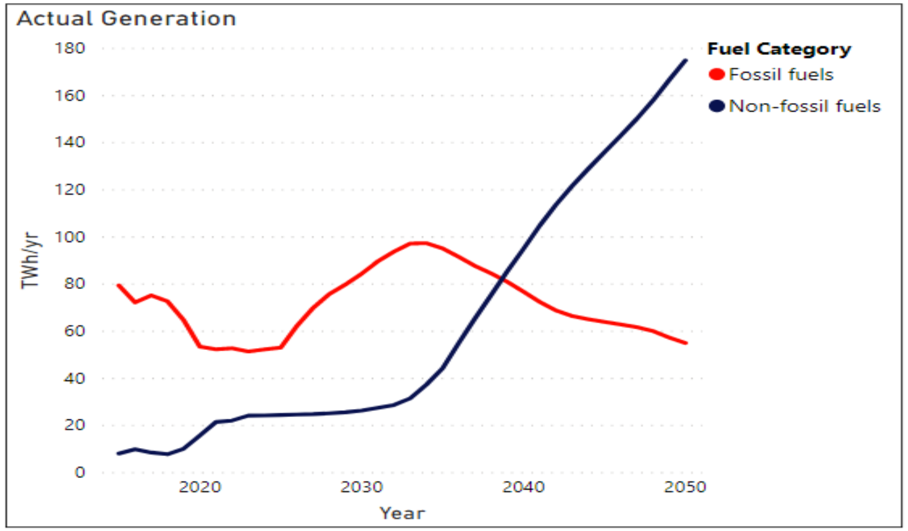

- As the level of electrolysis increased (from low to high cost scenarios), total grid+dedicated VRE generation also increases
  - the high scenario required 129% (238 GW) more capacity and 84% (627 TWh) more generation in 2050 compared to the reference scenario

- The 1000 TWh/yr milestone reached by 2040 for the High scenario

# ELECTRIC CAPACITY AND GENERATION IN ALBERTA

Alberta Electric Capacity and Generation by Fuel Category for the Medium Scenario




- Fossil fuel generating capacity in Alberta increases throughout the projections, while generation from these fossil fuels increases only in the early years before declining after 2035 when VRE generation started to increase sharply
  - That explains why the medium scenario had lower GHG reductions prior to 2035 compared to other scenarios.

# FUTURE IMPROVEMENTS

- Refinements to the electric capacity expansion and dispatch
  - allowing extra VRE capacity to compensate for limited availability

- Improve electricity storage dynamics and reflect seasonal generation differences

- Updates to capital costs for VRE and HDV vehicles

- Addition of air pollutants for $H_2$ combustion (e.g. $N_2O$)

# CONCLUSIONS

- E2020 model demonstrated its potential in evaluating the economy-wide GHG and electricity impacts of different hydrogen supply pathways

- Noticeable GHG reductions by 2050 compared to the reference scenario from H2 uptake:
  - Low cost scenario: -140 Mt by 2050
  - High cost scenario: -171 Mt by 2050

- Increases in electric generation & capacity to support electrolysis are substantial:
  - Up to 129% (238 GW) and 84% (627 TWh), respectively, above reference scenario levels in 2050