Informing the debate around the role of hydrogen in net zero pathways for Canada

Using the North American TIMES Energy Model (NATEM)

ETSAP Workshop, Colorado
June 2023
1. The NATEM model in brief
2. Examples of regional results in net-zero scenarios
   a) Taking into account multiple and conflicting views on the future of hydrogen in Canada
   b) A zoom on the gas grid and the of building sector
The NATEM model in brief
A comprehensive energy system model for North America

Geographical resolution
Canada: 13 Provinces/Territories
USA: 9 Census Regions + CA, NY, TX
Mexico: 1 Region

Temporal resolution
• Annual database 2016-2060
• Flexible time period definition
• Flexible sub-annual disaggregation
  • 4 Seasons
  • Several definition of intraday periods

➢ Model use in multiple consulting and research projects
For each jurisdiction

- All energy sectors and non-energy sectors:
  - Industrial processes
  - Agriculture
  - Waste
- 75 demands for energy services
- 5000 technologies
- All GHGs (replicate the National Inventories of the 3 countries)

➢ Net-zero pathways
A zoom on industrial demand sector: Cement
A technology rich database developed for 10 years

- **Consulting projects** for public and private organisations in North America.
- **Nation-wide expert panels** to review assumptions and data.
- Constant **technology watch and literature review** from ESMIA modellers.
- **Large scale research projects**, with funding from national and local research agencies.
  - Forestry sector and biogenic carbon accountability.
  - Modelling and decision-making for transport and climate policy.
  - Robust optimization to model smart grids with a strong renewable component.
  - The use of massive data from smart meters to model a fleet of buildings.
  - Replacing Portland cement with carbonation-activated slag material.
- Continuous work with **Canmet Energy** (NRCan) for industrial sectors.
- Joint project Canada-Germany funded by the **National research Council of Canada (NRC)** on hydrogen and climate partnership (H2Clip).
- Supervise **masters and PhD students** on energy-related topics.
- Participation to the **Energy Modeling Forum (Stanford University)**.
- Collaboration with **ETSAP-IEA** modellers.

➢ +25 peer-reviewed papers using NATEM
Conflicting views on the future of hydrogen
Our recommendations

- Natural Resources Canada should perform a comprehensive bottom-up modelling for the use of hydrogen. This modelling should account for the following:
  - emission reduction efficiencies by sector (cost of emission reductions per megatonne of carbon dioxide equivalent)
  - substitutional fuels (for example, biofuel, electrification, credit systems)
  - feasible deployment of technologies and supporting infrastructure.

- To improve consistency across departments, Environment and Climate Change Canada and other federal departments should adopt a standard framework to estimate emission impacts of proposed policies, clean technologies, and fuels.

Highly optimistic in energy transition
This diagram is a subset of the full energy system model. It highlights the potential hydrogen supply and demand pathways.
Canada has a large diversity of (non-coordinated) policies

**Canada**

- Federal Fuel charge
- Clean Fuel Regulation
- Incentives for LDZEVs and Zero-emission vehicle infrastructure
- Incentives for MDZEVs and HDZEVs
- Clean Technology Investment Tax Credit
- Investment Tax Credit for Clean Hydrogen
- Investment Tax Credit for CCUS
- Investment Tax Credit for Clean Electricity
- Federal Methane Goals from 2018
- HFC Regulation (Kigali amendment)
- Heat pump grants / funding
- Greener Homes Grant
- Funding under Canada’s Green Building Strategy
- GHG emissions standards for vehicles through 2027 (CAFE)
- Federal Oil and Gas Cap
- Landfill Gas Regulations
- Clean Electricity Regulations
- Other

**Province: Ontario example**

- Emissions performance standards (EPS)
- Cleaner Transportation Fuels Regulation
- Residential Electricity Peak Savings (TOU Pricing)
- Feed-in Tariff Program
- Landfill Gas Regulation (O. Reg. 216/08 and 217/08)
- Strategy for a Waste-Free Ontario
- Nuclear Refurbishment
- Energy Storage Contract with QC
- Gas savings from Demand-Side Management (DSM) measures
- Harmonization with energy efficiency standards of U.S. DOE and NRCan
- Ontario Building Code
- Government investments in phasing out coal use at steel facilities
- Electricity supply procurements
- Off-shore wind moratorium
- Comprehensive Electricity Plan (CEP)
- Ontario Electricity Rebate (OER)
- Framework for regulating geologic carbon storage (CCS)
- Forest Biomass Action Plan
- Other
GHG emissions are constrained to meet net zero

GHG constraint is applied in each year and is the same for all scenarios

- Matching GHG emissions in ECCC’s 5th Biennial Report through 2035
- Linear decrease from 2035 to 2050
- Assumes 28 MtCO$_2$e is sequestered by natural sources in 2035 and each year to 2050
# Stakeholder consultations across Canada

<table>
<thead>
<tr>
<th>Assumptions</th>
<th>Pessimistic</th>
<th>Optimistic</th>
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</thead>
<tbody>
<tr>
<td>Macro-economic growth</td>
<td>Canadian government - Reference</td>
<td>Canadian government - Reference</td>
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<tr>
<td>World oil price</td>
<td>Evolving scenario (CER)</td>
<td>Evolving scenario (CER)</td>
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<tr>
<td>Export price for H2 (2022$/kg)</td>
<td>1.6-1.8</td>
<td>1.6-1.8</td>
</tr>
<tr>
<td>GHG reductions from natural solutions (outside the model)</td>
<td>28 MtCO2e</td>
<td>28 MtCO2e</td>
</tr>
<tr>
<td>Electricity system constraints</td>
<td>none</td>
<td>yes - 5 years growth limit</td>
</tr>
<tr>
<td>Hydrogen technology cost assumptions</td>
<td>Pessimistic - keep costs and performance at 2025 values</td>
<td>Most Optimistic findings of the literature</td>
</tr>
<tr>
<td>Retrofit NG pipelines to H2</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Hydrogen blend (volume)</td>
<td>2%</td>
<td>20%</td>
</tr>
<tr>
<td>Biomass CCS constraints</td>
<td>Biomass sequestration limited at 5% max by 2035, 5% by 2050</td>
<td>Biomass sequestration limited at 35% max by 2035, 75% by 2050</td>
</tr>
<tr>
<td>Policies beyond GHG constraint</td>
<td>None</td>
<td>Financial benefits for H2, both capital cost and production cost subsidies) 20% reduction on capital cost, all demand and production, starting in 2025</td>
</tr>
</tbody>
</table>
Canada – Total hydrogen production by technology

A maximum of 10 Mt by 2050

- Hydrogen as by-product
- Coal
- Ammonia - Centralized - Steam methane reforming with CCS
- Ammonia - Centralized - Steam methane reforming
- Hydrogen - Centralized - Autothermal Reforming with CCS
- Hydrogen - Centralized - Autothermal Reforming
- Hydrogen - Decentralized - Steam methane reforming
- Hydrogen - Centralized - Steam methane reforming with CCS
- Hydrogen - Centralized - Steam methane reforming
- Hydrogen - Centralized - Solid oxide electrolyzer cell
- Hydrogen - Centralized - Polymer electrolyte membrane
- Hydrogen - Decentralized - Polymer electrolyte membrane
- Ammonia - Centralized - Biomass gasification with CCS
- Ammonia - Centralized - Biomass gasification
- Hydrogen - Centralized - Biomass gasification with CCS
- Hydrogen - Centralized - Biomass gasification
- Hydrogen - Centralized - Coal

ESMIA Energy Super Modelers and International Analysts
Canada – Total hydrogen consumption

Pessimistic: 2.6 Mt of hydrogen

- Use as feedstock: 45%
- Industrial - Pure: 29%
- Commercial - Pure: 0%
- Residential - Pure: 0%
- Industrial - Natural gas mix: 1%
- Residential - Natural gas mix: 0%
- Oil production and refining - Natural Gas mix: 0%
- Transport: 5%

Optimistic: 9.3 Mt of hydrogen

- Use as feedstock: 45%
- Industrial - Pure: 29%
- Commercial - Pure: 20%
- Residential - Pure: 0%
- Industrial - Natural gas mix: 1%
- Residential - Natural gas mix: 0%
- Oil production and refining - Pure: 20%
- Oil production and refining - Natural Gas mix: 0%
- Transport: 5%
- Electricity: 0%
Canada – Total final energy consumption

Hydrogen in the final mix
Hydrogen represents at most 12% of the final energy consumption mix (18% industries; 14% transport).

Electrification is dominant
Electrification remains the most cost-effective options in multiple segments of the economy.

Bioenergy play different roles
Biomass is used with CCS to generate net-negative emissions.
A zoom on the gas grid and the building sector
Debate on gas grid conversion to hydrogen

Gas heating technologies are highly used in most of the provinces in Canada.

There have been questions about proper functioning of heat pumps in cold climate and more particularly in dry environment (typically the prairies).

Risks of stranded assets in the extensive gas network infrastructure.
Modelling improvements for building decarbonization insights

**Increase time slice accuracy**: Explore time slices’ resolution through an external hourly database based on historical data

**Detailed building space heating performance**: Tuning parameters according to temperature

For each province:
- Extensive work on the gas network modelling
- Creating and analyzing yearly hourly database for the building sector and the renewable generation
- Modelling nonlinear heat pumps efficiency and capacity factor
Canada’s natural gas transmission grid

1. Westcoast or Enbridge’s BC Pipeline.
3. Alliance Pipeline.
4. Foothills pipeline system.
5. TC Canadian Mainline (Mainline).
6. Trans Québec & Maritimes pipeline (TQM).
7. Maritimes & Northeast Pipeline (M&NP).
8. Emera Brunswick Pipeline.
9. Vector Pipeline system.
10. Many Island pipeline system
For each province, we’ve gathered hourly data:

- Temperature for most populated city
- Electric utility total load (where available)
- Energy consumption by appliances or energy service
- Standardized load curves

We’ve calibrated load curves, especially space heating and cooling as a function of temperature.
Building sector – load curves

Quebec - Electricity average winter day

Quebec - Electricity peak winter day

160% increase - Average to peak
Hourly database – Wind and solar

Database of all current wind and solar farms
• Simulation via Renewable Ninja of the historical hourly generation

Literature review of resources potential
Evaluate annual site potential
• Create realistic supply curves based on “poor”, “moderate” and “best” site location by province

Evaluate short-term performance
• Analyze occurrences of few days' shortage of renewable generation
Heat pumps efficiency and capacity in cold climate

Hourly temperature

Efficiency as a function of temperature

Capacity as a function of temperature

ESMIA Energy Super Modelers and International Analysts
Hourly database – Modelling different time slice resolution

**Time slice definitions**

16 time slice scenario
- 4 season
- 4 intra-day periods

72 time slice scenario
- 3 season
- 24 hours

24 time slice scenario
- 6 seasons
- 4 intra-day periods

**TIMES attribute by time slice**

Wind and solar
- Availability factor
- Contribution to peak

Residential and commercial
- Load curves

Space heating and cooling technologies
- Efficiencies
- Capacity factor
- Share of natural gas vs electricity for dual heating systems
Scenario design
Conflicting visions of the future natural gas grid and space heating

**Reference scenario**
A reference case with federal and provincial policies

**Optimal net-zero scenario**
A scenario with Canada-wide GHG reduction of 40% in 2030 (2005) and net-zero by 2050

**Archetype A: High Clean Gas**
Achieving higher shares of biomethane and/or hydrogen in buildings by 2050 compared to the other scenarios.

**Archetype D: HighElectrification**
Achieving very high shares of electrification in buildings by 2050, compared to other scenarios.
Canada – GHG emissions
Canada – Total energy consumption for buildings

Still some natural gas in the NZ50
Small amount is used to fuel dual heating system to reduce winter peak consumption

High electrification scenario consumes less energy
The model invests largely in energy efficiency such as cold climate and geothermal heat pumps

Renewable natural gas resources is limited
Renewable natural gas reaches a high in the clean gas scenario, however, in other scenarios, biomass resources is used for industries.
Market share of space heating technologies in the residential sector

Alberta

Ontario

Quebec

- Ref, NZ50, High Clean Gas, High Elec
- Biomass Stove
- District heating
- Dual fuel system
- Electric baseboard
- Gas Furnace
- Geothermal heat pump
- Heat pump - Cold climate
- Heat pump - Standard
- Hydrogen furnace
- Oil Furnace
- Thermal storage
Canada – Hydrogen production

![Graph showing hydrogen production for different sectors and years](image-url)
Further analysis are required
**Energy transition impact on residential bills**

- **Currently different (gas and electric) utilities are moving from volumetric to fixed service charges for “fairer and more transparent way to recover distribution costs” (OEB)**
- **Exploring the impact of energy bill structure on consumers energy expenses:**
  - Proportion of fixed charges and volumetric rates in the bill
  - Consumers with different annual consumptions in a jurisdiction

*Figures are only for illustration purposes*
Energy transition impact - CGE

Economic shock:
- Direct with model variables: investment volume and stocks variation, foreign labor and labor offer, world export/import prices, taxes etc.
- Through coupling with NATEM

Inputs:
- Detailed economy snapshot for the base year 2016
- Parameters to simulate economic growth

Outputs:
- GDP
- Consumer price index
- Governmental savings
- Production, capital demand
- Employment: labor supply, demand, unemployment
  ...

Economic and socioeconomic impact, and drivers
Least-cost combinations of future energy and climate policies
Thank you!

Questions?

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