Canadian Energy Outlook 3e edition

REPORT #4: Infrastructure: Operationalizing the Transition to Carbon Neutrality

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Reviewed by Louis Beaumier

About the Trottier Energy Institute

Created in 2013 with funding from the Trottier Family Foundation, support renewed in 2023.

Mission: To mobilize science and governance to help catalyze the transition to decarbonized Canadian energy systems in order to support the achievement of carbon neutrality by our society, in a context of climate emergency.

Areas for action:

- ***Training and research*** - Mobilising expertise, sharing knowledge and developing know-how.
- ***Analysis and support*** - Helping to design responses to energy issues, guiding public policy and supporting key players in implementing solutions.
- ***Communication*** - Publicising the issues, communicating the urgent need for action and highlighting solutions.

Some of our projects

- Developing an evaluation grid for a biomass project in the context of a carbon-neutral Canada
- Reducing peak electricity demand and improving resilience in an increasingly electrified world
- Co-directing, with IESVic and the University of Calgary, the **Energy Modelling Hub**, a pan-Canadian, cross-border organisation that develops, maintains and makes available energy models and brings together public policy makers and the energy modelling community.

Presentation

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Moderated by

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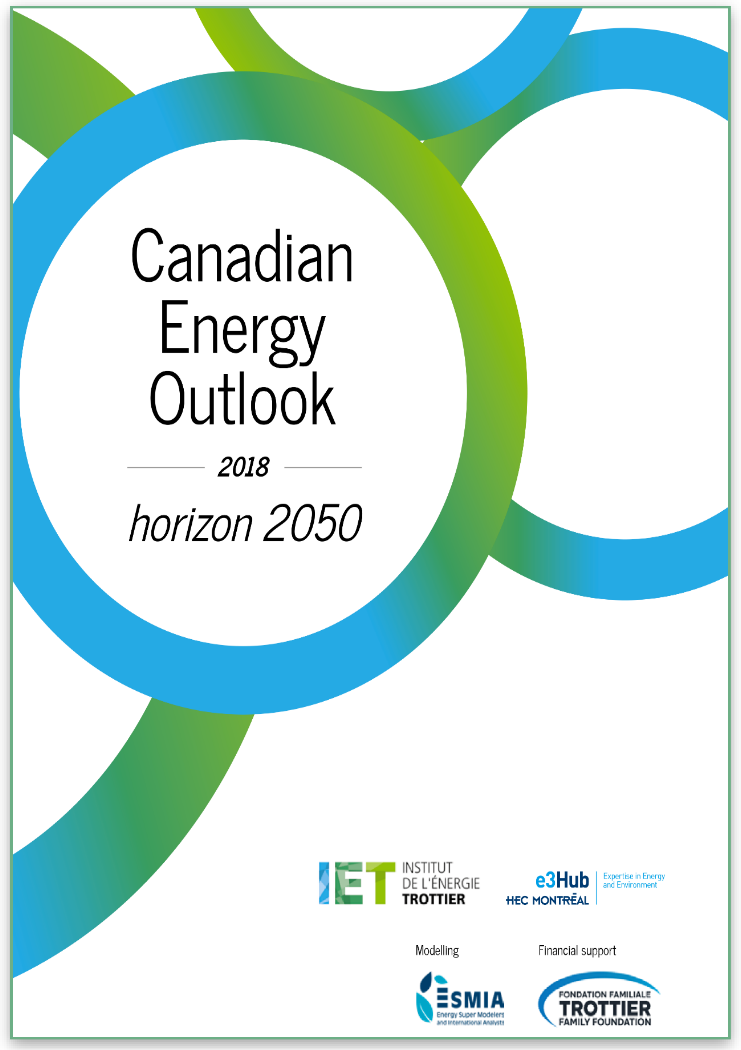
In this presentation

- **Exploring the nature of the transformations that Canada's infrastructure will have to undergo if we are to achieve carbon neutrality.**
- **Although these transformations will affect manufacturing processes and the consumption patterns, we will focus on the evolution of energy production and energy service technologies:**
  - **buildings, transport, CO_2 capture and sequestration, electricity, etc.**
- **Avenues for the operationalization of these transformations**

Work from the IET on decarbonization

Three editions of the Canadian Energy Outlook



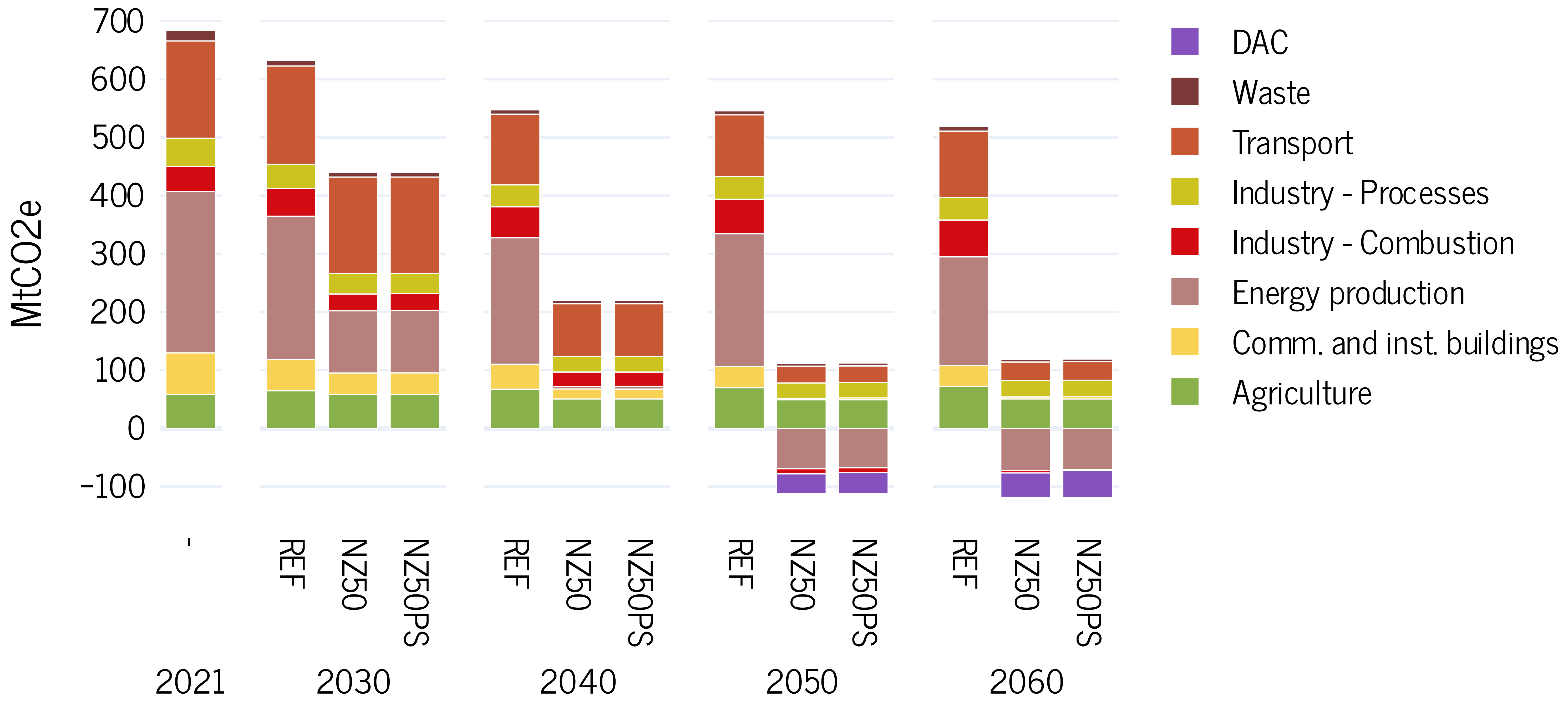
Other reports on strategic issues

The goal of carbon neutrality

- Canada's climate objectives require major technological changes.
  - In-depth transformation of energy production to energy service
  - A profound impact on everyday life.

DAC
Waste
Transport
Industry - Processes
Industry - Combustion
Energy production
Comm. and inst. buildings
Agriculture

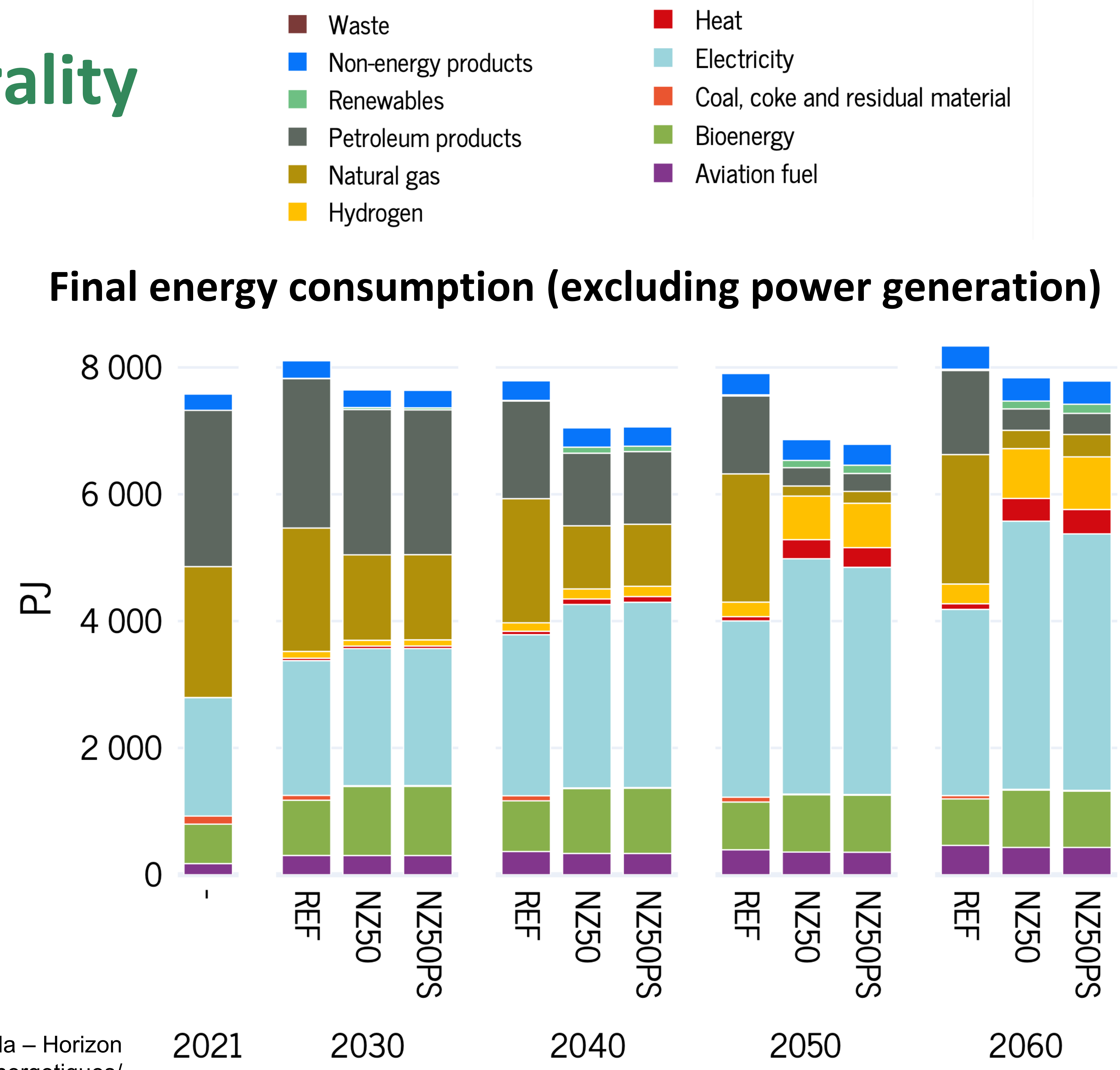
Greenhouse gas emissions



Langlois-Bertrand et al (2024) Pathways for a net-zero Canada – Horizon 2060 http ://iet.polymtl.ca/perspectives-energetiques/

The goal of carbon neutrality

- Reduce total energy demand by 9% by 2050, despite population and GDP growth.
- Two opposing trends:
  - (i) spectacular reduction in fossil fuels (from 5400 PJ to 800 PJ)
  - (ii) doubling of electricity production (from 1900 PJ to 3700 PJ).



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Scale of operational challenges

The models predict a profound transformation of the energy system; **however, they do not explain how this transformation will be put into practice, nor the collateral consequences.**

- Need for electricity infrastructure (power and timing)
- Development of new technologies to decarbonise processes
- Mastering CO2 capture and sequestration (CCS) for unavoidable emissions

Making the transition work: structural changes needed

- Creation of new supply chains and disappearance of old ones
- Adaptation of service chains (manufacture, use, installation, repair)
- The report focuses on energy production and consumption technologies

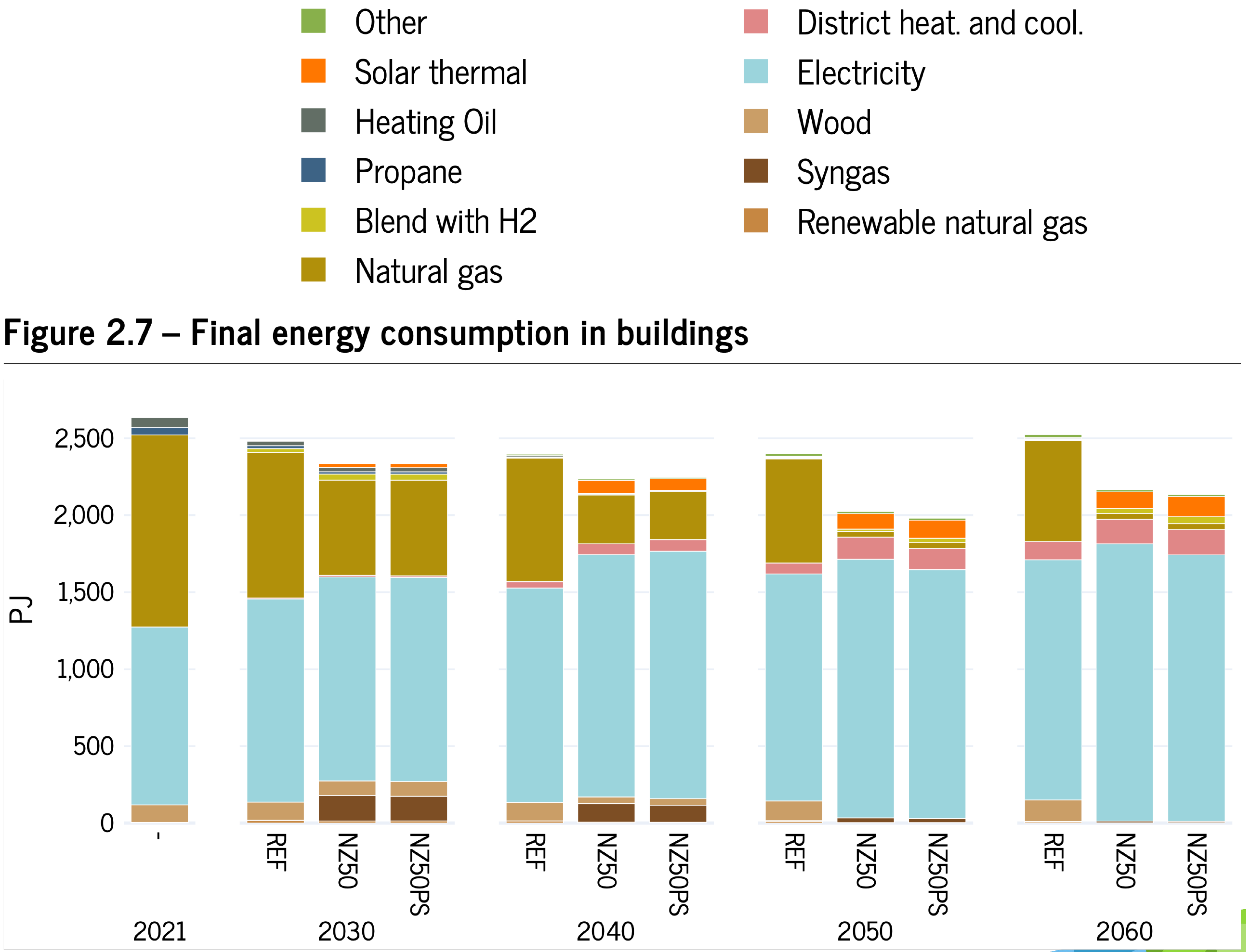
Analysis of the nature of the transformations required.

1. Three major sectors studied:
   (i) Buildings
   (ii) Transport
   (iii) Capture and sequestration of CO_2 (CCS).
2. The energy production required for this transformation
3. The costs of the transition
4. Can the timetable be met?

The building sector

- Almost complete decarbonisation of the building sector by 2050 (52% to 2% fossil fuels).

Figure 2.7 – Final energy consumption in buildings



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The building sector: the scale of the challenge

Table 1 – Number of households by main energy source for heating in 2021 (in thousands)

Electricity	Natural gas	Oil/Coal/Propane	Firewood	Total
6 702	7 337	773	353	15 164
44 %	48 %	5 %	2 %	100 %

Source: Natural Resources Canada 2025

53% of systems to be replaced by 2035

Table 2 – Secondary energy consumption for ICI space heating by energy source in 2021 (in PJ)

Electricity	Natural gas	Oil/Coal/Propane	Total	Total floor area
86	550	34	671	765 Mm^2
13 %	82 %	5 %	100 %	

Source: Natural Resources Canada 2025

87% of systems to be replaced by 2035

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How to approach the electrification of heating

- Need to replace gas/oil furnaces with heat pumps (air or geothermal).
- Importance of rapidly replacing existing heating systems with low-carbon technologies, given their long lifespan (20-30 years).
- Current barriers: high initial costs, lack of skilled labour, and perceived risks associated with new technologies.

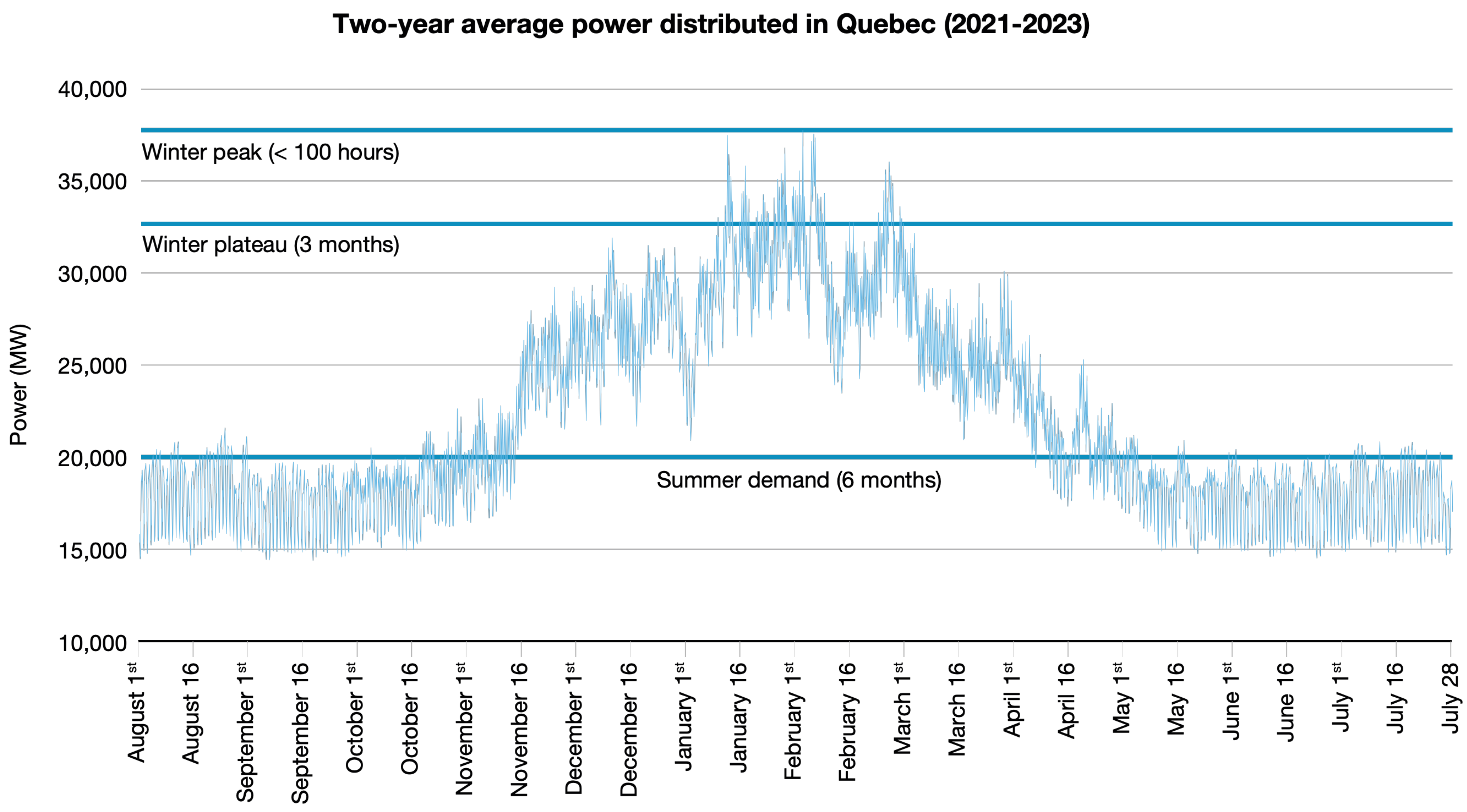
Operationalising the transition:

From a technological standpoint, Canada has largely been treading water when it comes to heating technologies for several decades. The options are therefore aimed at deployment:

- Support for the installation of equipment: training the workforce, standardisation, structuring the market, etc.
- Reduction of barriers (particularly institutional, commercial and multi-unit residential)
- **Canadian added value:** in the adaptation, installation and maintenance of systems.

Impact on the electricity network

- Profound change in the pattern of electricity demand: more pronounced seasonal pattern.
- Increase in the maximum power required due to winter heating (50 to 70%, or even >100% for extreme peaks).
- Example of Quebec: demand rises from <20 GW to almost 33 GW in winter, and 42 GW at peak.



Source: Hydro-Québec 2024a

Challenges for electricity distributors

- Significant increase in the level of electricity generation and network capacity (transmission and distribution).

- Need to meet basic winter demand and manage fine peaks.

  ➡ See Edom and Mousseau (forthcoming!)

- Importance of demand management to avoid overinvestment.

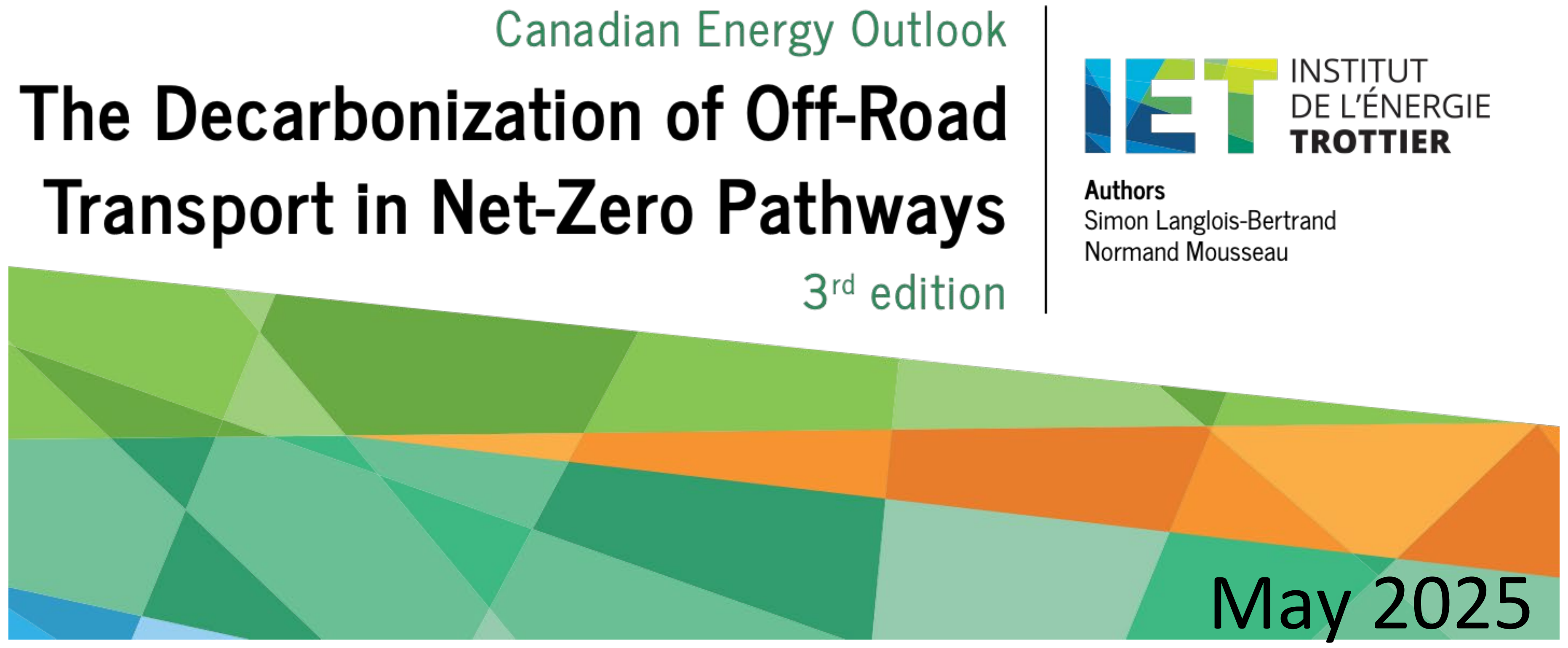
- Limits of interprovincial/interstate exchanges for peaks: demand matching.

- Risk of distributors refusing electrification, delaying decarbonisation.

The transport sector

More complex than buildings because of the diversity of modes, uses and maturity of solutions.

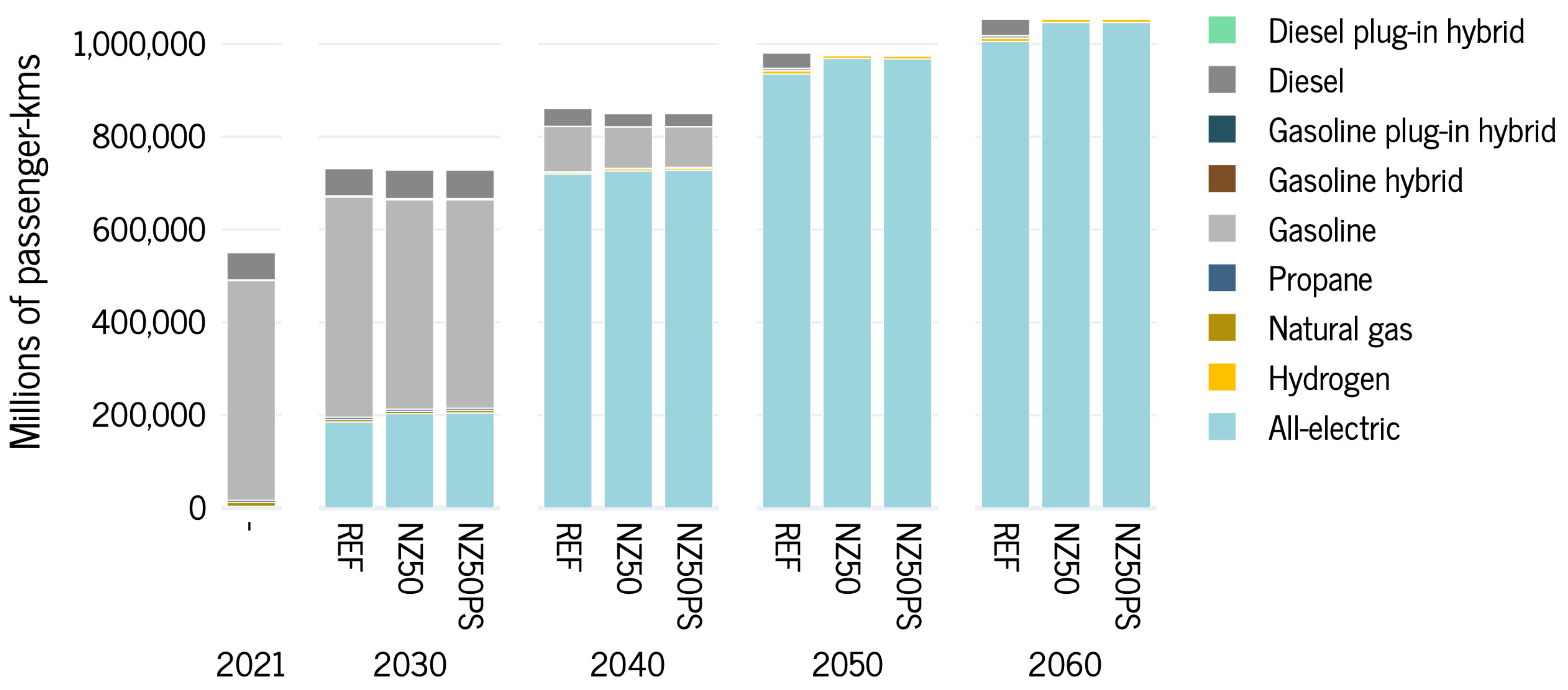
- Road transport - personal vehicles
- Road transport - goods
- Rail, sea and air transport
- Off-road transport →



Road transport - personal vehicles

- Close to total decarbonisation by 2050 thanks to regulation on zero-emission vehicles.
- More than 99% battery-electric fleet in all PEC scenarios.
- Public charging infrastructure still inadequate in several provinces.

Type of energy consumed per millions passenger-kms



The role of governments and public bodies is crucial for charging light vehicles.

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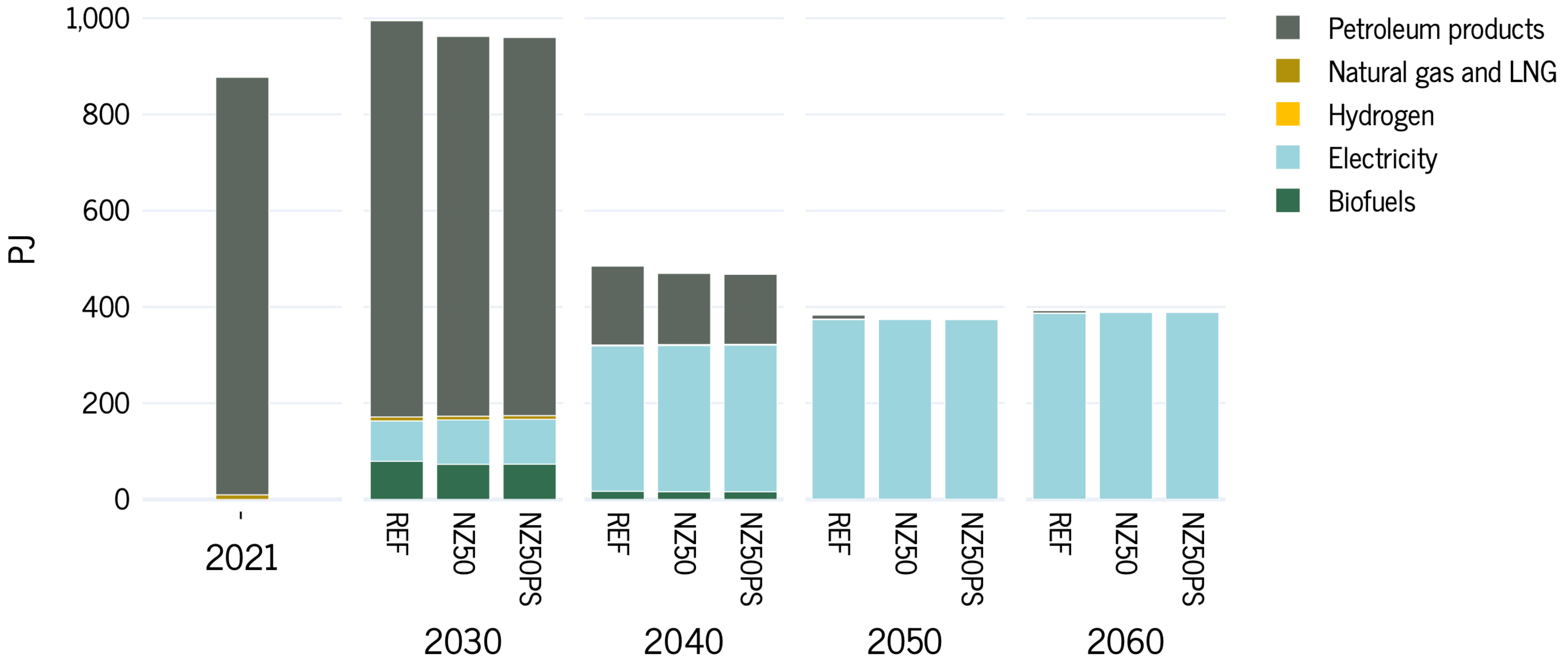

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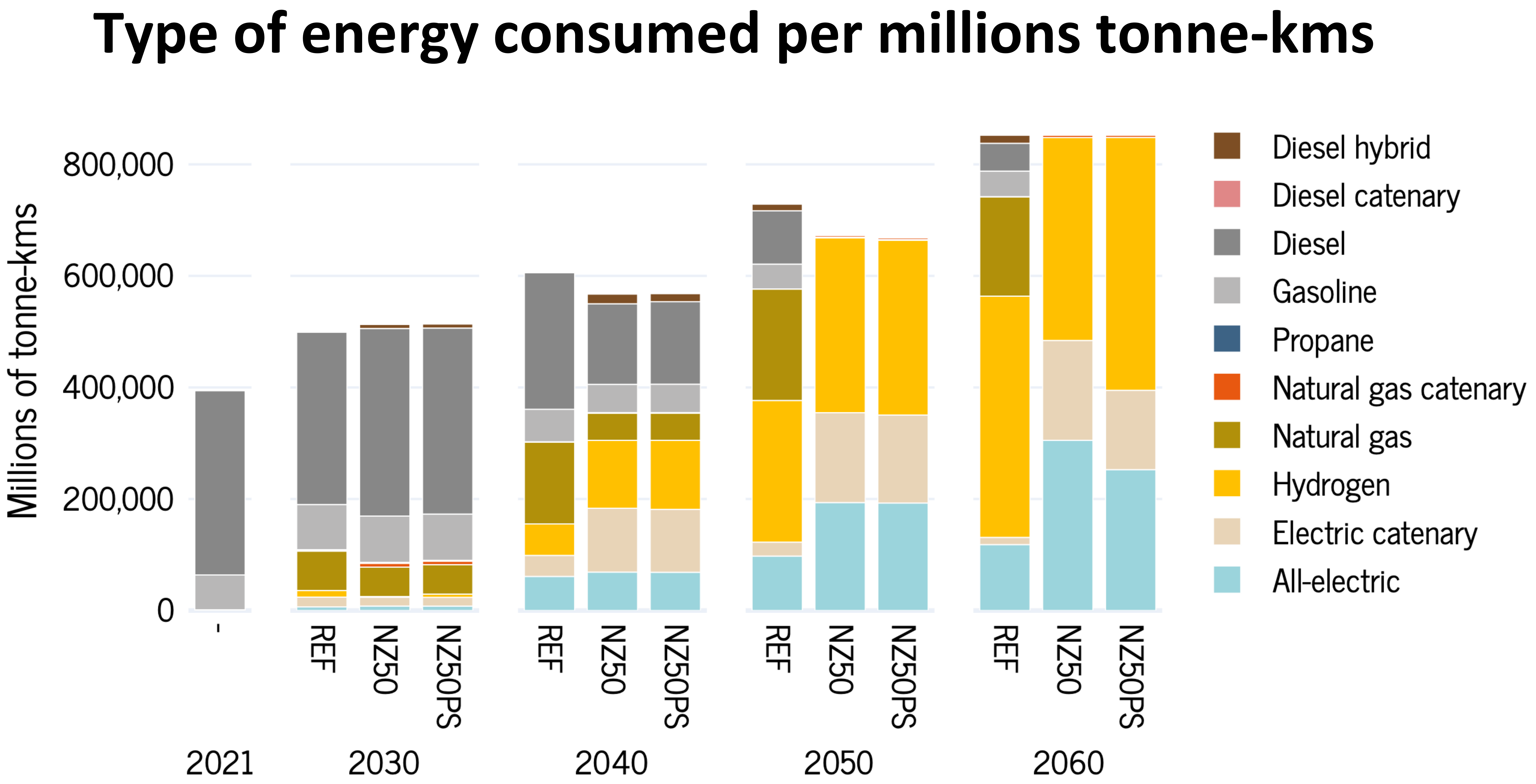
Road transport - freight

- Decarbonisation strategies still lacking for freight/commercial transport.
- Multiple low-carbon alternatives: hydrogen (47%), batteries (29%), catenaries (24%).
- Each requires major and costly infrastructure, making coexistence difficult.



Canada needs to identify the way forward quickly and roll out pilot projects.

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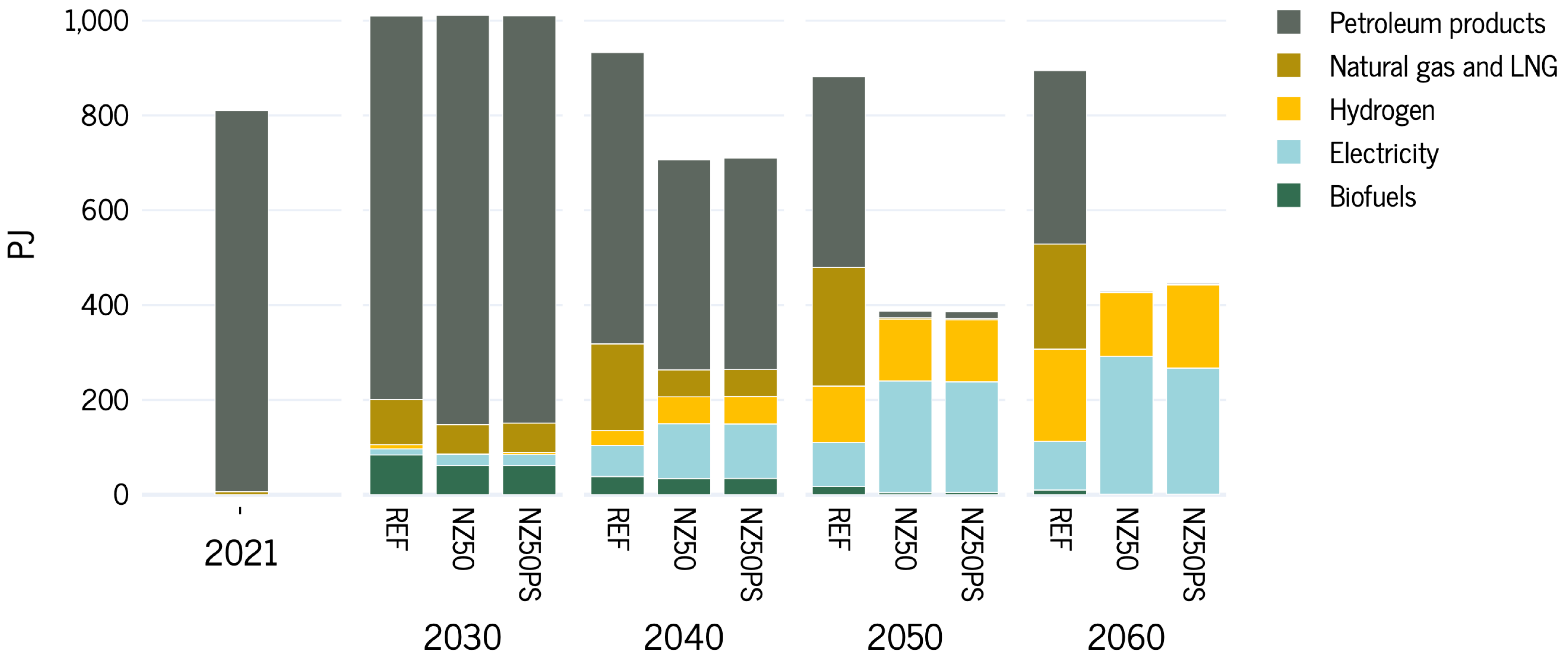
Energy consumed per type of energy



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Road transport - freight: strategic choices

- Regulations:
    - Influence of regulations (e.g. EU vs. North America for batteries).
    - Need for standardisation and regional/continental planning.
- Costly deployment (catenaries, hydrogen, high-power chargers).
- Impact on electricity networks:
    - Battery charging and catenaries require increased generation and fine alignment of power.
    - Hydrogen by electrolysis requires even more electricity, but offers storage flexibility.

Road freight transport: leadership and opportunities

- Models highlight technical and economic uncertainties.
- Rapid deployment of large-scale pilot projects necessary to test technologies.
- Risk for Canada of having technological choices imposed on it and not benefiting from the emergence of Canadian companies.
- Opportunity to rethink the balance between road, sea and rail transport.

Rail transport

- In the CEO 3rd edition: rail is almost entirely decarbonised thanks to hydrogen (60%) and electricity (40%)

- Many unknowns remain behind these projections:
    - nature of the sector (a few dominant players, significant revenues and profits)
    - diversity of vectors (electricity, hydrogen)
    - possible convergence towards regional/continental solutions

Operationalising the transition

- Importance of government support to accelerate the transformation; need for a continental vision in many cases

Maritime and air transport

- CEO models show the current absence of viable decarbonised solutions for aviation (not offset by negative emissions).

- Numerous challenges, requiring international coordination.

Operationalising the transition

- Canada has significant resources in bio-energy and low-carbon electricity.
- As well as a world-leading aerospace industry.
- Canada should get involved and lead efforts to decarbonise these sectors.

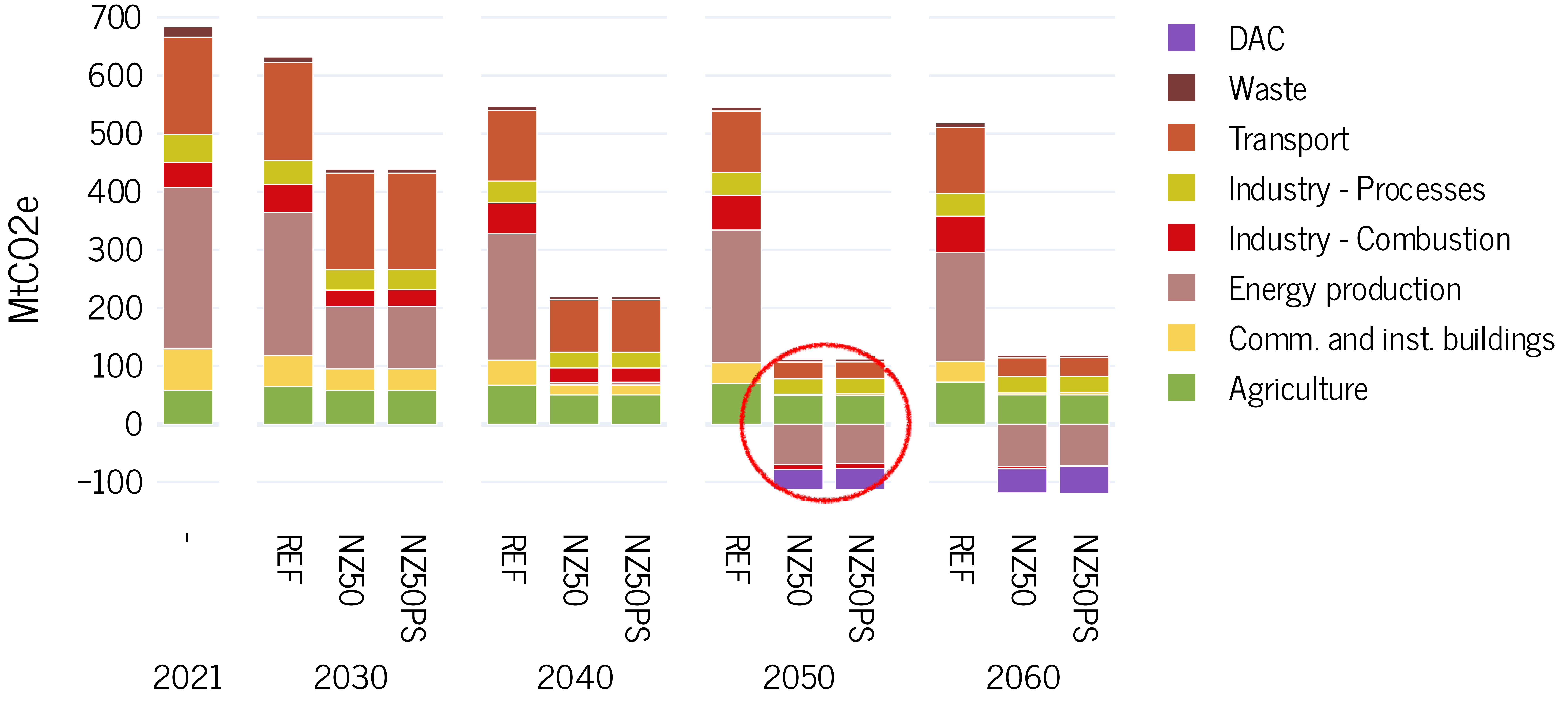
Transport - infrastructure deployment

- Transport energy infrastructure is larger and more diverse than building infrastructure.
- The choice of technologies will influence the infrastructure to be deployed, but also the transformation of vehicles.
- Need for public leadership (funding, regulation) to reduce risks and speed up the transition.

→ Example of the *Circuit électrique* in Quebec for charging stations.

- Additional productivity gains (e.g. more reliable and less expensive electric cars): electrification improves the control, performance and productivity of transport services.

The crucial role of CO2 capture and sequestration (CCS)



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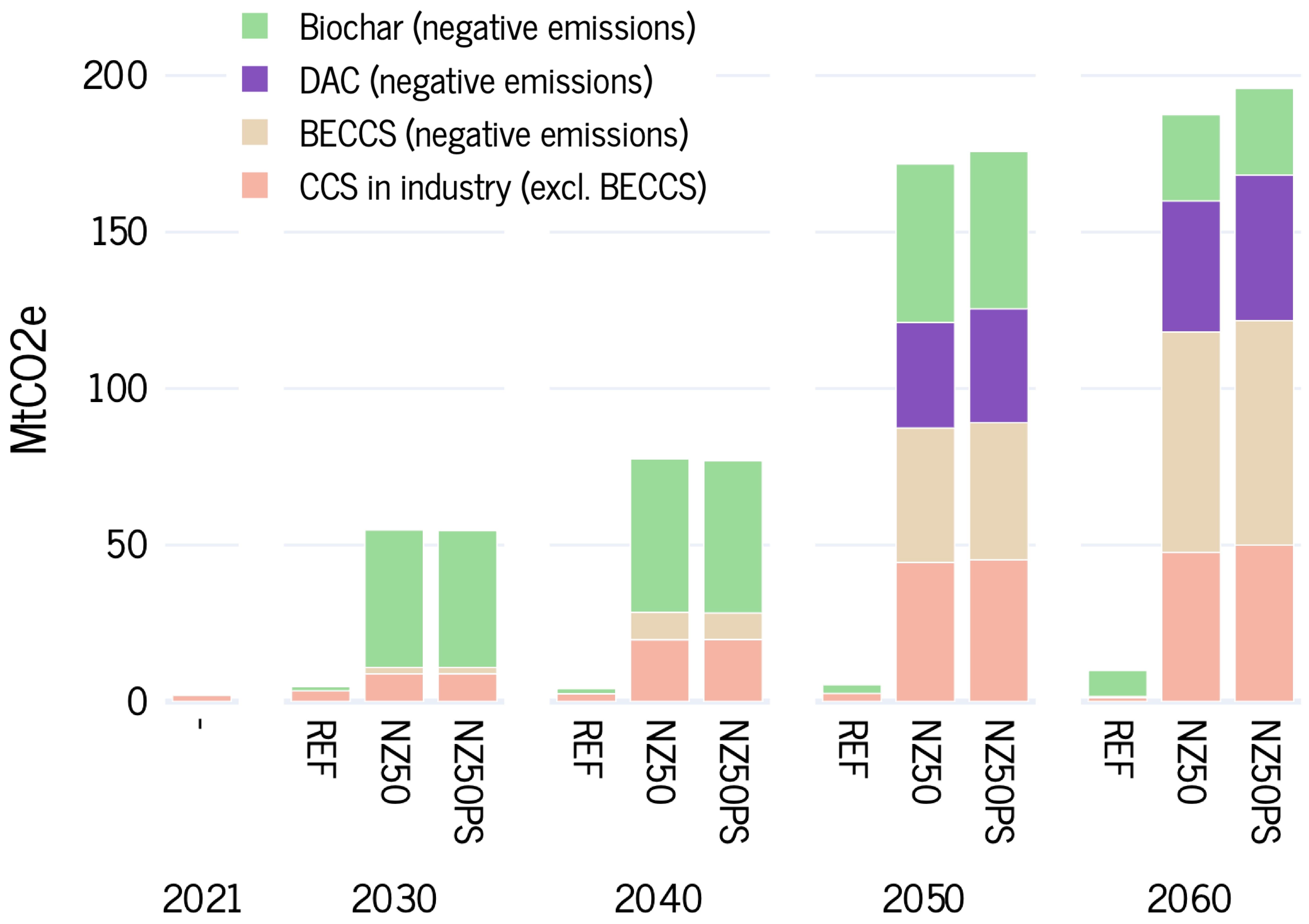
CCS: an important role for biomass energy

- Around 160 Mt CO_2e of emissions (25% of today's levels) are captured annually to achieve carbon neutrality by 2050.
- This represents as much as oil sands production (170 Mt in 2023)
- Negative emissions technologies are an essential part of the equation, but there is considerable uncertainty surrounding them

Captured and stored emissions



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What these figures mean

- The current level of CCS is very low: 1.5 Mt CO_2e captured per year, mainly from oil extraction; reaching the levels we model would require a massive increase in efforts.
    - These would have to be multiplied by more than 100 in 25 years - in comparison, oil sands production grew by just under 8 between 1995 and 2023.
- These projections underline the unknown factors involved in decarbonising heavy industry, transport and agriculture.
- A number of solutions are being developed at source (e.g. green hydrogen steel).
- Even with breakthroughs, CCS will still be necessary on a large scale, provided three major challenges are met:
    1. The capture rate
    2. Energy costs
    3. Resource validation

Three major challenges for CCS: 1. the capture rate

- Theoretical potential of 95% for concentrated emissions

  → but industrial reality is lower.

- Canadian examples: Boundary Dam (66%), Quest (75%), NWR Sturgeon (70%), Glacier (89%).

- Today, the CO_2 captured is generally reinjected to facilitate oil recovery, reducing the real environmental gain.

Challenge: significantly increase the rate of CO_2 capture

Three major challenges for CCS: 2. Energy costs

- Energy expenditure increases when CO_2 concentration decreases

→ Example of Glacier: 2 GJ (560 kWh)/tonne of CO_2 captured in the stack for a net cost of $32/tonne according to Entropy.

- Capturing 100 million tonnes of CO_2 at concentrations of over 5% would therefore require 56 TWh annually at a cost of around $3.2 billion (this can probably be multiplied by 3 or 4 to take account of lower concentrations).

Challenge: reduce the energy demand associated with capture and sequestration OR reduce the cost of energy.

Three major challenges for CCS: 3. Validation of resources

- Canada has potential reservoirs to store more than 100 billion tonnes of CO_2

  ➡ Scale tests are needed to identify real constraints and assess risks.

- Modelling predicts an important role for biochar in CCS:

  ➡ Transformation of biomass residues into stable carbon by pyrolysis.

  - Benefits: long-term carbon storage, improved soil quality.

Challenges:
1. validate sequestration resources and techniques
2. Support large-scale deployment to reduce costs.

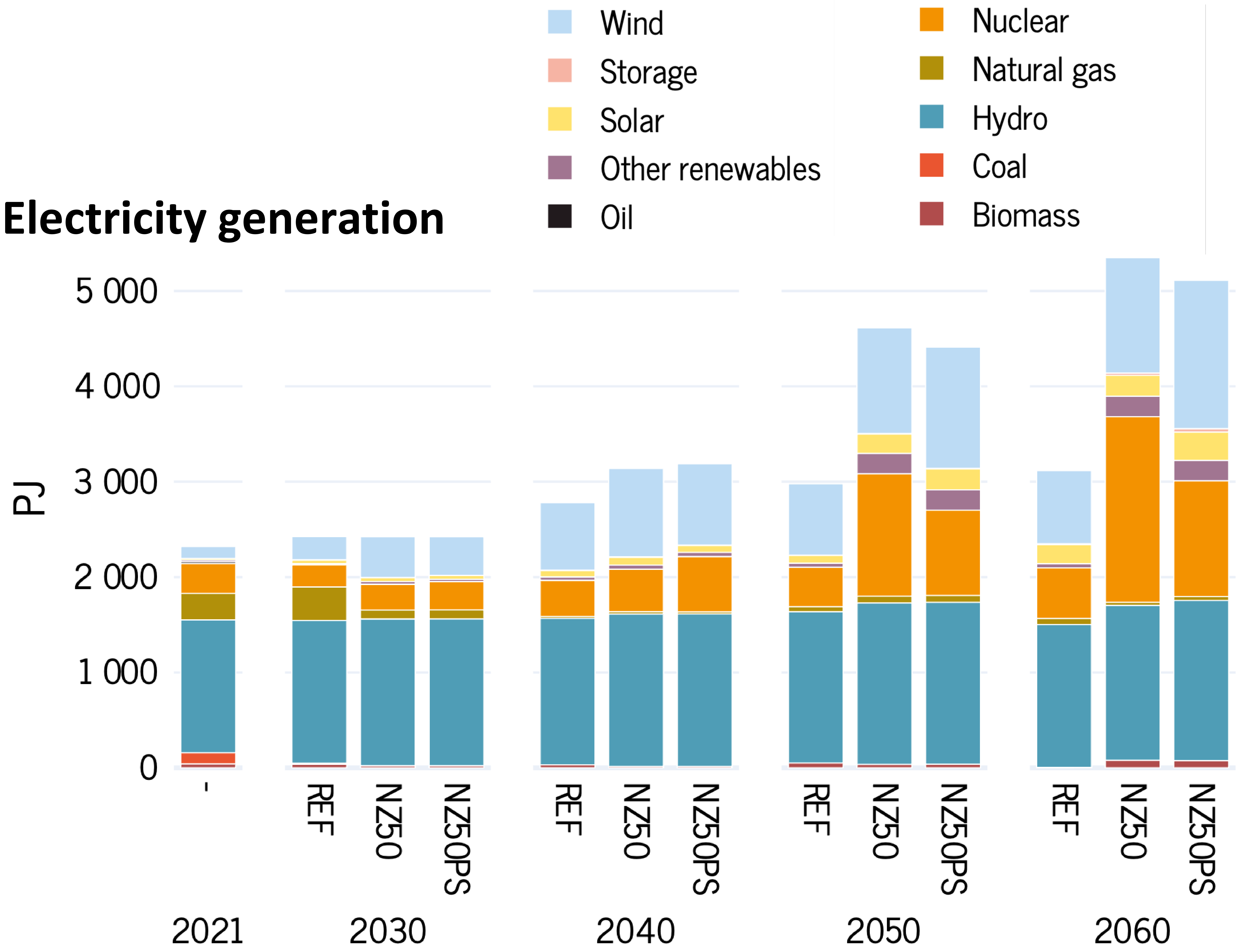
CCS deployment - an opportunity for Canada

- Creation of new industrial sectors, including
    - (i) production of chemical compounds
    - (ii) geological storage
    - (iii) construction of facilities
- These industries will have to rely on clean energy, mainly electricity.
- Current obstacles: lack of certainty about the price of carbon, infrastructure financing and a clear deployment strategy.

An exceptional opportunity for the forestry and oil industries to diversify their uses and revenues.

Energy production: massive electrification

- Achieving carbon neutrality requires a massive increase in electricity.
- Electricity production must more than double by 2050 (from 650 TWh to 1281 TWh).
- Production projections: hydropower (+20% – to 470 TWh), nuclear (x4 – to 360 TWh), wind (x8 – to 310 TWh), solar (to 56 TWh).



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Underestimating demand for electricity

Most models underestimate the increase in demand due to:

- Systematic biases in technical and economic models:
    - (i) conservative approach in including new sectors (AI, greenhouses)
    - (ii) energy use considered to be optimal

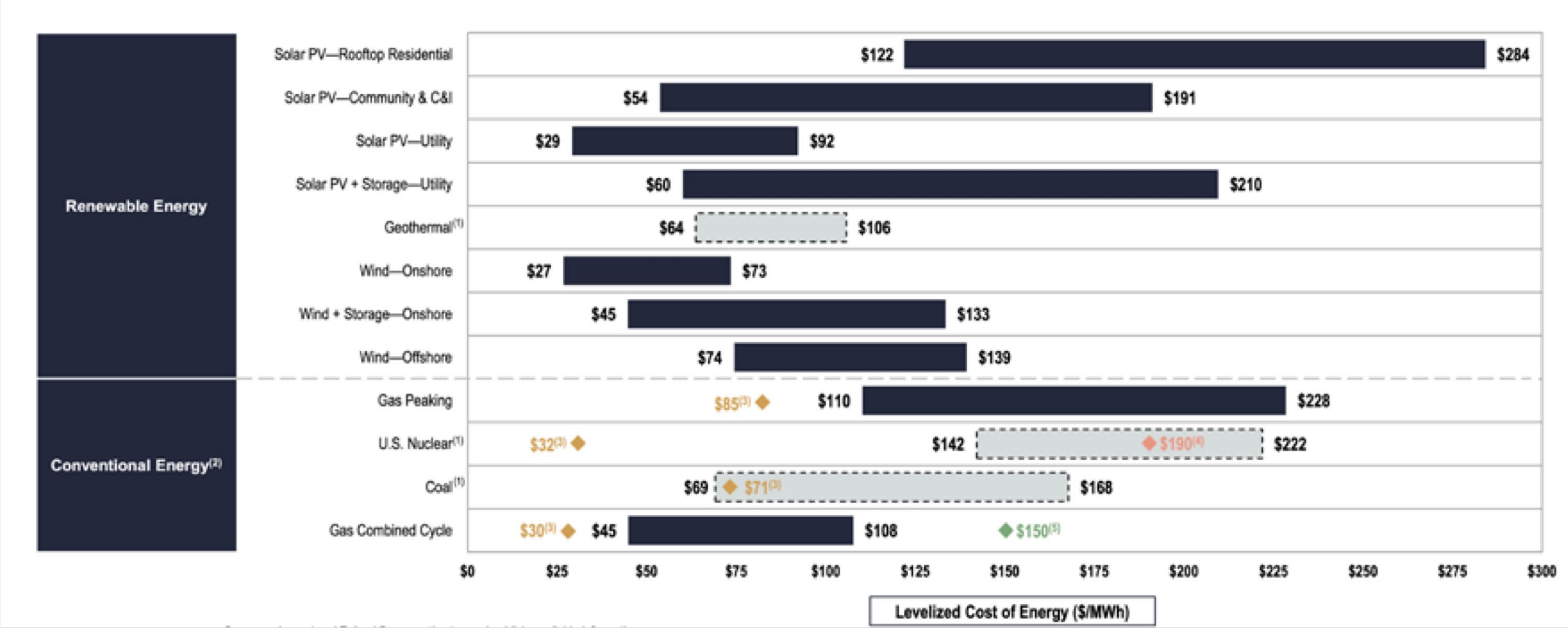
→ Example of Quebec: industrial projects represent 13 GW in new demand.

- Canada will need a lot of clean energy; we need to start building the system's capacity now.

Understanding the value of different sources of electricity

- Wind and solar power offer the cheapest electricity.

Figure 5 – Discounted energy costs for various types of production. In orange: production costs once infrastructure costs have been amortized

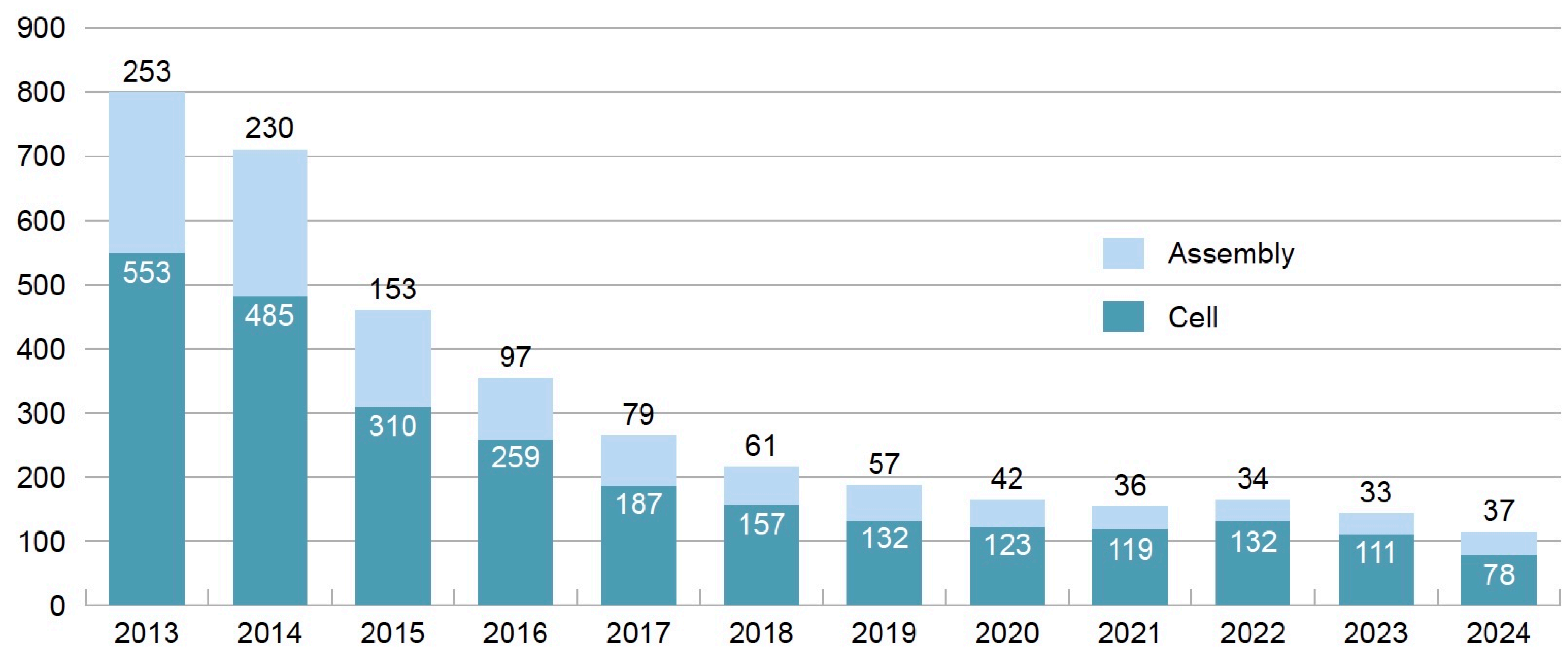


Source: Lazard 2024

Understanding the value of different electricity sources

- Mass storage solutions can transform the strategic balance.

Figure 4 – Lithium battery price trends in US dollars (2024).



Source: BloombergNEF 2024

Understanding the value of different electricity sources

- Don't just add intermittent sources; align production and demand:

  ➡ Wind is preferrable to solar in Canada because of better synchrony with winter demand.

- Factors beyond the average cost/kWh: flexibility, match with demand, resilience.
- Flexible sources (natural gas thermal power stations, hydraulic turbines), predictable (nuclear) and intermittent (solar, wind).
- Need for large-scale storage (chemical, physical, geological).

Production investment planning

- Major investment required, construction ahead of demand (1960-1980 model).
- Electricity becomes essential for civil security (heating, communications, transport).
- Electricity from renewable sources is now cheaper to produce than electricity from fossil fuels.
- The deployment of wind farms presents few risks.
- Need for low-carbon balancing solutions (inter-regional transmission lines, storage).

The cost of transition: a net benefit for the system

- Massive electrification will reduce the total cost of energy services.
- Major investments will not lead to an explosion in the cost of Canadians' energy portfolio, but to system savings.

Table 3 – Annual investment costs for electrification and fossil fuel expenditure

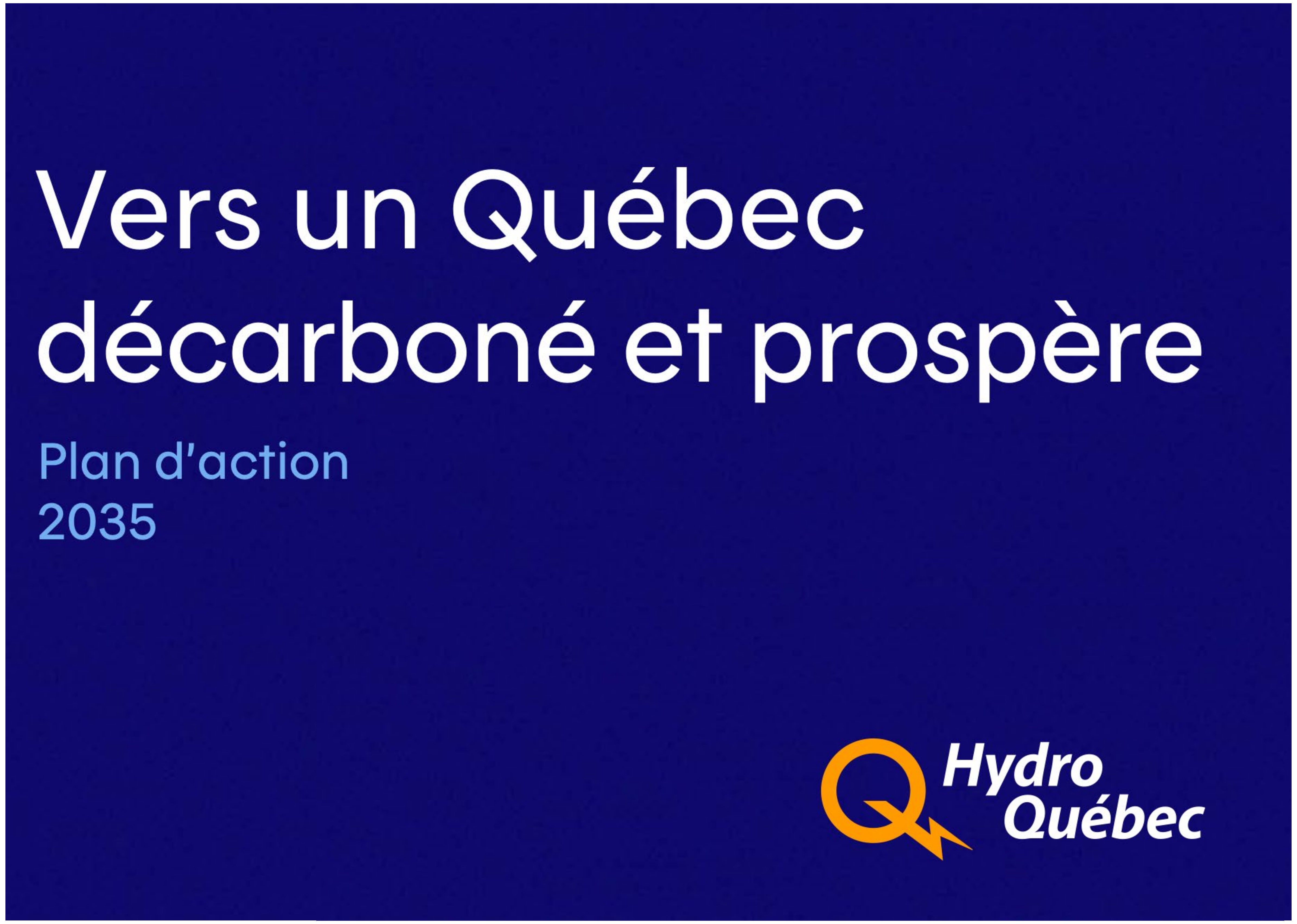
		REF	CP30	NZ60	NZ50	NZ45
Electrification investment costs	2016-2030	4.0	8.0	6.1	9.8	13.5
	2030-2050	4.8	7.2	37.6	47.7	46.0
	2050-2060	-4.8	1.1	41.6	14.7	14.4
Change in fossil fuel expenditures	2030-2050	10.3	4.9	-3.1	-13.5	-17.1
	2050-2060	29.2	20.6	-54.3	-75.5	-74.4
	2060+	43.3	34.3	-77.7	-76.8	-73.6

Source: Baggio, Joanis et Stringer, 2021

- Investments of $1,100 billion (about $48 billion/year between 2030 and 2050).
- Savings of $75 billion/year in oil and gas after 2050.

The challenge: redistributing these savings fairly (political, not engineering).

Electricity



	MW projected (MW)	Announced in 2024 (MW)
Energy savings	1 600 - 1 800	
Wind power (over 10,000 MW installed)	1 500-1 700	> 4 000
Hydropower	3 800-4 200	>2,400 (TN-Lab)
Solar, storage and other	500-1000	
Thermal power plant converted to RNG	400-600	
Total	**8 000- 9 000**	

2035 Action Plan - Hydro-Québec

Sommaire des investissements et des charges d'exploitation nécessaires

Investissements et charges	Montants totaux d'ici 2035	Moyenne annuelle
Investissements visant à assurer la fiabilité et la qualité du service (projets de pérennisation des actifs)	45–50 G$	4–5 G$
Investissements visant à répondre à la croissance de la demande (projets de développement)	90–110 G$	7–9 G$
Charges d'exploitation additionnelles	20–25 G$	1–2 G$
TOTAL	**155–185 G$**	**12–16 G$**

La moyenne annuelle des investissements et charges d'exploitation prévus d'ici 2035 est de trois à quatre fois supérieure à celle des cinq dernières années.

The importance of conversion: *less costly than you might think*

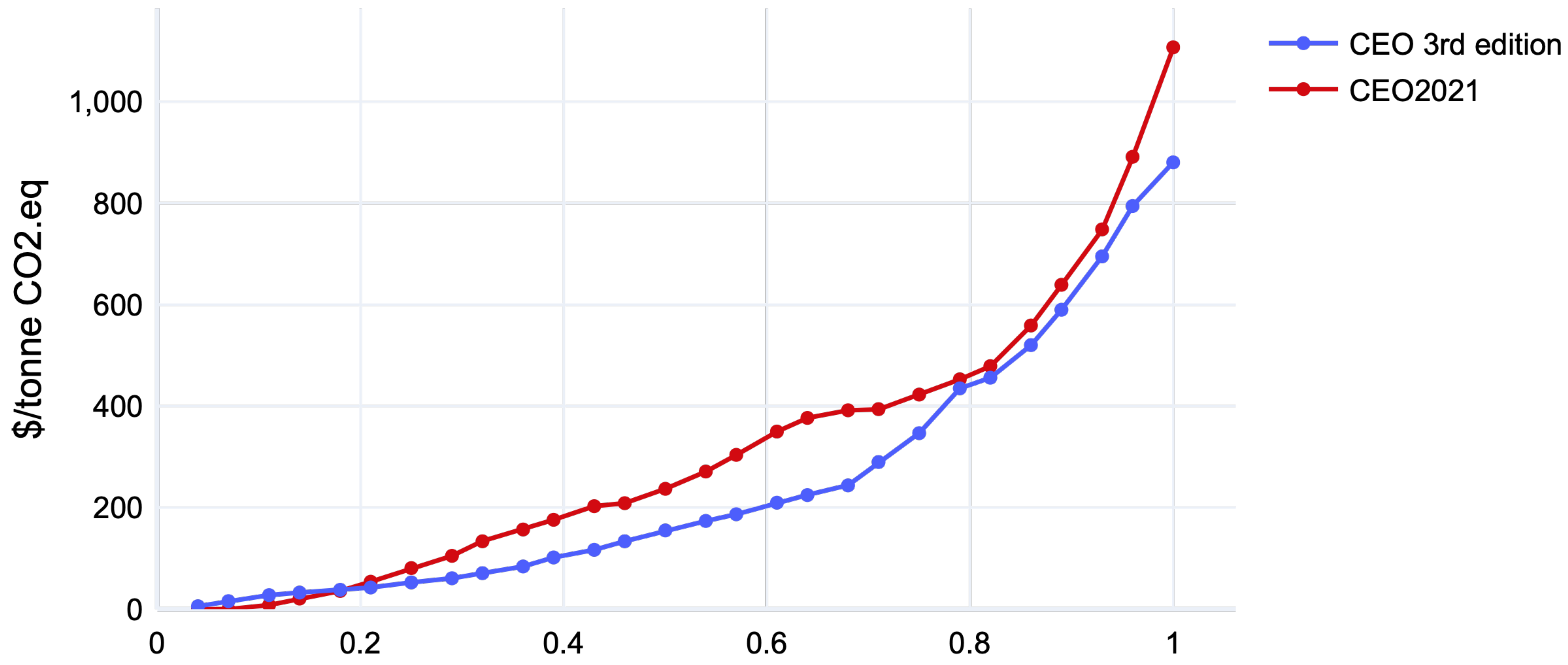
- In 2023, Quebecers bought 9.2 billion litres of gasoline **worth $10,1 billion** (before taxes) – for an effective price of 48¢/kWh.
- HQ's plan to generate an additional 50 TWh by 2035 is estimated at **$185 billion** (including historical investments).
- 9 billion is enough to pay the interest (5%) on this loan
- 21 TWh is enough to replace the 9.2 billion litres of petrol, leaving a substantial margin.

The investments announced by HQ are therefore a very good deal for Quebec.

The cost of transition: changes in the marginal cost of carbon

- Modelling shows that the costs of decarbonisation are falling continuously.
- It is possible to deploy targeted sectoral strategies (regulation, cost of pollution, technological support).
- The marginal price of reducing GHGs has almost halved between 2021 and 2024 (from $400 to $200/t CO2 eq.) for first 80 %.

Figure 6 – Evolution of the marginal price to eliminate one equivalent tonne of CO_2 in 2050.



Source : Langlois-Bertrand *et al.* 2024

- The last 20% of emissions (industrial processes, agriculture, shipping, aviation) remain costly and require CCS.

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Feasibility and timetable

- Canada has the means and the capacity to lead the transition by 2050, as shown by past achievements (Canada 1960-1980, China 2000-2020).
- We need to tackle the barriers that are slowing down investment and increasing costs.
- But also to adopt effective, targeted strategies for all sectors.

  Example: buildings, transport, electricity
- Additional investment estimated at $45 billion/year for the Canadian electricity network.
- Impact on the workforce: conversion of human resources (e.g. from car mechanics to heating technicians).
- The effort is considerable, but represents a manageable fraction of the economy.

How to go about it

- The necessary commitment from governments, private companies and citizens for a successful energy transition.
- Identification of priority actions to be taken immediately to accelerate Canada's energy transition.
- Valuing innovation and in-depth transformation

Conclusions

- A sustained pace of transformation is possible for sectors with identified decarbonisation technologies (buildings, part of transport, CCS, power generation).
- The cost of carbon-neutral technologies (excluding CCS) is falling, allowing transformation at zero total cost or with benefits.
- Need to develop competitive solutions for air and sea freight transport.
- It is in Canada's interest to develop intellectual property (IP) in CCS (including biochar) and in the heavy transport/aviation niches.
- There is an urgent need to act in the face of rapid progress by the rest of the world.
- We see a growing convergence between productivity and decarbonisation.

Q&A

Thank you !

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https://iet.polymtl.ca/en/energy-outlook